CURRENT STUDIES IN INNOVATIVE ENGINEERING TECHNOLOGIES

EDITORS

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ISRES Publishing

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Current Studies in Innovative Engineering Technologies

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About the Book

There is continuous progress and innovation in the studies developed in the fields of science, engineering and technology. This study titled "Current Studies in Innovative Engineering Technologies" brings together the most up-to-date studies, research and discoveries in these fields.

Today, innovative research conducted in a wide range from basic sciences to engineering and technology aims to find solutions to the challenges faced by humanity. This book includes studies presented by distinguished researchers in a wide range of fields from education to engineering, from health to basic sciences. Each chapter aims to provide the reader with in-depth information on the subject.

The content of the book focuses on the challenges, innovations and discoveries faced by scientists and engineers. In this way, we believe that our readers will not only update their current knowledge but also gain a perspective on the technological and scientific trends and innovations of the future.

While preparing this study, we have brought together many valuable pieces of content that are the product of intensive collaboration between the editors and authors. We believe that these studies will promote progress in academia and industry.

Finally, we hope that this book titled "Current Studies in Innovative Engineering Technologies" will increase your interest in science, engineering and technology and provide you with more in-depth knowledge on these subjects.

We wish you a pleasant reading.

December, 2024

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In This Book

Chapter 1,

This study examines the effects of various heat treatment processes on the dimensional tolerance of metallic materials. Firstly heat treatments such as annealing, normalizing, quenching, and tempering used to enhance mechanical properties like strength, hardness, and ductility were explained. These processes influence dimensional stability due to changes in the microstructure and the release or introduction of internal stresses. Techniques such as stress relief annealing and recrystallization annealing help mitigate dimensional distortions caused by prior deformation or machining. Surface hardening methods, including flame hardening, induction hardening, and cementation, are also evaluated for their impact on maintaining dimensional precision while improving surface hardness. The studies conducted to investigate the effect of heat treating on dimensional tolerances were summarized and finally dimensional tolerances changes of AISI 4140 material after the nitriding process were presented. This analysis highlights the importance of optimizing heat treatment parameters to achieve desired mechanical properties without compromising dimensional tolerances, which is critical for applications demanding high precision.

Chapter 2,

Sliding and rolling bearings are the basic components of machine construction. In machine systems operating at high speeds (>600 RPM) and not frequently performing stop-start movements, the use of sliding bearings is more meaningful both technically and economically. The oil film formed between the shaft and the bearing is of great importance for the efficient operation of sliding bearings. In this study, the increase in bearing performance was investigated by creating pockets on sliding bearing surfaces by shot peening. In the study where tin bronze was used as the sliding bearing material, it was aimed to increase both the fatigue strength of the bearing material and the adhesion surface of the oil by shot peening. Different oil pocket structures were created on the bearing surfaces by using different peening parameters and lubrication performance was tried to be increased by using nanoparticle-added oil as a lubricant. In the experimental study where nanosilver-added oil was used, it was aimed for nanoparticles to act as a tribological performance agent on the lubrication pockets. According to the results, ~125 HV hardness increase was achieved on the material surface and the fatigue life of the material was increased by 7 times. It was determined that the bearing performance increased under the conditions of using low Almen intensity peened and nanoparticle added lubricant.

Chapter 3,

Additive manufacturing is a key component of the fourth industrial revolution (IR4.0) that has received increased attention over the last three decades. Metal additive manufacturing is broadly classified into two types: melting-based additive manufacturing and solid-state additive manufacturing. Friction stir additive manufacturing (FSAM) is a subset of solid-state additive manufacturing that produces big area multi-layered components through plate addition fashion using the friction stir welding (FSW) concept. Because of the solid-state process in nature, the part produced has equiaxed grain structure, which leads to better mechanical properties with less residual stresses and solidification defects when compared to existing melting-based additive manufacturing processes. This chapter intends to highlight the working principle and previous research conducted by various research groups using FSAM as an emerging material synthesizing technique. The summary of affecting process parameters is discussed in detail based on open access experimental data.

Chapter 4,

As manufacturing methods advance today, the use of additive manufacturing and reverse engineering applications in casting technologies is becoming increasingly important. Modern and traditional manufacturing methods each have their advantages and disadvantages. Integrating these methods will make the production process more efficient by utilising their advantages. In this study, additive manufacturing and reverse engineering, which are among the modern manufacturing techniques in casting-die technology, are defined, examples are given in which areas they are used, and some suggestions are presented. Information was given about new developing technologies, especially about very fast molding in prototype casting studies.

Chapter 5

Research and Development (R&D) projects today focus on significant innovations and technological advances in various industries. In this context, Polgün's R&D studies have evolved into these areas. Polgün plays a leading role in the water slide industry with its innovative approach and use of advanced technology. With its continuous R&D studies, it develops safer, environmentally friendly products and maximizes the user experience. Polgün's innovative projects and forward-looking strategies are constantly raising the bar in the water slide industry and shaping the future of the industry. Polgün is committed to providing its customers with the highest quality products and services by increasing its competitiveness in the sector with its investments in innovation and technology.

Chapter 6,

The need to raise water to a higher level than it is has become a situation that mankind has emphasized and sought different solutions for throughout the ages. A water ram pump uses the energy of a low-level waterfall with a mechanical and hydraulic device to pump water to a certain height. The purpose of the pump is to pump some of the water to a much higher water tank with the pressure created by the water above the pump level. The first spontaneous worker This Coach pump , in Voiron in 1796 paper in his factory This to collect for Frenchman Joseph Michel Montgolfier (hot weather your bubble It was invented by (known as the co- inventor).

The working principle of the water ram pump is quite simple, only a water source (such as small streams) is enough for it to work. It can work continuously with the pressure of the water above the pump level without needing any energy. In this study, general information about the Water Ram (Ram Pump) is given and the studies on the subject are examined.

Chapter 7,

In this context, personalized education systems supported by artificial intelligence will help expand the boundaries of personalization in education and maximize the potential of each student. These technological developments have the potential to revolutionize education by enabling changes in teaching methods and allowing individuals to be more effective in the educational process.

Chapter 8,

Sandwich composites are frequently used in the fields of air, marine, mobile vehicles and construction industry due to their high strength-to-weight and stiffness-to-weight ratios. In addition to these important advantages, sandwich composites and fiber reinforced composites are very sensitive to bending and compression loads. Honeycomb core sandwich structures are preferred in many areas due to their high strength and lightweight. The thickness of the surface plates and core structures, the surface preparation of the layers before bonding are important criteria to increase the strength of the sandwich structure. In this study, a polypropylene honeycomb core sandwich structure was prepared. This structure can especially be used as a panel material by reinforcing with polyurethane and nano level additives. In engineering structures, unexpected damages may occur against any external impact, especially during manufacturing, assembly and use. These damages can be predicted by flexural and compression tests. In this study, the flexural and compression behaviors of sandwich structures are investigated experimentally.

Chapter 9,

In this chapter, it is mentioned that in the field of AI and data science, pattern recognition has emerged as a powerful tool for unraveling the complexities of complex data sets. This chapter delves into the core principles, techniques, algorithms, and diverse applications that underpin this transformative field. Pattern recognition empowers machines to identify and classify patterns within data. These patterns can manifest in various forms, ranging from sequential patterns like DNA sequences to spatial patterns like objects in images, statistical patterns like data distribution, rule-based patterns like medical diagnoses, and composite patterns that combine these elements. Effectively extracting valuable insights from data hinges on understanding the distinct characteristics of these diverse pattern types. Feature representation and extraction techniques play a crucial role in this process, transforming raw data into a suitable format that emphasizes relevant features for pattern identification. Classification, a cornerstone of pattern recognition, assigns data points to predefined categories. The chapter explores various supervised learning algorithms employed for classification. In essence, pattern recognition serves as a gateway to unlocking meaningful insights from data. By identifying patterns, we can gain a deeper understanding of the world around us and make informed decisions. As this field continues to evolve and refine its techniques, we can anticipate further advancements in the realm of data analysis.

Chapter 10,

In the Chapter, Seydişehir Ahmet Cengiz Faculty of Engineering (SACMF) is presented as an exemplary model in innovative engineering education. The chapter highlights the importance of analytical thinking, problem-solving, and innovative solution development in engineering. The "intern engineering education" program at SACMF enables students to apply theoretical knowledge in real-world projects. Innovative approaches such as the "social responsibility transcript" and sustainable participation in technical competitions combine technical expertise with social responsibility, fostering both professional skills and societal awareness. Additionally, the faculty’s license-oriented laboratories and exam systems modeled after centralized exams contribute to improving the quality of education.

Chapter 11,

In this study, Project/Studio courses, which form the backbone of industrial design education and are considered as a direct simulation of designing, developing or improving a product from scratch, which is one of the real-life engineering actions, are examined through case studies in the light of current technologies. First, the processes of product design and product development are briefly introduced. Then, possible bottlenecks and problems that may occur in the processes introduced are discussed. Then, it examines how innovative design and engineering approaches can be utilized. Finally, the study is completed by explaining the information in the literature and what is conveyed in the study through an example case analysis in order to comprehend it more effectively visually. This study makes a valuable contribution to the literature on design and engineering education by showing that introducing both professional industrial designers and industrial design students to current technologies and approaches in engineering and design disciplines can provide them with significant convenience and advantages in solving the problems they may encounter in product design and development processes.

Chapter 12,

The sheet metal forming processes are investigated. While in the past years, sheet metal die manufacturing was done by trial-and-error method, today, with the development of technology, the process can be modeled and simulated in the computer environment using the finite element method (FEM), even before the forming process is carried out. Problems in sheet metal forming processes such as tearing, necking, wrinkling and springback may occur during sheet metal forming processes. The occurrence of any of these or a combination of these makes the sheet metal useless, and these defects are the factors that define the deformation limit. During the stretching process, the sheet thins first uniformly and then regionally, and a regional thinning band known as necking occurs in the sheet. Sheet metals can only be formed up to certain limits without damage. Models have been developed to predict material behavior in forming operations. The forming limit curves are the most important technique for determining the sheet metal forming behavior. In this section, how fld graphics are obtained is explained in detail.

Chapter 13,

The aim of this study is to recognize garbage with artificial intelligence, open the lid of the relevant box according to the type of garbage and ensure that individuals exhibit correct behavior. Thanks to the cameras and artificial intelligence to be placed in front of the recycling bins, the garbage will be separated and only the lid of the garbage bin that needs to be thrown will be opened depending on the type of garbage. Separating waste in advance prevents waste of time and energy. If we accept that these are millions of tons of waste, we think that by ensuring that the waste is pre-separated and delivered to these facilities, we will reduce the carbon footprint and save money by using the electrical energy and human labor used in these facilities. It ensures that facilities are used more efficiently and prevents damage to the environment. Electronic circuit boards, servo motors and cameras were used in the design of the project. Pictoblox program and its integrated Machine Learning Environment plug-in were used as software. Codes were written in Pictoblox. With the Machine Learning Environment plug-in, waste was recognized by artificial intelligence. So the machine has been trained.

Chapter 14,

The subject of this study is to investigate the effect of cross-sectional geometry on the flexural and compressive strength of glass fibre reinforced composite profiles used for various purposes. In order for this comparison to give accurate results, profiles with equal cross-sectional area were divided into two groups and bending and compression tests were performed. Force-Displacement graphs of the obtained data were prepared and evaluations were made. In the first group of 330 mm2 cross-sections, the most suitable profile in terms of bending force/displacement ratio was found to be circular section profile, and in the 700 mm2 cross-section, the most suitable section in terms of bending force/displacement ratio was found to be angle profile. In the first group of sections with 300 mm2 cross-sectional area, it was seen that the most suitable profile in terms of compression force/displacement was serrated circular section profile, and in the 700 mm2 section, the most suitable profile in terms of compression force/displacement ratio was U profile. In this study, when GRP profiles are evaluated in terms of cost and lightness; it has a 30% price advantage compared to its metal counterparts and being 5 times lighter is the most powerful aspects of GRP profiles.

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Effects of Heat Treatments on Dimensional Tolerance

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Introduction

In the usage of metal materials, it is generally necessary to enhance their mechanical properties compared to their raw state. These enhancements often include improving important mechanical properties such as tensile strength, compressive strength, hardness, ductility, impact strength, fracture toughness, fatigue strength, and creep resistance. Depending on the desired mechanical properties, various heat treatments are used.

Heat treatment is a process conducted to alter the microstructure and mechanical properties of metal. This process usually involves heating the material to a specific temperature and then cooling it in a controlled manner. Among the heat treatments applied to metallic materials are processes such as annealing, hardening of steels, and precipitation hardening.

The heat treatment of steels is generally examined in two main categories: heat treatment and surface hardening. Heat treatments are processes aimed at providing steels with a specific microstructure and mechanical properties. Surface hardening, on the other hand, is a technique used to create a hard layer on the surface of steel locally.

Heat Treatments Applied to Metals

Annealing Processes

Annealing is the process of heating a part to a desired temperature, holding it at that temperature for a specific period, and then cooling it slowly. It is applied to reduce the hardness, increase the ductility and toughness, stress relief, and improve the internal structure of a workpiece that has undergone cold deformation or heat treatment.

Homogenization Annealing

This is a heat treatment applied to steels to eliminate chemical composition differences, or micro segregations, formed within the material as a result of primary crystallization, such as through casting. It is carried out by heating to a temperature range of 1100-1300 °C and holding for extended periods of up to 50 hours, followed by slow cooling. One of the objectives of this heat treatment is to prevent the formation of a banded structure in secondary crystallizations, such as hot forming. However, this method is costly due to the long duration and high temperature required, which can also cause significant material loss from the surface due to oxidation. Therefore, the heat treatment time is of great importance (Soy, 2017).

Coarse Grain Annealing

The aim of coarse grain annealing is to achieve a coarse-grained internal structure in hypo-eutectoid steels, which have low tensile strength and high ductility, to facilitate machining. In this heat treatment, steel is heated within the austenite region at 950-1150 °C and held at this temperature for 2-5 hours. It is then cooled very slowly to the A1 temperature, reaching 723 °C, where it is allowed to cool in the air. Following coarse grain annealing, the steel, which acquires a coarse grain structure, can undergo machining processes with minimized issues like continuous chip formation and sticking. After machining, it can undergo normalization to obtain a fine microstructure.

Normalizing

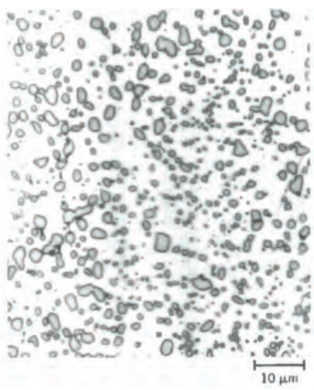
In manufacturing processes involving plastic deformation such as rolling and forging, the microstructure of steel usually consists of pearlite and ferrite. These phases, affected by deformation, are distributed irregularly within the internal structure, forming coarse grains of varying sizes. Through normalization annealing, a fine, homogeneously distributed microstructure containing ferrite and pearlite is obtained, which enhances toughness compared to coarser grain structures. Normalizing involves heating the steel to temperatures known as upper critical values, specifically A_3 for hypo-eutectoid steels and A_{cm} for hyper-eutectoid steels, at around 55 °C above these points. When the steel is sufficiently held at this temperature, it transforms completely into the austenite phase. The steel is then air-cooled to room temperature to complete the normalization process (Callister and Rethwisch, 2015).

Spheroidizing

Spheroidizing is a heat treatment applied to soften the steel and improve machinability by holding it just below the austenite (A_1) temperature for an extended period, typically at 700 °C for 24 hours, followed by slow cooling. During this process, the cementite phase transforms into spherical particles, softening the internal structure. This transformation, as illustrated in Figure 1, only affects the shape of the cementite in the internal structure by forming spherical particles (Aran, 2007).

Figure 1

Appearance of spheroidized cementite in the microstructure of a steel subjected to spheroidization process (Callister and Rethwisch, 2015)

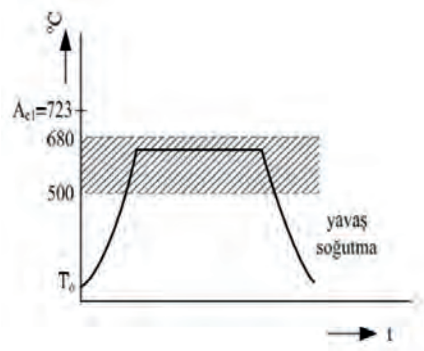


Stress Relief Annealing

The primary goal of this heat treatment is to eliminate internal stresses and prevent warping or cracking in steel. Although it varies according to the chemical composition of the steel, stress relief annealing is typically conducted by heating unalloyed and low-alloy steels to temperatures between 500-680 °C, followed by slow cooling (Figure 2). The holding time ranges from approximately 0.5 to 1 hour. A key consideration during the process is to cool the material slowly; otherwise, temperature differences between the surface and the center may lead to reformation of internal stresses. As a result of this treatment, internal stresses are eliminated, although the mechanical properties of the material do not change significantly (Eker, 2008).

Figure 2

The temperature to be heated during stress relief annealing according to the chemical composition of the steel and its change over time (Eker, 2008)



Recrystallization annealing

Recrystallization annealing is a heat treatment applied to eliminate the work hardening and grain orientation effects caused by cold deformation in metal alloys. This process softens the material, which has increased hardness and reduced ductility due to work hardening, thereby increasing its ductility. This makes it possible to subject the materials to further forming operations. When conducted at appropriate temperatures and durations, the grains in the new internal structure form as small and equiaxed. The driving force for grain rearrangement is the energy accumulated in the internal structure due to cold deformation. Therefore, recrystallization is only applicable to materials deformed by specific amounts.

During the process, the phenomena of recovery and recrystallization occur, depending on the heat treatment temperature. Recrystallization temperature is typically considered to be at or above half of the material's absolute melting temperature. Below this temperature, mechanical properties change only slightly, while electrical conductivity increases significantly. Dislocations are more orderly in certain locations, and some are eliminated, leading to an internal structural change known as recovery. Recrystallization annealing can also be applied specifically to obtain a fine-grained structure in materials. To avoid grain growth, it is essential not to apply the treatment at excessively high temperatures or for extended periods. Additionally, to prevent or minimize oxidation or scale formation on the material surface, care should be taken not to keep the annealing temperature too high or to conduct the process in a non-oxidizing atmosphere (Eker, 2008).

Hardening of Steels

The purpose of the hardening process applied to steels is to achieve a martensitic internal structure through diffusionless transformation, thereby increasing the strength and hardness of the steel. For this purpose, quenching and subsequent tempering processes are applied.

Quenching

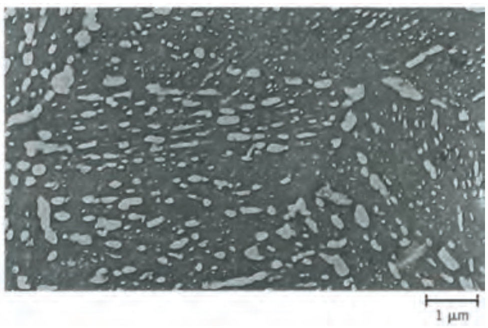
The main objective of the quenching heat treatment is to obtain a fully martensitic structure. The martensitic structure refers to iron's body-centered tetragonal lattice structure as a supersaturated solid solution with carbon. Due to the rapid cooling, carbon does not have the opportunity to diffuse within the crystal lattice, resulting in excessive stresses within the lattice. These stresses restrict dislocation movement, which leads to a significant increase in the yield and tensile strength of the steel while reducing its ductility. For this process, steel is heated within the austenitic region for at least one hour. The temperature should be 30-50°C above the A_3 critical temperature for hypo-eutectoid steels and above the A_{cm} temperature for hyper-eutectoid steels. The steel is then quenched in various media at cooling rates exceeding the critical rate required to achieve the desired martensitic structure, which depends on the alloying elements and their proportions within the steel.

Tempering

The martensitic structure formed following the quenching process results in extremely high hardness due to the excessive stresses within the crystal lattice, but it also makes the steel very brittle. To reduce this brittleness, which would otherwise limit the practical applications of the steel, a tempering process—also known as annealing—is applied. Tempering is generally performed at temperatures between 100-650°C, below the A_1 critical temperature. As a result of tempering, carbon atoms trapped within the body-centered tetragonal lattice find an opportunity to diffuse and exit the lattice, precipitating as fine iron carbide particles (cementite) on a micro-scale. This reduces lattice stresses, allowing dislocations to regain mobility and increase ductility significantly, depending on the tempering temperature and duration. While there is a relatively lower decrease in strength, the tempered steel remains tough with still relatively high strength. The high strength and hardness of tempered martensite result from the very fine and closely distributed iron carbide within the ferrite matrix, as shown in Figure 3. The size of cementite particles, or iron carbide, increases in parallel with the tempering temperature and duration. Larger carbide particles lead to a greater reduction in strength and an increase in ductility. The holding time in the furnace during tempering depends on the thickness of the part, typically ranging from 1 to 2.5 hours. For example, a 1-inch thick part usually requires one hour of tempering (Figure 3) (Callister and Rethwisch, 2015).

Figure 3

Iron carbide structure dispersed in the ferrite main phase after the tempering process (Callister and Rethwisch, 2015).



Surface Hardening Processes

Surface hardening is a treatment applied to steel parts to enhance their wear resistance and increase the cutting strength of tools by only hardening the surfaces of the components. This process is particularly beneficial for parts made from materials that have low carbon content, resulting in high ductility and softness. Surface hardening aims to create a hard and wear-resistant surface on such parts. It is also applied to components that have high carbon content, where the goal is to maintain a tough inner structure while achieving a hard surface.

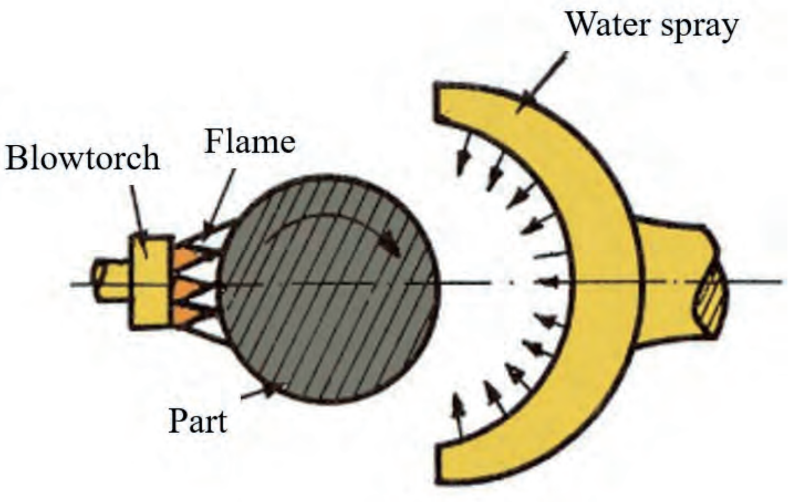
In surface hardening processes, only the surfaces that need to be hardened are heated, followed by rapid cooling of the workpiece. This method ensures that external surfaces become hard while the inner parts remain ductile. This is particularly important for components such as crankshafts, camshafts, gears, splines, coupling parts, and chain links, where it is essential for the outer surfaces to be hard while keeping the inner parts tough.

Flame Surface Hardening

Flame surface hardening is a process where the surface to be hardened is heated using gas torches, followed by rapid cooling. This method is cost-effective compared to other techniques due to its low equipment requirements and the speed with which it can be applied. It is particularly suitable for larger components with complex external geometries. Additionally, it is advantageous when localized hardening is desired. However, the process can be more challenging to control in terms of repeatability, as factors such as flame application time and temperature can vary when controlled manually.

A schematic illustration of the process is shown in Figure 4. The temperature generated by the torch directly heats the upper surface of the material, with temperatures reaching up to 3000°C during application. To achieve the martensitic transformation on the surface, the material's temperature must be raised to values that can facilitate the austenitic transformation. Therefore, the advancement speed of the flame must be controlled appropriately, which varies depending on the thickness of the part and the intensity of the flame produced.

Figure 4
Illustration of the flame surface hardening process (Megep, 2006)



Induction Surface Hardening

Induction surface hardening is a process that utilizes the rapid and high-temperature increase generated by high-frequency induction currents to heat the outer surfaces of parts, followed by rapid cooling. For this process to be effective, the material must contain a sufficient amount of carbon. It is typically applied to medium carbon steels with carbon content ranging from 0.35% to 0.60%. Compared to flame surface hardening, this thermal treatment is more controlled and is frequently used in the industry for hardening the surfaces of components such as shafts and gears.

During induction surface hardening, the workpiece is placed inside a thin copper coil that carries high-frequency electric current. This coil generates a magnetic field around the part, inducing opposing currents at the surface at the same frequency. These induced currents concentrate at the surface, leading to rapid heating. Once the part reaches the austenitizing temperature, it is cooled by spraying water on the surface, completing the hardening process (Davis, 2002).

Because the material heats up very quickly from the outer surface inward due to the induction effect, this thermal treatment method is well-suited for surface hardening and mass production. The depth of hardening can vary based on the applied frequency, ranging from 0.25 mm to 9 mm.

Cementation

Cementation is a hardening process that involves the diffusion of carbon into the surfaces of low-carbon steels (0.10% - 0.15% carbon content) to enhance their hardness, followed by rapid cooling. This treatment results in a surface layer where the carbon content increases to values between 0.6% and 0.8%. Low-carbon steel parts are exposed to carbon-rich atmospheres derived from various sources and are carburized at temperatures of 850 °C or higher. The carbon environment can exist in solid, liquid, or gas phases, with gas environments being preferred due to ease of control and cost-effectiveness. Common gases used include natural gas, methane, ethane, propane, and town gas.

Methane gas, in particular, decomposes at high temperatures, providing carbon to the iron. This carbon diffuses into the steel and penetrates the ferrite matrix, dissolving at high temperatures before quenching, which creates a martensitic structure. Similar to the annealing process, tempering is applied to soften the excessively hard and brittle surface structure. Since the carbon content is low in the inner regions of the part, these areas do not harden during the quenching process, resulting in a structure that is hard on the outside and ductile and tough on the inside.

Figure 5 illustrates the distribution of hardness following the cementation process, showing that even at depths exceeding 1 mm, the hardness value reaches 550 HV, which is adequate for most applications. The hardness depth is influenced by the cementation time and temperature. As shown in Figure 6, at a temperature of 900 °C, cementation for 10 hours achieves a depth of 1.5 mm, while 20 hours results in approximately 2.4 mm of cementation depth. Additionally, in low-temperature cementation applications, while increasing the cementation time does not significantly increase cementation depth, higher temperatures can yield depths up to 4-5 mm.

Figure 5

Relationship between cementation depth and hardness (Aktaş, 2016)

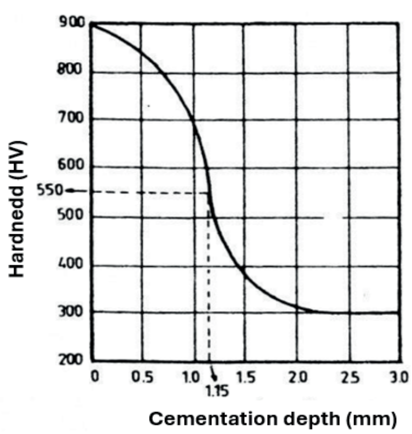
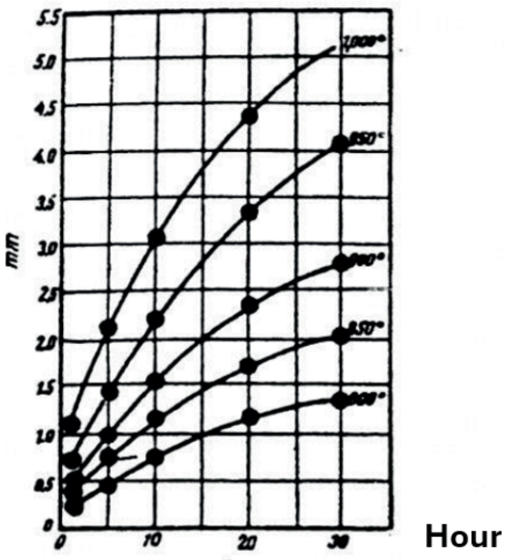


Figure 6

Relation between the cementation time of the workpiece and the cementation depth (Aktaş, 2016)



The solid-phase cementation process involves immersing a steel or cast iron workpiece in a mixture containing charcoal and additives that accelerate the reaction, all contained within a box. While this method is economical, achieving a thin cementation layer can be challenging. In the case of cementation performed in a salt bath, the composition of the bath is determined based on the desired cementation depth and the working temperature. During this process, a small amount of nitrogen also diffuses into the steel structure alongside the carbon, imparting additional hardness. The bath temperature is maintained between 900 °C and 960 °C, and the workpieces are preheated before the treatment to ensure uniform heating and effective carbon diffusion. This method allows for controlled carbon absorption, leading to the desired mechanical properties in the hardened surface layer while maintaining the ductility of the inner core.

Nitriding

Nitriding is a surface hardening process where nitrogen is diffused into the surface of steel by holding it in a nitriding furnace at temperatures between 480 °C and 650 °C, depending on alloy content, for 10 to 24 hours. The surface hardening occurs as nitrogen diffuses into the steel surface and combines with nitride-forming elements like aluminum, chromium, vanadium, and titanium to form a thin and very hard nitride layer. This layer enhances the fatigue and corrosion resistance of the steel (Seybolt, 1969). For nitriding to be effective, the material must contain nitride-forming elements (Dossett, 1991). Therefore, as shown in Figure 7, it is difficult to achieve hardening in unalloyed steels even with prolonged treatments of 48 hours at different temperatures. Nitriding can be performed at temperatures between 500 °C and 590 °C in solid, liquid, and gas environments, and quenching is not required after the process. The treatment duration varies between 10 and 48 hours, and as the treatment duration increases, the thickness of the hard layer also increases, as seen in Figure 8.

There are four types of nitriding applications: gas nitriding, salt bath nitriding, powder nitriding, and ion nitriding. In gas nitriding, the workpieces are placed in special containers and loaded into furnaces. The furnace operates at 510 °C to 550 °C, and the process occurs through the circulation of ammonia (NH_3) gas. The specific temperature is required because ammonia dissociates at 500°C. The treatment duration is approximately 10 to 24 hours, but in extended treatments of 30 to 100 hours, a hardened layer up to 0.8 mm thick can form (Tekin, 1987).

In salt bath nitriding, the temperature is maintained between 550°C and 570°C, with a holding time of around 2 hours. For powder nitriding, the workpieces are buried in a mixture of nitriding and accelerant powders within containers at 520°C to 570°C for 10 to 12 hours.

Figure 7
The effect of the alloy in the nitriding process on the workpiece surface hardness (Tekin, 1987)

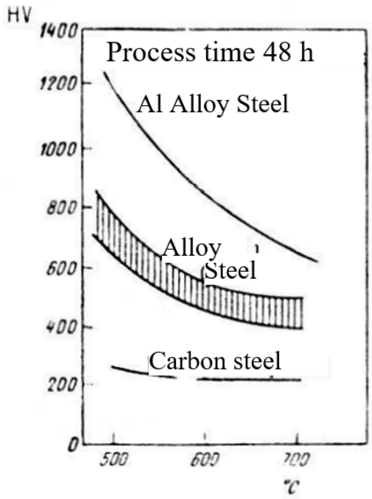
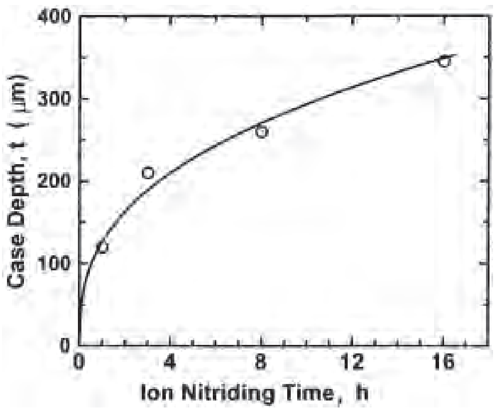


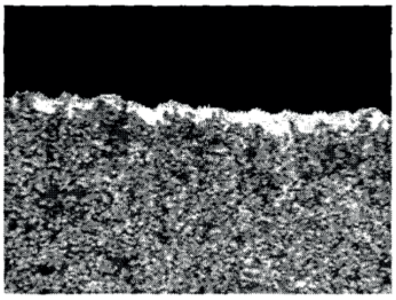
Figure 8
Effect of nitriding time on hard layer thickness formation in the nitriding process applied to AISI 4140 steel at 475°C (Genel et al., 2000)



Ion nitriding is a more modern nitriding technique compared to other nitriding methods. It is used to enhance the mechanical and surface properties of materials like steel, cast iron, and titanium. The ion nitriding process takes place in specialized vacuum furnaces, where process gases are ionized and directed toward the material surface with the aid of an electric current. This technology was first discovered in 1932 by Swiss engineer Bernard Berghaus in Germany, but the first industrial application occurred in 1967, as Germany and Switzerland began adopting the method. The process took its current form in the 1970s, where nitrogen-containing process gases are ionized by an electric current and accelerated onto the material surface (Yılmazer, 2008).

As shown in Figure 9, the surface layer of ion-nitrided material consists of three regions: the outermost layer is called the “white layer,” beneath it is the “diffusion layer,” and further inward is the “core region” (Şirin, 2004).

Figure 9
Surface layers of nitrided material



Effect of Heat Treatment on Dimensional Tolerance of Parts

During rapid cooling in heat treatments, different regions of a part contract at varying rates, as the entire cross-section cannot cool uniformly. This leads to thermal shrinkage at different rates across the part, causing thermal stresses along with deviations in dimensions and geometry. Particularly in the tempering process applied to steels, rough machining is typically followed by heat treatment, and then a final finish machining is performed to address dimensional changes and the effects of oxide films on the surface. Another solution is to secure parts to fixtures during quenching. Even in processes like nitriding, where rapid cooling is not involved, dimensional changes can still occur, potentially taking the part outside of the intended tolerance limits. The dimensional and surface effects caused by heat treatments increase production time and costs, as they necessitate additional precautions and processes. Therefore, considering the impact of heat treatments at the design stage of a part may enable the manufacturing of parts that meet functional requirements without the need for additional post-treatment processes.

Before mass production, necessary R&D studies are conducted in the industry to identify potential defects. Machine components are subjected to various heat treatments depending on their purpose, such as hardening and improving fatigue strength, and according to the conditions of use. Heat-treated materials expand and increase in volume according to their different thermal expansion coefficients. Controlled cooling results in phase transformations, such as austenite transforming into martensite, which causes volume changes due to the rearrangement of atoms. This change should be calculated during the design phase of a machine component. Otherwise, interacting parts with precise tolerances may not function properly. For example, a clearance of 0.1 mm between a gun slide and mechanism must be carefully considered, as it affects whether the clearance is given before or after heat treatment. Improper shrinkage in the female part or expansion in the male part after heat treatment could lead to assembly issues or improper functioning. Failing to conduct these calculations can result in costly errors. To avoid the adverse effects of heat treatments, it is important to understand how they impact dimensional tolerances and surface qualities. A review of the literature reveals that only a few studies have explored the effects of heat treatments on dimensional tolerances and surface quality.

Studies Conducted in the Literature on the Subject

In a study conducted by Dobrocki et al. (2020), changes in geometry were examined in test samples made from AISI 4140 tempered steel, which is commonly used in the production of components such as barrels, threaded spindles, and gears. In this study, heat treatment was initially applied to the samples, followed by plasma and gas nitriding. Five test samples with dimensions of 90x30x20 mm, each with a 0.3 mm grinding allowance, were subjected to a series of heat treatments as shown in Table 1, as illustrated in Figure 10. This investigation aimed to analyze how different heat treatment and nitriding processes affect dimensional stability in AISI 4140 steel, particularly relevant for high-precision components where tight tolerances are critical.

Figure 10

Nitrated test sample in the study by Dobrocki et al. (2020)

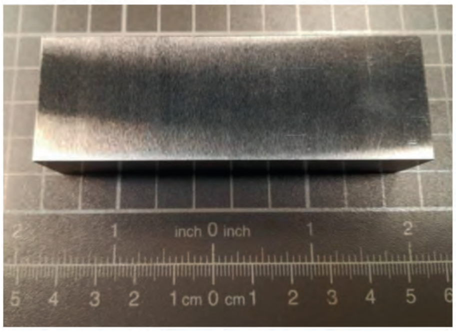


Table 1

Heat treatments applied to the test samples in the study by Dobrocki et al. (2020)

Normalization	Quenching	Tempering
860 °C/ 45 min / air	840 °C/ 45 min / water	600 °C/ 100 min / oil

After obtaining a fine-grained pearlitic structure with suitable mechanical properties through heat treatments, the samples were ground to achieve a surface roughness of Ra = 0.4 µm - 0.8 µm. Following grinding, the samples were measured five times using a CMM (Coordinate Measuring Machine) to ensure accuracy and prepare them for the nitriding process. The parameters of the furnaces used for plasma and gas nitriding were adjusted in terms of temperature and processing time, as shown in Table 2, to achieve a diffusion layer thickness of 0.25 mm - 0.35 mm.

Table 2

Dobrocki ve ark. (2020) çalışmasında nitrasyon işlemi parametreleri

Process	Temp (°C)	Time (s)	Atmosphere
Plasma Nitriding	520	14	$1N_2$: $3H_2$
Gas Nitriding	530	7	NH_3/ N_2 / H_2

After the heat treatment and nitriding processes applied to the samples, their microstructures were examined. In Figure 11a, tempered martensite and fine pearlitic structures are shown, respectively. Figure 11b displays a continuous, very thin nitrided white layer on the material surface following plasma nitriding, whereas Figure 11c shows a thicker nitrided white layer resulting from gas nitriding. Additionally, the diffusion layer and the core region formed by the nitriding process can also be seen in the figures. The depths of these layers and surface hardness are provided in Table 3. Depths and hardness measurements were taken at five different points on each of the five samples, and average values are presented as the final results. As seen in the table, although the thickness of the white layer in plasma nitriding is significantly less than in gas nitriding, the diffusion layer depth is greater. Moreover, the hardness achieved in gas nitriding is higher.

Figure 11

Microstructure images after a) heat treatments, b) plasma, c) gas nitriding treatments applied to 4140 steel.

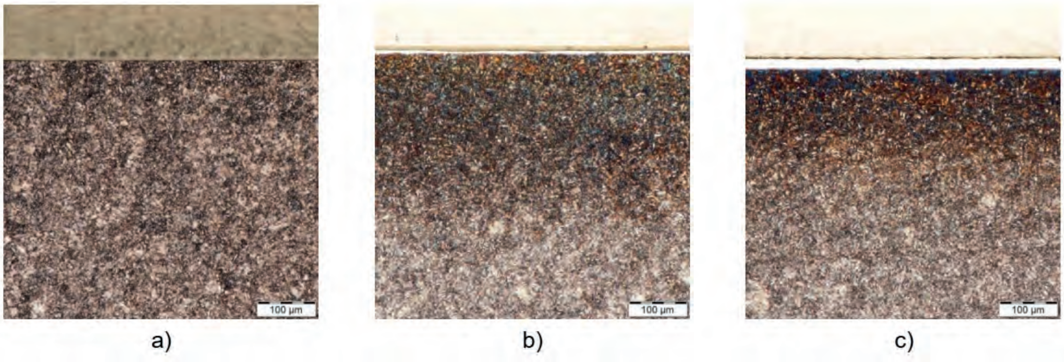


Table 3

Depths and hardness of diffusion and white layers after nitriding processes (Dobrocki et al. 2020)

Process	Diffusion layer thickness (mm)	White layer thickness (µm)	Surface Hardness HV10
Plasma Nitriding	0,319	6,4	665
Gas Nitriding	0,224	18,4	705

After nitriding processes, samples were measured 5 times from the 90 mm dimension of the prismatic sample with a CMM device. As a result of the measurements, an increase of **0.032 ± 0.001** mm was observed in the part dimensions in plasma nitriding and **0.036 ± 0.002** mm in gas nitriding. Changes in other dimensions were not given in the study. After the heat treatments and nitriding processes related to surface roughness, the Ra, Rz, Rp and Rt values of the samples were measured and the values seen in Table 4 were obtained. It is clearly seen from the results that there was a decrease in the surface roughness parameters after both nitriding processes. However, it can be said that there was no significant change in the roughness parameters of the ground surfaces and surfaces after the nitriding processes.

Table 4

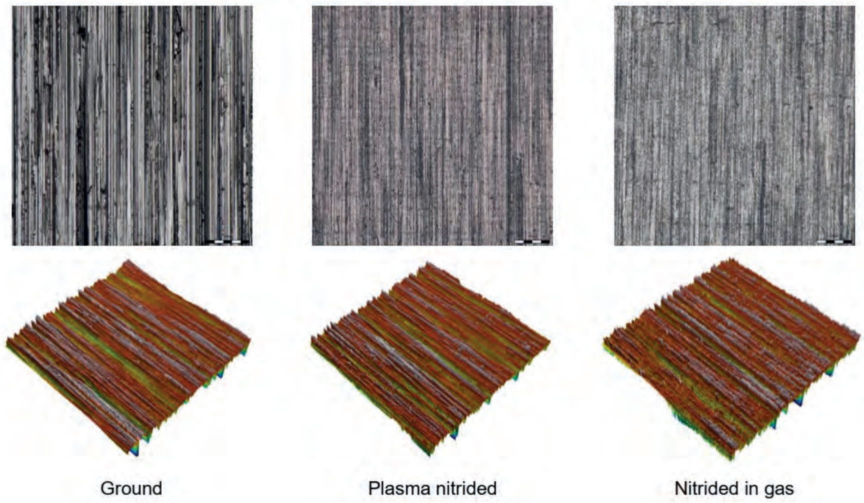
Results of surface roughness measurements Dobrocki et al. (2020)

Parameter (µm)	Ground surface	Plasma Nitriding		Gas Nitriding	
		Measured value	**Decrease**	**Measured value**	**Decrease**
Ra	0,96 ± 0,06	0,87±0,06	-0,09	0,87±0,11	-0,09
Rq	1,30 ± 0,05	1,18±0,09	-0,12	1,16±0,17	-0,14
Rz	7,06 ± 0,18	6,26±0,35	-0,80	6,43±0,59	-0,63
Rt	7,16 ± 0,18	6,38±0,27	-0,78	6,52±0,59	-0,14

In the study, the surface morphology of the parts after heat treatment and both nitriding processes was also measured, as shown in Figure 12. In the images, traces of the grinding tool can be seen on the base surface. Dark, deep grooves and light gray peaks appear parallel to the grinding direction. After the nitriding processes, the dark grooves (valleys) disappeared, indicating that these valleys or grooves were filled with the nitrided compound formed by the diffused nitrogen. This filling process resulted in a reduction in surface roughness. Each surface's 3D texture exhibits a similar morphology, with the peaks on the surface slightly rounded after the nitriding processes.

Figure 12

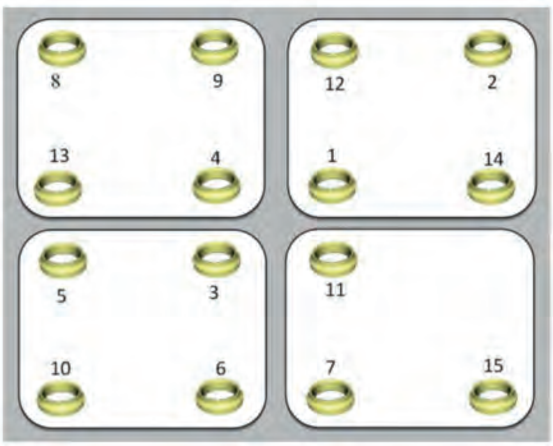
Morphology of the evaluated surfaces (500x magnified) and their 3D texture (Dobrocki et al., 2020)



In another study by Vicen et al. (2018), the dimensional changes of a bearing made from 100Cr6 bearing steel were examined by measuring the dimensions before and after the heat treatment and recording the changes. This study investigated how the heat treatment applied to the inner ring of the bearing wheel affected its dimensions. The bearing rings were measured with a CMM device immediately before being placed in the furnace for quenching and were positioned in the furnace as shown in Figure 13.

Figure 13

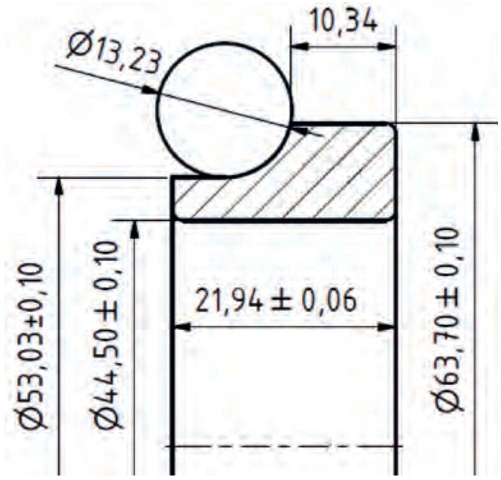
Ways of placing bearings in the furnace in the study conducted by Vicen et al. (2018)



The dimensions expected to change as a result of heat treatment are shown in Figure 14.

Figure 14

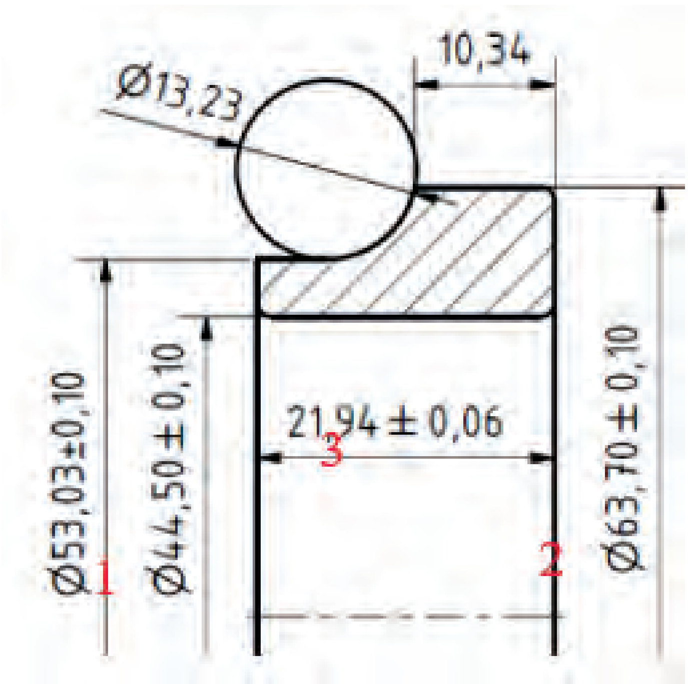
Dimensional measurements made on the inner ring of the rolling bearing before heat treatment (Vicen et al., 2018)



For the quenching process, the austenitization of the test samples was carried out in a salt-based furnace at a temperature of 860 ± 5 °C. This was followed by cooling in a salt bath at 220 ± 5 °C. The dimensional changes of the samples after the quenching process were then measured, and the results are illustrated on the technical drawing in Figure 15.

Figure 15

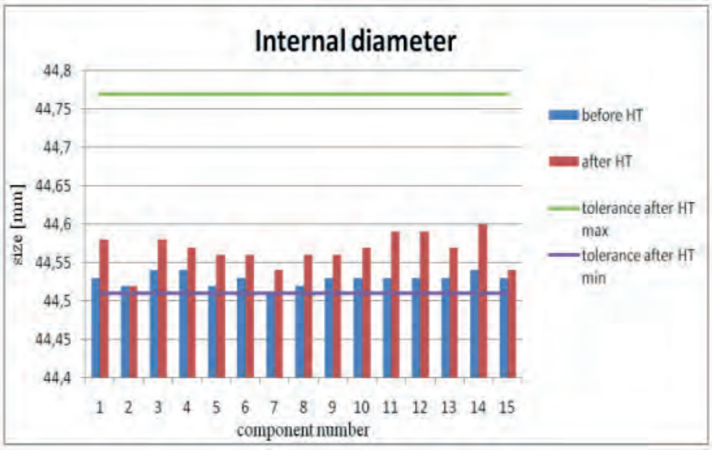
Dimensional measurements after heat treatment on the inner ring of the rolling bearing (Vicen et al., 2018)



For 15 parts, the individual inner and outer diameter measurements before and after the heat treatment are shown in Figures 16 and 17. In Figure 16, the inner diameter measurements before heat treatment are indicated in blue, while the post-treatment measurements are shown in red. Accordingly, the inner diameter values ranged from 44.51 to 44.54 mm before heat treatment and from 44.52 to 44.60 mm after. The maximum observed change was 0.06 mm, while only sample number 2 showed no change among the 15 samples. The average diameter increase was measured as 0.037 mm, and the inner diameter changes remained within the tolerance range specified in the part design.

Figure 16

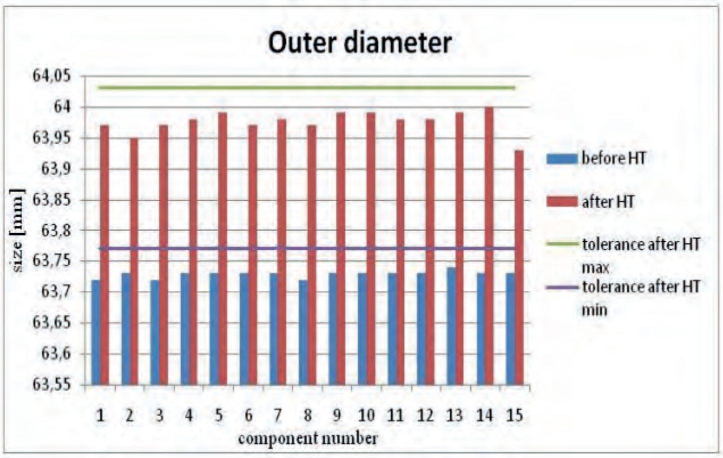
Changes in bearing inner diameters before and after heat treatment (Vicen et al., 2018)



In Figure 17, the outer diameter measurements before heat treatment are shown in blue and are in the range of 63.72-63.74 mm, while the outer diameter measurements after heat treatment are shown in red and are in the range of 63.95-64.00. The maximum change in the outer diameter was measured as 0.27 mm, while the minimum change was measured as 0.2 mm. The average outer diameter change after heat treatment was calculated as 0.247 mm, and the changes in the outer diameter remained within the tolerance range determined in the design of the part. The fact that the average change in the inner diameter was 0.037 mm and the outer diameter was 0.247 mm shows that the heat treatment has quite different effects on the dimensions of the part depending on its regions.

Figure 17

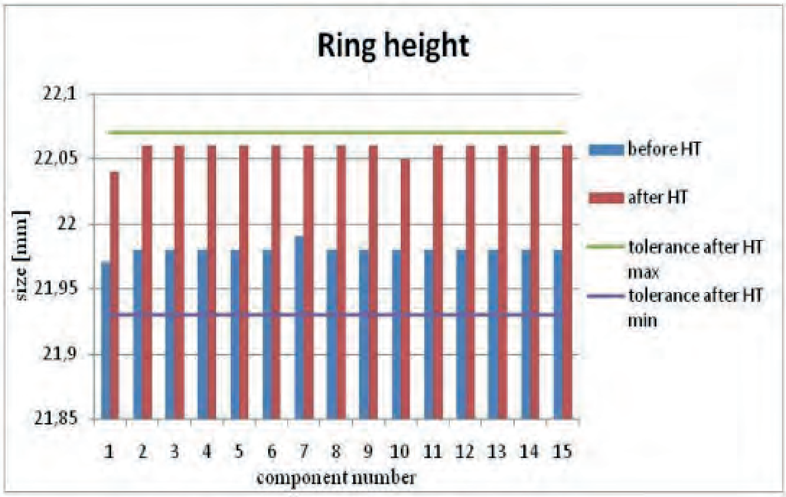
Changes in bearing outer diameters before and after heat treatment (Vicen et al., 2018)



In Figure 18, before heat treatment, the widths of 15 samples were measured as 21.97 mm for only the 1st piece and 21.99 mm for the 7th piece, while the other samples were measured as 21.98 mm. The smallest and largest changes in width were measured as 0.07 and 0.08 mm. The average width increase after heat treatment was calculated as 0.078 mm, and the dimensional change in width remained within the tolerance range determined in the design of the part.

Figure 18

Changes in bearing heights before and after heat treatment (Vicen et al., 2018)



In the study conducted by Vicen et al. (2018), it was stated that the dimensional changes after the treatment process remained within the tolerance. The study did not clearly explain to what extent the size increase in the heat treatment varies according to the geometry or to what extent the size changes in the inner and outer diameters depend on factors such as wall thickness.

In order to enrich the studies on the subject in the literature, the authors applied gas nitriding process to 6 parts made of AISI 4140 steel, the shape and design dimensions of which are shown in Figure 19, under the conditions shown in Table 5. The head parts were measured before and after the nitriding process and the measurement results are given in Table 6. The measurements were carried out with an Insize brand 3109-25A model micrometer with a precision of 0.001. The micrometer used for the measurement is calibrated in TSE-approved calibration laboratories at regular intervals of 6 months. The measurement environment is at a constant temperature of 22°C. The measurements before and after nitriding were made 3 times and the values in the table were read the same in each measurement.

The manufacturing dimensions of the part are as in the technical drawing in Figure 19 and are also given as nominal dimensions in Table 6.

Figure 19

Part made of 4140 material subjected to nitriding process

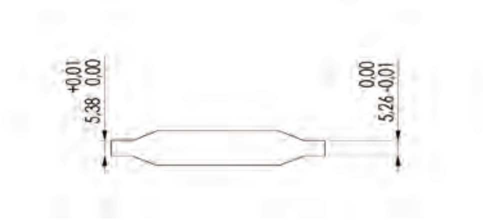


Table 5
Nitriding process conditions

Temperature [°C]	Time [saat]	Atmosphere
565°C	3 saat	NH_3

Table 6
Measurements before and after nitriding

Part Num	Pre-Nitriding Value	Value after Nitriding
Nominal Size	(5,38), (5,26)	
1	(5,363), (5,238)	(5,374), (5,248)
2	(5,364), (5,236)	(5,371), (5,24)
3	(5,365), (5,233)	(5,37), (5,245)
4	(5,364), (5,231)	(5,373), (5,241)
5	(5,362), (5,235)	(5,372), (5,25)
6	(5,351), (5,232)	(5,364), (5,243)

As a result of the values read, the maximum increase in the 5.38 dimension was 0.013 mm in piece number 6, and the minimum increase was 0.005 mm in piece number 3. The maximum size increase in the 5.26 dimension was 0.015 mm in piece number 5, and the minimum size increase was 0.004 mm in piece number 2. The average size increase in the 5.38 dimension of the 6 pieces was calculated as 0.009 mm, and the average size increase in the 5.26 dimension was calculated as 0.01 mm. From this result, it was seen that even if there was no possibility of thermal distortion, an average dimensional change of around 0.01 mm occurred in a wall thickness of around 5 mm due to the effect of nitrides formed in the material by nitrogen atoms diffusing from the surface of the piece after the nitriding process. In order to more comprehensively address the effect of wall thickness, a convex or concave geometric form, and size on the change in size of the nitriding process, it is necessary to prepare samples of different sizes, different wall thicknesses, and different geometries and monitor the change in dimensions with the nitriding process.

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Interaction between Mechanical Surface Treatment and Tribological Performance in Sliding Bearings

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Introduction

Bearing elements are one of the most critical parts of machine construction in assembly, maintenance, selection, and operation. Bearing elements, divided into sliding and rolling bearings based on sliding and rolling friction, ensure that radial and axial loads are carried safely. Increasing the wear resistance and load-carrying capacity of bearings, which are exposed to friction and wear due to their function as load-carrying elements, is important for the efficiency of enterprises from a micro perspective and for the efficient use of natural resources from a macro perspective.

Rolling bearings are generally not exposed to catastrophic friction and wear because they are exposed to rolling friction, and their lifespan can be calculated approximately depending on the load they carry. However, in sliding bearings, dry, semi-liquid, and liquid friction zones are formed on the cooperating surfaces until the nominal regime speed is reached, and especially in the semi-liquid zone, friction occurs that is severe enough to result in shaft-bearing adhesion. Accordingly, improving the wear resistance of sliding bearings with material (alloy development), lubrication, and geometry-oriented solutions is necessary for efficiency, quality, and sustainable use. In addition, the design, operation, and lubrication of sliding bearings pose severe difficulties in terms of both solid mechanics and fluid mechanics. However, changing the sliding bearing design is a situation that requires a long process to bring the new design to optimum functionality and to spread its industrial use. For this reason, it is essential to use advanced lubricants in terms of mechanical surface treatments and tribological performance to increase the efficiency of sliding bearings in the current design.

The most important problem in mechanical elements, which consist of components in relative motion, is wear and fatigue performance. Depending on the continuity of the movement, wear mechanisms occur at the delamination level, and fatigue-related deformations result from repeated stresses caused by dynamic loads acting on the bearing material in the long term. The main reason for the wear and fatigue mechanisms occurring in mechanical parts is the exposure of synchronously operating parts to friction. Dry and semi-fluid friction processes between the shaft and the bearing material create roughness on the material surfaces in hydrodynamic sliding bearings. The geometrically and dimensionally uncontrolled increase in roughness leads to the formation of catastrophic wear mechanisms and a shortening of the fatigue life. Within the scope of the study, it was predicted that wear would be minimized and fatigue life could be increased by creating controlled surface roughness through the shot peening process. In the shot peening process, the kinetic energy of the shots acts on the material as impact energy, and this energy transfer causes tensile stress in zones close to the surface, creating pits in convex geometry. As a result of the repeated impact of the balls, the convex pits tend to expand, and the effect of these stresses is tried to be prevented by the compressive stresses formed in the subsurface region. This situation causes residual compressive stress formation in the subsurface region (Han et al., 2020; Qian et al., 2023; Soyama et al., 2021; Can Wang et al., 2023). In addition, repeated impacts on the material cause grain refinement in the material's microstructure. This situation makes dislocation movement difficult and causes stress concentration at the grain boundaries (Fu et al., 2013; Hou et al., 2023; Z. Wang et al., 2023). Residual compressive stress and stress concentration reduce the propagation rate of cracks caused by fatigue and wear (Maleki et al., 2021).

Lubricant performance is one of the most critical factors in minimizing friction between the bearing and shaft in hydrodynamic sliding bearings. The thermophysical properties of the lubricant and its chemical interaction with the bearing material are of great importance in terms of uncontrolled roughness increase and the resulting increased deformation. Recently, the lubrication and cooling performance of metallic nanoparticle-reinforced lubricants in mechanical systems that move synchronously and are subject to friction has attracted attention. The most important problem in systems in relative motion is the high heat generation at the micron level occurring in the friction zone. The increasing heat with the continuity of the movement causes the shaft and the bearing material to stick and, depending on this, the formation of wear mechanisms.

Especially in sliding bearings, the sliding movement without sticking between the bearing and shaft must be at an acceptable level (5%-30%) (Klebanov et al., 2022). For this reason, a lubricant prepared with nano-sized silver metal in a spherical geometry with the highest heat transfer coefficient was preferred within the scope of the study. The nano size of silver particles increases the surface area. In this way, the nanosilver-added lubricant affects a larger surface area and minimizes the increased heat in the friction area more effectively. Silver nanoparticles obtained in spherical geometry are colloidally stable and reduce the contact area by rolling motion in the friction region (Cetin et al., 2020; Cetin & Korkmaz, 2020; Korkmaz et al., 2024). In this way, the roughness caused by friction is reduced, and deformation is minimized. However, in hydrodynamic sliding bearings, when the clearance between the shaft and the bearing material is not sufficient, the lubricant between the shaft and the bearing material continues to move in the form of turbulent flow, and this negatively affects the tribological performance of the lubricant (Niu et al., 2022). The distance between the shaft and the bearing material must be sufficient for the lubricant to provide the expected tribological performance. The turbulent flow that occurs when the clearance between the shaft and bearing material decreases causes the lubricant to heat up more and reduces the lubricant's viscosity. This reduces the thickness of the tribo-film layer formed by the lubricant, increasing the contact area of the shaft-bearing material and increasing friction.

It has been stated in the literature that partially rough surfaces in the sinusoidal waveform increase the load-carrying capacity and reduce the friction coefficient (Félix Quiñonez & Morales-Espejel, 2016; Niu et al., 2022). The original value of this study is the investigation of the collective effect of the shot peening process and nano silver-added lubricant on the tribological performance of hydrodynamic sliding bearings. It is thought that the convex geometry of the pits formed in the bearing material, thanks to the shot peening process, will prevent the thinning of the tribo-film layer by increasing the distance between the shaft and the bearing material. Additionally, it is anticipated that the lubricant will spread more rapidly by filling the pits created by the shot peening process, increasing the penetration of the nanoparticles. Within the scope of the study, optimum shot peening and wear parameters were investigated by experimental and statistical analysis methods to improve the tribological performance of sliding bearings.

Material and Methods

Tin bronze is used in hydrodynamic sliding bearings due to its ability to embed abrasive particles, high wear, and corrosion resistance, solid lubrication ability, and compatibility with steel shafts (Babu et al., 2015; Nascimento et al., 2021; Zeren et al., 2007). However, the low fatigue strength and hardness of tin bronze limit its use (Babu et al., 2015; Feyzullahoğlu & Şakiroğlu, 2010; Mathavan & Patnaik, 2016; Nascimento et al., 2021). Considering the mentioned disadvantages, it is predicted that the fatigue strength and hardness of tin bronze will be increased by the shot peening process.

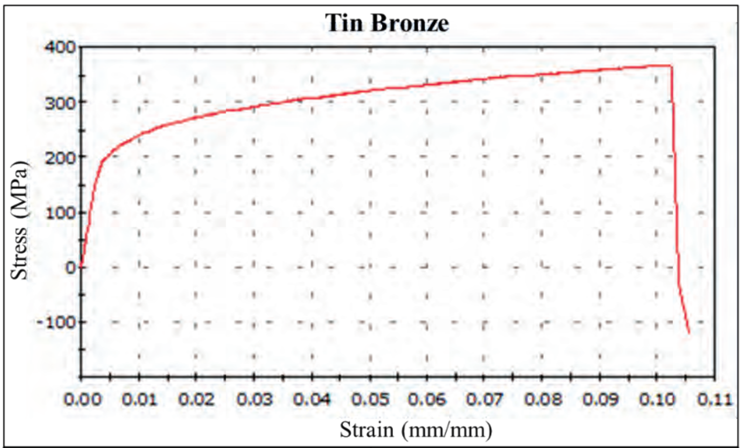
The chemical composition of the tin bronze used in the study is given in Table 1, and the tensile test results are presented in Figure 1.

Table 1

Chemical composition of tin bronze (wt-%)

Material	Cu	Zn	Al	Pb	Ni	Fe	Mn	Sn	P
CuSn12	87.05	0.40	0.05	0.35	0.65	0.05	0.15	11.20	0.10

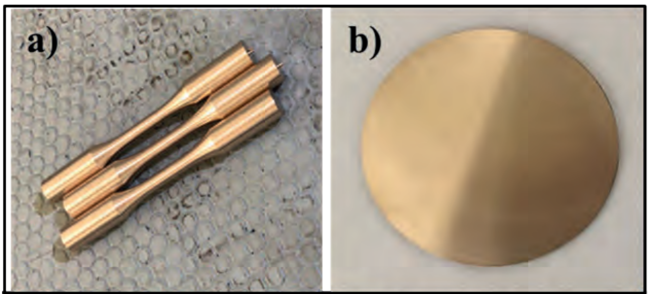
Figure 1
Tensile test results of tin bronze material



Tensile Stress	Elongation
365.69 MPa	10.13%

Samples prepared for the fatigue test (ASTM E-466) and wear test are given in Figure 2.

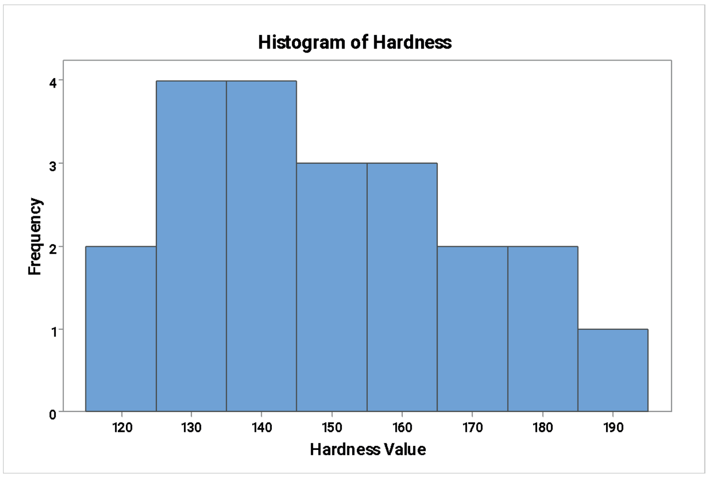
Figure 2
Fatigue and wear test specimens



Diameter: 16 mm **Length :** 150 mm	**Diameter:** 60 mm **Thickness:** 2 mm

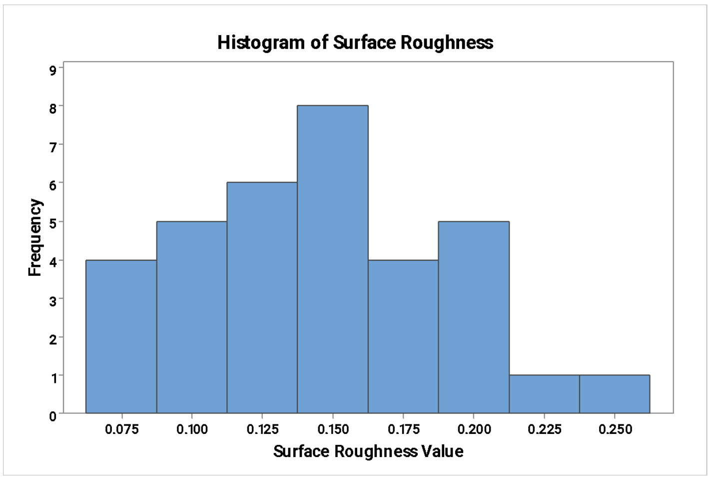
The average of the values obtained as a result of the hardness measurements of the tin bronze samples (QNESS Q250M Vickers hardness tester, 0.5 kg load, 15 s duration, three repetitions) was determined as 149.52 HV, and the standard deviation value was determined as 20.8. This result shows that 68.26% of the hardness values obtained are 149.52 ± 20.8 (±1σ). The histogram graph obtained for data distribution analysis is given in Figure 3. According to Figure 3, the data shows normal distribution behavior. This indicates that the hardness values of the samples are close. These results determined that the tin bronze samples were homogeneous in terms of hardness distribution and could be used safely for wear and fatigue tests.

Figure 3
Histogram graph of hardness values of tin bronze samples



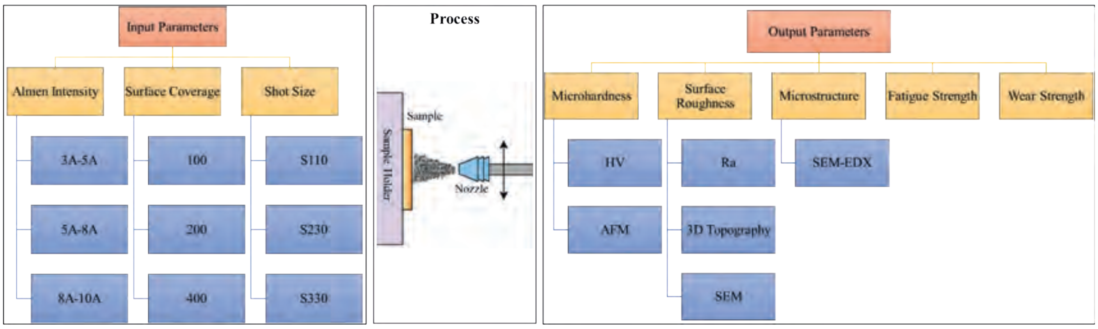
The average of the surface roughness measurements of tin bronze (Portable Surface Roughness Tester (SJ-410 Series)) was determined as 0.139 µm. The standard deviation value was determined as 0.0503. This result shows that 68.26% of the surface roughness values obtained are in the value range of 0.139 ± 0.0503. The histogram graph obtained for data distribution analysis is given in Figure 4. According to Figure 4, the data shows normal distribution behavior. This situation indicates that the surface roughness values of the samples are close. The values obtained are within the acceptable deviation range in terms of surface roughness and wear test.

Figure 4
Histogram graph of surface roughness values of tin bronze samples



The schematic picture of the shot peening process and the parameters determined for the process are given in Figure 5. The parameters were determined by taking into account literature studies.

Figure 5
Schematic picture of the shot peening process



The experimental design was created using Taguchi's L9 fractional factorial approach with the determined parameters, and the resulting experimental design is given in Table 2. Since Taguchi's experimental design was used, statistical analyses were performed according to signal/noise (S/N) and Taguchi's optimization equations.

Table 2
Experimental design for shot peening process

Experiment No	Almen Intensity	Surface Coverage	Shot Size
1	3A-5A	100	S330
2	3A-5A	200	S230
3	3A-5A	400	S110
4	5A-8A	100	S230
5	5A-8A	200	S330
6	5A-8A	400	S110
7	8A-10A	100	S330
8	8A-10A	200	S110
9	8A-10A	400	S230

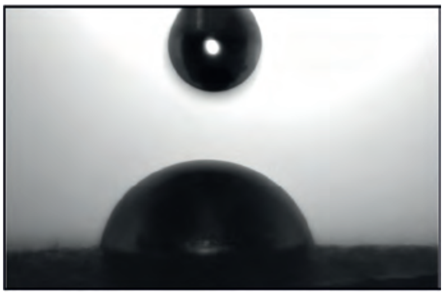
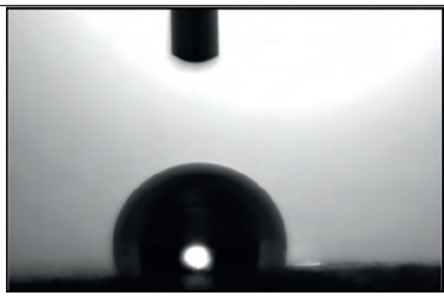
Fatigue tests were carried out on a rotary bending testing machine. The fatigue testing machine and the parameters considered for the fatigue test are given in Figure 6.

Figure 6
The fatigue testing machine and the parameters

Experimental Device Features
Power: 2 kW Rotation: 1500 rpm
Experiment Parameters
Dynamic stress ratio: R=-1 Dynamic stress : 120 MPa

Detailed information on nano-silver synthesis and characterization is given in the literature (Korkmaz et al., 2024). The nanoparticles used in the study have an average diameter of 20 nm and a spherical morphology. The wettability behavior of the lubricant obtained with nano-silver added to the sliding bearing surface was investigated by measuring the wetting angle (Figure 7). According to Figure 7, the wettability angles on the sliding bearing surfaces with minimum and maximum surface roughness were obtained as 83.991° and 108.701°, respectively. It has been determined that surfaces with increased roughness by being peened with high Almen intensity have a negative effect on the minimization of the wettability angle.

Figure 7
Wettability analysis results of nano-silver added lubricant

The condition with the lowest surface roughness (Sa=5.15 µm) 3-5A 200% S230	The condition with the highest surface roughness (Sa= 8.78 µm) 8-10A 400% S230
 **Wettability Angle: 83.991°**	 **Wettability Angle: 108.701°**

In the experiments, the ball-on-disc test was performed for wear characterization. 20 N load, 95 rpm speed, three different lubrication conditions (dry, pure water and pure water + 2% nanoparticles) and 1000 m wear distance were considered as input parameters. Friction coefficient, weight loss, and surface roughness parameters were analyzed as output parameters. 100Cr6 ball with 64 HRC hardness was used in the experiments.

Results and Discussion

Shot Peening Results

Surface Roughness Results

The surface roughness values (Sa) were measured using a 3D topography device for tin bronze after the shot peening process, and the results are given in Table 3. According to Table 3, the lowest surface roughness value (5.15 µm) was obtained with 3A-5A Almen intensity, 200% coverage, and S230 shot size. In comparison, the highest surface roughness value (8.78 µm) was obtained with the experimental combinations of 8A-10A Almen intensity, 400% coverage, and S230 shot size parameters.

Table 3
Surface roughness values obtained for tin bronze

Exp. No	Almen Intensity	Surface Coverage	Shot Size	Surface Roughness (µm)
1	3A-5A	100	S330	5.37
2	3A-5A	200	S230	5.15
3	3A-5A	400	S110	5.92
4	5A-8A	100	S230	6.67
5	5A-8A	200	S330	6.84
6	5A-8A	400	S110	7.67
7	8A-10A	100	S330	8.15
8	8A-10A	200	S110	8.36
9	8A-10A	400	S230	8.78

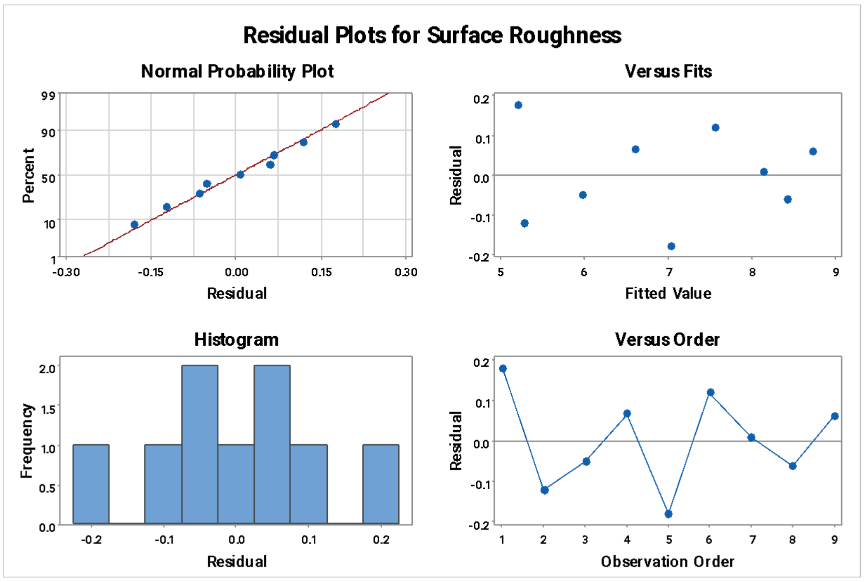
The effects of Almen intensity, coverage, and shot size parameters determined for the shot peening process on the surface roughness were analyzed by the ANOVA method, and the results are given in Table 4. According to Table 4, it was determined that the Almen intensity parameter (95.07%) was the most effective parameter for surface roughness. Coverage and shot size parameters affect the surface roughness by 4.14% and 0.54%, respectively. These impact rates are negligible compared to the Almen intensity. It is seen that the coverage parameter is at the borderline statistical significance level ($p=0.057\geq0.05$). It was determined that the shot size ($p=0.319>0.05$) parameter was not statistically significant in terms of surface roughness because the "p" values were greater than 0.05. The obtained "p" values are consistent with the effect ratios. In addition, the R-Sq (adj) value obtained with ANOVA was determined, and the ability of the input parameters to explain the surface roughness was analyzed, and this value was obtained at 99.02%. A value above 70% indicates that the explanatory ability is high (Cetin et al., 2011; Cetin & Korkmaz, 2020; Korkmaz et al., 2024).

Table 4
ANOVA results for tin bronze

Source of variance	Degree of freedom (DF)	Sum of squares (SS)	Mean squares (MS)	F Ratio (α=5%)	P value	Effect Rate (%)
Almen Intensity	2	13.0758	6.53790	377.04	0.03	95.07
Surface Coverage	2	0.5685	0.28426	16.39	0.057	4.14
Shot Size	2	0.0741	0.03703	2.14	0.319	0.54
Error	2	0.0347	0.01734			0.25
Total	8	13.7531				100
Significance	**R-Sq= 99.76%**			**R-Sq(adj)= 99.02%**		

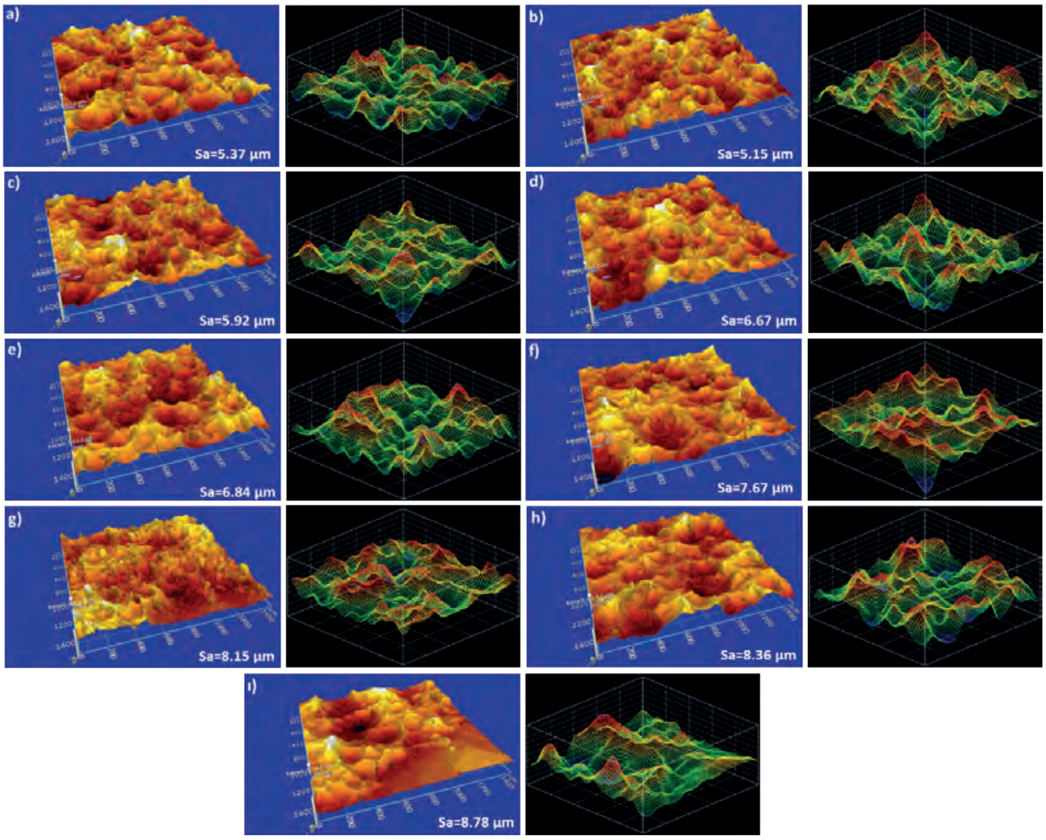
To increase the reliability of the R-Sq (adj) value obtained as a result of the ANOVA analysis, normal probability graphs, histogram graphs, and scatter graphs were obtained by the regression method (Figure 8). In the normal probability graph, it is seen that the data is concentrated on the linear line, and the amount of deviation of the data not on the line is negligible. It is seen that the data distribution conforms to the normal distribution curve behavior in the histogram graph, and this shows that the data is distributed homogeneously. In scatter plots, it is seen that the data is close to the "zero" line, and there are a few insignificant data.

Figure 8
Regression graphs for surface roughness



The interaction between the shot peening process and surface morphology was investigated with 3D topography images. The red tone indicates intense roughness, while the yellow tone indicates low roughness in the images. Figure 9 shows that as the parameter levels increase, the roughness values increase between 2% and 10%, and there is a 70% increase between the minimum and maximum roughness values. Accordingly, as the parameter levels increased, the red tone increased, and the yellow tone decreased. According to the ANOVA results in Table 4, the Almen density is the main parameter that increases the roughness.

Figure 9
3D topography images after shot peening process



The effect graph was obtained with the help of the Minitab program to analyze the effect of the change in input parameters on the change in surface roughness, which is given in Figure 10. According to Figure 10, the surface roughness increases as the Almen intensity increases. The increase in the kinetic energy acting on the surface due to the increase in Almen density increases the plastic deformation. The pits formed due to the increase in plastic deformation increase the curve height and roughness. As the coverage increases from 100% to 200%, the surface roughness increases to negligible.

The surface quality deteriorated to a great extent when the coverage increased from 200% to 400%. When the coverage on the material surface increases to 400%, the increase in roughness can be explained by the stress relaxation effect. The stress relaxation that occurs with the increase in coverage can be partially likened to the Bauschinger effect (Zhang et al., 2020). The yield strength that occurs when stress is applied in the opposite direction to the stresses occurring on the material surface is lower than the initial yield strength. This causes the plastic deformation at 400% coverage to be higher than 100% and 200%. It is observed that as the shot size increases, the surface roughness decreases. Depending on the increase in ball diameter, the width of the pits formed on the surface also increases. This reduces the amount of roughness. The physical effect of the shot size on the surface is seen in the SEM images given in Figure 11.

Figure 10
Effect graph for surface roughness

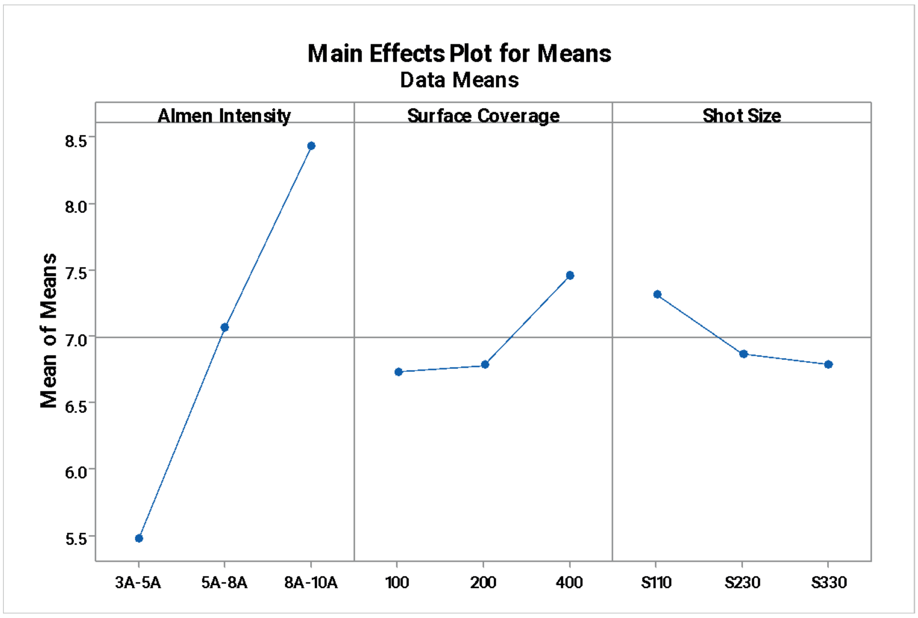
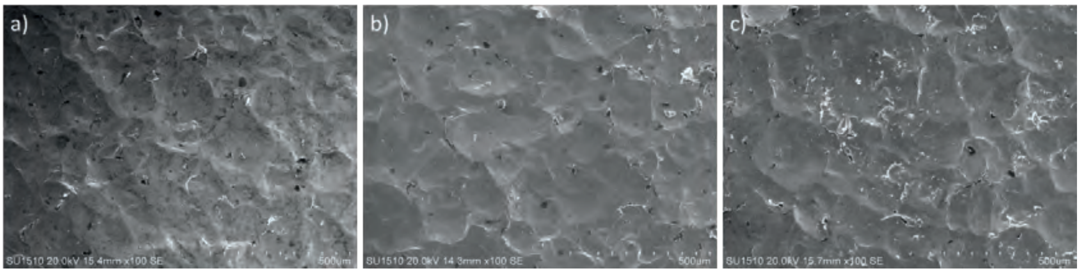


Figure 11
SEM images of shot peened tin bronze a) 3-5A b)5-8A c) 8-10A



The optimum parameters for maximizing the surface roughness were obtained using the S/N graph, and the results are given in Figure 12. According to Figure 12, the optimum parameters for Almen intensity, coverage, and shot size were determined as 8-10A, 400%, and S330, respectively. The obtained optimum parameters can be explained by the energy balance of the shot peening process. The plastic deformation on the surface increased as the momentum effect (pressure and peening time) created by the balls hitting the surface increased, and, accordingly, the surface roughness increased. In addition, the energy accumulated on the surface negatively affected the interatomic bond forces and lattice structures in the nano-sized layers from the outer surface of the material to the inner, causing an increase in surface roughness. According to S/N, 3-5A Almen intensity, 100% coverage, S330 shot size were determined as the parameters where the surface roughness was minimum, 5-8A Almen intensity, 200% coverage, S230 shot size were determined as the parameters where the nominal surface roughness was maximum, 8-10A Almen intensity, 400% coverage, S110 shot size were determined as the parameters where the surface roughness was maximum. The AFM images in Figure 13 confirm the parameters defined for minimization, nominal, and maximization. As the amount of energy acting on the surface increases, the increase in roughness at the nanoscale is seen in Figure 13.

Figure 12
S/N graph for surface roughness

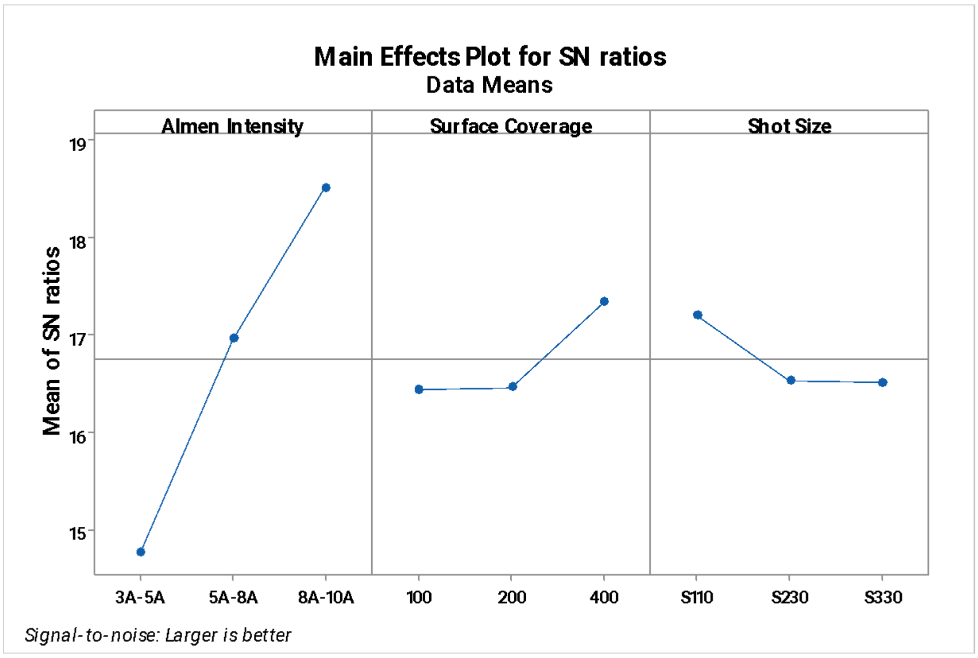
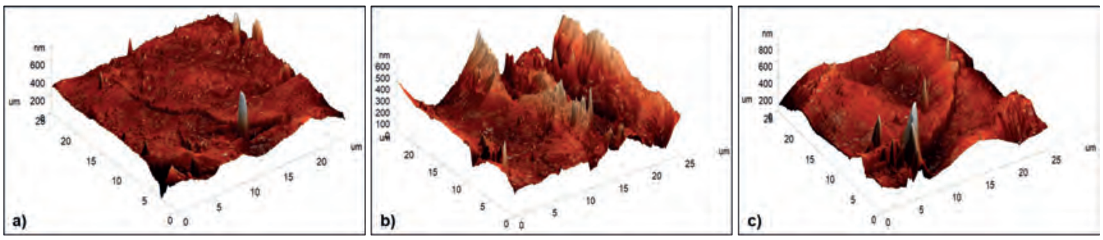


Figure 13
AFM images for surface roughness a) 3-5A b)5-8A c)8-10A



Hardness results

The shaft material is harder than the bearing material in the sliding bearing process, causing the bearing material to wear. For this reason, the hardness of the bearing materials must be investigated. Within the scope of the study, the hardness values (HV) of the bearing materials subjected to the shot peening process were measured, and the results obtained are given in Table 5. According to Table 5, the highest hardness value (299.780 HV-30 HRC) was obtained at 8-10A Almen intensity, 400% coverage, and S230 shot size parameters, the lowest hardness value (255.225 HV-23 HRC) was obtained at 3-5A Almen intensity, 100% coverage, and S330 shot size parameters. Considering the hardness values (~40-50 HRC) of shaft materials used in the industry, it can be claimed that the hardness values obtained by shot peening are at a significant and acceptable level for shaft-sliding bearing compatibility. For this reason, maximization was considered the target function in the hardness values obtained by shot peening.

Table 5

Hardness values of tin bronze subjected to shot peening process

Exp. No	Almen Intensity	Surface Coverage	Shot Size	Hardness (HV)
1	3A-5A	100	S330	255.225
2	3A-5A	200	S230	262.450
3	3A-5A	400	S110	276.600
4	5A-8A	100	S230	262.050
5	5A-8A	200	S330	274.360
6	5A-8A	400	S110	280.050
7	8A-10A	100	S330	285.287
8	8A-10A	200	S110	292.476
9	8A-10A	400	S230	299.780

A quantitative analysis of the effect of the determined input parameters on the hardness parameter was carried out using ANOVA, and the results obtained are given in Table 6. According to Table 6, the effect rates of Almen intensity, coverage, and shot size parameters on the hardness parameter were determined as 79.69%, 18.57%, and 0.9%, respectively. The statistical significance of the Almen intensity ($p=0.010<0.05$) and coverage ($p=0.043<0.05$) parameters and the insignificance of the shot size ($p=0.482>0.05$) support the obtained effect ratios. R-Sq(adj) value was obtained to analyze the ability of the determined input parameters to explain the hardness change. The obtained value of 97.01% (>70%) shows that the determined parameters have a high ability to explain the change in hardness. The histogram and normal distribution graphs in Figure 14 confirm the statistical and physical significance between the input and output parameters. The minimum level of residual values (maximum 4) in the regression graph and the compatibility of the histogram graph with the Z test graph show the high compatibility of the physical relationship between the input and output parameters selected for shot peening.

The change in the Almen intensity and shot size parameters creates a change in the kinetic energy level created in the material by the impact. Obtaining the Almen intensity by interacting with the pressure and time parameters increases the effect rate. In addition, the high physical and statistical significance of Almen intensity on the hardness parameter reduces the effect of shot size. This explains the statistically low significance of shot size in terms of hardness.

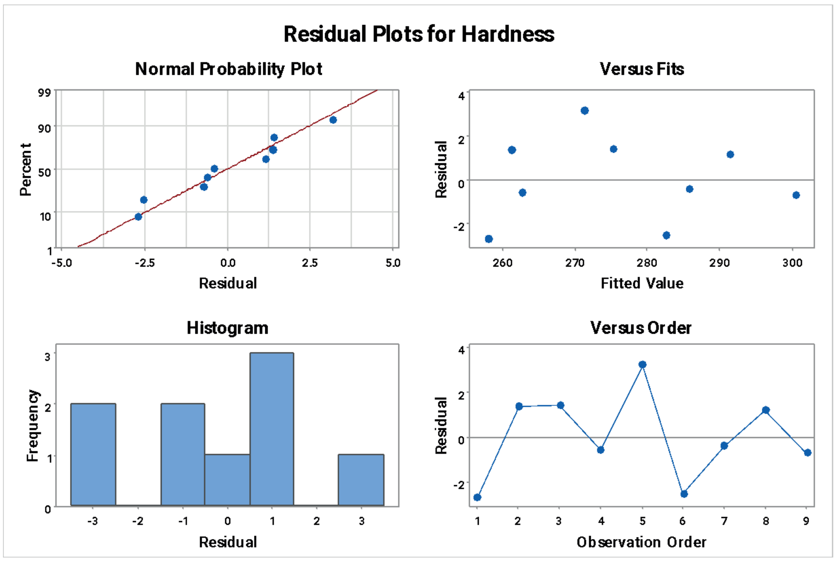
Table 6

ANOVA results for hardness values of tin bronze

Source of variance	Degree of freedom (DF)	Sum of squares (SS)	Mean squares (MS)	F Ratio (α=5%)	P value	Effect Rate (%)
Almen Intensity	2	1239.65	619.826	94.88	0.010	79.69
Surface Coverage	2	288.91	144.453	22.11	0.043	18.57
Shot Size	2	14.07	7.033	1.08	0.482	0.9
Error	2	13.07	6.533			0.84
Total	8	1555.7				100
Significance	**R-Sq= 99.25%**			**R-Sq(adj)= 97.01%**		

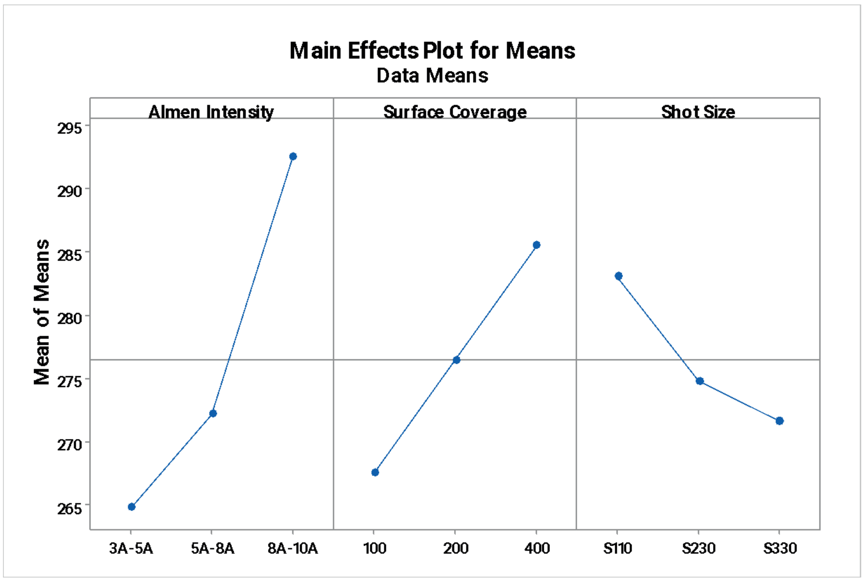
Figure 14

Regression graphs for hardness values



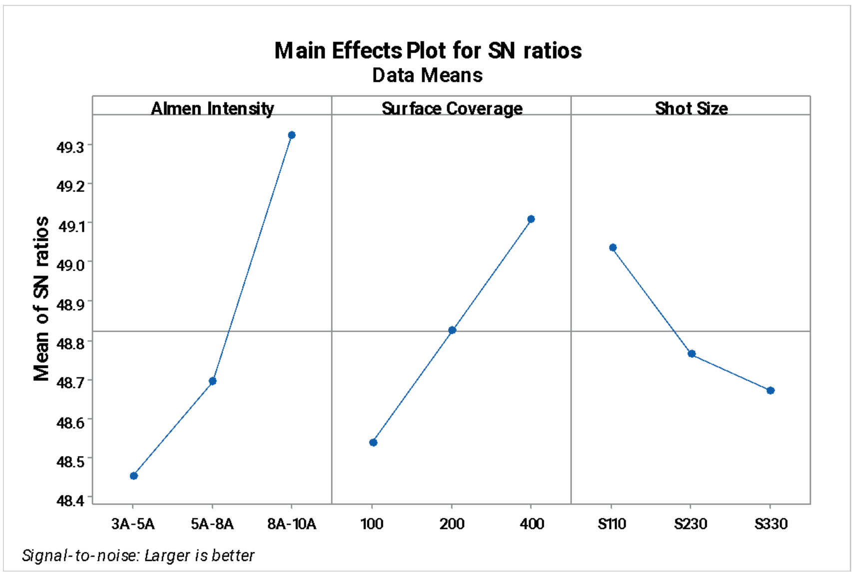
The influence graph in Figure 15 is given to analyze the effect of the change in the Almen intensity, coverage, and shot size parameters on the hardness. Figure 15 shows that as the Almen intensity and coverage increase, the hardness increases, and as the shot size increases, the hardness decreases. The energy transferred to the material increases as the Almen intensity and coverage increase, resulting in grain breakage and the grain size decrease. In addition, the layer thickness that undergoes plastic deformation increases due to the effect of energy. The specified conditions increase the hardness of the material. The decrease in hardness value with increasing shot size can be explained by the Hall-Petch behavior occurring in the internal structure (AlMangour & Yang, 2016; Hou et al., 2023; Chengxi Wang et al., 2016). The grain size decreases as the shot size increases, and this increases the grain boundaries. Increased grain boundaries create an obstacle to the movement of dislocations formed between the planes, increasing the yield strength of the material and making plastic deformation more difficult. However, when the grain size is smaller than a specific value (10-20 nm), reverse Hall-Petch behavior occurs, and atomic sliding motion occurs instead of planar sliding at the grain boundaries. This situation facilitates planar sliding and accelerates plastic deformation. It is thought that when a ball with a diameter larger than the S110 shot size is used, the grain size reaches smaller values than expected, and therefore, the hardness of the material decreases.

Figure 15
Effect graph for hardness



The optimum parameters for maximizing and minimizing the hardness of the tin bronze material were determined using the S/N graph, and the results are given in Figure 16. According to Figure 16, the optimum parameters for maximizing the hardness were determined as 8-10A Almen intensity, 400% coverage, and S110 shot size parameters, and the optimum parameters for minimizing the hardness were determined as 3-5A Almen intensity, 100% coverage, and S330 shot size.

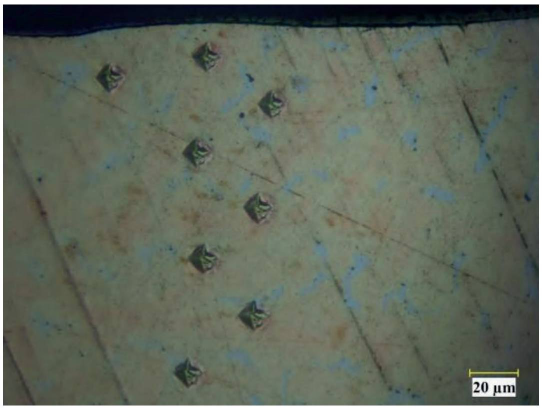
Figure 16
S/N graph for hardness values



Metallographic Analysis of Shot Peening Process and Fatigue Test Results

Shot peened samples were subjected to grinding, polishing, and etching for the metallographic process. After polishing, the microhardness (HV) values of the sample sections were measured (Figure 17). As a result of the measurements made at approximately 20 µm intervals, it was determined that the central hardness of the tin sample was 200 HV, and the subsurface hardness was 260 HV - 280 HV, proportional to the Almen intensity. The hardness value of 280 HV measured on the surface decreased to 200 HV at a distance of 260 µm from the material surface towards the core.

Figure 17
Traces of microhardness measurement performed on the sample section



Subsurface grain orientation and color differentiation are seen in the images given for tin bronze in Figure 18 (optical microscope), Figure 19 (SEM), and Figure 20 (SEM). It is seen that the discernibility of the tin spectrum decreases in the EDX images given in Figure 21. In general, it can be said that the spectral responses of low-strength alloy elements decrease with the shot-peening process.

Figure 18
Micrograph obtained from the sample section for the lowest Almen intensity (Sn-3 test) condition

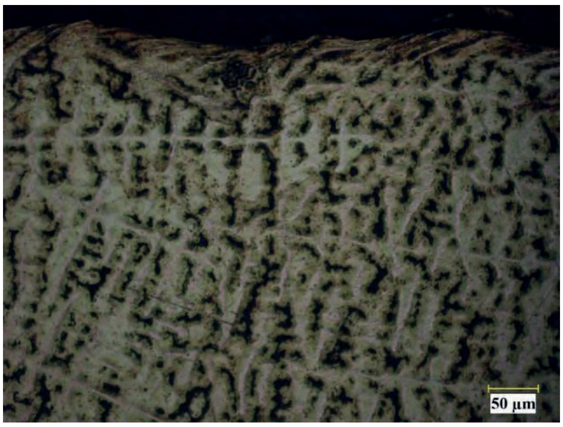


Figure 19
SEM image obtained from the sample cross section for the highest Almen intensity (Sn-10 test) condition

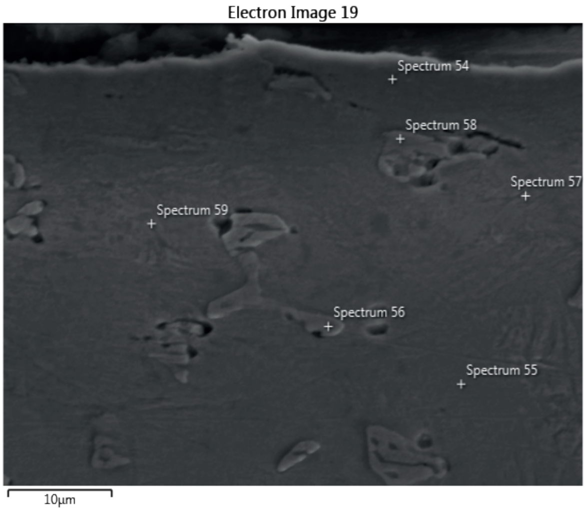


Figure 20
SEM image obtained from the sample cross section to obtain EDX for the highest Almen intensity (Sn-10 test) condition

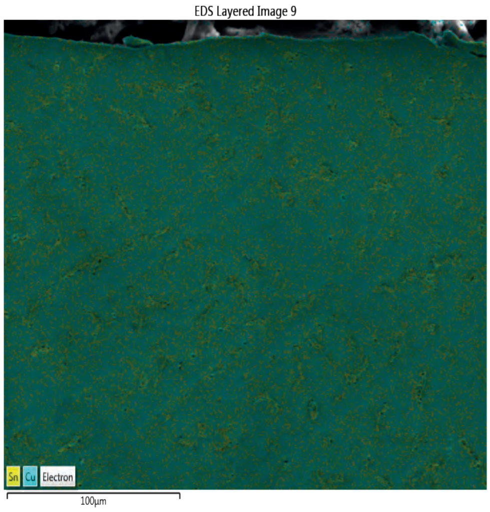
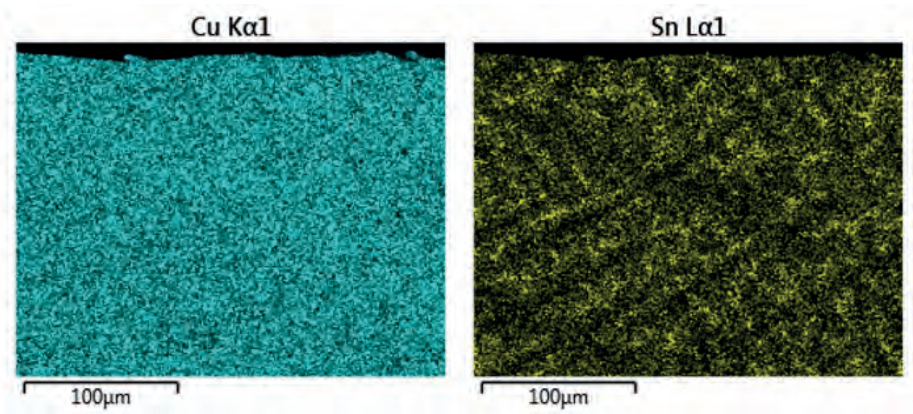


Figure 21
EDX mapping images obtained from the sample section for the highest Almen intensity (Sn-10 experiment) condition



According to micrographs, it was determined that hardness increase and residual stress formation occurred after the shot peening process in tin bronze. This situation was also mechanically confirmed by the fatigue test results. According to Table 7, it was determined that the fatigue strength of the tin bronze material could be increased by more than ~7 times with the shot peening process. This value reached 22 times in samples processed with low Almen intensity. Although the surface roughness values have increased with the shot peening process, the increase in fatigue strength also shows that the shot peening process increases the performance of sliding bearings.

Table 7

Fatigue test results

Exp. No	Almen Intensity	Surface Roughness	Fatigue Life
3	3-5A	5.92	875773 (±28000)
5	5-8A	6.84	542078 (±34000)
8	8-10A	8.36	243188 (±17000)
Unprocessed			38419 (±3500)

Wear Test Results of Shot Peened Tin Bronze

Coefficient of Friction

The ball-on-disc test was applied to the shot-peened samples to determine their tribological properties. The experimental results obtained for the coefficient of friction are given in Table 8.

Table 8

Coefficient of friction values

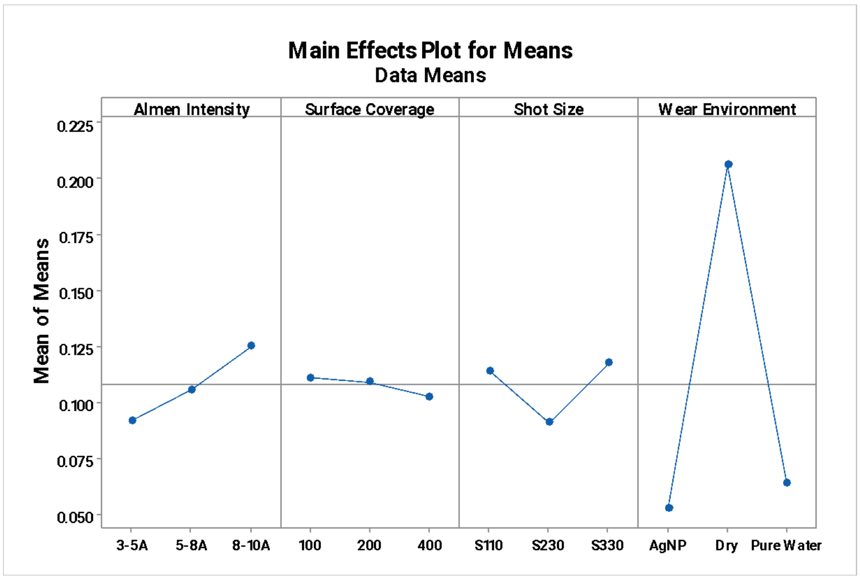
Exp. No	Almen Intensity	Surface Coverage	Shot Size	Wear Environment	Friction Coefficient
1	3-5A	100	S330	Dry	0.1980
2	3-5A	200	S230	Dry	0.1760
3	3-5A	400	S110	Dry	0.2030
4	5-8A	100	S230	Dry	0.1830
5	5-8A	200	S330	Dry	0.2050
6	5-8A	400	S110	Dry	0.2150
7	8-10A	100	S330	Dry	0.2210
8	8-10A	200	S110	Dry	0.2310
9	8-10A	400	S230	Dry	0.2220

10	3-5A	100	S330	Pure Water	0.0880
11	3-5A	200	S230	Pure Water	0.0200
12	3-5A	400	S110	Pure Water	0.0239
13	5-8A	100	S230	Pure Water	0.0600
14	5-8A	200	S330	Pure Water	0.0800
15	5-8A	400	S110	Pure Water	0.0420
16	8-10A	100	S330	Pure Water	0.1000
17	8-10A	200	S110	Pure Water	0.0950
18	8-10A	400	S230	Pure Water	0.0680
19	3-5A	100	S330	AgNP	0.0660
20	3-5A	200	S230	AgNP	0.0340
21	3-5A	400	S110	AgNP	0.0194
22	5-8A	100	S230	AgNP	0.0260
23	5-8A	200	S330	AgNP	0.0430
24	5-8A	400	S110	AgNP	0.1000
25	8-10A	100	S330	AgNP	0.0600
26	8-10A	200	S110	AgNP	0.0990
27	8-10A	400	S230	AgNP	0.0320

The effect graph obtained to determine the effect of Almen intensity, coverage, shot size, and different nano lubricants on the friction coefficient is given in Figure 22. According to Figure 22, as Almen intensity increases, the friction coefficient increases to 47%. With the increasing Almen intensity, the deterioration of the morphological structure caused more friction coefficient. The friction coefficient decreased by ~4% as the coverage value increased. The increasing hardness depth due to the increase in the coverage ensured the preservation of the surface form; thus, the friction coefficient decreased. There is no significant change between the change in shot size and the friction coefficient. When the effect of the lubrication conditions is analyzed, it is seen that the friction coefficient is at the average value in the pure water environment and the lowest value in the AgNP-reinforced lubricant environment. The friction coefficient decreased due to the formation of semi-liquid friction in the pure water environment. In the AgNP-reinforced lubricant environment, it can be said that the formation of the lubricating effect, in addition to the effect of pure water and the presence of a more durable tribofilm layer, significantly reduces the friction coefficient.

Figure 22

Main effect graph for friction coefficient



The optimum parameters for minimizing the friction coefficient are given in Figure 23. Figure 23 shows 3-5A Almen intensity, 400% coverage, S230 shot size, and AgNP-reinforced lubricant as optimum parameters. It is seen that 8-10A Almen intensity, 100% coverage, S330 shot size, and dry parameters cause the maximization of the friction coefficient, and 5-8A Almen intensity, 200% coverage, S110 shot size, and pure water parameters are nominal level experimental conditions. After the wear experiments were carried out under the worst, nominal and optimum experimental conditions in terms of minimizing the friction coefficient, SEM images obtained from the wear scar region were obtained, and the images are given in Figure 24. According to Figure 24, in the experimental condition where the friction coefficient is maximum (Figure 24 (a)), due to the high value of Almen intensity, the energy acting on the material is at a high level, and due to dry friction, severe plastic deformation has occurred on the surface of the material. Due to the adhesive wear mechanism that occurs due to the plastic deformation, delamination, and deep cracks have occurred on the surface. In the medium experimental condition (Figure 24 (b)), the surface has been deformed less due to the smaller size of the ball and the use of pure water compared to the worst environmental condition. In addition, it is seen that the fragmentation in the surface layer is at a lower level. In the optimum experimental condition, it is seen that more superficial wear mechanisms have formed and superficial channel-shaped traces have formed due to the formation of the abrasive wear mechanism. This situation can be explained by the formation of roughnesses at less depth due to the low Almen intensity and the repair feature of the AgNP-reinforced lubricant. Thanks to the completion of the pits and wear-induced deformation zones formed by the shot peening process with the AgNP-reinforced lubricant, the material surface is formed in a planar rather than wavy form. In addition, the force acting on the material decreases as the AgNP-reinforced lubricant forms a protective film layer, which minimizes the friction coefficient. The presence of silver particles in the EDX image obtained from the wear zone for the optimum condition supports this situation (Figure 25).

Figure 23
S/N graph for coefficient of friction

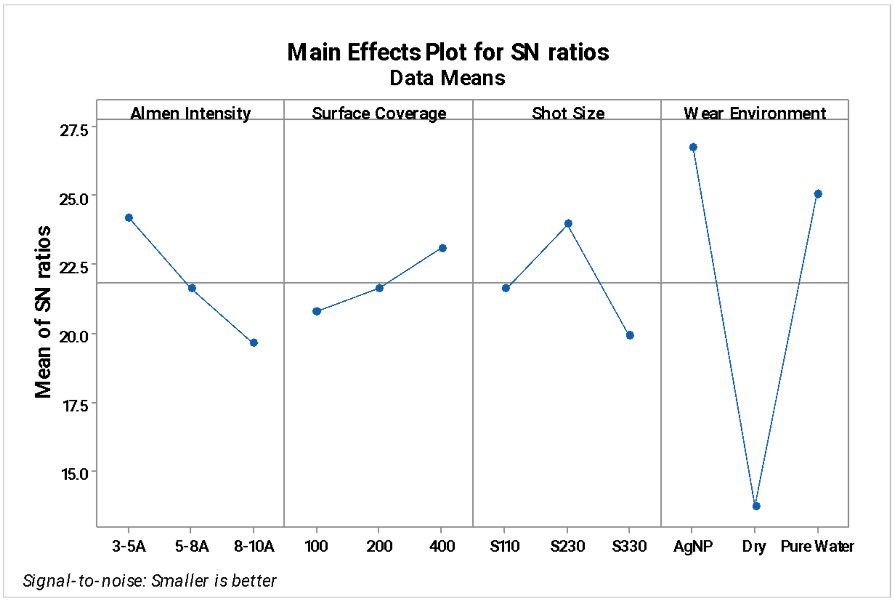


Figure 24
SEM images obtained from the wear scar

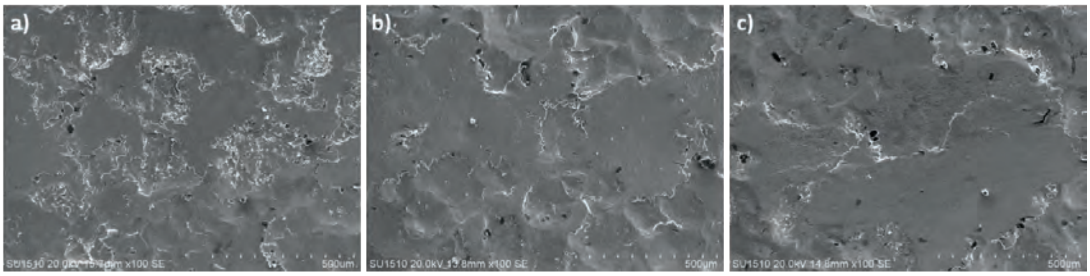
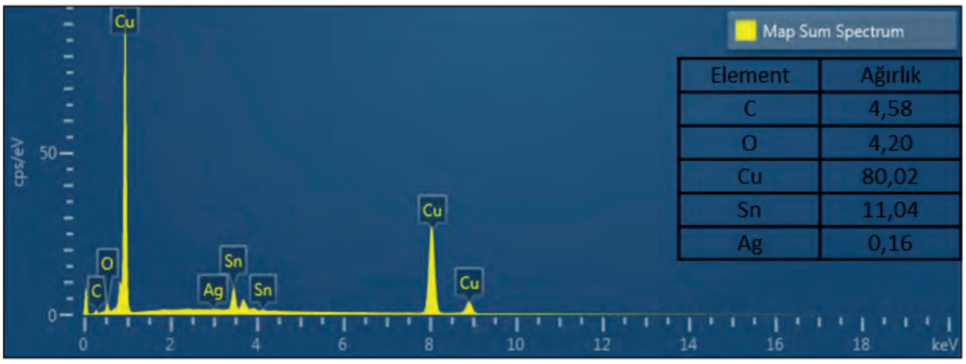


Figure 25
Elemental analysis results obtained from the surface of tin bronze



Weight Loss Results

Due to the heat generated by the friction effect, the material softens, and its strength decreases. This facilitates deformation and causes wear. Depending on the situation, the number of broken particles changes, and the weight loss analysis provides information about the size of the deformation. For this reason, the weight loss values were measured after the wear tests, and the results are given in Table 9.

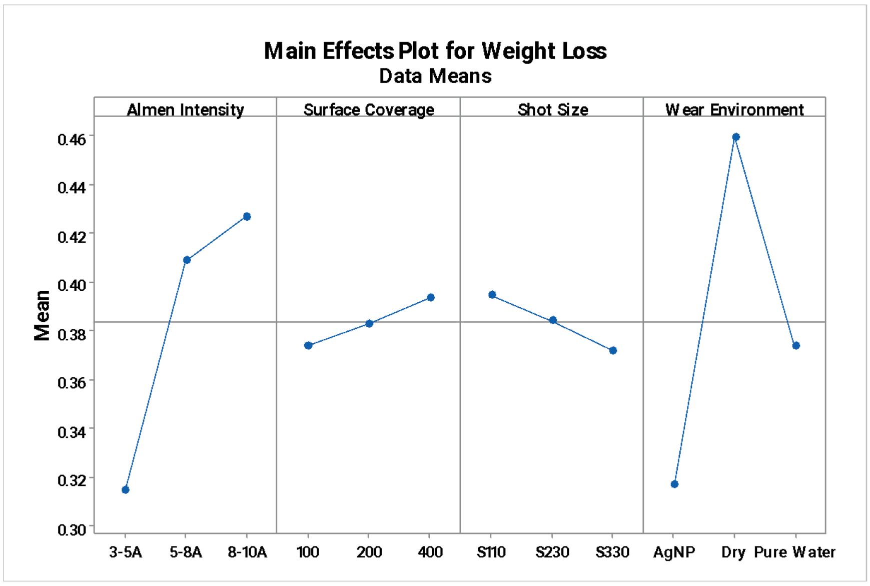
Table 9

Weight loss values obtained for tin bronze

Exp. No	Almen Intensity	Surface Coverage	Shot Size	Wear Environment	Weight Loss
1	3-5A	100	S330	Dry	0.385454
2	3-5A	200	S230	Dry	0.305251
3	3-5A	400	S110	Dry	0.402299
4	5-8A	100	S230	Dry	0.383657
5	5-8A	200	S330	Dry	0.501339
6	5-8A	400	S110	Dry	0.515056
7	8-10A	100	S330	Dry	0.520266
8	8-10A	200	S110	Dry	0.549737
9	8-10A	400	S230	Dry	0.573438
10	3-5A	100	S330	Pure Water	0.297594
11	3-5A	200	S230	Pure Water	0.342752
12	3-5A	400	S110	Pure Water	0.288389
13	5-8A	100	S230	Pure Water	0.441994
14	5-8A	200	S330	Pure Water	0.368547
15	5-8A	400	S110	Pure Water	0.405777
16	8-10A	100	S330	Pure Water	0.397818
17	8-10A	200	S110	Pure Water	0.439271
18	8-10A	400	S230	Pure Water	0.383310
19	3-5A	100	S330	AgNP	0.225035
20	3-5A	200	S230	AgNP	0.304399
21	3-5A	400	S110	AgNP	0.283689
22	5-8A	100	S230	AgNP	0.386063
23	5-8A	200	S330	AgNP	0.324449
24	5-8A	400	S110	AgNP	0.354339
25	8-10A	100	S330	AgNP	0.330021
26	8-10A	200	S110	AgNP	0.312514
27	8-10A	400	S230	AgNP	0.337221

ANOVA-based effect graphs were obtained to analyze the effect of changes in input parameters on weight loss, and the results are given in Figure 26. Figure 26 shows that as Almen intensity and coverage increase, weight loss increases, and as shot size increases, weight loss decreases. The fact that Almen intensity is obtained depending on spray pressure and time explains this situation. To increase Almen intensity, pressure and/or time must be increased. With the increase in pressure and time parameters, the force acting on the material and the stress increase. This situation increases wear and material loss. Coverage and shot size parameters are not statistically significant for weight loss. Due to the higher friction coefficient values in dry environment conditions, tin bronze deforms more than in pure water and AgNP-reinforced lubricant conditions. This situation increases the amount of wear and weight loss.

Figure 26.
Parameters interaction with weight loss according to the ANOVA



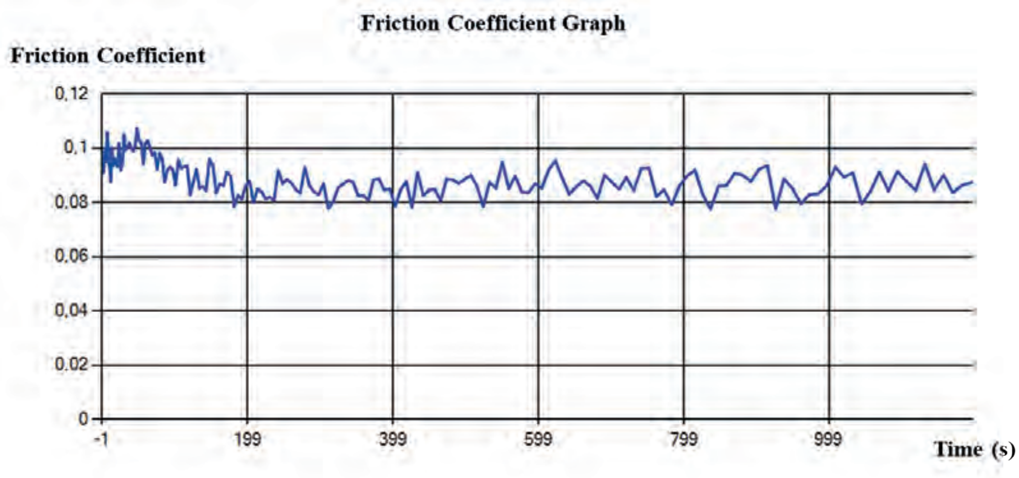
According to Figure 26, 3-5A Almen intensity, 100% coverage, S330 shot size, and AgNP reinforced lubricant were determined as optimum parameters. Having low Almen intensity and coverage values reduces the amount of energy affecting the material. This situation reduces the deformation and significantly reduces the amount of particles breaking off from the material. Since the change in shot size is not statistically significant, the effect of the shot size parameter was not considered. In the AgNP-reinforced lubricant, the spherical morphology of the silver particles creates rolling friction between the abrasive and tin bronze, facilitating the movement of the abrasive. In addition, thanks to the durability of the film layer formed by the AgNP-reinforced lubricant, the force acting on the tin bronze decreases, and this reduces wear.

According to Figure 26, the graph showing the effect of Almen intensity has a high slope compared to other parameters. This indicates that weight loss is highly affected by Almen intensity. The ANOVA (Table 10) analysis results confirm this situation. According to Table 10, the effect rates of the statistically significant Almen intensity ($p=0.000<0.05$) and lubricant ($p=0.000<0.05$) parameters were determined as 31.79% and 44.93%, respectively. At the beginning of the movement of the abrasive, the roughness peaks formed by the effect of Almen intensity were torn from the material. It is seen that the friction coefficient values were high during this process (Figure 27). The friction coefficient showed stable behavior after the material became planar on its surface. The process in which the roughness peaks were torn increases the weight loss of the material. For this reason, the effect of Almen intensity is important, and the obtained friction coefficient graph supports this idea.

Table 10
ANOVA results for weight loss of tin bronze

Source of variance	Degree of freedom (DF)	Sum of squares (SS)	Mean squares (MS)	F Ratio (α=5%)	P value	Effect Rate (%)
Almen Intensity	2	0.065194	0.032597	48.69	0.000	31.79
Surface Coverage	2	0.000180	0.000090	0.13	0.887	0.009
Shot Size	2	0.000701	0.000350	0.52	0.617	0.34
Environment	2	0.092131	0.046066	68.81	0.000	44.93
Almen Intensity*Environment	4	0.015102	0.003775	5.64	0.031	7.37
Surface Coverage*Environment	4	0.011803	0.002951	4.41	0.053	5.76
Shot Size*Environment	4	0.015919	0.003980	5.94	0.028	7.76
Error	6	0.004017	0.000669			1.96
Total	26	0.205047				100
Significance	**R-Sq=98.01%**			**R-Sq(adj)= 91.36%**		

Figure 27
Friction coefficient graph obtained during the wear test of tin bronze



Surface Roughness Results

One of the most important physical effects that occur on the material after the shot peening process is surface roughness. The roughness values of the material surfaces were measured after the wear tests, and the measured values are given in Table 11.

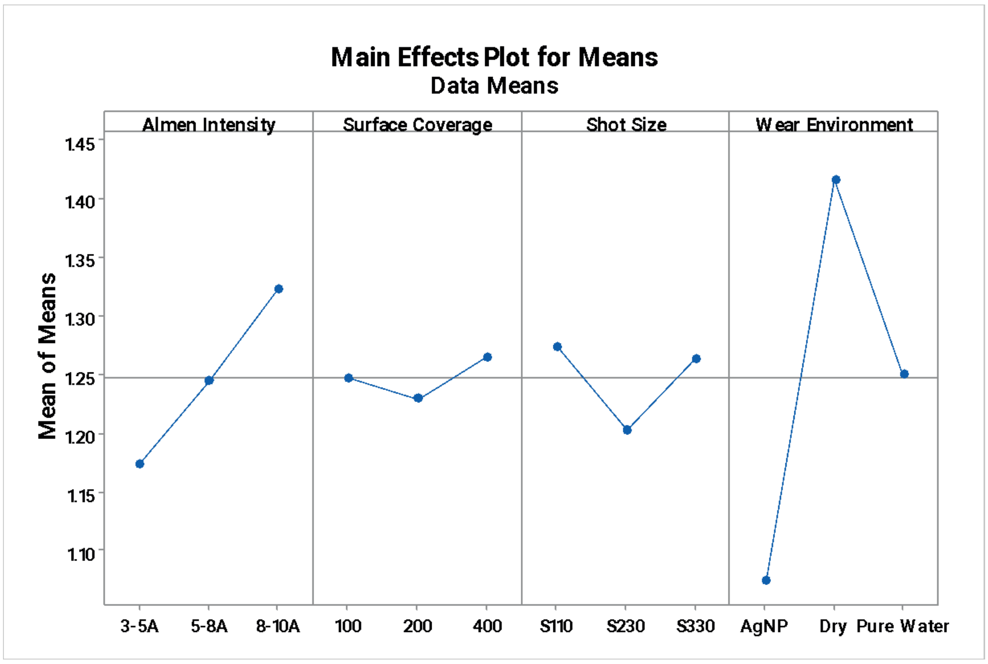
Table 11
Surface roughness values obtained for tin bronze

Exp. No	Almen Intensity	Surface Coverage	Shot Size	Wear Environment	Surface Roughness (Ra)
1	3-5A	100	S330	Dry	1.355
2	3-5A	200	S230	Dry	1.315
3	3-5A	400	S110	Dry	1.351
4	5-8A	100	S230	Dry	1.360
5	5-8A	200	S330	Dry	1.432
6	5-8A	400	S110	Dry	1.442
7	8-10A	100	S330	Dry	1.490
8	8-10A	200	S110	Dry	1.521
9	8-10A	400	S230	Dry	1.483
10	3-5A	100	S330	Pure Water	1.206
11	3-5A	200	S230	Pure Water	1.203
12	3-5A	400	S110	Pure Water	1.203
13	5-8A	100	S230	Pure Water	1.223
14	5-8A	200	S330	Pure Water	1.234
15	5-8A	400	S110	Pure Water	1.271
16	8-10A	100	S330	Pure Water	1.308
17	8-10A	200	S110	Pure Water	1.308
18	8-10A	400	S230	Pure Water	1.297
19	3-5A	100	S330	AgNP	1.082
20	3-5A	200	S230	AgNP	0.787
21	3-5A	400	S110	AgNP	1.067
22	5-8A	100	S230	AgNP	1.022
23	5-8A	200	S330	AgNP	1.085
24	5-8A	400	S110	AgNP	1.129
25	8-10A	100	S330	AgNP	1.179
26	8-10A	200	S110	AgNP	1.178
27	8-10A	400	S230	AgNP	1.140

Influence graphs were obtained to analyze the effect of the change in parameters on surface roughness, and the results are given in Figure 28. According to Figure 28, the surface roughness increases as the Almen intensity increases. Similar results were obtained for the friction coefficient and weight loss parameters. Surface roughness is a parameter related to the friction coefficient, and since the material is deformed more due to the increase in the friction coefficient, roughness occurs on the surface. For this reason, it is expected that the increase in Almen intensity will cause an increase in the friction coefficient and surface roughness. The coverage parameter is not statistically significant in terms of surface roughness. When the effect of the lubricant parameter is analyzed, the roughness density is higher due to the greater plastic deformation in the dry friction condition. The formation of semi-liquid friction in pure water and AgNP-added lubricant conditions reduces roughness. In addition to the semi-liquid friction provided by the AgNP-added fluid, the lubricant effect reduces roughness.

Figure 28

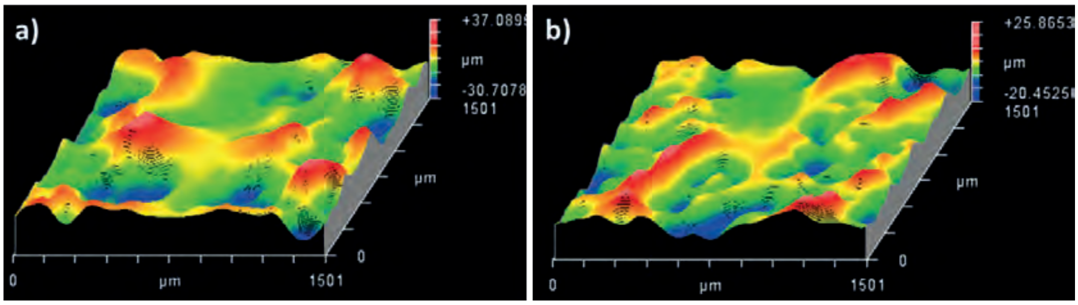
Effect graph obtained for surface roughness of tin bronze



According to Figure 28, 3-5A Almen intensity, 200% coverage, S230 shot size, and AgNP reinforced lubricant were determined as optimum parameters. After the wear experiments were carried out under conditions where the surface roughness was maximum and minimum, 3D topography images were obtained to analyze the surface morphology (Figure 29) visually. In the topography images, the AgNP-reinforced lubricant minimizes wear and significantly reduces the roughness density and depth compared to the dry environment.

Figure 29

Topography images obtained from the wear zone



Conclusions

This study investigated the effect of shot peening and nano-silver added lubricant on the tribological performance of tin bronze, a sliding bearing material. Within the scope of the study, shot peening and wear experiments were carried out. The results obtained from the experiments are given below.

The surface roughness of tin bronze increased up to ~8 µm (Ra) with the shot peening process, and the hardness increase effect was obtained from the surface to ~280 µm depth. A minimum of 40% hardness increase was obtained on the surface of the tin bronze material with the shot peening process compared to the material center.

It was determined that the shot peening process increased the fatigue strength of the tin bronze material by at least 7 times. However, as the Almen intensity and roughness value increased, the fatigue strength of the sliding bearings decreased. It was determined that excessive shot peening gave negative results in increasing the surface quality, fatigue strength, and tribological performance. The output parameters obtained at minimum Almen intensity were observed to provide optimum results.

The results obtained from the wear experiments show that the nano-silver particle added lubricant/coolant increased the tribological performance (wear resistance) of the CuSn12 sliding bearing material by ~10% by holding on to the roughnesses formed on the shot-peened surfaces.

It was determined that the shot-peening process and the use of nano-silver-added lubricant created a significant interaction in terms of increasing the tribological performance of sliding bearings. However, the specified interaction was valid for low Almen intensity values, and it was observed that no significant interaction occurred under increasing surface roughness conditions (>5 µm) due to high Almen intensity. In addition, it was determined that the material planarity was disrupted in materials exposed to high Almen intensity. It can be said that sliding bearings exposed to low Almen intensity provided optimum results for fatigue strength, wear resistance, and nano-silver-added oil interaction, and the obtained results can be used safely in the industry.

Acknowledgment

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Investigation of Friction Stir Additive Manufacturing (FSAM) Parameters of Aluminum Alloy

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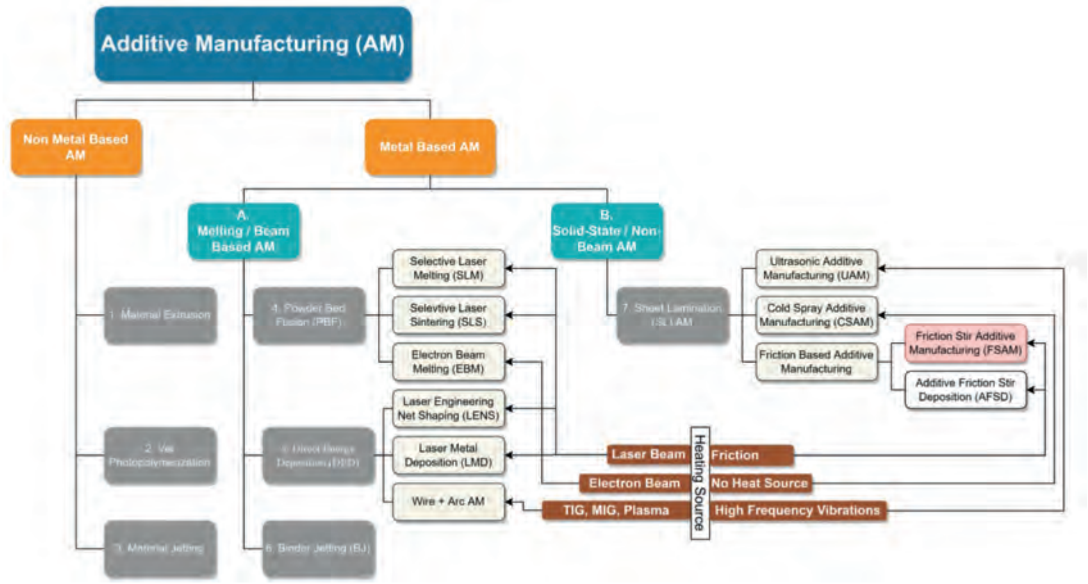
Introduction

The core component of Industry 4.0 is additive manufacturing (AM), which is the process of using 3D CAD data to create physical objects by layer-by-layer joining materials (such as metal, ceramic, or polymers) (ISO/ASTM5290, 2013). This technology has advanced over the last thirty years, and in the last 10 years, it has found widespread use in industrialized sectors. (Harun et al., 2017). The AM technique has several benefits over conventional production, including reduced human involvement, superior part precision, little material waste, and environmental friendliness (Anderson et all., 2018, Huang et al.,2013). Although it is used in crucial engineering domains like aerospace and the automotive sector, producing tangible metallic components is still a difficulty (Srivastava et al., 2021). American mechanical testing standard Current and upcoming AM technologies were categorized into seven families by ASTM-F2792-12a; Figure 1 depicts the entire AM process family tree (ISO/ASTM5290, 2013). According to the ASTM standard, AM processes are divided into the following categories: (i) binder jetting (BJ), (ii) direct energy deposition (DED), (iii) material extrusion (ME), (iv) material jetting (MJ), (v) powder bed fusion (PBF), (vi) sheet lamination (SL), (vii) and vat photopolymerization (VP). Material can be broadly categorized into three classes: metal, polymer, and ceramic. The class of potential material that AM technologies primarily rely on is determined by this (Mishra et al., 2022). Binder jetting is an AM method that uses a liquid-based binding agent to selectively bind powder particles. This technique uses powdered polymer, ceramic, and metallic materials as feed materials. As a result, this method yields steel components with superior mechanical qualities. The main drawback of this approach is high level part shrinkage, although no support structure is needed (Li et al., 2020). Direct energy deposition additive manufacturing (DED-AM) is a process that creates physical parts by depositing metallic powder or feed wire simultaneously in a moving substrate under vacuum or inert gas protection. It can also be used for metallic repair work. (Thompson et al., 2015, Liu et al., 2017). Because binder jetting operates at a lower temperature than DED-AM, it produces superior grain structure (Nandwana et al., 2017). Material extrusion additive manufacturing (AM) employs thermoplastic composites or polymers in wire or powder form as the feed material, as opposed to traditional AM techniques. The feed material is then pushed out via an aperture and piled to rapidly and economically construct a physical 3D standard component. (Gonzalez-Gutierrez et al., 2018, Gao et al., 2015). Material jetting AM is another popular AM method in the realm of polymer printing. In contrast to conventional polymer printing techniques, this method deposits building material droplets and produces high-quality, thin-walled feature components with minimal staircase effect. (Gülcan et al., 2021; Mirzaali et al., 2018). In powder bed fusion AM (PBF-AM), dense parts are produced by selectively diffusing high-source thermal energy into the powdered build material that has been pre-deposited on the bed (ISO/ASTM 5290, 2013). Despite advancements over the last 20 years, PBF-AM still has limited process repeatability and a lower deposition rate than DED-AM (Malekipour et al., 2018; Dowling et al., 2020). The next classification process is called sheet lamination, or SL-AM for short. Originally known as "coating object manufacture," this is among the first AM technologies used in commerce (LOM). The input material is cut into the desired form, stacked, and glued together to make a bulky item; improperly pasted material is usually deleted after usage (Gibson et al., 2021). Vat photopolymerization is the process of solidifying liquid resin, which polymerizes when exposed to a particular wavelength of light (Bagheri and Jin, 2019). The dentistry profession uses this method extensively (Revilla-León et al., 2018). Of these classes, DED-AM, PBF-AM, SL-AM, and BJ-AM show the most potential for the production of metal functional components for uses in industry. (Gisario et al., 2019). If a person selects a metallic feedstock material from the range available in the present AM processes, two types of AM processes emerge: melting AM, also known as beam-based AM, and solid-state AM, also known as non-beam-based AM.

Figure 1
Family tree of current and future additive manufacturing processes-ASTM F2792



Melting Based Additive Manufacturing

The feed metallic material (powder or wire that has been pre-deposited on the bed or fed through a nozzle) is melted using an electric arc, high energy laser, or electron beam. Direct energy deposition (DED) and powder bed fusion (PBF) are two well-known beam-based additive manufacturing techniques for making metallic components (Agrawal et al., 2020). As high-energy beams interact with feed material, complicated physical processes such as melting, melting combine flow, and consolidation occur. (Raghavanet et al., 2016; Vilaro et al., 2012). When a high intensity beam gets into interaction with a supply substance, there will be metal condensation, increased sprinkling and a broader heat affected zone (HAZ) (Gao & Li, 2021). Rapid cooling (102-106 Ks−1) during solidification can promote epitaxial development and complete reheating of previously formed layers due to complex cycles of heat and significant heat gradients. Substantial reheating of an already formed surface promotes a textured columnar grain structure and functions as an eradication agent for created equivalent particles on the highest point of the melting pool (Zhang et al., 2020). The microstructure of a piece has a significant impact on its ultimate mechanical and structural qualities. According to the majority of researchers, elements made using current fusion-based AM methods exhibit anisotropic behavior, which results in an uneven microstructure and less desirable mechanical qualities compared to the base material (Sun et al., 2015). In summary, the present beam-based AM techniques follow a methodological framework that resembles micro-casting or micro-welding, namely melting and depositing one slim sheet all at sudden. The advantages of each melting-based additive manufacturing technique vary, but they all include flexible component customization, good to decent surface polish, and the capability to print complicated forms with minimal material wastage (Panchagnula and Simhambhatla, 2015; Paoletti, 2017). The automotive and aerospace industries prioritize excellent mechanical and structural performance with excessive manufacturing rates among these. Therefore, solid-state AM could be used to get around these ongoing restrictions.

Solid-State Additive Manufacturing

The current beam-based AM is being replaced with solid-state AM to prevent the flaws associated with the liquid-solid transformation. Since this is a solid-state technique, no melting or excessive power beam is required, the entry substance is connected underneath the solvent point. As a result, it was possible to simply remove solidification flaws, which further produced superior mechanical qualities and microstructure. The subclasses of solid-state AM processes include additive friction stir deposition (AFSD), cold spray additive manufacturing (CSAM), friction stir additive manufacturing (FSAM), and ultrasonic additive manufacturing (UAM) (Yin et al., 2018, Rathee et al,. 2021).

Friction stir additive manufacturing is a relatively new technology compared to the four well-established solid-state techniques (UAM, CSAM, FSAM, and AFSD), which explains why not as much work has been published on it yet. To more fully assess the application of the currently developing material synthesis technology, data collection and assessment are still necessary.

Friction Stir Additive Manufacturing (FSAM)

A new AM method that belongs to the sheet lamination AM category is called friction stir additive manufacturing. White filed a patent in 2002 to introduce friction stir welding as an additive approach (White, 2017). The suggested method was commercially used by Airbus in 2006 to manufacture Al-Li 2025 wing ribs (Palanivel and Mishra, 2017). Excellent interlayer bonding was observed, resulting in a higher production rate, greater environmental impact, and less material waste (Lequeu et al., 2006). It is unlikely that the shortage of nomenclature and inadequate studies prevented this from receiving plenty of interest from the commercial and studies communities, which would have impeded future advancement. Friction surfacing and friction welding were employed by Dilip et al. as possible AM techniques, and they dubbed this process friction stir deposition (FSD) (Dilip et al., 2012). After that, Boeing assessed the method in 2012 and proposed FSAM as a construction tool for the production of energy-efficient structures (Baumann, 2012). Strangely, before the work of Palanivel et al. in 2015, there had not been a publication on FSAM following the activities of Airbus and Boeing (Palanivel et al., 2015). Palanivel et al.'s research has effectively opened up new directions in the field of FSAM.

The fundamental principles of friction stir additive manufacturing (FSAM) and FSLW are similar, except FSAM adds many laps gradually rather than all at once, requiring sintering and reheating, which modifies the internal physics slightly (Zhang et al., 2019, Li et al., 2021).

As illustrated in Figure 2, the process of incorporating two layers through FSLW with a single pass consists of four stages: plunging, dwelling, welding, and retracting.The unconsumable implement is pressed downward below longitudinal pressure from the starting place as far as the instrument ledge contacts the plate boundary during the descending phase, while sustaining a steady rotational speed. At this stage, the alteration procedure initiates. To produce sufficient warmth and a malleable workpiece, the rotating tool under axial pressure is held for 5 to 10 seconds (contingent on the material's characteristics and density) once the shoulder makes contact with the surface. During the welding process, the rotating implement that carries the softened mass beneath the shoulder traverses the shoulder driven zone (SDZ), which is the upper seam of the second layer. In the "pin driven zone (PDZ)" at the bottom of the second layer and the upper part of the first layer, the molten material swirled around the tool pin from the advancing side (AS) to the retreating side (RS). The shoulder effectively fills the void created by the pin's ahead movement by forging material behind it. Because of material mixing and atomic diffusion brought on by temperature and pressure, two layers were successfully connected. As the tool completes the welding process and retracts in its final phase, it detaches from the layer that has been deposited and is permitted to cool down (Padhy et al., 2018). Until the desired height is reached, the same steps are repeated. The thickness of each plate affects the build height (Gao et al., 2015). Figure 3 provides a graphic representation of the entire FSAM process and the completed build.

Figure 2
Stages involved in two layer joining (FSLW) (Padhy et al., 2018)

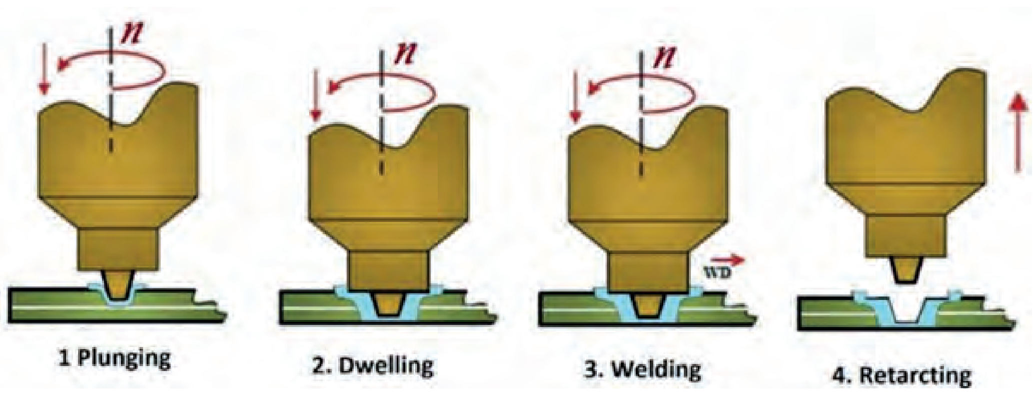
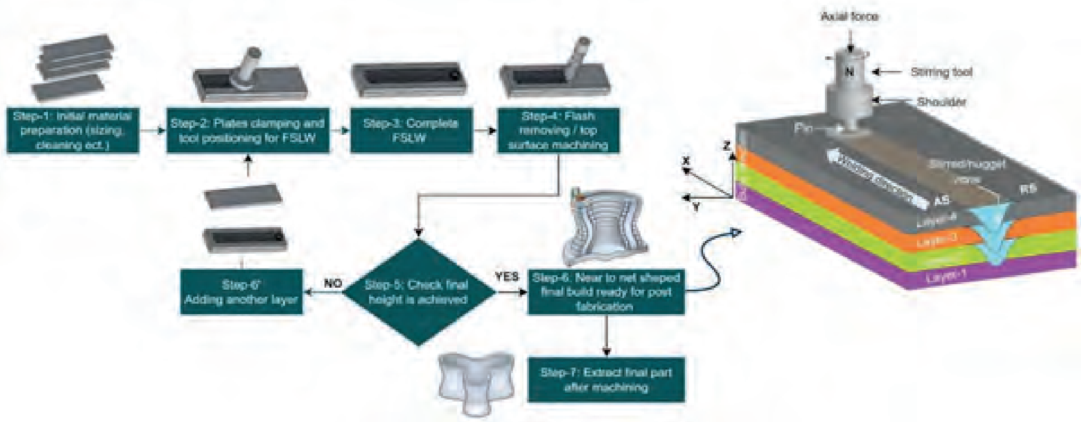
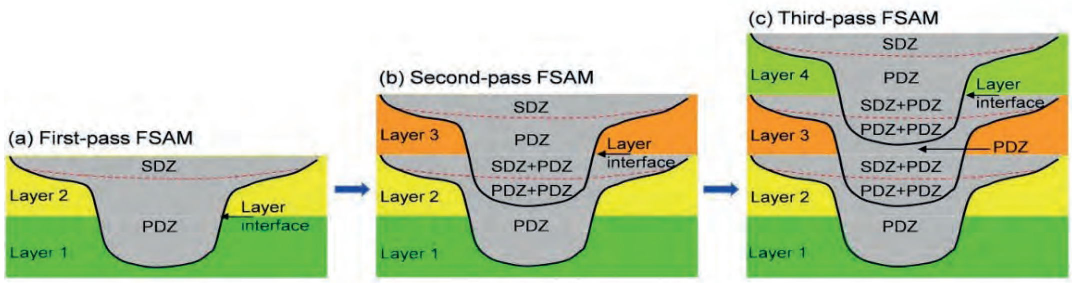


Figure 3
FSAM schematic illustration and final four-layered build obtained



The FSAM configuration comprises multiple lap joints, resulting in increasingly intricate stir areas. The FSAM's second pass is when complexity starts to emerge. As the upper section of the secondary sheet is inherently propelled by pins and shoulders, the existing SD and PD areas transform into SD + PDZ and PD + PD zones upon the addition of the tertiary layer. The shoulder and pin control the SD + PD area, which indicates material flow, in turn. Similar to this, the PDZ + PDZ area denotes that the tool pin controls this portion of the material flow twice. Until the desired height is not obtained, the stir zone transformation process is repeated in the same order. As a result, the final build's layers receive varying amounts of heat exposure from the bottom to the top, which causes the parts' intricate microstructural development. Figure 4 provides a graphic representation of these zones.

Figure 4
Schematic of stir zones of the FSAM build: (a) first pass FSAM; (b) second pass FSAM; and (c) third pass FSAM (Li et al., 2021)



In summary, the FSAM approach uses frictional warming to soften the substance without the need for lasers, melting, or binders. Peak temperature during processing occurs in the shoulder driven zone (SDZ) and varies from 60 to 90% of the feed material's melting dot (Li et al., 2021). It is possible to make parts with customized mechanical qualities and microstructures, although post-processing in the form of machining or grinding is necessary (Khodabakhshi & Gerlich, 2018). Table 1 compares the advantages and some drawbacks of the aforementioned manufacturing process.

Table 1

Merits and limitations of FSAM compared to current meting-based AM (Mishra et al., 2022; DebRoy et al., 2014; Frazier, 2014; Phillips et al., 2019)

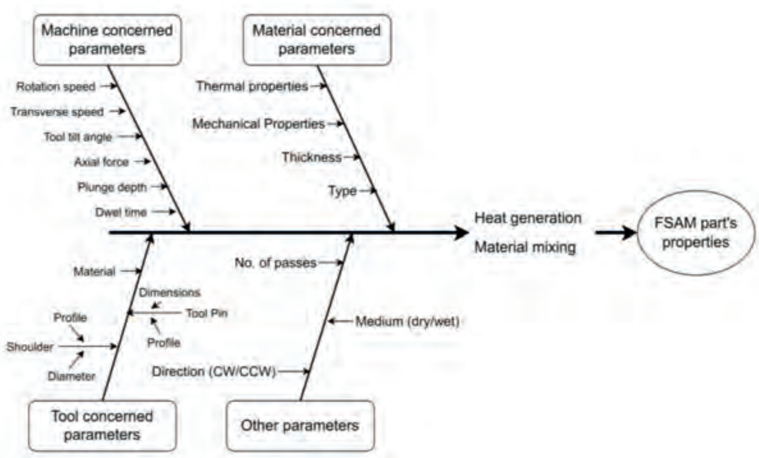
Merits	Limitations
• Equiaxed, homogeneous ultrafine microstructure. • High mechanical qualities combined with structural integrity. • Defects in solidification are minimal. • High volume and rate of manufacturing because no inert gas chamber or vacuum is needed. • Less energy used (around 2.5 percent of fusion-based processes). • Since the feed material is in plate form, there are no restrictions pertaining to powder. • Reduced area affected by heat (HAZ). • More environmentally friendly because it uses no fumes or emits very little greenhouse gas. • It is possible to process high-strength non-welded alloys as well as dissimilar alloys in a graded manner.	• Unable to create complicated geometry or elaborate shapes. • Problems with workpiece clamping and tool wear. • Large residual stresses. • Flash removal of the previous layer is required before adding the following layer. • Post-processing was required in order to get net form.

Parameters Affecting FSAM

Better material mixing and enough heat production are essential for an effective FSAM process because they have a bigger impact on the final part's mechanical and microstructural qualities (Gao et al., 2015, Khodabakhshi and Gerlich, 2018). The process parameters are mostly related to the mixing of the materials and the creation of heat. Figure 5 elaborates on the parameters of the FSAM processes, which are characterized as machine related, tool related, and material related. The majority of these parameters are similar to those of FSLW/FSP.

Figure 5

Factors affecting the microstructure and quality of the part produced through FSAM



Machine Concerned Parameters

Concerning the Machine The rotating speed, transverse speed, diving depth, axial force, waiting time, and orientation are some of the machine's parameters. The two primary input parameters for heat control are rotational speed and transverse speed. The friction velocity among the device and plates is really the rotation velocity, and the proportion of friction warmth rises as the friction velocity increases (Gao et al., 2015). A welded distance traveled quickly is known as transverse speed. While high transverse speed results in less heat generation and a weaker stirring action, slow transverse speed raises warmth in concise displacement (Zhang & Zhang, 2009). While slow transverse speed and rapid rotational speed can both raise warmth, rapid rotational speed causes the temperature to increase more than slow transverse velocity. It isn't necessarily true that components without flaws possess better mechanical properties when operating at elevated rotational velocities and reduced transverse velocities. This combination may result in observable weld flash, excessive heat generation, and certain microstructural flaws. However, concurrently increasing both speeds may cause the part to experience additional residual stresses, which would further impact its mechanical characteristics (Zhang & Zhang, 2009). Another crucial mechanism factor for assessing the micro configuration and mechanism characteristics of components is the tool post tilt angle, which creates a non-contact area while allowing a portion of the device shoulder to come into connection with the sheet. In comparison to a zero tilt angle, a tilted tool promotes improved material mixing and heat generation. The forging force increases and energy consumption increases when the tilt angle is used (Zhai et al., 2020).

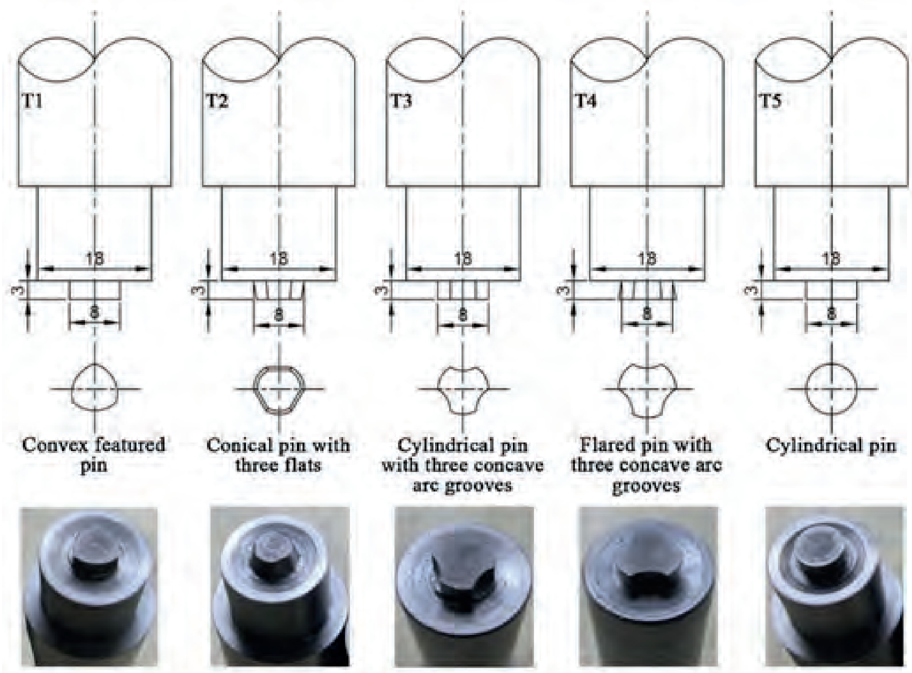
FSAM was carried out by S. Palanivel et al. using magnesium-based WE43 rolled condition sheets that were 1.7 mm thick. Right-handed stepped spiral tool pins with 1.5◦ title angle and a constant transverse speed of 102 mm/min were used to create the multi-layered build (Palanivel et al., 2015). The study examined the microstructure and flaws at two distinct rotational speeds, namely 800 rpm and 1400 rpm. Inadequate material mixing caused problems at higher rotation speeds (1400/120). Z. Zhao et al. investigated the impact of rotation speed on the creation of multilayer layers of aluminum lithium 2195-T8 alloy (Zhao et al., 2019). Three rotational speeds 800, 900 and 1000 rpm as well as a steady transverse speed of 100 mm/min were tested by FSAM. Rather than at a higher rpm, the ideal micro configuration was obtained at a reduced rate (800 rpm). These two studies suggest that increased rotation velocities do not necessarily lead to improved material blending, thermal generation, or component durability. Two layers of Al-2024 alloy were piled together in a lap arrangement at different welding and rotating rates (Zou et al., 2017). The findings of the experiment indicate that the impacts of dive depth on NZ quality are not as great as those of transverse and rotation velocity. The ratio of ω to ν should be maintained at 10:3 to achieve optimal warm entry at different rotational (ω) and transverse (ν) speeds. Compared to the configuration of a butt joint, the effective range of parameters in one or plural lap junctions is quite modest. Therefore, obtaining the precise collection of these characteristics to generate parts free of defects is quite difficult.

Tool Concerned Parameters

Major machine-related parameters require the parameters connected to the tool. The geometry and material of the tool's component elements (shoulder and pin) are the most important factors to consider. In the process of blending pin shape, factors such as kind (quadrate, cylindrical, conical, or threaded), length, and thickness are considered, while the tool shoulder's shape involves the shoulder's width and whether it is curved or level. Changes in these parameters will consequently have an impact on the part's final microstructure as well as the warm entry, ingredient shuffling, and material inflow. The stirring pin creates the remaining 15% of the heat, with the tool shoulder producing 85 % of it (Schmidt et al.,2004). Heat generation is derived from the shoulder to pin diameter rate (D/d) and is straight commensurate to the shoulder touching. According to reports in the literature, aluminum alloy has good mechanical qualities at a 3 "D/d" ratio (Vaidyanathan et al., 2021). In terms of pin profile selection, all you need to do is choose the pin profile primary and adjust the other parameters to get a nice microstructure. There is a great deal of discussion over pin profiles. Some reports state that conical pins show inadequate material mixing, making them unsuitable, while other publications assert that conical pins can yield defect-free parts by adjusting other parameters. In summary, every parameter listed above is related to the others and we are unable to disregard any of them. Therefore, with the exception of Z. Zhao et al.'s work, the majority of researchers for FSAM employed conical and cylindrical threaded pins and subsequently adjusted the other parameters (Zhao et al., 2019). Five different pin profiles—T1: convex featured, T2: conical with three flats, T3: cylindrical with three arc grooves, T4: flared with three arc grooves, and T5: plain cylindrical—were selected for comparison in his pin profile-specific research. A snapshot of the drawing and actual instrument is shown in Figure 6 below. According to experimental data, tool T2 with its tapered pin with three layers and tool T5 with its simple cylindrical pin produce undesirable ingredient shuffling throughout bind interfaces. On the forward-facing aspect of NZ (featuring minor structural flaws), though, instruments T1, T3, and T4 facilitate effective material blending; however, this does not hold true for the retreating aspect. Similarly, double-scrolled fixed and rotating tool shoulders were employed by M. Sigl et al. to carry out (Sigl et al., 2022). Similar to this, M. Sigl et al. reported that the combination of turning and fixed vehicle shoulder created an Al-7075 construction devoid of defects after using dual-scrolled fixed and revolving vehicle shoulder to apply FSAM (Sigl et al., 2022).

Figure 6

Various tool pin profiles utilized to generate high-quality Al-li 2195 build. (Zhao et al., 2019)



Material Concerned Parameters

The parameters related to the material in question include its thickness, kind, chemical compound, thermal qualities, and mechanical properties. Every ingredient behaves as distinct throughout the warmth production and ingredient inflow phases due to its unique set of mechanical and thermal properties. Vehicle pin length and shoulder diameter (3.5 times plate-thickness) are determined by plate thickness, which makes tool pin design even easier (Malarvizhi & Balasubramanian, 2012). Integrated models were created by Z. Zhang et al. to search the impact of varying layer thickness on the build's temperature and microstructure (Zhang et al., 2020). Using finite element (FE) simulation, three structures with sheet thicknesses of 2 mm, 4 mm, and 6 mm, respectively, were examined. The findings shown that while layer thickness increases strength and hardness, it also lowers construction temperature and average particle size. Tables 2 provide a detailed summary of the parameters used in the different studies.

Table 2
Summary of the material and machine parameters used by the different researchers

Material	Parameters				Ref.
	mm/ min	Rpm	Tilt Angle	Pin Profile	
Al–Zn–Mg–Cu	160	700	2.5°	—	(Li et al., 2022)
Al–Zn–Mg–Cu	160	700	-	Conical threaded	(Li et al., 2022)
Pure Cu cold rolled T3	50	600	3°	Tapper threaded	(Liu et al., 2022)
Mg alloy AZ31-H24	100	1000	0.5°	Threaded taper triangular	(Wlodarski et al., 2021)
Al-5083, Al-7075	55	850	-	Tapper threaded	(Jha et al., 2022)
AA6061-T6	100	1200	-	Plain conical	(Li et al., 2022)
7N01-T4	80	1200		Conical threaded	(He et al., 2022)
AA5083-O	152	500	1.5°	Triple flat left-handed stepped spiral	(Palanivel et al., 2017)
PMMA, S304 AISI	45	850	2.5°	Threaded corner-removed triangle	(Derazkola et al., 2020)
Pure copper and steel	50	600	2°	Plain tapper	(Guo et al., 2022)
AA5083-O solid sol. Strength	152	500	1.5°	Triple flat left-handed stepped spiral tool	(Palanivel et al., 2017)
AA 7075-O/9	60	600	2°	Left cylindrical threaded pin	(Yuqing et al., 2016)
AA2050-T3	204	250	1°	Threaded taper with 3 flats	(Stir, 2019)
2195-T8 Al-Li	100	800,900,1000	-	Convex featured and conical with 3 flats Cylindrical and flared with 3 concave arc grooves Plain Cylindrical	(Zhao et al., 2019)

AA6061-T6, AA-6082	100	1000	-	Conical Pin	(Zhang et al., 2019) (Zhang et al., 2020) (Tan et al., 2021)
AA 7N01-T4	60	1200	-	Right-handed stepped spiral	(He et al., 2021)
2195-T8 Al-Li alloy	200	700	-	-	(Shen et al., 2022)
A357/SiC AMMC and Al-6XXX	100, 200	500, 1000	3°	-	(Yan et al., 2022)
AA 6061-T651, Steel 1018	300, 600	600, 1000	1°	Cylindrical	(Liu et al., 2022)
Al plates	100	800, 1000, 1200	-	-	(Tan and Zhang, 2022)
Al-7A04-T6	160	700	2.5°	-	(Li et al., 2022)
7N01-T4	80	1200	-	Conical threaded	(He et al., 2022)
AA6061-T6	100	1200	-	Conical	(Li et al., 2022)
Al–Zn–Mg–Cu sol. Treated	160	700	-	Conical threaded	(Li et al., 2022)
Al–Zn–Mg–Cu 7A04-T6	160	700		Conical threaded	(Li et al., 2021)
Al-Cu pipes AA5086 and C12200	40, 60, 80	400, 500, 600, 700	3°	Cylindrical	(Falahati Naqibi et al., 2021)
Al 5059-O	63	450	2°	Tapper threaded	(Srivastava and Rathee, 2020)
Al-5083-O. 6061-T6, 7075-T6	55	750	3°	Tapper threaded	(Kumar Jha et al., 2022)
Al-7075-T6	65, 80, 95	2000	0.5°	Threaded taper with 3 flats	(Sigl et al., 2022)
Al-6061, Al-7075	40, 50	1100, 1200	2°	Tapper threaded	(Venkit and Selvaraj, 2022)
Al-5083, Al-7075	55	850	-	Tapper threaded	(Jha et al., 2022)
Al-2060	300, 500	1500, 1800	-	Conical	(Jiang et al., 2022)
Mg-AZ91, Cu, Al-7075	40	2000	0	Cylindrical threaded	(Kumar et al., 2021)

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Reverse Engineering and Additive Manufacturing Applications in Casting Technologies

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Introduction

The utilisation of additive manufacturing and reverse engineering applications in casting technologies is also a prominent issue with the development of modern production methods. The advantages and disadvantages of both traditional and modern production methods must be acknowledged. The integration of these production methods and the evaluation of the benefits of each production method will be very efficient from a production standpoint. In this study, the areas in which additive manufacturing and reverse engineering, which are among the modern production technologies, are used in casting technology are discussed and some suggestions are made. Thus, this study has been performed with the objective of increasing the utilisation of additive manufacturing and reverse engineering in the field of casting technology. The study consists of casting technologies, reverse engineering and its applications, and additive manufacturing and its applications.

Casting Technologies

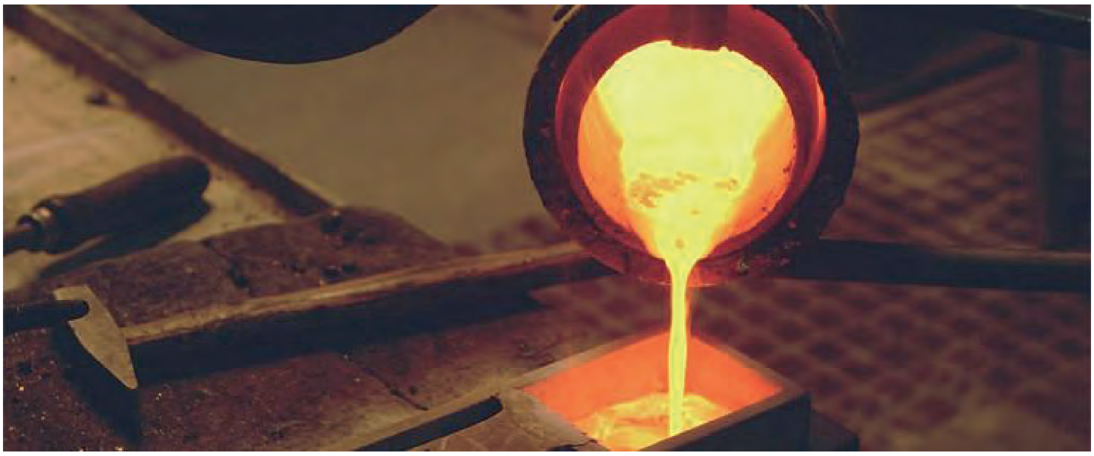
A variety of traditional manufacturing techniques are employed by industries to produce an extensive range of products for diverse applications. These techniques encompass forging, casting, machining, welding, stamping and rolling, among others. Casting is a manufacturing technique that is widely employed for a number of reasons, not least because it offers significant advantages over alternative processes, especially when the item in question requires an intricate geometry. The casting process permits manufacturers to produce sophisticated products without the constraints typically encountered in assembly (Shah et al., 2022).

Casting is a forming method that involves the pouring of liquid plastic or metal into a mould in order to create a solid object. After allowing the material to solidify within the mould, the resulting fabricated part is ejected or broken. The earliest documented use of casting dates back to prehistoric times (Vijaya Ramnath et al., 2018).

In ancient times, copper was melted in wood-fired melting furnaces and then poured into moulds made of baked clay. While open moulds created by primitive methods allowed the production of simple, one-piece parts, the casting method showed the first developments with the use of moulds consisting of multiple parts for the production of circular-shaped products. In the 2000s BC, clay cores were made to produce hollow parts. At the same time, a precision casting method using wax models was developed. These developments were followed by the production of complex parts with multi-part moulds. The casting method, the oldest traces of which are seen in Anatolian lands, reached Europe with wars and nomadic life (Işık, 2021).

The casting process is a highly intricate undertaking, encompassing a multitude of intricate steps. There are numerous fundamental casting techniques, including sand, plaster, shell, centrifugal, investment, and die casting. The casting is a process comprising several stages, the most common of which are the creation of the mould, the production of the core, the casting of the metal, its melting, pouring and finishing. The process of machining or manually creating models, moulds and cores is inherently complex. Therefore, it is feasible to integrate sophisticated methodologies such as additive manufacturing into the casting procedure. Additive manufacturing (AM) technology can be utilised for the production of moulds, cores, patterns and, on occasion, castings (Shah et al., 2022). Figure 1 shows the casting process.

Figure 1
Casting process (Tüdöksad, 2024)



In order to create a shape from molten metal, it is necessary to use a mould with a negative surface that corresponds to the intended design of the object to be produced. Additionally, the casting process can be facilitated through the utilisation of a positive mould, otherwise referred to as a pattern. A distinctive configuration will be imprinted on the granular material as a result of the pattern. The shape is retained through the precise mixing of quartz sand, an additive, and a binder in a predetermined ratio. In order to recover the pattern, it is necessary to remove the structure from the mould (Le Néel et al., 2018).

Casting methods include a wide range of techniques that allow the production of both very small parts and large parts weighing many tonnes. Almost all metal alloys can be produced by casting. Some materials (e.g. cast iron) can only be produced by casting. Casting techniques have been developed for mass production (Aran, 2007).

The incorporation of sophisticated manufacturing techniques into more conventional methods represents a crucial necessity within the present context. AM technology represents the pinnacle of fabrication technology, having been embraced by a multitude of industries. Casting industries constitute a significant proportion of manufacturing output and are able to produce components exhibiting intricate geometries, a feat which other manufacturing processes are often incapable of achieving. The combination of AM technology with the casting process has the potential to usher in a new era of innovation within the casting industry (Shah et al., 2022).

In addition to the advantages of casting, it is generally not an economical option for the fabrication of a limited number of components. For this reason, this disadvantage can be eliminated by integrating some modern manufacturing technologies into the casting sector.

Today, the foundry industry has been positively impacted by the development of modern technologies. These include reverse engineering and additive manufacturing. It is frequently seen in the studies that the utilisation of additive manufacturing and reverse engineering has become widespread, especially in the production of models and moulds used in the casting of reverse angled and complex shaped parts, spare parts production and product development.

Reverse Engineering

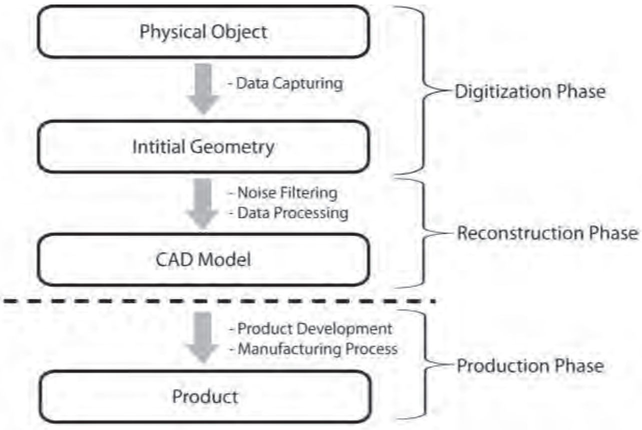
Engineering is a speciality that deals with the design, manufacture, construction and maintenance of products, structures and systems. The discipline of engineering may be broadly categorised into two principal branches: forward engineering and reverse engineering. The process of forward engineering is initiated with the abstraction of a system and progresses through the stages of logical design and physical realisation (Türkücü & Börklü, 2017).

Reverse engineering (RE) is a technique that entails the process of remanufacturing or repairing parts for which no data is available or damaged. In recent years, it has been employed for a multiplicity of purposes, encompassing the acquisition of new parts with modifications, large-scale production, prototype development, and quality control, even in the absence of CAD data. This method has been employed in a number of different fields, including industry, medicine, art and archaeology. RE accelerates the product development process by completing the modelling and manufacturing processes of complex surfaces in less time than traditional design approaches. The rapid production process offers significant cost and time savings. It is of great importance to effectively integrate RE and 3D printing technology and to use these methods in the new product development process (Karadeniz et al., 2022).

Techniques developed to rapidly digitise existing parts have increased interest in the practise of reverse engineering. To utilize TM techniques, it may be sufficient to take measurements from the existing product even with simple techniques, while the methods used to digitise part geometries and 3D modelling techniques enable faster 3D modelling of complex parts by shortening the time spent in this work. The basic steps in the TM process are as follows: Determining the geometric model properties, defining the relevant surfaces, decomposing the model, creating simple and free geometry surfaces and obtaining accurate Computer-Aided Design (CAD) models. In simpler terms, reverse engineering involves product design, determination of functional characteristics and reconstruction of a detailed and functional model of the product (Türkücü & Börklü, 2017). Figure 2 shows the RE process diagram.

Figure 2

RE process diagram (Nawawi et al., 2018)



In reverse engineering, 3D scanning is very important if there is no prototype product or product dimensions for the production of the desired part. Thanks to 3D scanning, the dimensions of the part can be extracted.

The advent of 3D scanning has enabled numerous developers, manufacturers and engineers to produce moulds, prototypes and parts of the highest quality for a vast array of products and research projects. The quality of scans is of paramount importance to automotive engineers, aerospace specialists and medical researchers, as they utilise these images to create moulds, castings and printed parts, which in turn facilitate more detailed study and improvement of their processes (Haleem et al., 2022).

Reverse Engineering Applications

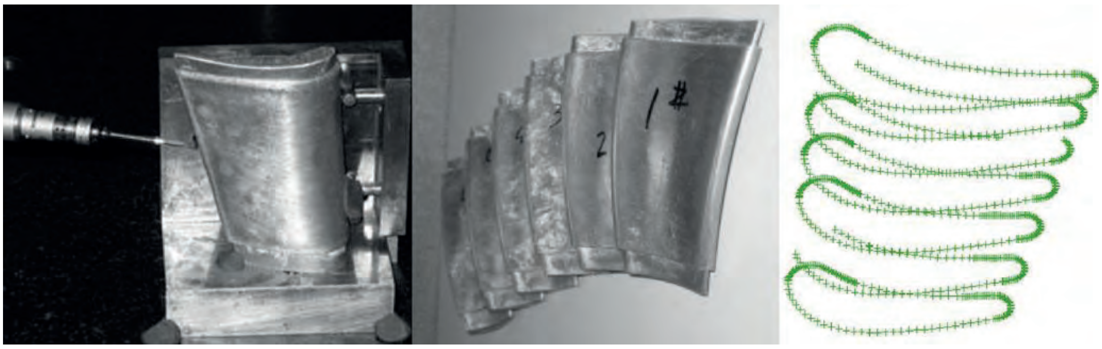
Reverse engineering applications are frequently used in the foundry industry. The development of a reverse engineering method has enabled the manufacture of cast products characterised by a high surface quality. In this approach, the initial step is to scan an existing casting and prepare the surface mesh data. The data is processed through the application of a bespoke geometric modelling technique, the aim of which is to facilitate the delineation of the cast and machined surfaces. The subsequent step is to adapt the existing boundary in order to generate a digital casting model. This allows for the production of high-quality castings for large-scale manufacturing applications (Urata et al., 2019). In another study, researchers investigated the application of RE in crankshaft manufacturing. This study aimed to derive all the parameters required for the design of engine components via the use of the RE approach. The crankshaft was reverse engineered using a coordinate measuring machine for unknown data. The aim of this study was to undertake a dynamic finite element simulation of three crankshafts, comprising aluminium alloy forged steel and cast iron. Consequently, a dynamic analysis was performed and validated through simulations conducted using the ANSYS software (Vijaya Ramnath et al., 2018).

Reverse engineering is also used in the production of moulds required to produce cast products. Researchers examined the use of RE methods in the production of prototype moulds with model-free process technology and aimed to use high technologies that accelerate and enhance the efficiency of the prototype mould production process. In the study, digital data were obtained by 3D measurement and scanning of the part that functions as a footrest bracket on the historical bicycle. A computer-aided design (CAD) model of the mould and cores was created. Then, the desired shape of the moulding compound block, which was placed on a 5-axis or 3-axis CNC machine, was achieved by milling. By pouring copper alloy into the produced mould by gravity casting method, bronze casting, which functions as a footrest bracket in historical bicycles, was obtained (Krivoš et al., 2014). In another study, the researchers investigated the restoration of casting techniques in the Bronze Age based on the study and visualisation of casting moulds. Casting moulds of sickles, axes, spearheads, razors and chisels from the Bronze Age were discovered. A comprehensive analysis of the moulds was conducted using both analytical methods and computer-aided technological processes, with the objective of determining their suitability for utilisation in Bronze Age casting technology. Three-dimensional scanning was utilised for the purpose of obtaining the geometric specifications of the castings that were produced in the aforementioned moulds. This was achieved through a process referred to as reverse engineering. The data were employed in the execution of design and research studies through the utilisation of software. Simulations were conducted to examine the variations in casting processes and the solidification of alloys within the confines of the archaeological moulds. The outcomes were employed to elucidate the fabrication of Bronze Age castings in stone and clay moulds in terms of their qualitative attributes and the potential for the emergence of casting defects stemming from the mould construction process (Garbacz-Klempka et al., 2017).

As well as producing the mould for a new part to be cast, reverse engineering can also be used to produce defective moulds. In this study, the researcher investigated the manufacturing of a defective mould element by reverse engineering. In the absence of a 3D solid model, a 2D scan of the defective part was performed using a three-dimensional scanner. The study demonstrated the efficacy of utilising simple corrective techniques in the computer-aided design (CAD) program to swiftly generate a solid model from a worn initial template. The solid model was brought to the production stage using computer-aided manufacturing (CAM) software and machined on a CNC vertical machining machine. The produced part was re-mounted to the mould and a successful print was obtained from the mould (Sofu, 2019). In another study, the researchers employed a combination of RE and CAD methodology for the purpose of modelling moulds in the context of casting simulations. In the study, a methodology based on reverse engineering is proposed for the creation of a 3D CAD model of a casting, derived from the physical characteristics of the casting itself. The proposed method encompasses four stages: (1) pre-digitisation, (2) digitisation of equipment components, (3) reconstruction of surface and (4) 3D CAD modelling. In the study, the ATOS Standard optical scanner was employed for the purpose of digitisation. In order to ascertain the viability of this methodology, the production of an aviation gearbox housing manufactured via sand casting was selected as a case study. The findings demonstrated that the inverse methodology is adequate for the virtual reconstruction of the geometry of each component and the complete geometry of the assembled mould (Salmi et al., 2014).

RE can also be used to optimise the cavity of casting moulds. The researchers investigated a new method based on RE and related core techniques to optimise the cavity of a precision casting mould for a turbine blade. Furthermore, a coordinate measuring machine (CMM) was employed to ascertain the dimensions of the casting blades, and subsequent post-processing was conducted to determine the displacement. Subsequently, the inverse deformation method was employed for the purpose of optimisation. In the inverse deformation technique, the resulting profile was created by superimposing on the original profile of the void the displacement representing the nonlinear shrinkage. This displacement was compensated for by the shrinkage of the alloy and wax solidification. The results of the study showed that, from a practical engineering point of view, design time and cost are significantly reduced with the present approach (D. H. Zhang et al., 2010). Figure 3 shows the measurement of the casting wings.

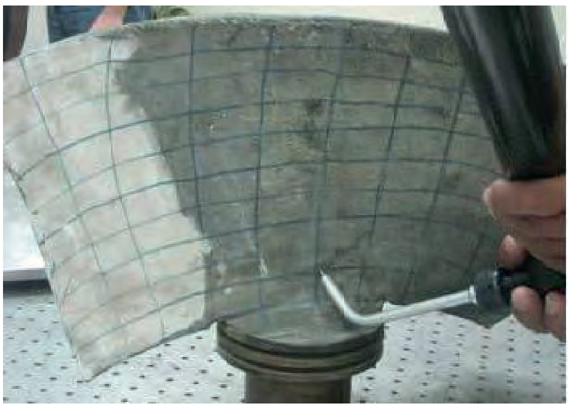
Figure 3
Measurement of casting wings (D. H. Zhang et al., 2010)



Reverse engineering is also used in the industrial replication of parts with complex geometry. In their study, the researchers employed a reverse engineering process to investigate the industrial refabrication of objects with freeform surfaces. In the study, CMM was employed with a laser scanner in order to digitise the part. A computer-aided design model was generated and a prototype was manufactured using a fused deposition modelling (FDM) 3D printer, resulting in the creation of a replica (Ferhat et al., 2019).

One of the areas where reverse engineering is applied is the model-free casting production process. In this method, the model is completely removed and only the mould is used to cast the casting part. Some researchers have conducted research on the model-free casting process using CAD and computer-aided manufacturing (CAM) applications, scanning and digitising, CMM and 5-axis machines. A reverse-engineered and model-free process was employed to produce an adjustable diffuser blade intended for utilisation in the oil and gas industry. This process commenced with a worn sample. The blade was first digitised with a 3D Coordinate Measurement machine. The acquired point cloud data was transferred into CAD/CAM software with a view to developing a three-dimensional model and designing moulds. Subsequently, the sand blocks were milled directly on the 5-axis computer numerical control (CNC) machine, thereby eliminating the necessity for the use of models. The moulds were employed directly in the casting process (Babu & Thumbanga, 2011). Figure 4 shows the digitalisation of the wing surface with a point probe.

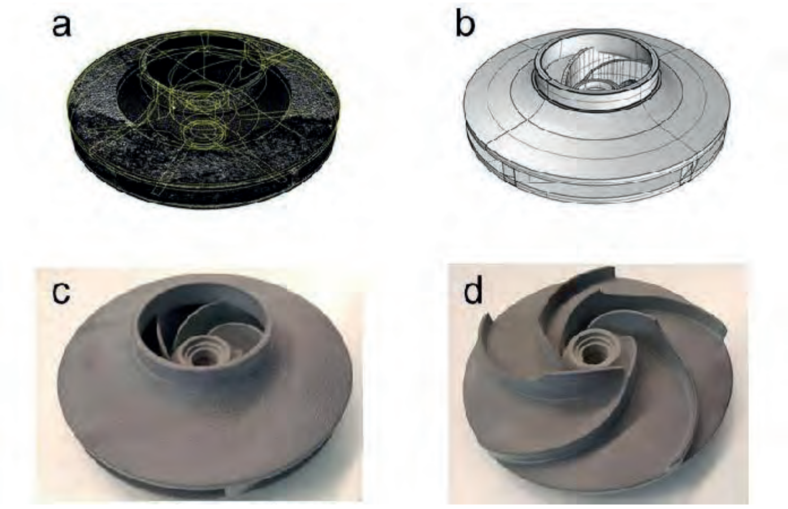
Figure 4
Digitalisation of the wing surface with a point probe (Babu & Thumbanga, 2011)



The feasibility of integrating RE and rapid manufacturing methods has been examined in various studies. Researchers have investigated the potential of integrating RE and rapid technologies to accelerate the investment casting process for gas turbine blades. The second step of the gas turbine located in the turbine compressor section was selected for examination as a case study, in order to illustrate the application of RE and rapid investment casting procedures. A coordinate measuring machine was utilised to facilitate the digitisation of the blade, and a wax solid model was subsequently created through the application of an additive manufacturing method. A ceramic shell was formed by the lost wax technique and a nickel-based superalloy was cast (Vaezi et al., 2011). In a different investigation, the manufacture of a stainless-steel pump impeller utilising combined three-dimensional sand printing and casting techniques was examined. The initial stage of the process involved scanning a closed vane pump impeller with a 3D scanner. The subsequent step entailed the fabrication of the impeller's cavity geometry through the utilisation of a 3D sand printer, employing the binder jet printing methodology for the casting operation. The impeller was cast in a 3D sand mould using AISI 316 stainless steel as the casting material. The burrs on the produced part were cleaned and subjected to thermal treatment and thus the final part was obtained (Hernández & Fragoso, 2022). Figure 5 shows the digitisation and design of the propeller.

Figure 5

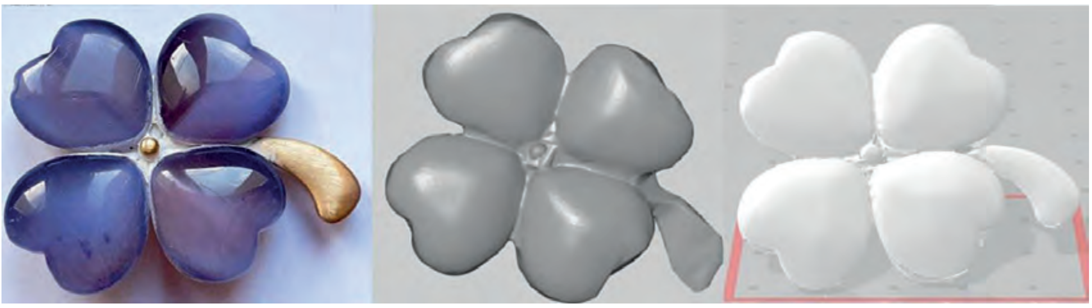
Digitalisation and design of the propeller: (a) Three-dimensional scanning with curves, (b) appearance of solid surface, (c, d) PA12 communication model (Hernández & Fragoso, 2022)



In another study on the integration of RE and rapid manufacturing methods, researchers investigated 3D face modelling and rapid casting procedures with a focus on reverse engineering. In order to obtain a three-dimensional (3D) representation of the human body, a preliminary stage of the study involved the use of software derived from a 3D scanner to create a digital model based on the subject's physical form. The model was created through the utilisation of 3D printing technology, which facilitated the rapid prototyping process. The 3D-printed prototype was removed from the wax model through the process of reprocessing silicone rubber. Thereafter, the model shell was constructed through the application of high-temperature dewaxing and baking processes, which were followed by casting (Liu et al., 2020). In another study, researchers investigated modern reverse engineering methods used in the modification of jewellery. The 3D digitisation of the part was carried out using special scanners. The created model was produced by 3D printing using FDM and DPP (Daylight Polymer Printing) techniques. In the final phase of the study, tin-phosphorus alloy castings were produced through the investment casting technique, and their surface roughness was subsequently evaluated. The findings demonstrated that the utilisation of DPP printing in the fabrication of casting models led to the generation of castings with a substantially reduced roughness level, approximately threefold lower than that observed in FDM technology (Kroma et al., 2020). Figure 6 shows the real objects and the objects obtained from the scanner.

Figure 6

Real objects and models generated by DAVID-SLS3 and Aicon SmartSCAN-HE R8 scanner (from left side) (Kroma et al., 2020)



Reverse engineering applications are also used for the construction of patient-specific moulds and prostheses for the human body. The researchers put forth a pragmatic approach to the CAD of custom 3D printable moulds for the treatment of wrist fractures. The aim of this research is to create a robust, dependable and straightforward framework for modelling patient-specific moulds, thereby facilitating the implementation of a rapid and dedicated scanning system for the hand-wrist-arm region. The moulds created using the proposed system were produced using a commercially available three-dimensional printer. Subsequently, the device was evaluated in order to ascertain whether it met the requisite medical standards. The findings revealed that the fabricated casts were produced with precision by medical professionals, thereby eliminating the necessity for engineering input. Furthermore, the users who took part in the experiment provided positive feedback (Buonamici et al., 2020). In another study, CAD data was created by using the reverse engineering method for parts for which CAD data was not available. As an example of reverse engineering application, a personalised prosthesis project was realised. Computed tomography images were converted into 3D surface texture forms using the relevant digitiser program. The prosthesis was designed using the 3D CAD model and a model was created for the mould. In order to produce the designed prosthesis, mould design and production of the prosthesis mould were carried out. Silicone casting compatible with the human body was made from the mould (Demir, 2018).

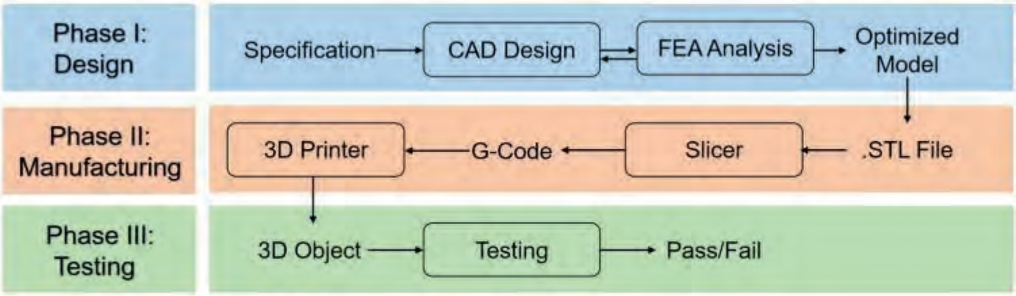
Reverse engineering is also utilised in the foundry industry for the purposes of dimensional measurement and the assurance of dimensional accuracy, particularly in the context of the production of complex components. For example, a study was conducted to assess the potential applications of three-dimensional optical scanning technology in the automotive sector. In the study, the processes involved in scanning and remanufacturing of the defective sheet metal cutting mould were examined utilising the technique of three-dimensional scanning. Furthermore, the scanned point cloud data was subjected to a comparative analysis with 3D CAD data for examination purposes. The application of 3D optical scanning technology has been demonstrated to offer a solution to the precision measurement of large and intricate sheet metal components, as utilised across the automotive manufacturing sector. Three-dimensional scanning applications are an indispensable component of mass production automation lines and reverse engineering applications within the automotive industry (Kuş, 2009). In another study, researchers presented a digitised inspection technique based on RE and implementation pathway for complex part measurement. The technique proved to be an effective means of overcoming the technical limitations associated with the measurement of complex parts. With this technique, the manufacturing defects of complex castings were quickly and accurately inspected (Ligang & Xiaoyu, 2009). In another study, the accuracy of the dimensions of parts in the digital casting process was investigated through reverse engineering. The objective of the study was to assess the dimensional accuracy of the sand mould and metal components throughout the digital casting process. This would facilitate the implementation of more accurate dimensional compensation in subsequent iterations. The precision with which the 3D-printed sand mould and the final aluminium-based tyre mould cast with the sand mould matched the desired dimensional specifications was evaluated using a 3D laser scanner. This reverse engineering approach has the potential to be applied beyond the field of tyre moulding, offering a promising avenue for the development of industrially relevant component manufacturing processes (Y. Zhang et al., 2019).

Additive Manufacturing

The term "additive manufacturing" (AM) is used to describe a method of creating objects from 3D model data. This is typically achieved by combining materials in layers, in contrast to the subtractive manufacturing methods, such as those used in conventional machining, as defined in the ASTM standard. The term has been described in a number of ways in academic literature, including as an additive process, an additive technique, additive layer manufacturing, additive manufacturing, freeform manufacturing, and freeform additive manufacturing (Mellor et al., 2014). AM techniques have the potential to generate an extensive range of materials, including ceramics, metals, glass, composite materials, and polymers (Sun et al., 2021).

In comparison with conventional manufacturing procedures, additive manufacturing (AM) techniques possess several distinctive advantages. Unlike conventional subtractive manufacturing, which necessitates the removal of a substantial quantity of material, AM enables the efficient utilisation of raw materials by constructing components in successive layers. It is common practice in traditional manufacturing processes to require the utilisation of auxiliary materials and devices, including jigs, cutting tools, fixtures, and coolers, in conjunction with the primary machine tool. It is evident that AM does not necessitate the utilisation of supplementary resources. In the absence of tooling constraints, the production of parts exhibiting intricate features in a single piece is a viable option. Additionally, a single part can be manufactured with varying mechanical properties, resulting in a component that is flexible in some areas and more rigid in others. The use of AM machines does not necessitate the implementation of costly set-ups, thereby rendering them an economically viable option in the context of small-batch production. The quality of the component parts is dependent upon the manufacturing procedure, rather than the operator's skill level. This allows for seamless synchronization of production with customer demand (Prakash et al., 2018). Figure 7 shows the additive manufacturing process stages.

Figure 7
Additive manufacturing process stages (Kirkman et al., 2019)



The expansion of the field of AM can be attributed to the unceasing advancement of technologies and the capacity to work with an expansive array of materials. The advancement of technology is propelled by a multitude of factors, including the demand for bespoke products, compressed product development cycles, an intensified emphasis on sustainability, diminished production costs and delivery times, and the emergence of novel models of business. The ISO/ASTM 52900 standard provides a comprehensive classification of additive manufacturing processes, categorising these processes into seven distinct categories: binder jetting, material extrusion, directed energy deposition, powder bed fusion, material spraying, vat polymerisation, and sheet lamination (Pérez et al., 2020).

Binder jetting is a process whereby liquid is deposited in droplets in order to bind powdered material. Directed energy deposition comprises a series of processes that utilise concentrated thermal energy to melt and fuse materials introduced in wire or powder form. Material extrusion is the most prevalent AM technology, largely due to the considerable number of fabricators utilising this method and the relatively low cost of the equipment required. The feedstock is conveyed through a nozzle that defines the volumetric pixel size. The process of material spraying involves the deposition of material droplets in a selective manner onto a build platform. In powder bed fusion, the bonding of materials is achieved through the superficial exposure of a powder bed to a heat source. The process of layer lamination entails the utilisation of raw materials in the form of sheets, which are then integrated into the structure as individual layers. In the context of vat polymerisation, the term 'crosslinking' refers to the process of forming a solid by using a photolithographic method on liquid thermoset polymers (Bourell et al., 2017).

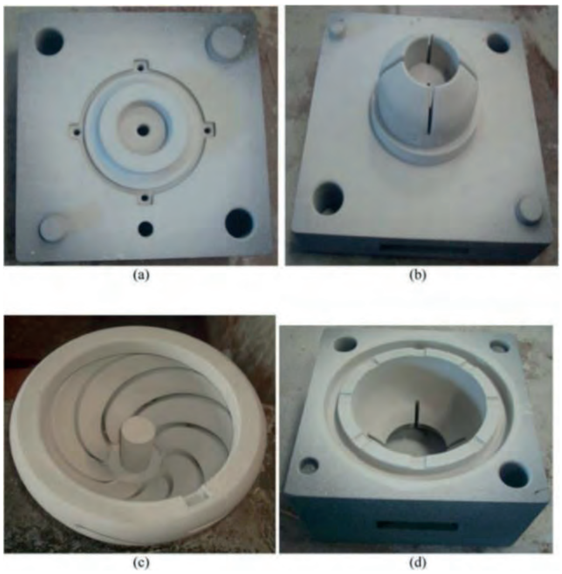
The creation of moulds, sprue systems, and cores represents the most time-consuming and costly stage in conventional sand casting. This is particularly the case for geometrically complex parts, where the use of machining techniques is prevalent (J. Wang et al., 2019). The accelerated evolution of AM techniques is precipitating a series of modifications to the design of foundry machinery. AM methods are of particular significance in the advancement of technology for the production of small castings or single castings of intricate shapes, such as skeleton castings, which are also manufactured by alternative technologies. AM methodologies facilitate the fabrication of disposable moulds, cores, and wax moulds, as well as those crafted from thermoplastic polymers for prolonged utilisation (Piekło & Maj, 2014). The creation of a 3D digital model is a fundamental requirement for all AM processes. This model may be generated either through direct input into CAD software or through RE of a 3D point cloud representing the desired geometric configuration of the final component (Campbell et al., 2011).

3D printing technology has a number of applications in casting. Among the most common techniques employed in this regard are those involving the expedited fabrication of moulds, the direct printing of metal products and the repair of defects. Additionally, AM is frequently employed in casting operations, encompassing sand and investment casting, due to its capacity to swiftly generate moulds that align with the specific demands of the casting process. Conventional AM can be utilised at each stage of the casting procedure, including the printing of wax moulds, ceramic shells, sand cores and sand moulds (Gao et al., 2022).

Additive Manufacturing Applications

The utilisation of AM applications in the foundry industry is increasing, especially for producing casting moulds of parts with complex shapes. The aim of the study was to undertake a comparative investigation of two processes for manufacturing casting moulds. These were the traditional sand casting process and an alternative approach known as additive manufacturing. A comparison was undertaken between the two processes in order to ascertain their respective advantages in terms of the weight saved, surface finish achieved, design allowances permitted and fettling work necessitated. The findings indicated that there are considerable benefits associated with the utilisation of AM for the production of moulds. The utilisation of 3D-printed moulds has been demonstrated to result in notable reductions in the quantity of sand employed, the allowances incorporated into the design, and the fettling work required. Additionally, the mechanical properties of three-dimensionally printed moulds demonstrated superiority over conventional moulds, attributable to the enhanced bond strength attained during the 3D printing process (Hawaldar & Zhang, 2018). Figure 8 shows the components of the 3D printed mould.

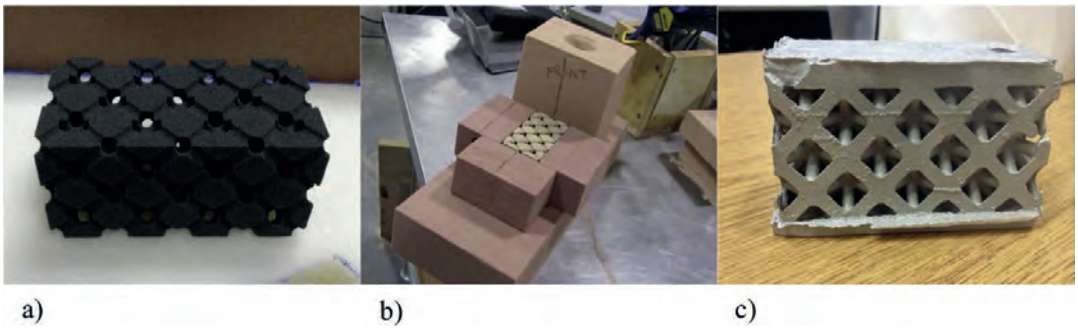
Figure 8
3D printed mould components: a) lower casting grade, b) upper casting grade, c) core, and d) sidewall (intermediate section) (Hawaldar & Zhang, 2018)



In another study on mould manufacturing, researchers investigated the use of additive manufacturing for production, as advanced, complex cooling channels in casting moulds allow for rapid and reliable cooling, as well as more effective control of the solidification process. Additionally, a comparative analysis was undertaken to ascertain the efficacy of an advanced cooling system versus an alternative configuration featuring enhanced cooling channels in the context of cooling a mould insert. The improved cooling ducts were shown to be highly efficient in air cooling (Hovig et al., 2016). A further study explored potential disparities in the material properties of A356-T6 castings produced with two distinct commercial 3D printing media. The study encompassed microstructure, porosity and mechanical strength. The castings produced in ExOne moulds demonstrated superior performance compared to alternative materials, as evidenced by their superior quantitative mean values in all conducted tests. Furthermore, the mean values obtained across all tests fell within the acceptable range for industrial castings (Snelling et al., 2019). Figure 9 shows the complex printed mould, oven-free outer mould and casting complex structure created using binder jetting.

Figure 9

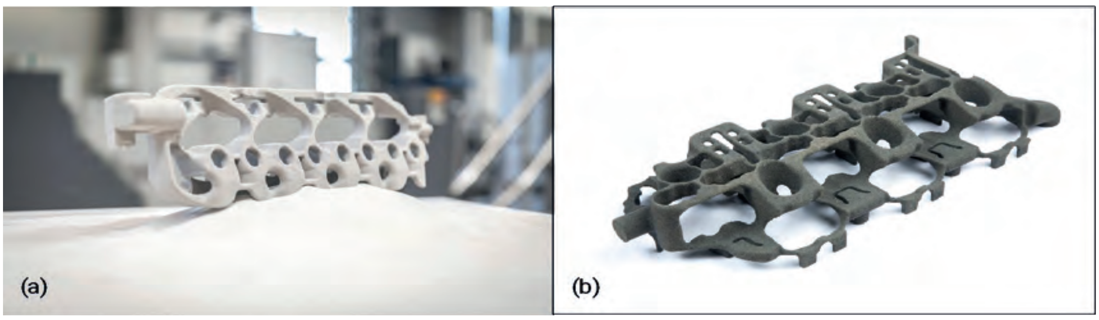
a) complex 3D printed structure was produced utilising the binder jetting technique, b) external mould without oven and c) cast complex structure (Snelling et al., 2019)



There are global companies such as ExOne and Voxeljet that produce high-tech 3D printers that enable sand mould manufacturing with binder jet additive manufacturing. With these 3D printers, sand moulds and cores with complex shapes, strength and high dimensional accuracy can be produced. Figure 10 shows sand moulds produced with various 3D printers.

Figure 10

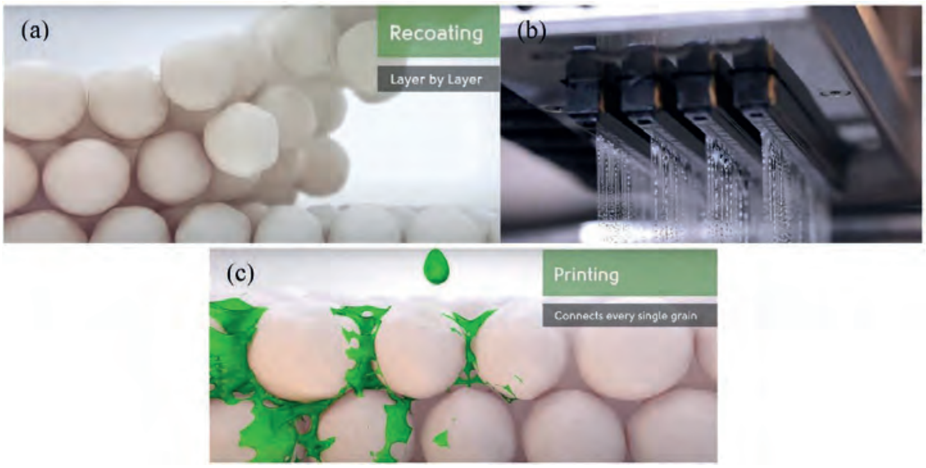
Sand moulds a) ExOne® sand mould (ExOne, 2024a) b) Voxeljet sand mould (Voxeljet®, 2024)



The spraying systems of industrial 3D printers used for sand mould manufacturing with binder jetting additive manufacturing are generally provided with binder spraying cartridges. The casting mold printing process continues with the process of wetting the recoated sand grains with resin. This process is shown in Figure 11-a-c. Figure 11-b shows the 3D printer spray print head of ExOne® company.

Figure 11

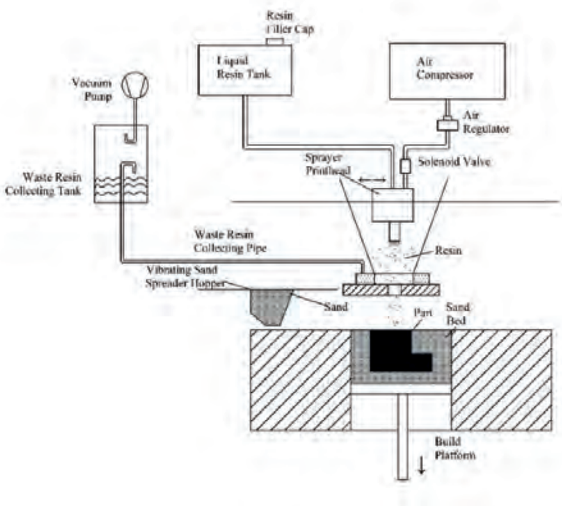
ExOne® binder spray printing Process (ExOne, 2024b), (Feng et al.,2020)



In a study, the researcher made an investigation by developing a different spraying system to eliminate the disadvantages of cartridge systems such as high cost and clogging. In the study, he developed a new spraying system and produced sand moulds at different printing parameters and examined the effects on their mechanical properties and microstructures. Figure 12 shows the working schematic of this 3D printer. The results of the study demonstrated that the manufactured components were suitable for utilisation as sand moulds. In the working schematic of this 3D printer, the construction platform, vibrating sand spreader hopper, sand spreading system, waste resin collection system, air resin spraying system, etc. are given. In the system, sand mixed with catalyst is placed in the spreader hopper and laid on the construction area with vibration at the desired layer thickness, then resin is sprayed to create resin vapour in the resin hopper and resin is selectively applied on the sand grains laid by passing through the resin filter according to the shape of the part to be produced. These processes continue until the desired sample size is obtained. In addition, the excess resin in the resin reservoir is collected and returned to the collection tank. This method allows the production of complex reverse-angle components with intricate shapes. In addition to these, since no cartridge is used in the spraying system, problems such as clogging etc. do not occur (Aslan, 2023).

Figure 12

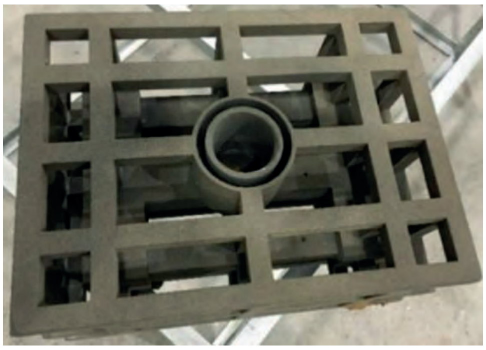
Operation schematic of the binder jetting 3D printer (Aslan, 2023)



In addition to investigations into the production of moulds by additive manufacturing, some studies have employed 3D printing technology to develop new feeder designs, with the aim of enhancing casting performance. The aim of this research was to investigate the impact of two recently developed feeder designs, the ellipsoidal and the spherical feeder, in addition to the conventional cylindrical feeder, on the solidification time and the entrained air volume fraction in aluminium alloy (A319) castings. It was determined that the ellipsoid feeder, which was the subject of the study, resulted in an enhancement in casting yield. The proposed feeder designs will facilitate the optimisation of the casting design and enhance the performance of the casting process, particularly in the feeding and solidification stages, for materials and geometries that are challenging to cast (Shuvo & Manogharan, 2021). In a different study, a skeleton mould for castings was designed and manufactured using the additive manufacturing method. This mould comprised two structures: a lattice-shell structure and a rib-reinforced shell structure. The utilisation of this sand mould structure design facilitates the expeditious and uniform cooling of the casting process, which has the potential to enhance production efficiency and mitigate the occurrence of casting deformations and residual stress. Furthermore, it offers additional space and flexibility to modify the cooling conditions in specific areas of the casting. The study revealed that the innovative sand mould design resulted in a minimum of 60% reduction in sand usage and a minimum of 20% reduction in demoulding time for casting (Kang et al., 2018). Figure 13 illustrates the local hollow structure sand mould employed for the casting of tensile frames.

Figure 13

Local hollow structure sand mould employed for the casting of tensile frames (Kang et al., 2018)

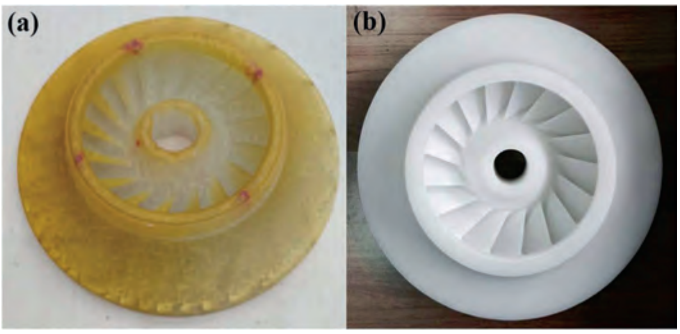


Developing a production method using more environmentally friendly consumables in the production of moulds by additive manufacturing, the researchers investigated the forming method in the additive manufacturing of frozen sand moulds. The aim of this study was to propose a novel method for the additive manufacturing of frozen sand moulds, which employs the use of water as a binder in lieu of resin binders. This approach addresses two significant challenges inherent to low-temperature manufacturing environments. Firstly, this approach effectively eliminates the release of harmful gases during the pouring process. Secondly, it facilitates direct recycling of mould sand, a crucial advancement for the sustainable production of complex castings (Yang et al., 2023).

The production of casting models with various additive manufacturing methods is also important in the casting industry. In a study, the manufacturing cycle of stainless-steel closed propeller casting was shortened, and surface shrinkage and internal defects were prevented by printing a complex-shaped propeller wax model using SLS and SLA methods. Upon completion of the study, a sophisticated propeller was successfully created by combining the use of a 3D-printed wax pattern with a process of simulation optimisation. The new process was observed to have several benefits in comparison to conventional investment casting, with notable reductions in processing time, lower product cost, and an enhanced production yield (D. Wang et al., 2019). Figure 14 shows the rapid prototyping of wax moulds through the utilisation of UV (photosensitive) resin and HIPS (high-impact resistant polystyrene).

Figure 14

Rapid prototyping of wax moulds employing a) UV (photosensitive) resin and b) HIPS (high impact resistant polystyrene) (D. Wang et al., 2019)

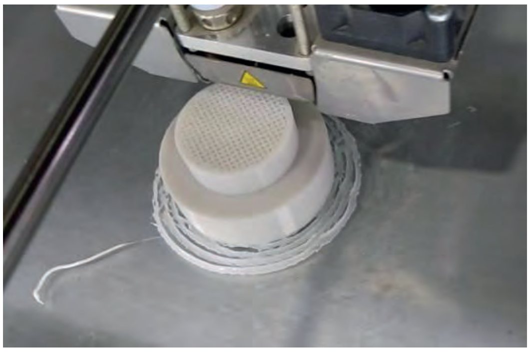


In a different study, the surface finish of 3D-printed ABS and PLA models was examined as a potential replacement for traditional wax models in the production of models. The finishing process for 3D-printed ABS and PLA models was undertaken to enhance the surface finish, as this approach effectively eliminates the line marks that are commonly observed in printed models as a result of additive manufacturing. The surface quality of the moulds exhibited greater improvement in PLA and ABS models compared to those crafted from wax (Vyas et al., 2021). In a different study, an innovative, cost-effective method for the fabrication of regular lattice structures through an AM-assisted investment casting technique was explored. The FDM method was used to produce a gypsum-infiltrated lattice structure model. The model was then burned and aluminium was cast in a vacuum. This process allows for the fabrication of non-stochastic metallic lattices comprising thin struts/ribs and exhibiting reduced relative density. The results of the study demonstrated that aluminium alloy truss frames possess considerable dimensional tolerance and exhibit precise control over intricate details (Carneiro et al., 2020).

The use of additive manufacturing models is gaining importance due to the disadvantages such as design limitations of wooden models that have been used in the traditional casting process. A study was conducted to assess the potential of replacing a wooden prototype with a 3D-printed model in the rapid prototyping process of aluminium sand casting. The 3D-printed model incorporated a stepped roller for manufacturing purposes and was designed with this objective in mind. The cast aluminium was subjected to a series of quality control assessments, including cross-checking for surface quality and geometrical irregularities. Additionally, its physical attributes were benchmarked against those of cast aluminium produced with either a wood or metal pattern. The cast aluminium obtained from the 3D printed model was found to exhibit superior surface quality, accuracy of dimensional and shape accuracy (Kumar et al., 2019). Figure 15 shows the 3D printed model.

Figure 15

3D printed model (Kumar et al., 2019)



In addition to mould and model production, core production is also provided by additive manufacturing. A study was conducted to investigate the production of low-shrinkage alumina cores for casting single-crystal nickel-based superalloy turbine blades using the SLA 3D printing production method. The findings of the investigation indicated that the materials under consideration for stereolithography (SLA) 3D printing have significant potential for the manufacturing of intricately shaped alumina ceramic cores in high-precision investment casting. This includes applications such as single-crystal nickel-based superalloy hollow turbine blades for use in cutting-edge aviation engines (Tang et al., 2022).

In the production of casting moulds by additive manufacturing, moulds are usually made of sand. However, in some studies, researchers have also investigated the usability of gypsum moulds. The objective of the research was to ascertain the viability of utilising binder injection for the fabrication of gypsum moulds for direct cast metallic components, with the aim of achieving a cost-effective alternative to conventional metallic AM processes for the casting of aluminium alloys. A variety of infiltrate types and post-processing parameters were employed in order to enhance the mechanical and thermal resilience of the moulds. All moulds were found to have good heat resistance during casting (Garzón et al., 2017).

The developing technology will enable the direct production of high-strength metal parts using additive manufacturing methods such as casting. However, the disadvantages of these methods such as material cost and processing time reduce the usage rate for the time being. In a study, the reproducibility of metallic parts by additive manufacturing was investigated. In the study, parts were made from five different metals using SLM (selective laser melting) and their mechanical properties were investigated. The findings indicated that SLM represents a dependable approach to producing metallic materials with uniform and replicable properties. It was also observed that the specimens produced by casting have lower strength compared to the SLM method (Prashanth et al., 2017). In another study, high-density bulk Cu-10Sn bronze specimens were produced by SLM, after which a comparative analysis was conducted between the microstructure and mechanical characteristics of the material produced by SLM and those obtained from casting. Upon conclusion of the study, in addition to the increased strength observed, the SLM material also demonstrated a notable increase in ductility. The results of this study illustrate the effectiveness of SLM in the manufacturing of high-strength tin bronze, and provide a basis for the creation of high-performance Cu-based parts with precision-engineered forms and geometries via AM (Scudino et al., 2015).

Conclusion

With the advancing technology, it is important to integrate modern technologies in order to increase the efficiency of traditional production methods such as casting, which has a wide usage area. Reverse engineering and additive manufacturing are among these modern technologies. The studies examined revealed that reverse engineering is commonly employed in casting technology for the fabrication of casting parts and moulds, industrial refabrication of objects with free-form surfaces, the production of defective mould parts lacking 3D solid model data, the generation of 3D models, the rapid development of complex castings, custom mould modelling, the resolution of technical limitations in the measurement of complex parts through practical application, and the determination of the dimensional accuracy of components in the digital casting process. This shows that reverse engineering is used in many stages of casting technology. The use of AM in casting technology is frequently used in sand mould and core production, wax model production, plaster mould production, 3D printed polymer model production, direct production of metallic parts, and alumina cores production. The progressive development of AM technology is positioned to supersede conventional machining techniques, which are utilised for preliminary preparation tasks such as mould, runner and core production in traditional casting methodologies. AM offers a more expedient production process and the utilisation of an array of materials. By integrating reverse engineering and additive manufacturing into casting technology and increasing their use, it will be seen that better quality, faster and lower-cost parts can be produced by using traditional and modern technologies together.

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R&D Studies in the Water Slides Industry

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Introduction

Research and Development (R&D) projects today focus on significant innovations and technological advances in various industries. In this context, Polgün's R&D studies have evolved into these areas. Polgün plays a leading role in the water slide industry with its innovative approach and use of advanced technology. With its continuous R&D studies, it develops safer, environmentally friendly products and maximizes the user experience.

Polgün's innovative projects and forward-looking strategies are constantly raising the bar in the water slide industry and shaping the future of the industry. Polgün is committed to providing its customers with the highest quality products and services by increasing its competitiveness in the sector with its investments in innovation and technology.

What is R&D?

Research and development (R&D) is the activities carried out to increase technical knowledge and to use this knowledge in new applications. Research is a process of learning the unknown, while development is an activity to improve the current situation (Üsküdar University, 2024). According to the OECD, R&D is defined as "the creative work carried out systematically to increase knowledge and the use of this knowledge to create new applications" (Wikipedia contributors, 2024).

R&D is considered an important resource in revealing new products, production techniques, information, and processes. R&D investments increase the value of businesses and provide a competitive advantage over productivity and profitability (Demir, 2019).

The R&D process usually includes the following stages:

- Needs and Market Analysis: The R&D process begins with an assessment of consumer needs, market trends, and the shortcomings of existing products. At this stage, new product or process ideas are created.
- Literature Review and Technology Analysis: A literature review is conducted for the selected ideas and existing technologies are analyzed. This stage evaluates the viability of ideas and their innovation potential.
- Project Planning: The goals, objectives, and scope of the project are determined. In addition, financial and material resource planning is done, and a business plan is created.
- Design and Prototype Development: The first concept design of the product or technology is made. Once the design is complete, physical or digital prototypes are created. As a result of the tests and feedback on the prototypes, possible risks are determined, and necessary improvements are made.
- Technical Drawings and Simulations: Designs are detailed with technical drawings and engineering calculations. The product is tested in a virtual environment and verified with simulations.
- Production of Physical Prototypes and Tests: Physical prototypes are produced in line with detailed designs. These prototypes are subjected to laboratory and field tests to get feedback in terms of performing in real-world conditions (Dincer, 2002).
- Commercialization: It is the process of presenting the product or service to consumers. At this stage, the marketing strategy of the product or service is created, and the sales channels are determined (Lab Academy, 2024).

These processes highlight the importance of R&D in developing innovative products and processes, and the role businesses play in gaining competitive advantage.

What is Innovation?

Innovation, in general, is the process of innovation, change, and value creation. Innovation, which is defined as "innovation" according to the Turkish Language Association, is defined by ISO as "a new or modified entity that realizes or redistributes value" (Turkish Language Association, 2024; Wikipedia contributors, 2024). Lundvall (1992), on the other hand, defines innovation as a system that includes all parts of the economic structure and the institutional structure in which research and development activities that affect learning are carried out. Innovation is an important factor that promotes both national and international competitiveness and overall development. While it supports economic growth, it also leads to positive improvements in the services provided to the public. With the impact of globalization, innovation is of critical importance in every field.

Innovation can be studied in five main types: Product Innovation, Marketing Innovation, Service Innovation, Organizational Innovation, and Business Model Innovation (Albert Solino, 2024). The effects of these species in the water slide sector are as follows:

- Product Innovation: Product innovation in the water slide industry includes developments such as the use of new materials, and the production of more durable, environmentally friendly, and aesthetically appealing slides. In addition, advanced safety features and energy-efficient technologies improve user safety, reduce operational costs, and minimize environmental impacts. These innovations increase the competitiveness of water slides, improving the user experience and customer satisfaction.

- Marketing Innovation: Marketing innovation aims to enable water slides to reach the target audience more effectively and increase customer loyalty. Digital marketing strategies and methods to increase brand awareness strengthen the market advantage of water slides and maximize sales.
- Service Innovation: Service innovation aims to make visitors' experiences more attractive and satisfying. In the waterslide industry, providing innovative services increases customer satisfaction and improves the visitor experience.
- Organizational Innovation: This type of innovation focuses on increasing efficiency within the business, increasing employee motivation, and improving customer service. Organizational innovation in the water slide industry improves the overall performance of the business and the quality of customer service.
- Business Model Innovation: Business model innovation involves restructuring the way the business does business. Such innovations in the waterslide sector can promote sustainable growth through the development of new revenue models and operational strategies.

In conclusion, various types of innovation in the water slide industry play a critical role for businesses to gain competitive advantage and achieve sustainable growth. In addition to technical and design developments, innovations in market and service quality are becoming indispensable elements to maintain leadership in the sector.

The Importance of R&D and Innovation in Water Slides

Today, information has become the most important input in the production process. In the water slides industry, R&D and innovation are critical to providing a competitive advantage and meeting customer expectations. In addition to developing new and innovative products, R&D activities create added value in many areas such as improving existing products, reducing costs, and increasing the efficiency of production processes.

Innovation allows elements such as safety, fun, and aesthetics to be optimized in water slides. For example, the use of new materials increases the durability of slides, while solutions to ensure energy efficiency contribute to environmental sustainability.

Another important dimension of R&D and innovation is the reflection of customer feedback in product development processes. In this way, personalized and innovative solutions can be offered that are more suitable for user needs. Investments in R&D and innovation activities in water slides provide businesses with a competitive advantage in the long run, helping them to be in a leading position in the industry.

As a result, the importance of R&D and innovation in the water slides sector stands out as the main factors that support sectoral development and sustainable competitive advantage. In this context, companies need to constantly update and improve their R&D and innovation strategies.

Polgün R&D Center and R&D Studies

Polgün started its activities in 2002 in Muğla-Menteşe. Since then, Polgün has been a pioneer in its sector and has become one of the rare companies in the field of steel construction and fiberglass manufacturing. In its modern factory of 70,000 m², it not only imports water slides and playgrounds in the sector but also makes a name for itself in the sector by producing its own brands Legends Water Slides, Splash Tower, Animations Splash Adventure, Splash Zone, Mountain Coaster products and projects such as water parks, hotels, camping areas, pools.

Since its establishment, it has been a company that continues to seek innovation by acting with both customer demands and its mission and vision. Thanks to the knowledge gained in this context, Polgün received approval from the Ministry of Industry and Technology in 2021 and became the first and only R&D center in Muğla province. Today, it has the status of the only R&D center in Muğla province.

Splash Adventure

Our Splash Adventure project is the only pedagogue-approved adventure trail. During the design of the track, many pedagogical dimensions were taken into account, and the thematic track combined children's developed play materials with creativity and fun. Due to these features, it is preferred by facilities. The image of the Splash Adventure course is shown in Figure 1.

Figure 1
Splash Adventure parkour

There are different levels of difficulty in parkour games, and the games are open-ended (Polgün Waterparks, 2024). Games can be played from any starting point and can be set up with a variety of logic. Players can use and challenge them as they wish. In Splash Adventure, the entire area is modified, adjusted, created, and recreated each time by the individuals who play there. Players take on the responsibility of problem-solving, taking risks, working together, and existing to create their unique playgrounds (Türkhan, Uzun & Arıkan, 2024). With these features, Splash Adventure has been introduced to the market as a new product developed in the R&D center.

Themed slide development with five-axis sliding behavior

Developed by Polgün R&D center, the water slide offers a unique geometry by combining the rotational sliding movement of the slides with climbing and returning movements. Thanks to these features, it has become the first and only one of its kind in the world. It is an R&D center project that combines two different sliding dynamics, helical climbing, the possibility of sliding with 2 4-person boats at the same time, interactive climbing detection with LEDs, and an electronic scoreboard system, which constitute the innovative aspects of the project. The themed slide with five-axis sliding behavior is shown in Figure 2.

Figure 2
Themed slide with five-axis sliding behavior

Mini Splash

Since the general purpose of the project is to use narrow spaces effectively and the structure is desired to have modular features, it is one of our proprietary designs designed and produced for this purpose in all details (Kayrıcı, Uzun & Yaz, 2024). The Mini Splash design is shown in Figure 3.

Figure 3
Mini Splash design

Babochka

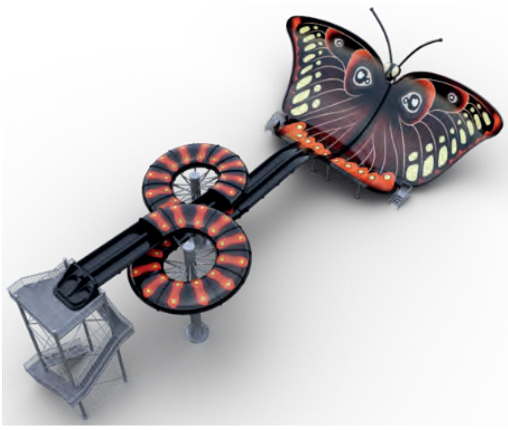
An impressive work of art, the center of attention, and a source of adrenaline for any water park, the butterfly Babochka slide sends the user on a boat adventure on its gorgeously colored wings (Polgün Waterparks, 2024). A visually quite impressive slide, Babochka is a proprietary design that can be immediately noticed by guests wherever they see it. The design of the Babochka slide is shown in Figure 4.

Figure 4
Babochka slide design

Monarch Butterfly

The Monarch Butterfly slide, which was developed in our R&D center and received national support from KOSGEB, includes a structure that offers high adrenaline and provides the opportunity to have fun together (Uzun, Kayırcı, Türkhan & Yaz, 2024). During the design process, a slide was created that could be compatible with various themes and at the same time self-themed. This project aims to provide users with an unforgettable experience by offering an innovative approach in the sector (Uzun, Kayırcı, Türkhan & Yaz, 2024). The Monarch Butterfly slide design is shown in Figure 5.

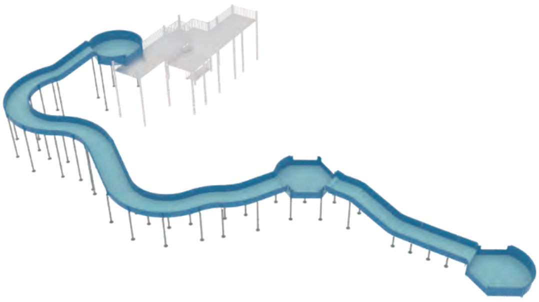
Figure 5
Monarch Butterfly slide design



Body River

Within the scope of this project developed in our R&D center, it is ensured that the slides generally reach the user to the fall pool or area with various variations from the starting part. This innovative design leaves it to the user's initiative not to move forward without leaving the user a choice, but to stay at various stations and continue to slide (Uzun, Kayrıcı & Yaz, 2024). This proprietary slide design, where users can interact with each other at the stations, adds a new dimension to water parks. The design of the Body River slide is shown in Figure 6.

Figure 6
Body River slide design



Hydra slide

Within the scope of the project developed in our R&D center, a new element has been added to water parks (Kayrıcı, Uzun, Türkhan & Yaz, 2023). This element provides the user with both entertainment and an unforgettable experience. Thanks to the interactive structure of the theme used, the awareness created by the product in the user and the feeling of slipping again make the competitiveness and added value it will add to our company unique (Kayrıcı, Uzun, Türkhan & Yaz, 2023). This product of your company is considered a signature slide in the sector and is one of Polgün's registered designs. The Hydra slide design is shown in Figure 7.

Figure 7
Hydra slide design

Innovative Technology and Designs

Material Technologies

The materials used in the construction of water slides have undergone great changes over time. While traditional materials such as wood and metal were used in the early periods (Garden Guides, 2024), fiberglass and special composite materials are preferred today (Yaman, 2016). These new materials are preferred because the slides are more durable and safer, as well as facilitating the design process and being environmentally friendly (Ağırgan, 2023).

Coating technologies such as UV-resistant coatings, non-slip surfaces, and water-repellent coatings are also an important areas of innovation. These coatings extend the life of the slides and increase user safety and comfort.

As Polgün, many innovative studies have been carried out in this field. These studies have ensured that the slides are both safer and more durable. In this way, the production costs of the slides have been reduced and their environmental impact has been reduced. Polgün's innovative approach to material technologies reinforces its leading position in the sector and enables it to offer the highest quality products to its customers. R&D studies carried out in this context are constantly developed and supported by the latest technologies.

Design and Engineering Studies

The design and engineering processes of water slides are constantly evolving, considering critical factors such as safety, aesthetics, and user experience. Design and engineering studies are carried out in most of our R&D studies. Polgün design team has carried out many successful projects as aesthetically attractive and themed designs make water slides more preferred by users. These designs, inspired by Greek mythology, king butterflies, and large land animals, have attracted the attention of users with various themed slides. Polgün's thematic slides are described as "signature slides" because they are almost a signature.

Polgün, which is not limited to theme studies, has carried out many studies to make the sliding experiences extreme, primarily by prioritizing the safety of the users. Features such as turns, loops and free-fall sections integrated into its slides make the skating experience more adrenaline-filled and give users the feeling of sliding repeatedly. Water spray mechanisms integrate light and sound effects into the slides, enriching the sliding experience. Users who use a water slide have unforgettable experiences while feeling themselves in a different world.

Environment and Sustainability

Today, environmental sustainability and conservation of natural resources are becoming more and more important all over the world. The use of energy-saving, water-saving, and low-energy consumption systems in the design of modern water slides, together with environmentally friendly materials, reduces the environmental impact of water slides.

As Polgün, we play a leading role in environmental sustainability and energy efficiency. We attach great importance to environmentally friendly practices in the design and production of our water slides. We carry out R&D studies that address issues such as using fluorescent lighting instead of LED lighting in our projects, applying water circulation systems instead of high-water consumption systems, and using recyclable, environmentally friendly materials.

In addition, we aim to bring more entertainment to more people by spending less water on our projects. This approach both saves water and increases efficiency for businesses. As Polgün, we continue to offer water slides that are both environmentally friendly and economically advantageous by developing such sustainable and efficient solutions.

Security

Water slides are constantly inspected to ensure compliance with international safety standards. Standards such as EN1069-1 set specific criteria to improve the safety of slides (ASTM, 2024).

As Polgün, we attach great importance to material quality and durability to ensure the structural safety of water slides. By designing structures resistant to natural disasters such as earthquakes and wind, we minimize possible risks.

Polgün's Leading Role in the Sector and Its View to the Future

Polgün is a company that has proven itself in terms of speed and reliability with its pioneering role in the sector. Standing out in the sector with its wide product range and ability to respond instantly to customer needs, Polgün aims to be the world's largest company in its vision for the future.

In recent years, due to the increasing population and climate change, the importance of water management has been increasing worldwide (StartUs Insights, 2024). In sectors where water is used intensively, such as water parks, it is of great importance to carry out R&D studies to prevent water scarcity. As a leading company known for its innovative approaches and use of advanced technology, Polgün has directed its R&D studies in this direction.

With the project launched in 2021, Polgün has taken important steps in energy efficiency. In addition, it has set itself the goal of providing innovative solutions for water management and sustainability issues (Polgün Waterparks, 2024). While these projects reinforce Polgün's leadership in the sector, they enable it to take solid steps toward the future with its environmentally friendly and sustainable practices. With these efforts, Polgün aims to set an example for other companies in the sector and to be the leading name in the water parks sector on a global scale.

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A Review of Studies on Water Ram Pump

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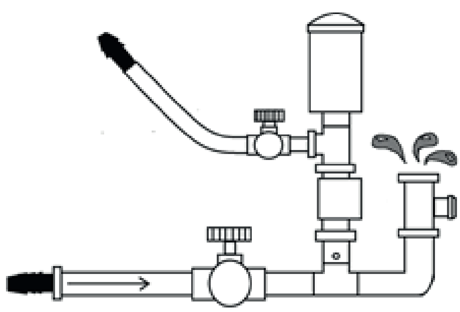
Introduction

The devices that create a "pressure difference" with water in a pipeline with a height difference and that enable the water to be carried meters (50-150m) up by converting this pressure difference into kinetic energy are called "water hammer pumps". In this device, no external energy is needed and the pressing energy is produced naturally. Water hammer has been used in Europe for 200 years and in our country for 60 years (Hacıfazlıoğlu, 2020).

Hydraulic water hammer pump is widely used to provide energy for agricultural and domestic purposes. This type of pump is used by farmers and middle class people in rural areas due to its zero operating cost. It is a falling water pumping device that works by using the energy of water flowing through a drive pipe into the body of the water hammer pump. It pumps water from streams, creeks and other water sources with flowing water. This device uses the kinetic energy of falling water to raise it from the source to a higher level (Salins, 2015).

Figure 1
Water Ram Pump System

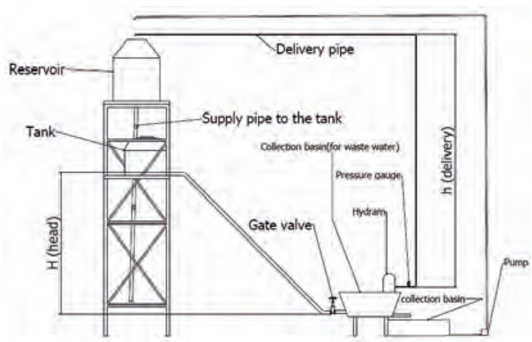


No energy is consumed for the pump. The aim is to press some of the water into a much higher water tank with the pressure created by the water above the pump level. For this process, there are valves in the mechanism that can be opened and closed with the pressure of the water. If you lock the instantaneous high pressure to the check valve, it will press the first channel it finds until the pressure is gone. On the other hand, the valve that is closed will open itself when the pressure drops and the water above will press again. When the pressure builds up, the 2nd valve will close itself and the pressure will increase even more as it closes, opening the valve in the tower and reducing the pressure. It will close again when it drops and this continues. The pump does not provide a continuous water flow while it is operating. Some of the water entering the pump reaches the target while some of it is thrown out. Kinetic energy is created in the system with the opening and closing of the valves and this energy is used to press the water (Görcelioğlu, 1975).

Water Coach The pump Design And Experimental Results

RN Mbiu And friends in 2015 made "Performance Testing of Hydraulic Ram Pump " in the study cheap and by designing a water hammer pump with easily available materials, testing the system with different parameters to obtain a longer life and higher efficiency. One pump system emerge removal intended.System in his work necessary valve By making the necessary settings , optimum points are determined and the aim is to select the system that best meets the water pumping needs of the users (Mbiu et al., 2015).

Figure 2
Test Pump System



Was set up as in Figure 2. system in different waste valve weights ,different study room temperatures and system efficiency was evaluated with different pressure values on the distribution pipes.

Figure 3
Mass vs. Discharge Graph at Different Excitations

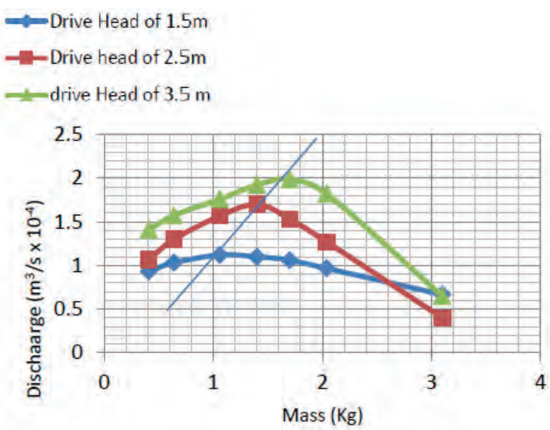


Figure 4

Discharge Graph Against Different Frequencies

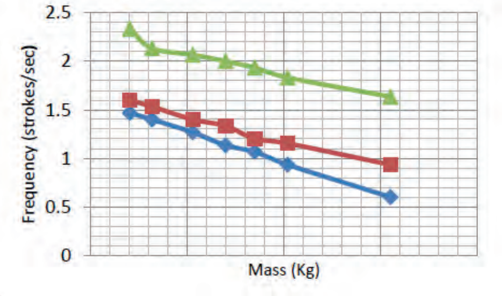
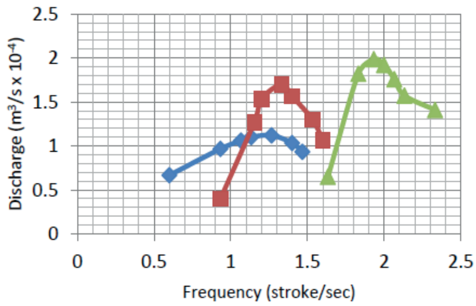


Figure 5

Graph of Q Discharge at Different Frequencies



The test period different supply heads , distribution heads , stroke frequencies And waste The weights on the valve were tested. Maximum water hammer pump performance measurement discharge optimum weights maximum in frequency This optimum level has been observed for 4 m press height for most less than 0.5 m'lik One tarik head requires . Also open And closed valves continually movement in is for It is important to replace the materials after wear .

Wanchai Asvapositekul And friends in 2019 made In the study titled "Determination of Hydraulic Ram Pump Performance: Experimental Results", the ratio of the discharge head to the drive head was investigated in order to increase the efficiency of the hydraulic ram pump. speed like parameters in line with supply height , air room pressure and waste valve per minute My horse number of data over experiment Experiments have been carried out. as a result print height , feed flow speed,press flow speed like parameters efficiency It has been found that the air chamber pressure tends to increase and the efficiency tends to decrease (Asvapoositkul, 2019).

Figure 6

Water Ram Test Setup

Figure 7

Feed 3 Flow Rate and Distribution 3 Flow Rate at Differential Height, hs = 2.0 and 2.5 m

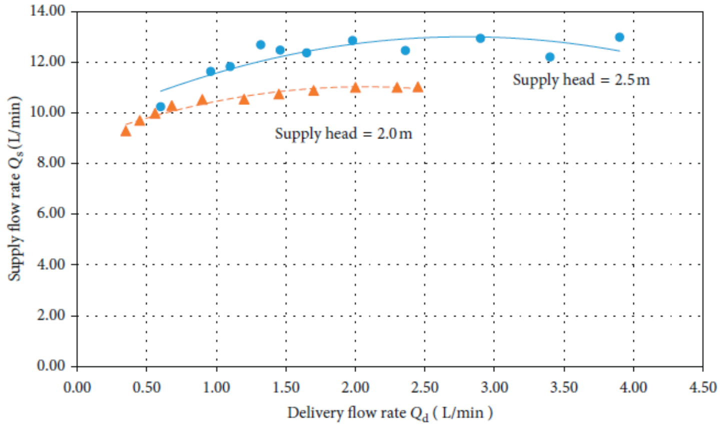


Figure 8

Difference Height Between Outlet Height and Outlet Flow Rate, hs = 2.0 and 2.5 m

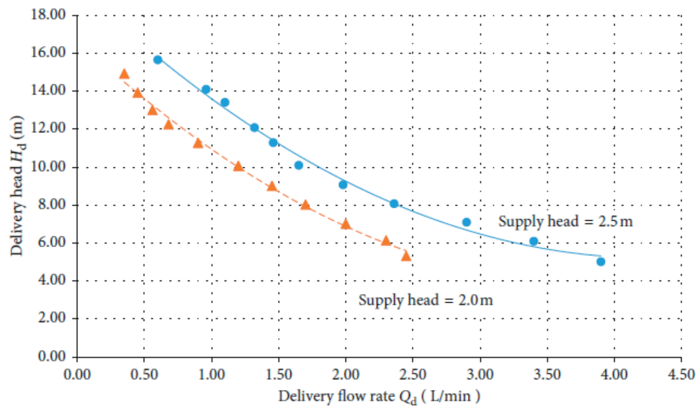


Figure 9

Height Ratio and Flow Velocity Ratio at Differential Height, hs = 2.0 and 2.5 m

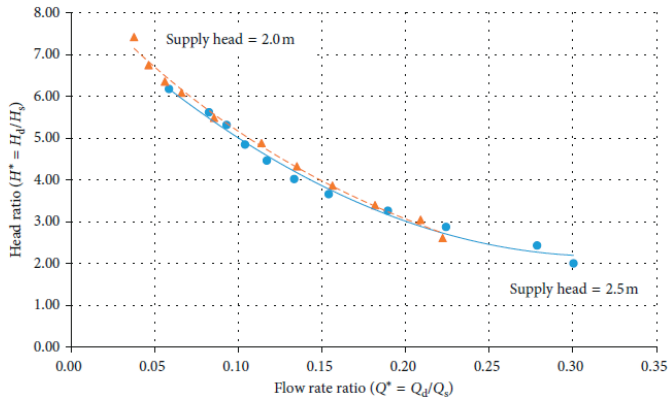
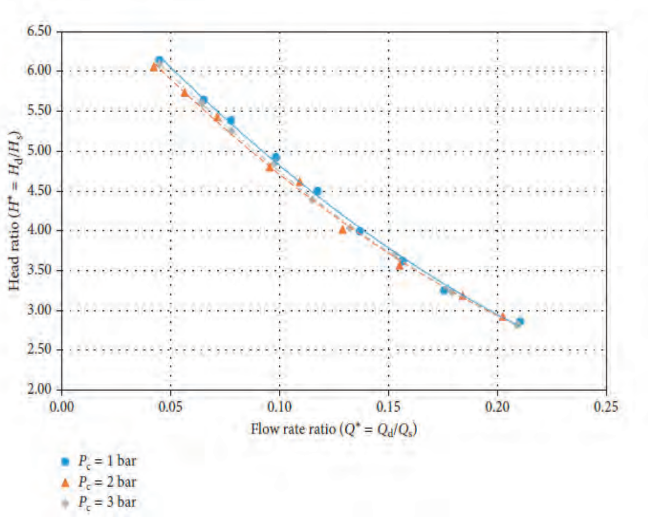
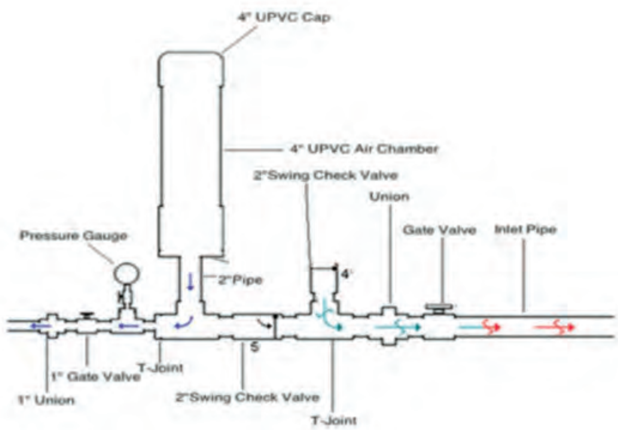


Figure 10
Load Ratio and 3 Flow Rate Ratio at Differential Pressure (Pc = 1, 2 and 3 Bar) inside the Air Chamber



Sampath Suranjan Salins in 2015 made In the study titled "Estimation of Power and Efficiency of Hydraulic Ram Pump with Recirculation System", a mechanical device operating on the principle of converting potential energy into kinetic energy driven by gravity and operating with zero operating cost was designed. The present study includes the design and manufacturing of a hydraulic ram pump driven by water falling from a small height and lifting a portion of the water to the required height. The present study focuses on the calculation of the discharge, power and efficiency of the ram pump. The above was modified to provide a recirculation system to prevent water wastage. The obtained results were verified according to standard fluid mechanics calculations (Salins S, 2015).

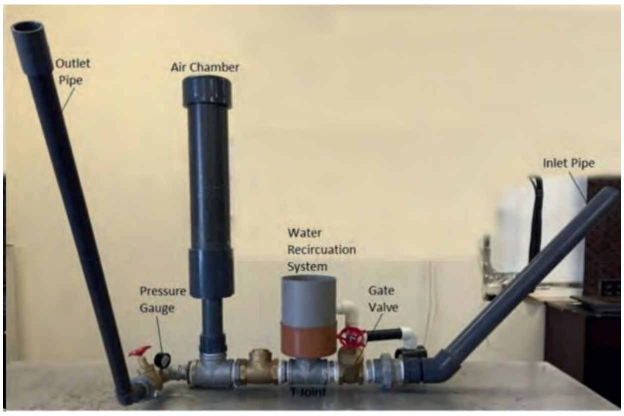
Figure 11
Hydraulic Ram Pump Design



Involved in the construction of a hydraulic cylinder . Water flows from a height along the inlet pipe, passes through the slide valve and fitting, and reaches a T-joint on which a downward swing check valve is located. The speed at which the water flows downward causes the check valve to close, and the water is forced to move forward to the second swing check valve, which is located forward. The water is then closed cellular with foam filled 4” UPVC (plastic free poly- vinyl chloride) moves towards another T-junction which has a chamber made of T -junction with itself in the air chamber between mounted 2”-4” reducer Water is found in the reducer passes And air fills the chamber and the foam causes the water pressure to increase helper It happens , more later of water to the reducer back return This increases the pressure even more. At this high pressure, the water can move backwards , at which point the second swing check valve closes and forces the water to move forward. The water then 2”-1” size Another One from the reducer passes .

This increases the pressure even more due to the change in diameter, allowing the water to be pumped to a higher level. The water is pumped 3 m at a 45° angle . One can be pumped up to 9 m high with a drop . As the angle of the feed line decreases, water can be forced to the maximum distance.

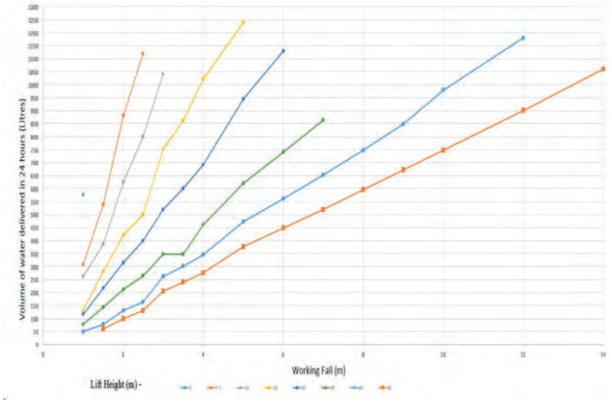
Figure 12
Hydraulic Ram Pump Design



In the study, the output data were analyzed by changing the dimensions of some parts of the hydraulic system. The diameter of the inlet and outlet pipe is 50.8 mm and 25.4 mm. The diameter of the swing check valve is 50.8 mm. The important roles in increasing the pressure are 50.8 mm and 25.4 mm, respectively. as follows two reducer The diameter of the air chamber is 101.6 mm and its length is 500 mm. The outlet pipe is at a 45° angle where the water rises. In the experiment, it was determined that the water flows at a rate of 4 liters/minute at the inlet due to gravity and that the water is pumped out at a rate of 0.8 liters/minute at the outlet. The reservoir is equipped with a waste valve . in the region water by collecting to the entrance again Circulate has done And This In this way, water waste, which is of vital importance in rural areas, has been prevented to the maximum extent.

Figure 13

Graph of Change in Daily Distributed Water Volume According to Working Decline



With the increase in the length of the drive pipe, together exit the pressure also increases It has been proven. However available In this case , the discharge at the outlet for a 2 meter long drive pipe is maximum compared to the other two cases. The current designed system produces 0.73 kW power and an ideal efficiency of 59.5%. By changing the inlet flow rate, the power can be calculated and displayed with the help of a graph.

Shuaibu Ndache MOHAMMED in 2007 made titled "Design and Construction of a Hydraulic Ram Pump" in the study source A water hammer pump was designed to carry water 2 m above the water level and the efficiency and power parameters were calculated. Based on the design, the flow rate in the pipe was measured as 4.5238 × 10-5 m3 /s (2.7 l/ min), the power was measured as 1.273 kW and the efficiency was measured as 57.3% (Mohammed, 2007).

Figure 14

Typical Hydraulic Ram Installation

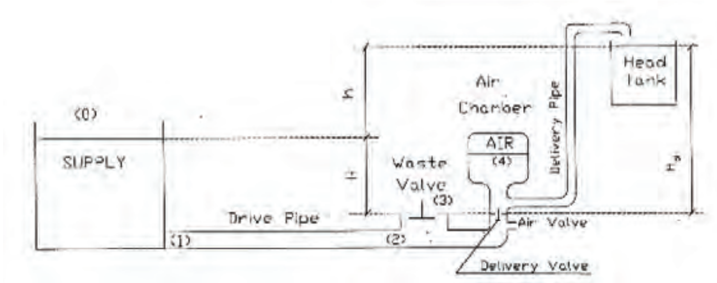
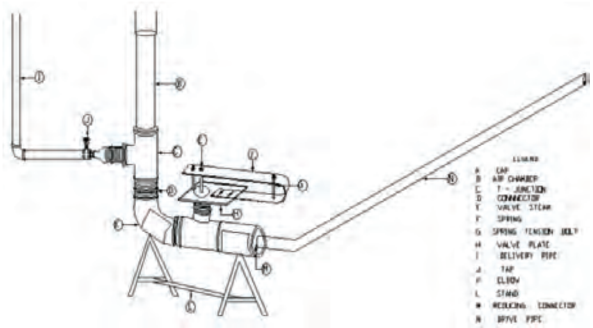


Figure 15

Fabricated Hydram Pump System



The parameters for the design were determined as in the table below and the results are also given in the same table . supply Its height is 1.5 m. Delivery Its height is 2.87 m.

Table 1
Results of Calculated Parameters

Parameters	Values
Drive Pipe Diameter	25 mm
Drive Pipe Length	90 mm
Aperture Speed	96 atm/minute
Flow Discharge in Drive Pipe	2,3 l/dak
Total Load Losses in the System	11,71x 10^-4 m
Force on Waste Valve	7,2 n
Pressure at Waste Valve	3668 kN/m2
Power Developed by Hydram	1273 Kw
Hydraulic Pump Efficiency	57,30%

Conclusion And Suggestions

This article necessary in detail The water ram described has been widely used in many countries of the world since the beginning of the last century . On the other hand, it is a sad fact that it is not sufficiently known in our country. Because, as can be seen, with the water ram, it is possible to lift water from its current location to a higher place without the need for any motor power and to store it there for later needs. It is possible for the water ram to work for years without stopping day and night and also without requiring almost any maintenance and control. Especially in mountainous countries and regions where electricity and engine fuels are expensive, as in our country, it can be said that the water ram is an ideal tool for providing drinking, utility and irrigation water. For this reason, citizens should be made more aware of the Water Ram, especially in agricultural regions.

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Personalized Education Systems with Artificial Intelligence

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Introduction

Personalized education has become one of the most important elements of modern education systems. The traditional education model offers the same content to all students at the same pace, but the shortcomings of this model have become increasingly apparent, especially in recent years. Different student profiles and learning styles mean that not all students can achieve the same success in the same way. At this point, a personalized education model has been developed to meet the individual needs of students better. This model provides students with learning content tailored to their learning pace, interests, and weaknesses. Research shows that a personalized education system improves students' academic performance and increases their interest in learning (Smith & Lee, 2022).

While traditional education models ignore the individual needs of students, personalized education systems provide a more efficient learning process by taking into account the learning style and pace of each student. This student-centered approach allows students to take an active role in their learning and be more involved in the learning process. The impact of personalized education systems has become much more widespread thanks to developments in artificial intelligence (AI) and data analysis technologies. Artificial intelligence technologies, especially big data and machine learning (ML), have created new opportunities to analyze students' learning behaviors and provide dynamic, personalized educational content based on this data (Jones et al., 2021).

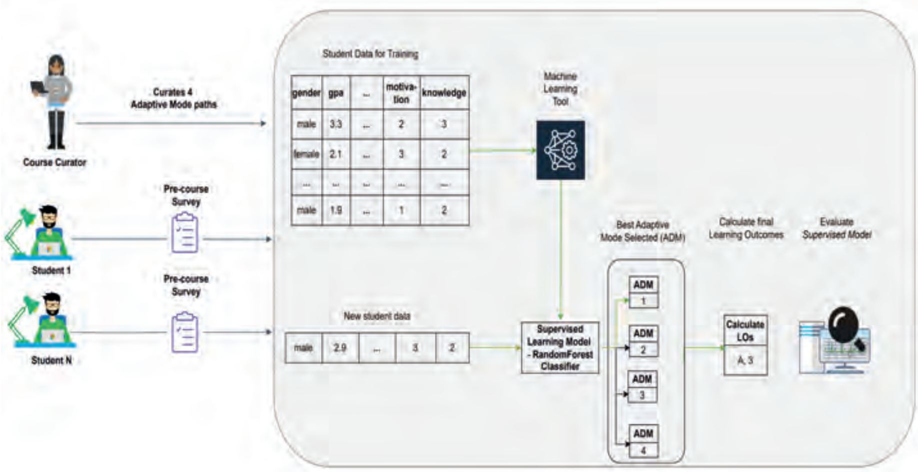
Adaptive learning algorithms are considered one of the basic building blocks of artificial intelligence-supported education systems. Adaptive learning analyzes each student's learning journey and creates a personalized learning plan. These algorithms continuously analyze data such as the student's performance in the learning process, previous test results, and learning speed, and adapt the material and questions to the student's level. Students' strengths are strengthened while they are allowed to work more on their weaknesses. Adaptive learning systems are one of the most important technologies that enable personalization in education and will find more application areas in the future (Brown & Green, 2020).

For example, major online education platforms allow for personalized learning experiences through adaptive algorithms. Online learning platforms such as Coursera and edX provide personalized course materials and assessments based on the student's previous success and performance in the course. These platforms identify the gaps in the learning process of students, allowing them to focus on the necessary points and optimize the learning process (Roberts & Martínez, 2023). Moreover, such a system benefits not only students but also instructors as they can manage classes more effectively.

Learning management systems (LMS) also play an important role in personalized education. These systems analyze student data and tailor learning to individual needs. Popular LMSs such as Moodle and Blackboard are integrated with AI-based tools that aim to increase student achievement through personalized feedback. These systems identify subjects in which students are weak and provide special study materials and tests to overcome these weaknesses. Every step of the students is carefully monitored and their next steps are planned accordingly (Clark & Taylor, 2022).

Figure 1

Overview of the proposed Supervised Learning Framework for personalized learning with student survey data as input using a Random Forest Classifier (Fernandes, C. W., Rafatirad, S., & Sayadi, H., 2023)



The increasing need for personalization in education and the development of technology require new approaches and innovative solutions in the education sector. Personalized education systems are based on data-driven structures to meet the individual learning needs of students, and thanks to this data, each student is offered a unique learning experience. Adaptive learning systems based on artificial intelligence not only improve students' academic performance but also strengthen their motivation to learn and lay the foundation for a more equitable approach to education (Garcia & Hernandez, 2021). In this context, personalized education systems supported by artificial intelligence will help expand the boundaries of personalization in education and maximize the potential of each student. These technological developments have the potential to revolutionize education by enabling changes in teaching methods and allowing individuals to be more effective in the educational process.

Artificial Intelligence and Adaptive Learning Algorithms

Artificial intelligence (AI) is one of the technological developments that has the potential to revolutionize every aspect of education. AI-based systems can analyze student data and provide personalized educational content according to student needs. One of the most important applications of AI technology in education is adaptive learning algorithms. These algorithms constantly analyze the data collected by students during their learning processes, creating a unique learning path for each student and offering content that suits their learning styles. Adaptive learning systems aim to maximize each student's learning experience by taking individual differences into account (Jones et al., 2021).

Adaptive learning algorithms are the basic components of artificial intelligence-based education systems. These algorithms personalize learning materials and questions based on the student's performance in the learning process, response speed, and correct and incorrect answers. As students encounter different levels of difficulty, these algorithms automatically adjust the difficulty according to their individual needs, allowing each student to learn at the most appropriate pace. According to a study by Jones et al. (2021), adaptive learning systems provide effective results in improving individual student performance, especially in crowded classes.

Adaptive learning systems powered by artificial intelligence detect the topics that students have the most difficulty with during the learning process and provide targeted content that will strengthen these weaknesses. These algorithms monitor student performance in real-time based on big data analysis and instantly change the curriculum if necessary. For example, online education platforms such as Coursera and edX use adaptive algorithms to monitor student performance and provide personalized learning plans (Roberts and Martínez, 2023). These platforms optimize the learning process by determining what content to offer next based on students' previous failures and successes.

Popular learning management systems (LMS) such as Blackboard and Moodle also integrate adaptive learning algorithms to deliver content tailored to students' individual needs. Clark and Taylor (2022) emphasize that LMS also provides significant benefits to teachers through the use of this technology. Adaptive learning algorithms help teachers manage their classes more effectively by identifying students' weaknesses and providing them with opportunities to strengthen them. With these algorithms, teachers can determine which students should focus on which topics and provide personalized feedback.

One of the biggest benefits of adaptive learning systems is that they continuously collect data and can use this data to improve students' learning process. These systems create unique learning paths for students by taking into account factors such as past grades, wrong answers, and learning pace. Research by Garcia and Hernandez (2021) shows that AI-powered adaptive learning systems can help students learn more deeply by allowing them to work at their own pace. Students can have a more effective learning experience with course materials tailored to their individual needs.

The most critical feature of artificial intelligence and adaptive learning algorithms is that they make the learning process dynamic. While traditional learning methods present the same content to all students at the same speed, adaptive learning systems provide materials specifically tailored to each student's learning style. These systems provide students with personalized feedback at each stage of the learning process and help them overcome difficulties encountered in the learning process. For example, if it is determined that a student does not have sufficient knowledge on a particular topic, the system will provide additional study materials and tests on that topic (Brown & Green, 2020).

However, for adaptive learning algorithms to be successful, data security and ethical issues must also be taken into account. AI-based systems collect large amounts of student data, so it is important to store and process this data securely. In addition, an unbiased approach should be adopted in the presentation of content that suits each student's learning style. Jones et al. (2021) emphasize that ethical principles should not be ignored when designing adaptive learning systems and that equal opportunities should be provided to all students.

For these reasons, artificial intelligence and adaptive learning algorithms play an important role in the process of personalizing education. These technologies make the learning process more efficient by dynamically adapting learning content to the individual needs of each student and allowing students to learn at their own pace and in their way. Such innovative teaching approaches not only increase student achievement but also strengthen motivation to learn. The increasing use of AI-supported adaptive learning systems will push the boundaries of personalization in education even further in the future.

Benefits and Challenges of Personalized Learning Systems

Personalized education systems powered by artificial intelligence will bring new opportunities and significant benefits to the education sector. Providing an individualized approach to the student's learning process, these systems aim to increase efficiency and educational success, but they also bring with them various challenges. This section details the benefits and challenges of personalized education systems.

Personal Learning Speed and Flexibility

One of the main advantages of a personalized education system is that students can learn at their own pace. While each student tends to learn at different speeds, these systems provide flexibility by allowing students to learn at their own pace. Adaptive learning algorithms powered by artificial intelligence determine which subjects students are good at or weak at and provide specific course content and tests (Jones et al., 2021). This allows fast learners to move on to more advanced material, and students who need more time to receive more resources and guidance on the subjects they need.

Increasing student motivation

Personalized education motivates students to learn by providing content that is relevant to their interests and needs. In a standard education model, some students may not be interested in a particular subject, but in a personalized education system, each student is better served by providing lessons and assignments tailored to each student's interests. This increases their chances of success by allowing students to participate more actively in the learning process. Clark and Taylor (2022) state that personalized learning environments increase student engagement in the learning process and positively affect student success, especially those with low motivation.

Real-time feedback and evaluation

A personalized learning system powered by artificial intelligence that provides instant feedback to students and continuously monitors their learning progress. Such systems provide dynamic assessments based on each student's performance, determining in real time where students make mistakes and in which areas they need to improve. According to a study by Garcia and Hernandez (2021), a personalized learning system increases the efficiency of students' learning by accelerating the process of receiving feedback. With real-time feedback, students can instantly identify and correct their deficiencies, making the learning process more effective.

Effective use of resources

Personalized learning systems allow for more efficient use of classroom resources. Roberts and Martinez (2023) emphasize that adaptive learning systems allow teachers to exercise more personalized leadership in the classroom and provide a more balanced allocation of resources. Teachers can make better use of classroom time and materials by providing learning plans tailored to the needs of each student.

Privacy and Security Issues

One of the biggest challenges faced by AI-powered personalized education systems is the privacy and security of the large amounts of student data collected. These systems analyze students' study habits, grades, and even behavioral characteristics; however, this data needs to be properly secured and kept out of the hands of unauthorized third parties. Jones et al. (2021) state that data security is a major challenge for personalized education systems and that these systems may be vulnerable to security vulnerabilities. It is emphasized that the risk of misuse of such personal data should not be ignored, especially for large education platforms.

Unequal Access

In personalized education systems, especially because they are based on advanced technology, not all students have equal access to these systems. Students who are economically disadvantaged or live in areas where there is insufficient access to technology may have difficulty benefiting from the opportunities provided by such systems. Brown and Green (2020) argue that the digital divide must be closed for personalized education systems to be more widely available. Since this situation has the potential to deepen educational inequalities, a solution must be sought.

The Role and Adaptation of the Teacher

The use of personalized education systems will change the traditional role of teachers in adapting to these new technologies. The integration of artificial intelligence-based systems into education requires teachers to receive the necessary training to use these systems effectively. However, some teachers may have difficulty adapting to these technologies or may be concerned that these systems will replace them. Garcia and Hernandez (2021) state that for personalized education systems to be successfully implemented, teachers must play an active role in this process and that these technologies should be used as complementary elements of education.

Algorithmic Bias

When using AI-based systems to assess student performance and make decisions, there is a risk of algorithmic bias. If these systems are trained using datasets that are not diverse enough, they can disadvantage certain groups of students. For example, students from certain socio-economic or cultural groups may be misjudged due to algorithmic misdirection. Roberts and Martínez (2023) emphasize that datasets must be carefully prepared and systems must be constantly reviewed to avoid algorithmic bias in personalized education systems.

Technological Infrastructure Requirements

The effective implementation of a personalized education system requires a strong technological infrastructure. These systems are based on advanced technologies such as artificial intelligence, big data, and cloud computing. However, these technologies require a constant Internet connection, powerful servers, and sufficient data storage capacity to function properly. Clark and Taylor (2022) state that schools and educational institutions must invest in this infrastructure to successfully implement a personalized education system. Otherwise, there is a risk that the system will not work efficiently and the desired educational outcomes will not be achieved.

The Future of Personalized Education Systems with Artificial Intelligence

The role of artificial intelligence and adaptive learning algorithms in education is increasing. With the rapid development of these technologies, the future of personalized education systems holds great promise. However, the full realization of this potential depends on solving current technical and ethical problems and integrating innovations into the education process. This section describes how personalized education systems will be designed in the future and the opportunities and obstacles they may face.

Advanced Artificial Intelligence Systems and Adaptive Learning Models

The integration of AI into the learning process enables more effective and personalized solutions in education. Adaptive learning algorithms currently in use provide personalized learning materials based on student performance. However, in the future, these algorithms will become more complex and will also take into account students' emotional states, motivations, and interests. Clark and Taylor (2022) state that in the future, AI-based systems will be able to understand students' psychological states and create the most appropriate learning environments for them. This means that new systems will emerge that support the individual's emotional and psychological development as well as their academic success.

Wide Data Analytics and Learning Analytics

AI-powered systems provide critical information for teachers and education administrators by using comprehensive data analytics to deeply examine student behavior and performance. Thanks to big data analytics, these systems can continuously monitor students' learning processes and make more accurate predictions about their personal development. Jones et al. (2021) emphasize that the development of learning analytics will make teaching strategies for students more targeted and individual. You can be more proactive in your education by learning how students approach the content of each subject, which subjects they are weak in, and which subjects they are interested in.

Autonomous Teachers and Digital Mentors

One of the most remarkable aspects of the future of education systems supported by AI is the development of digital teachers and digital mentors. These digital systems act as autonomous teachers, constantly accompanying and guiding students. In the future, these AI-supported systems have the potential to significantly improve the educational process by providing instant feedback and providing guidance when necessary, according to the individual needs of students. Garcia and Hernandez (2021) suggest that autonomous teachers integrated with AI can reduce the burden on teachers and create more effective teaching systems in education, especially in classes with large groups of students.

Robotic-Assisted Learning Systems

The use of robotic technology in education provides students with a more interactive and application-oriented learning experience. Robots integrated with artificial intelligence can support experience-based learning processes, especially in STEM (mathematics, science, technology, and engineering) courses and education. These robots can be used as a system that mimics one-on-one interaction between teachers and students and can help students better understand complex subjects. Roberts and Martinez (2023) claim that robotic technology is increasingly used in education and that in the future, these systems will gain more autonomy and be able to provide personalized learning materials to students.

Algorithmic Biases and Social Inequality in Education

The proliferation of AI-powered education systems also raises important ethical issues such as algorithmic bias and social inequality. As AI systems become more integrated into decision-making processes in the future, the impact of these systems' biases on students may become even more apparent. These systems must be transparent and fair so that students, especially those from disadvantaged backgrounds, do not face unequal educational opportunities. Brown and Green (2020) point out that AI systems in education must be carefully designed and ethically implemented, or else these systems risk reinforcing social inequalities.

Data Privacy and Security

As the use of AI-based personalized education systems increases in the future, privacy and security issues will become even more important. These systems constantly record students' personal information and learning, so protecting this data is an important issue. Jones et al. (2021) emphasize that ensuring data security in AI-based education systems is one of the most important factors for the successful implementation of the system. Educational institutions should take the necessary measures to protect student data and prevent misuse of data when using these systems.

Accessible Education Worldwide

AI-based personalized education systems have the potential to improve access to education worldwide. Especially in developing countries, these systems can provide students with previously inaccessible materials. Making such systems more universal and affordable can help achieve equity in global education. Garcia and Hernandez (2021) state that personalized education systems powered by AI have the potential to bring educational opportunities from developed countries to developing regions.

The rise of global education platforms

Educational platforms that use artificial intelligence are expected to become popular worldwide in the future. These platforms provide a cross-border learning experience by reaching students from different cultures and educational systems at the same time. Clark and Taylor (2022) state that global educational platforms create a global educational network by supporting both the academic and cultural development of students.

Contributions of Artificial Intelligence-Based Personalized Education Systems to Educators and Students

Personalized education systems powered by artificial intelligence (AI) offer a variety of benefits for teachers and students. As the digital transformation of the education process accelerates, these systems offer the opportunity to provide learning materials customized to the needs of individual students, optimize the learning process, and reduce the burden on teachers. This section details the impact of AI-based personalized education systems on teachers and students.

Customized Content for Students' Individual Learning Needs

Personalized AI-based education systems offer the opportunity to create content that suits students' individual learning needs. Students can be directed to different learning paths depending on their performance in each subject. Smith et al. (2021) state that AI-based systems can significantly increase learning speed and understanding by providing students with a personalized learning experience. These systems continuously monitor student achievement, identify strengths and weaknesses, and provide students with personalized learning materials.

Monitoring Students' Learning Processes and Providing Feedback

The system, based on artificial intelligence, closely monitors the student's learning process and provides instant feedback. Jones and Taylor (2022) emphasize that these systems help optimize the learning speed of students, while the feedback mechanism deepens students' understanding and makes the learning process more efficient. This instant feedback allows students to notice and correct their mistakes, making the learning process more effective.

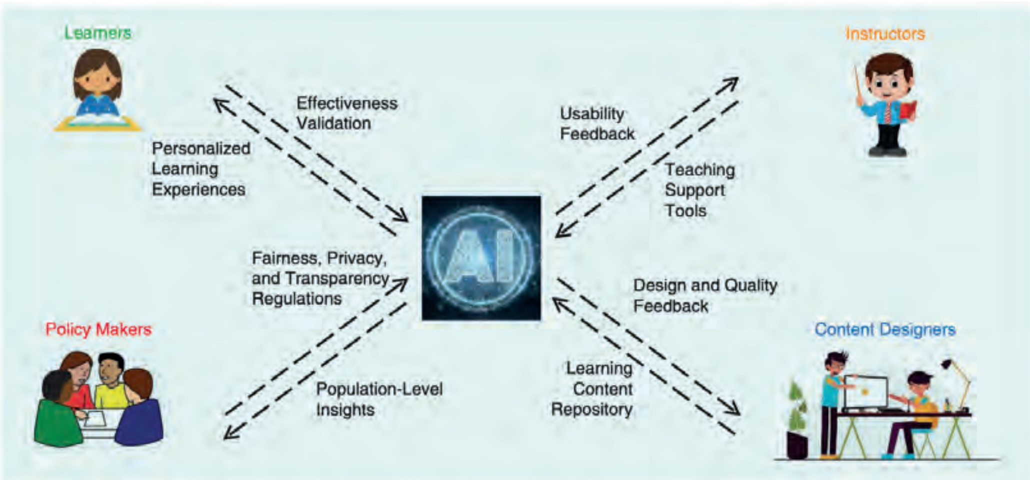
Relieving Teachers' Workload and Supporting Classroom Management

AI systems reduce the burden on teachers and free up their time. AI-based algorithms relieve teachers from the burden of constantly monitoring student performance and providing personalized feedback. Clark et al. (2020) argue that personalized learning systems powered by AI allow teachers to develop more effective classroom management strategies by optimizing their lesson plans. These systems automate teachers' daily tasks and enable them to develop more pedagogical strategies.

Data-backed Guidance and Decision-making Support for Teachers

Figure 2

The baseline ecosystem of AI-empowered personalized education (Maghsudi, S., Lan, A., Xu, J., & van der Schaar, M., 2021)



AI-based systems are helping teachers make more informed educational decisions by providing data support based on student performance. Garcia and Hernandez (2021) state that AI-powered data analysis tools can facilitate the development of teaching strategies based on individual needs by indicating to teachers which students need additional support. Teachers can use this data to make more informed and specific interventions.

Supporting Students with Different Abilities in the Classroom

Adaptive learning algorithms are an important tool for ensuring that students of different abilities have comparable learning experiences in the same classroom. These algorithms can match the needs of students who learn faster with the needs of students who need more time. Roberts and Lee (2023) argue that adaptive learning algorithms help teachers manage complex classroom structures more effectively by allowing students of different ability levels to learn at their own pace in the classroom. This allows each student to progress at their own pace, increasing overall success in the classroom.

Increasing Students' Motivation and Participation

A personalized education system helps motivate students to learn. When students are presented with content that is specifically tailored to their individual needs, their interest and participation in the learning process increases. Smith and Taylor (2021) state that personalized systems based on artificial intelligence can increase student motivation and enable them to engage in a more active learning process. Customized content captures students' attention and leads to a deeper learning experience.

Dissemination Potential and Cost Advantage

The spread of education systems supported by artificial intelligence can lead to a decrease in the cost of the education process. Especially in crowded classes, artificial intelligence-based systems can replace individual lessons by teachers and provide personalized learning opportunities. Jones et al. (2020) emphasize that these systems can be used more widely in education in the future and that education can be made more affordable. As the cost of these systems decreases thanks to developing technology, more schools and teachers will be able to access these systems more easily.

Technological Infrastructure and Inequality Issues

Although AI-based systems offer great benefits in education, the implementation of these systems can also bring some challenges. The use of these systems can be limited, especially in regions where technological infrastructure is lacking. Brown et al. (2021) state that the effective implementation of AI-based education systems requires a strong technological infrastructure, and if this infrastructure is not provided, inequalities in education can increase. Therefore, education policy needs to take steps to make these technologies available to everyone.

Increased Use of Artificial Intelligence in Personalized Education

The use of AI in personalized education is expected to become more widespread in the future. Thanks to systems supported by AI, students can have more say in the education process. Clark and Taylor (2022) state that these systems increase student learning flexibility and make it easier to achieve individual learning goals. In the future, personalized education will become the norm with greater integration of AI systems and adaptive learning algorithms.

Challenges and Solutions in Artificial Intelligence-Based Personalized Education Systems

In addition to the opportunities offered by AI-supported personalized education systems, various challenges in the implementation of these systems should not be ignored. Technical, ethical, and socio-economic challenges pose significant problems in terms of the dissemination and sustainability of such education models. In this section, we discuss the fundamental problems of AI-based personalized education systems and propose solutions to these problems.

Data Privacy and Security Issues

Personalized education systems based on artificial intelligence require the collection of large amounts of data to analyze students' learning processes and provide appropriate learning materials. This situation also brings about serious concerns about privacy and data security. Jones and Wang (2020) state that data breaches that may affect student privacy may occur in the collection and processing of personal data. In particular, there are risks such as students' study habits, academic performance, and personal information falling into the wrong hands, making it difficult to implement AI-based systems. To solve this problem, more secure and transparent protocols need to be included in the data collection and storage process. Smith et al. (2021) emphasize that introducing data encryption, anonymization, and authorization mechanisms are effective ways to increase the security of these systems. In addition, ensuring that students and parents know how their data is used can increase trust in these systems.

Access Inequalities

Effective implementation of AI-based education systems requires a solid technological infrastructure. However, many regions of the world do not have sufficient technological infrastructure. These systems are particularly difficult to use in regions with limited internet access. Garcia and Lee (2021) point out that such regions can widen the digital divide and lead to inequality in education. In this context, students without technological infrastructure are at a disadvantage in benefiting from a personalized education system based on AI. To solve this problem, governments and educational institutions need to invest more in expanding internet access and technology devices. Brown et al. (2022) suggest government-funded programs and collaborative solutions to increase access to AI-supported education systems in low-income regions, but do not believe that these investments will promote equity in education.

Adaptation and Acceptance Difficulties

For AI-supported personalized education systems to be successfully implemented, both teachers and students need to adapt to these systems. However, it can be difficult for teachers and students to adapt to new technology. Roberts and Taylor (2020) point out that if teachers have insufficient digital skills, it can be difficult to use AI-based systems effectively in the classroom. Similarly, students may have difficulty adapting to new learning systems, which can lead to decreased motivation. To overcome this difficulty, comprehensive training programs should be organized for teachers and students. Smith et al. (2021) emphasize that professional development programs and user-friendly interfaces can facilitate this process when integrating AI-based systems with educators. This adaptation process can be accelerated by providing students with instructions on how to use the system.

Ethical Issues

The fairness of the algorithms used in developing AI-based systems is an important issue. Algorithms may cause conscious or unconscious biases against certain groups of students, depending on the dataset they are designed for and programming decisions. Garcia et al. (2021) state that AI algorithms may contain biases based on factors such as gender, race, and socio-economic status, which can lead to inequalities among students. Especially if the training process of algorithms using data is not comprehensive enough, learning opportunities for certain groups may be limited. To solve this problem, we need to use more comprehensive and unbiased datasets in the development process of AI algorithms. Clark et al. (2020) argue that ethical rules and independent reviews in the algorithm development process can be effective in preventing such problems. In addition, algorithmic transparency and accountability mechanisms will also play an important role in this process.

The Limits of Personalized Learning

Another important limitation of AI-based personalized education systems is that overly personalized learning processes can negatively affect students' social interactions. Roberts et al. (2022) emphasize that when students focus on their learning paths, they reduce their interactions with classmates, which can hinder the development of social skills. Overly individualized learning can cause students to deviate from group work and collaborative learning processes. To solve this problem, AI-based systems need to have structures that balance individual learning experiences with collaborative learning processes. Jones and Taylor (2021) state that equipping these systems with features that encourage social interaction between students will balance the learning process and improve students' social skills.

Future Challenges and Solutions

With the proliferation of personalized education systems based on AI, future challenges should also be anticipated. While the rapid pace of technological development has enabled AI to be used more effectively in education, questions regarding the sustainability and accessibility of these systems still need to be resolved. Smith and Lee (2023) argue that monitoring the long-term impact of AI systems and adopting continuous improvement processes to address current challenges are key to the success of such systems.

The Future and Development Areas of Artificial Intelligence-Based Personalized Education Systems

The future of personalized education systems supported by artificial intelligence (AI) will be shaped by various technological and methodological developments. In the future, artificial intelligence algorithms will analyze students' study habits more deeply and provide real-time feedback, allowing for a more dynamic and personalized educational experience (Smith et al., 2021). In addition, adaptive learning algorithms will be able to provide deeper personalization by using natural language processing and machine learning techniques to understand students' emotional states and motivation levels (Garcia et al., 2020). These innovations increase the personalization of education and make the learning process more effective for students. AR and VR technologies make the learning experience more interactive and immersive for students. Especially in STEM fields, these technologies make learning more effective and increase students' interest in courses (Brown & Taylor, 2022). However, the ethical and socio-economic consequences of artificial intelligence systems are also important issues. Issues such as data security and unequal access require the development of comprehensive and equitable solutions (Clark et al., 2020). AI is not expected to replace teachers, but it will enable effective collaboration between teachers and AI. This collaboration will provide a more balanced learning experience and allow teachers to make more informed decisions based on the data provided by AI systems (Smith et al., 2023). Ultimately, AI-based education systems will offer more personalized and interactive learning opportunities, but ethical and access issues must also be taken into account in this process.

Application Areas and Case Studies of Artificial Intelligence-Based Personalized Education Systems

Personalized learning systems based on artificial intelligence (AI) have various applications that are revolutionizing education. These systems provide an effective learning experience by providing customized learning paths according to the individual needs of students. For example, Lee et al. (2021) state that personalized learning systems analyze students' past performance data and learning styles to create personalized lesson plans. This approach allows students to focus on their weak subjects and supports them with necessary study materials. Intelligent teaching assistants support student learning through instant feedback and guidance. Johnson et al. (2022) state that such a system can quickly answer student questions and reduce teachers' workload. Moreover, the intelligent assistant can detect common difficulties of students and recommend appropriate resources to make the learning process more effective.

The use of AI in language learning is also having a major impact. Garcia et al. (2020) explain how language learning apps use AI algorithms to improve students' speaking and writing skills. These apps analyze students' pronunciation and grammar errors in real-time and provide personalized feedback. Integrating AI into STEM (science, technology, engineering, and mathematics) education provides apps that improve students' problem-solving skills and creativity. Brown and Taylor (2022) emphasize that AI-based apps increase students' theoretical knowledge through practical applications in STEM courses. In particular, simulation and modeling tools can facilitate the understanding of complex problems and make the learning process more effective for students. A case study demonstrates the impact of AI-based personalized learning systems. Roberts et al. (2021) report that an AI-powered learning platform increased math performance by twenty-five percent. The platform analyzed students' past exam results and learning behaviors, providing personalized study materials and feedback. In addition, Smith et al. (2023) show that language learning apps significantly improve students' language skills and make the learning process more interesting.

In the future, it is expected that the areas of use of individualized education systems that utilize artificial intelligence will expand and diversify even further. New technologies and algorithms will provide better and more effective personalization options in education, making the learning experience more efficient and interactive.

Challenges and Solutions in Artificial Intelligence-Based Personalized Education Systems

Although artificial intelligence (AI)-based personalized education systems have many advantages, they also face various challenges. These challenges primarily include data security and protection, system adaptation, and ethical issues. Data security and privacy are key concerns in AI-based education systems. Clark et al. (2020) emphasize that students' data must be protected and that it is important to process this data securely. AI systems collect extensive data on student learning, increasing the risk of data breaches and misuse. Strengthening security measures and complying with data protection laws are important steps in solving this problem. Adapting the system is another challenge for teachers and students. Smith et al. (2022) emphasize the difficulties of transitioning to new technologies and the training required for teachers to use these technologies effectively. It can take time for educational systems to adapt to this technology. This process requires the provision of supportive training and resources. In addition, students' adaptation to technology should be facilitated. Ethical issues also affect the role of AI systems in education. Garcia et al (2021) state that AI algorithms can introduce bias into education and make it difficult for students to benefit from equal opportunities. Rephrase Transparency and fair design of algorithms used in education can help prevent such problems. In addition, algorithms need to be constantly reviewed and improved. Solving these challenges in AI-based education systems will make these technologies more effective and accessible. Developing a comprehensive strategy that addresses issues such as data security, system customization, and ethical issues will increase the success and sustainability of the integration of these systems.

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Investigation of the Effects of Aluminium Trihydroxide Additive on Mechanical Strength of PP Honeycomb Composite Panels with Polyurethane Matrix

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Introduction

Nowadays, the development of technology is increasing at an accelerated rate. Monolithic materials, which are limited in nature and have a limited purpose of use, are insufficient in the face of rapidly developing technology. At this point, composite materials are becoming increasingly widespread as a solution. Theoretically, creating new materials with composite material combinations in which at least two materials are physically combined has an important place in the development of material technology (Sönmez, 2017: 68). Composite materials, which have many advantages over other materials with their characteristic properties, are preferred due to their long life, lightweight and high mechanical strength. The properties desired to be developed by the production of composite materials are as follows;

- Mechanical strength,
- Fatigue strength,
- Fracture toughness,
- Corrosion resistance,
- High-temperature resistance,
- Thermal conductivity
- Electrical conductivity
- Acoustic conductivity
- Rigidity,
- Lightness (Alçı, 2016: 107).

Sandwich composites are a special type of composite material. It is obtained by placing a thick but very light core material between two thin and rigid upper and lower surface layers. Sandwich composites have found a wide range of applications in many fields ranging from the aerospace industry to the marine, automotive, and construction industries thanks to their lightweight, high "strength/weight" ratio and durability, especially compared to conventional materials. One of the biggest advantages of sandwich materials is that optimal designs can be obtained by selecting the bottom and top surface layers and the core from different materials and geometric structures for various applications (Engin, 2020: 108).

One of the most important material groups used in the aviation industry is honeycomb composite structures. The most important properties of honeycomb composite structures are the strength/weight ratio. Since the strength/weight ratios of such materials are considerably higher than other metallic materials, they are widely preferred in many areas.

The sandwich structure is lightweight and has high strength. In a sandwich structure, the core is usually PP and aluminum. The adhesive is usually epoxy. TiO2 with epoxy increases adhesion and increases strength. Roughness and thickness are directly proportional to strength (Sönmez, 2017: 68). Observed an increase in impact reaction forces when the cell width decreases and the cell height increases in honeycomb samples obtained with MWCNT reinforced adhesive according to the results of low-velocity impact test (Akkuş, 2016: 127).

PP is used in the maritime industry because it burns quickly. Al, Nomex, etc. are used in aviation. In honeycomb structures, water detection experiments were carried out separately for the surface and inside the material by thermography method. The purpose of thermography is to determine the thermal difference caused by discontinuity (Ercümen, 2018: 89). Concluded that when the density of honeycomb material decreases, its ability to stretch increases. It was determined that honeycomb material is 6 times lighter than steel, 6 times lower in density but 6 times harder than steel, and 13 times more flexible (Kozal, 2012: 126).

The surfacing material was generally carbon fiber plate and the core material was Al, PP, Nomex. It was observed that the matrix material reduced crack propagation. Damages detected in the honeycomb are surface fracture, transverse shear fracture, local core fracture, general buckling, and shear compression. In terms of strength, it was determined that Al was the best, then PP and then Nomex (Gül, 2018: 161). The surface material related to the interior design of light commercial vehicles carries bending stresses, the core structure carries shear stresses, and the core of 30x10mm provides a higher stiffness value. Since glass fiber is superior in terms of strength, it is reported that the strength will increase with the increase in fiber volume and the deformation will increase with the increase in cell size (Tetik, 2018: 157).

The sandwich structure has a high strength-to-weight ratio. This is why it is used in aviation, the space industry, maritime, and automotive. All sandwich material absorbs energy. It was determined that the core and surface layer directly affect the impact resistance (Engin, 2020: 108). Honeycomb has high specific strength, impact damping, and compressive strength. As disadvantages, microcrack calculation is difficult, curing is not homogeneous, and physical properties are different (Balcı, 2017: 72).

The energy resulting from the impact is absorbed in honeycomb structures, it can be used in constructions requiring high mechanical strength, and the bending stress is high due to the high moment of inertia of the honeycomb structure. It was concluded that the impact damping rate will increase with the increase in the thickness of the sandwich structure, and the impact damping rate will decrease if the thickness of the surface plate increases. (Yiğit, 2010: 93).

The impact trace will increase with the increase in cell diameter and unit cell slip will occur in large diameter cells. It was observed that supported composite structures were more rigid than unsupported composite structures because there was no cell slippage in the supported composite, the bottom surface was not damaged but the top surface was damaged and other damages such as shear curling and surface crushing were observed in the honeycomb structure (Danacıoğlu, 2013: 81). Honeycomb material is mechanically suitable for motorcycle headgear. Factors such as strength and conduction were examined experimentally and a suitable design was desired to be created (Yildiz, 2018: 176).

Made 2 types of modifications. With the addition of mass, the damping loss factor increases. The 2nd system is to create a resonator by drilling a hole. This is done with a thermographic test. The temperature increases. Mass addition differs according to the structure (Joshi, 2014: 96). A normal honeycomb material cannot be compared with a different honeycomb material. Therefore, an equivalent model should be used. In this way, cheap and easy change can be provided (Aydıncak, 2017: 196).

The greater the thickness of the intermediate material, the higher the compression modulus and strength, and if the intermediate layer thickness increases, the intermediate layer shear stress and surface plate bending stress will decrease. In the bending test, the material weakened at the center point. Compression modulus and strength were high in the surface layers. The impact energy absorption of the core is high. He concluded that core thickness does not affect fracture toughness (Sezgin, 2008: 76).

The absorbed energy will increase as the impact velocity increases, the regular structure will provide more absorption energy than the auxiliary structure, the auxiliary model elastic property is high because there are more cores in this core (He, 2012, p. 105). As the energy level increases, the damage will increase, small diameter pipes are more rigid, and small diameter reduces the core shear stress in the sandwich structure and makes the structure more rigid since the moment of inertia increases, the bending rigidity will increase (Yıldırım, 2017: 91).

The core provides the stiffness of the sandwich by carrying the shear load, and said that the core structure is anisotropic, the adhesive should be homogeneous and thin, and the adhesion performance should be good (Jegorova, 2014: 96). Isocyanate should generally be used as blocked since its synthesis with another substance is dangerous (Hayırlıoğlu, 2009: 104).

Filler matrix compatibility is important and tries to provide the desired mechanical properties by increasing the filler compatibility with TPU. Fillers increased the mechanical properties (Tayfun, 2015: 149). The dynamic behavior of the sandwich structure with reinforcing elements. They found that the material should be isolated in the compression test and that the composite plate gives different responses in different geometries (Özcan, 2016: 75). The superelement method for favorable results of calculations in design. The elasticity constant is calculated. It is concluded that the number of cells will increase if the cell size decreases for total potential energy and maximum displacement (QIU, 2008: 89).

The stiffness of the sandwich structure increases as it transitions from metal-rich to ceramic-rich, so the deformation and collapse values will increase with increasing impact velocity energy, while the contact time will remain constant. They found that decreasing the honeycomb wall thickness will increase the deformation and collapse, but the sandwich structure absorbs most of the impact energy for each parameter (Aslan, K., Güneş, R., Apalak, M.K., Reddy, J.N. 2015). The addition of ATH increases tensile strength, toughness, and viscosity. These substances can be used in two ways. Reactive additives are used as fillers and do not react with other components. There are two purposes. The first is flame retardancy; the second is not to impair mechanical properties (Kaya, M., Öz, D. 1999).

In this study, polyurethane matrix was injected into the PP honeycomb core structure and nano-additives were added to the polyurethane matrix at different ratios, both the contribution to the mechanical strength by filling the honeycombs and the effects of the use of nano-additives on the mechanical strength were examined.

Sandwich Building Materials

Sandwich structures are structures obtained by placing a thick and lightweight core material between two plates. Sandwich structures are used in many sectors such as marine, automotive, aviation, aerospace, and construction industries thanks to their high flexural strength-to-weight ratio compared to other material types. One of the biggest advantages of sandwich materials is that the most suitable designs can be obtained by selecting the bottom and top surface layers and the core from different materials and geometric structures for various applications.

Sandwich Composites

Sandwich composites are lightweight composite structures with high flexural and torsional strengths obtained by bonding a light and thick core in the middle and thin but strong surface plates below and above it. The layer bonding between the core and surface plates is usually neglected because it is too thin compared to the surface plates and core. However, as their thickness increases, the adhesives that act as a separate layer should be taken into account and included in the calculations.

Basic Usage Areas of Sandwich Honeycomb Structures

Sandwich composite materials are increasingly being used in technology-intensive sectors. Composite material developments, which have long been driven by the needs of the aircraft industry, have recently been used in many new sectors for many different purposes.

Honeycomb Sandwich Composite Technology

Honeycomb sandwich composites consist of a honeycomb-shaped core in the center and surface plates spaced between the core. These composites are widely used in many engineering applications due to their high flexural and torsional strength, light weight, and ability to absorb energy under impact.

Application Areas of Honeycomb Sandwich Structures

Today, honeycomb core sandwich structures are used in automobiles, sports vehicles, and construction equipment to provide resistance against impacts that may occur and to increase capacity and workforce. Honeycomb core sandwich structures are used especially to strengthen the nose and body parts of racing vehicles and to increase the carrying capacity of the load-bearing body of cranes. Lightweight structures used in the shipbuilding industry have an important place. Today, passenger ships consist entirely of aluminum sheet and aluminum honeycomb core sandwich structures. Especially aluminum sandwich panels are the materials that can respond to the desired features in the shipbuilding industry in the most appropriate way. The use of polyurethane as an adhesive when manufacturing aluminum sandwich panels for use in ship constructions ensures high mechanical strength and damping capability, as well as being lightweight. Due to the lightweight feature of the sandwich structure, it is a structure that is frequently used in the construction of sports equipment today. Although sports equipment has a high cost for this sector, it has found a significant application area. In sports equipment, aluminum foam is used in the construction of shin guards to protect the foot health of football players due to its good energy absorption. It is possible to see that sandwich structures are used in bicycle frames, walking bands, and tennis rackets (Ercümen, 2018: 89).

Material And Method

Production Methods of Honeycomb Materials

Two basic techniques are generally used in the production of honeycomb structures: stretching and bending. This method is used in the manufacture of metal and non-metal cells. In general, it involves cutting the sheets into strips and applying adhesive, stacking the sheets on top of each other, and processing the honeycomb block in a press at the selected temperature. Another widely preferred method in the manufacture of honeycomb structures is the crimping method. This method is preferred in the manufacture of honeycomb structures that operate under high temperatures and have high wall thickness and density. In this method, strip sheets are bent in the desired shape, and adhesive is applied to the knots (Alçı, 2016: 107).

Surface plates

The outer surface plates used in sandwich structures are thin but strong materials. The main function of the face plates is to meet the required bending stress and in-plane shear stresses. Various materials can be used as surface plates. These are;Aluminum

- Stainless steel
- Fiberglass
- Carbon/epoxy
- Wood

Surface plates were not used in our study. Therefore, we tried to reveal the net effects of the system we studied without considering the effects of the surface plates on the strength.

Core materials

The core material placed between the face plates has lower strength and is lighter in weight. The main task of the core material is to maintain the distance between the outer surface plates; because this distance ensures that the moment of inertia and bending strength of the sandwich structure in the cross-sectional area are high. Core materials are generally divided into three groups: honeycomb, cellular, and corrugated. Commonly used core materials are;

- Polypropylene
- Aluminum
- Nomex

In this study, the production method by mold method was used. Honeycomb materials were placed in a double mold made of Al 7075 material, polyurethane matrix components were prepared separately and poured into the honeycomb core compartments and mechanical pressure was applied to it. The mold temperature was set to 30°C.

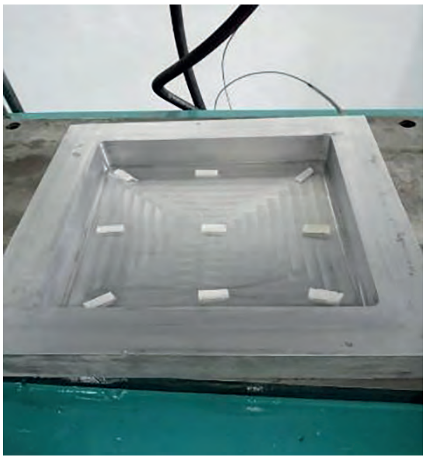
Used Materials

PP Honeycomb Core Sheets

Initially, a PP core structure was placed in the heated mold. The physical dimensions of these structures are below. The PP honeycomb core has a height of 10 mm and a diameter of 8 mm. The PP honeycomb core is given in Figure 1 below.

Figure 1
PP Honeycomb Kernel

Figure 2
Aluminum mold and cover



Nano Additives

The technical data of ETI FINE 510 and ETI FINE 704 nano additives obtained from Seydişehir ETİ aluminum plants are given in Table 1 and Table 2 below.

Table 1
ETI FINE 510 and ETI FINE 710 Technical Specifications

		ETI FINE 510	ETI FINE 704
	Humidity [105ºC, 2h]	<0.3	<0.4
	Glow Loss 1000ºC	34.6	34.6
Chemical Content	$Al(OH)_3$	>99.7	>99.7
	SiO_2	≤0.013	≤0.015
	Fe_2O_3	≤0.015	≤0.015
	Na_2O Total	≤0.25	≤0.05

	D10 [µm]	2.0-5.0	0.5-1.0
Grain Size Distribution	D50 [µm]	9.0-12.0	1.5-2.5
	D90 [µm]	19-30	3.5-6.0
	Whiteness [nm]	≥92	≥93
	Refractive Index [%]	1.58	1.58
	Conductivity [µs/cm]	≤100	≤80
Physical Feature	Surface Area [m^2/g]	2.5-3.5	3.5-5.5
	Oil Absorption	25-35	24-34
	Bulk Density [Kg /m^3]	600-750	300-500
	Actual Density [g / cm^3]	2.42	2.42

Table 2
Polyol Technical Specifications

Non-additivity	%99
Melting point	57-61ºC
Color	Pure white
Density	25ºC'de 1.095g/mL

Table 3
Isocyanate Technical Specifications

Non-additivity	%99.5
Melting point	40-41ºC
Combustion point	156-158 ºC
Flash point	196 ºC
Density	(50ºC/ 4ºC) 1.19g/mL
Storage	2-8 ºC

Sample Preparation

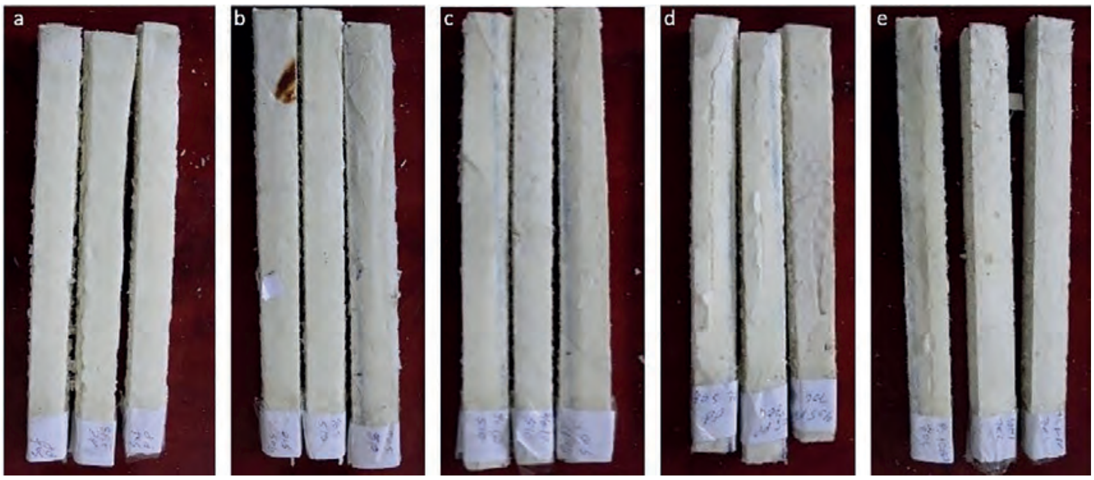
The aluminum mold was placed in a hydraulic press heated to 30°C and PP core material was placed inside. Then 100/120 gr polyol/isocyanate mixture by weight without nano additives was mixed in a mechanical mixer at 15°C material temperature for 2 minutes poured into the PP core structure and subjected to 2 bar mechanical pressure with a density of 42 density and after the material cooled, the composite structure without additives was obtained.

In the same way, 5 wt% ETI FINE510 - 10 wt% ETI FINE 510 - 5 wt% ETI FINE704 - 10 wt% ETI FINE 704 nano additives were added to the polyol material at 15°C and mixed with a mechanical mixer for 10 minutes, then isocyanate was added and mixed for another 2 minutes, and with the onset of chemical reaction, it was poured into the core structures in the mold heated to 30°C and subjected to 2 bar mechanical pressure and after the material cooled, nano-added composite structures were obtained. The composite structure combinations obtained are shown in Table 4.

Table 4
Produced Samples

a	Nano Additive Free	PP core	3 pieces
b	5% ETI FINE 510 Additive	PP core	3 pieces
c	10% ETI FINE 510 Additive	PP core	3 pieces
d	5% ETI FINE 704 Additive	PP core	3 pieces
e	10% ETI FINE 704 Additive	PP core	3 pieces

Figure 3
Produced Samples



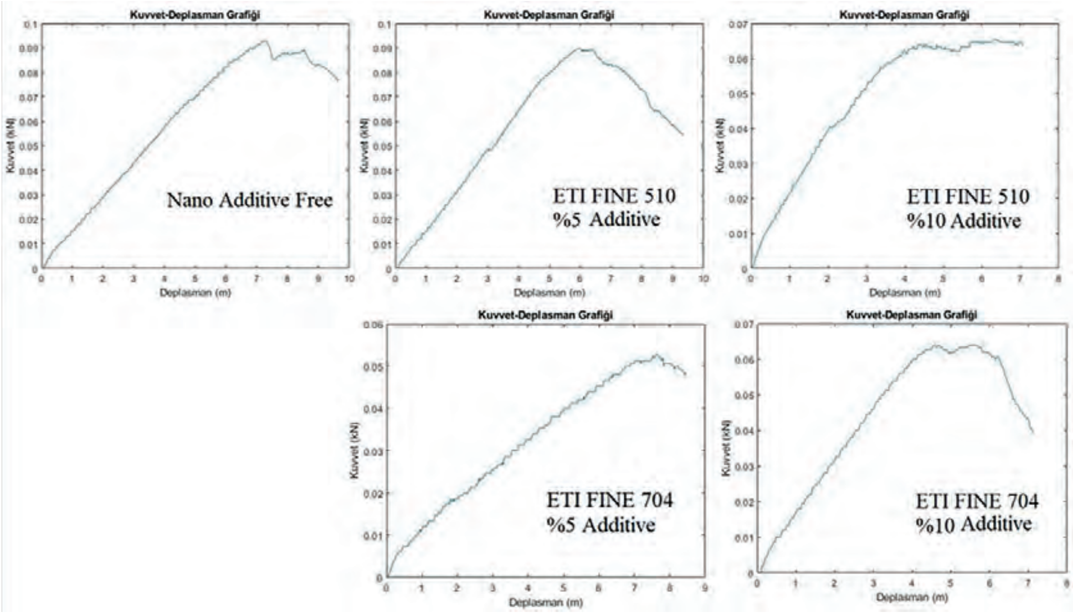
In this study, the differences in flexural and compressive strength of the composite structures filled into the PP honeycomb core structure with 42 density value without and with nano additives, as well as the effect of 5% and 10% ETI FINE 510 nano additive on flexural and compressive strengths, Bending and compression tests were performed on the specimens to determine the effect of 5% and 10% ETI FINE 704 nano additives on flexural and compressive strengths and the differences in the effect of ETI FINE 510 ETI FINE 704 nanomaterials on mechanical strengths.

Three Point Bending experiment Results

The three-point bending test was performed on a Universal bending machine (Instron, 8872) according to standard C696. The capacity of the testing machine is 200 kN, crosshead accuracy is 0.001, and feed rate is 5 mm/min. The experimental design method Taguchi was applied to investigate the effect of different adhesive treatments and surface roughnesses (Alçı, 2016: 107). ASTM D-7264/D7264M-07 standard was taken as a basis.

Figure 4

Three-Point Bending Test Graphs



ETI FINE 510 5% nano additive did not cause any strength change in PP material compared to the material without nano additive, but it decreased the strength at 10% nano additive. ETI FINE 704 5% nano additive did not cause any strength change in PP material compared to the material without nano additive, but the material decreased the strength by 20% without 10% nano additive.

ETI FINE 510 5% nano additive did not change the strength much compared to the undoped material, but ETI FINE 5% additive decreased the strength of the material and made the material more elastic. ETI FINE 510 and 704 10% nano-additives generally decreased the strength of the material.

Figure 5

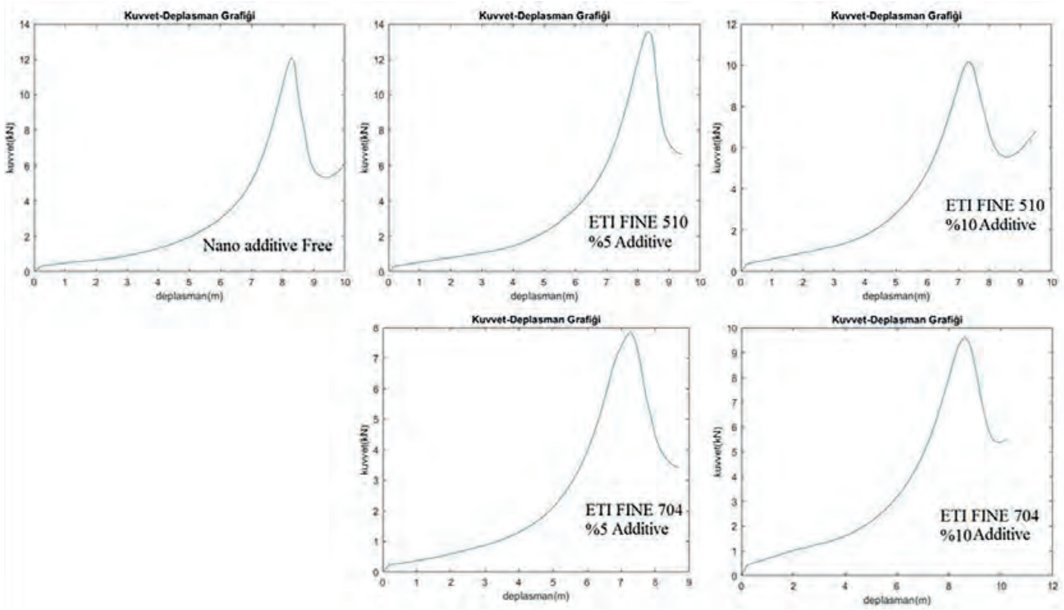
Microscope Images

In the PP core nano-doped material, flexural deformation separations followed the core wall geometry and no deformation occurred in the polyurethane matrices.

Compression Test Results

It was concluded that ETI FINE 510 5% nano additive increased the compressive strength of the undoped material but decreased the strength when the additive ratio was increased. It was observed that ETI FINE 704 5% nano additive significantly decreased the compressive strength compared to the undoped material.

Figure 6
Compression Test Graphs



While normal flame bags were observed in the undoped PP core structure, both flame bag and core wall separations were observed in the doped structures due to increased strength.

Figure 7
Microscope Images

Conclusions

The strength of the material without nano additives decreased with ETI FINE 510 5% nano additive, but when the nano additive ratio was increased to 10%, the material became more rigid and its strength increased.

It was concluded that ETI FINE 510 ETI FINE 704 ATH nano-additives decreased the strength of the material at a 5% additive rate and a 10% additive rate, it approached the strength of the material without additives but made the material rigid at lower displacement rates.

In PP core structures, ETI FINE 510 and 704 5% nano additive did not cause any strength change, but 10% nano additive decreased the material strength. In these structures, the strength gains of ETI FINE 510 and 704 nano additives were not observed.

When the flexural deformation images of the PP core structures were examined, the separations followed the core hexagonal structure walls. No flexural separation was observed in the matrix.

It was concluded that ETI FINE 510 5% nano additive increased the strength of the material in PP core structures, the strength started to decrease as the additive ratio increased, and ETI FINE 704 nano additive decreased the material strength by 40% at both additive ratios.

While normal flame bags were observed in the undoped PP core structure, both flame bags and core wall separations were observed in the doped structures due to increased strength.

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Pattern Recognition: Unveiling Hidden Patterns from Data

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Introduction

Pattern recognition, a cornerstone of machine learning, empowers machines to decipher and understand patterns within data. It is the process of identifying and classifying patterns using a machine learning algorithm. These patterns can be anything from shapes in images to sequences in sounds or even complex relationships in data sets (Alpaydin, 2020).

At its core, pattern recognition involves extracting meaningful information from raw data. This data can come in various forms, such as images, text, audio, or even sensor readings. The goal is to transform this raw data into a format that a machine can comprehend and analyze.

Pattern recognition algorithms can be broadly categorized into two main types: supervised and unsupervised learning. In supervised learning, the algorithm is provided with labeled data, meaning each data point is already assigned a known category or class. The algorithm learns from this labeled data and develops a model that can classify new, unlabeled data points.

In contrast, unsupervised learning explores data without predefined labels, seeking to uncover intrinsic patterns and relationships within the dataset. This approach is often used for tasks like clustering, where the algorithm groups similar data points together (James et al., 2021).

Pattern recognition finds applications across a wide spectrum of fields. In image processing, it is used to identify objects, faces, and scenes in images. In speech recognition, it enables machines to understand spoken language. In bioinformatics, it aids in analyzing DNA sequences and protein structures.

The power of pattern recognition lies in its ability to extract knowledge from vast amounts of data. By identifying patterns and relationships, machines can make informed decisions, solve complex problems, and even predict future events. As machine learning techniques continue to evolve, pattern recognition is poised to play an even more significant role in shaping our world.

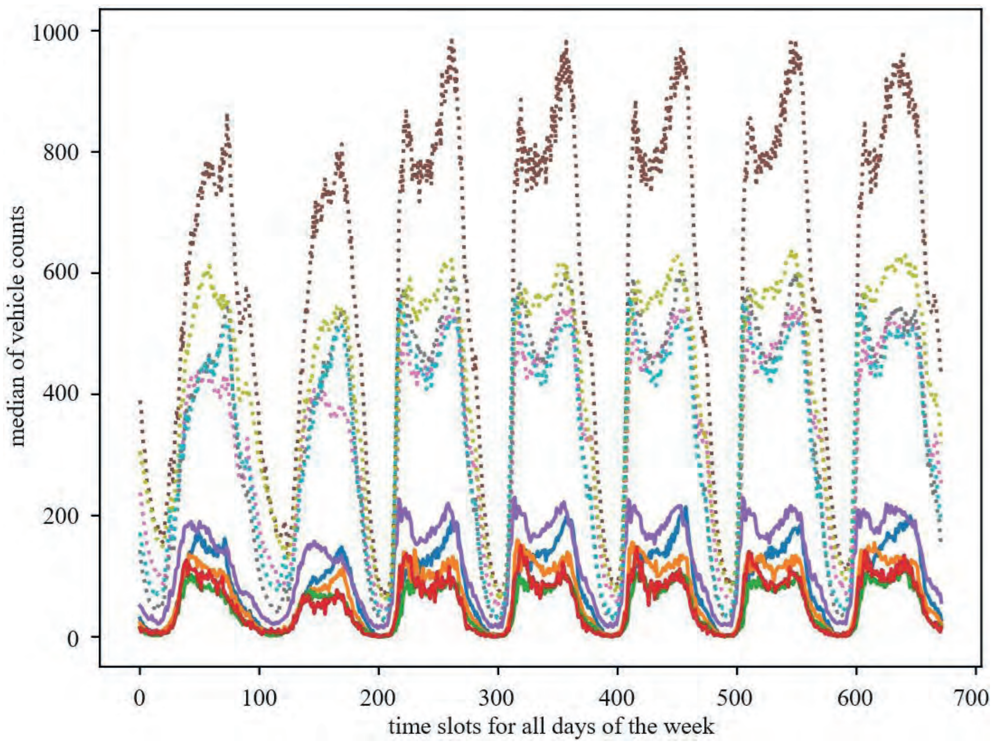
Types of patterns and their characteristics

Pattern recognition, a cornerstone of artificial intelligence and data science, empowers us to extract meaningful structures and regularities from complex data. These patterns, often hidden beneath layers of information, hold the key to unlocking valuable insights across diverse fields, from medical diagnosis (Heneghan et al., 2009) to financial market prediction (Chen and Chen, 2016). Understanding the different types of patterns and their characteristics is crucial for effectively leveraging pattern recognition techniques in various applications.

Sequential Patterns

Sequential patterns, characterized by an ordered arrangement of elements, reveal relationships between data points over time. They are often used in time series analysis, where data is collected at regular intervals. For instance, figure 1 shows the median time series. Common examples include stock price fluctuations, weather patterns, and DNA sequences (Göktepe et al., 2016; Göktepe and Kodaz, 2018) as seen in Figure 1. These patterns can be identified using techniques like Hidden Markov Models (Elmezain et al., 2008) or Recurrent Neural Networks (Mou et al., 2017).

Figure1
Examples of median time series (Alam et al., 2019)



Spatial Patterns

Spatial patterns describe the arrangement of elements within a specific geometric space. They are prevalent in image and video analysis, where pixels or features are organized in two-dimensional or three-dimensional structures. Applications involve object detection, image segmentation, and anomaly detection in spatial data sets. Techniques like convolutional neural networks (Patil and Rane, 2021) have proven highly successful in extracting spatial patterns from images.

Statistical Patterns

Statistical patterns describe the distribution and relationships between data points, often represented by statistical measures like mean, variance, and correlation. These patterns offer insights into the central tendencies and variability within a data set. Clustering algorithms (Rodriguez et al., 2019) are frequently used to group data points based on their statistical similarities, revealing hidden structures within unlabeled data.

Rule-Based Patterns

Rule-based patterns involve discovering a set of logical conditions that accurately predict a specific outcome. These patterns are often expressed as "if-then" statements and can be learned from labeled data sets using decision trees (Quinlan, 1986) or rule learning algorithms. Applications include medical diagnosis based on symptom sets and fraud detection by identifying anomalous financial transactions.

Composite Patterns

Composite patterns represent a combination of the aforementioned types. They involve identifying complex relationships between elements across different dimensions. For example, analyzing weather patterns might involve a combination of temporal (daily temperature variations) and spatial (geographic distribution of rainfall) patterns. Techniques like deep learning models (Bai et al., 2021) are well-suited for handling such complex pattern discovery tasks.

Pattern recognition offers a powerful framework for exploring and commenting on intricate datasets. By understanding the diverse types of patterns and their characteristics, researchers can strengthen appropriate techniques to unlock valuable insights from complex data sets. This paves the way for advancements in various applications, empowering us to make better decisions and solve real-world problems.

Pattern recognition serves as a robust framework for exploring and interpreting intricate datasets. By understanding the diverse nature of patterns and their characteristics, researchers can effectively employ tailored techniques to extract valuable insights.

Pattern Representation and Feature Extraction

The success of pattern recognition hinges on the selection and representation of informative features. These features act as the building blocks for characterizing patterns and differentiating them from noise or irrelevant information. Feature selection involves identifying the most salient characteristics of the data that are essential for capturing the underlying patterns. For instance, in image recognition, features might include edge orientation, color intensity, and spatial relationships between pixels (Liu, 2018) Feature extraction techniques, such as principal component analysis and Gabor filters, are employed to transform raw data into a more compact and informative feature space that facilitates pattern recognition tasks (Ahsan et al., 2021).

The raw data encountered in real-world applications often requires transformation into a suitable feature space before effective pattern recognition can occur. Feature extraction techniques play a pivotal role in this process. They bridge the gap between the raw data and the patterns embedded within it by generating a lower-dimensional representation that highlights the most relevant characteristics for the specific pattern recognition task.

The optimal feature extraction method is contingent upon the data's characteristics and the desired patterns (Sebastiani, 2002).

Numerical Vectors

Numerical vectors offer a versatile and widely applicable method for representing patterns. Each element in the vector corresponds to a specific feature or attribute of the pattern. This allows for efficient storage, comparison, and manipulation of patterns using mathematical operations. For instance, in sentiment analysis, a document can be represented by a numerical vector where each element reflects the sentiment score for a particular emotion category (e.g., positive, negative, neutral) (Pang et al., 2002). Similarly, image data can be translated into a vector by concatenating the pixel intensities of each channel (RGB) to form a single feature vector. The effectiveness of numerical vectors hinges on the selection of informative features that accurately capture the essence of the pattern.

Graphs

Graphs provide a powerful tool for representing patterns that involve relationships and connections between entities. They are particularly well-suited for scenarios where the interactions and dependencies within the data are crucial for understanding the underlying patterns. In social network analysis, a graph can be used to represent individuals as nodes and their relationships (e.g., friendship, collaboration) as edges, enabling the exploration of network communities and information diffusion patterns (Krithika and Priya, 2021). Similarly, molecular structures can be effectively represented by graphs, where nodes depict proteins and edges denote interactions, facilitating the study of protein-protein relationships in bioinformatic applications (Yang et al., 2020).

Strings

String representations excel at capturing patterns that exhibit sequential order or a specific arrangement of elements. Text data, such as DNA sequences or musical pieces, are naturally represented as strings of symbols (nucleotides in DNA, musical notes in a melody). This sequential nature allows for pattern recognition techniques like dynamic programming to identify similarities or differences between sequences (Göktepe and Kodaz, 2018).

Hybrid Representations: Combining Strengths for Complex Patterns

Real-world patterns often exhibit characteristics that necessitate a combination of different representation techniques. By combining multiple representational formats, hybrid approaches offer a more holistic understanding of complex patterns. For instance, a protein in a biological system can be represented by a combination of a numerical vector capturing its amino acid composition (sequence information) and a graph depicting its three-dimensional structure (Whisstock and Lesk, 2003). This combined representation allows for the exploration of relationships between protein structure and function.

Classification and Pattern Recognition Algorithms

A key component of this field is classification, a process that assigns data points to predefined categories or classes. This chapter delves into the concept of classification and explores its crucial role in unlocking the potential of pattern recognition.

Classification algorithms act as decision-makers in the realm of pattern recognition.

They learn to distinguish between different patterns by constructing boundaries in the feature space that separates the classes. This process typically involves training the classifier on a labeled dataset. By analyzing these labeled examples, the classifier learns the characteristics that differentiate between classes and generalizes this knowledge to classify unseen data points.

Applications of Classification

The power of classification extends to a wide range of applications. In image recognition, classification algorithms are used to identify objects within an image, such as distinguishing between cats and dogs in a photograph. Similarly, in medical diagnosis, classification models can be trained to differentiate between healthy and diseased tissue samples based on their features extracted from medical images. Classification also plays a vital role in spam filtering, where emails are classified as spam or legitimate based on their content features.

Multi-Class and Hierarchical Classification

Real-world scenarios often involve more than two distinct classes. Multi-class classification algorithms address this challenge by enabling the classification of data points into more than two categories. For instance, a sentiment analysis system might classify reviews as positive, negative, or neutral. Additionally, hierarchical classification tackles scenarios where classes exhibit a hierarchical structure. For example, a document classification system might categorize documents by genre (fiction or non-fiction) and then further classify them by subgenre (mystery or romance) within the chosen genre.

Supervised Learning Algorithms

Classification, a cornerstone of pattern recognition, empowers us to categorize data points into predefined classes. Supervised learning algorithms play a pivotal role in this process by learning the decision boundaries that separate these classes.

The choice of a supervised learning algorithm for classification hinges on the specific problem and data characteristics. Support Vector Machines (SVMs) excel at identifying the optimal separation boundary between classes in high-dimensional data, making them robust to outliers. Decision trees offer a human-friendly approach by utilizing a tree structure with interpretable rules based on feature values. k-Nearest Neighbors (kNN) provide a simple and computationally efficient method for classification by leveraging the majority vote of a data point's closest neighbors in the feature space. Random forests address the limitations of single decision trees by leveraging ensemble learning, where multiple decision trees trained on random subsets of features and data points collectively make predictions, leading to a more robust and generalizable model. Finally, logistic regression, well-suited for binary classification problems, models the probability of a data point belonging to a particular class using a linear function and interpretable coefficients, offering insights into the relationship between features and class labels (Ros and Riad, 2024).

Unsupervised Learning Algorithms

Supervised learning algorithms excel at classification tasks by learning from labeled data. However, a vast amount of real-world data lacks predefined labels. This is where unsupervised learning algorithms come into play. They empower us to discover hidden patterns and structures within unlabeled data, offering valuable insights for pattern recognition tasks.

Unsupervised learning offers a powerful lens for pattern recognition in unlabeled data. K-Means clustering groups similar data points, revealing communities within the data. Hierarchical clustering builds a hierarchy of clusters, uncovering nested structures. Dimensionality reduction techniques like PCA project data into a lower-dimensional space, simplifying visualization and highlighting the underlying patterns. Anomaly detection algorithms, on the other hand, identify outliers and rarities that deviate from the majority of the data. By leveraging these unsupervised techniques, we can unlock valuable insights from unlabeled data, offering a deeper understanding of the hidden patterns residing within.

Ensemble Methods

Supervised learning algorithms excel at classification tasks, but their performance can be limited by factors like data complexity or model bias. Ensemble methods offer a powerful approach to address this challenge. They combine the predictions from multiple learning models, often referred to as "base learners," to create a more robust and generalizable classifier. This ensemble approach leverages the strengths of individual models while mitigating their weaknesses, ultimately leading to improved classification performance.

Ensemble methods provide a powerful approach to classification tasks by leveraging the collective intelligence of multiple learning models. Through techniques like bagging and boosting, ensembles offer improved accuracy, reduced variance, and the ability to handle complex data sets. While factors like computational cost and interpretability need consideration, ensemble methods are valuable tools for researchers and data scientists seeking to unlock the full potential of pattern recognition in various applications.

Pattern Recognition Applications

Pattern recognition plays a central role in various image-processing tasks, empowering us to extract meaningful information from visual data. Here's a glimpse into how it manifests in three key applications:

Image Classification

Imagine sorting a giant photo album filled with unlabeled images. Image classification, a core application of pattern recognition, automates this process. Classification algorithms are trained on labeled datasets where images are associated with specific categories (e.g., "cat," "mountain," "car"). By learning to identify patterns in these labeled images, the algorithms can then classify unseen images into predefined categories. Image classification powers functionalities like content-based image retrieval, where users can search for images based on their content (e.g., searching for pictures of beaches based on a beach photo). It also underpins automatic image tagging in social media platforms, suggesting relevant tags based on the image content.

Object Detection

Beyond simply classifying the entire image, object detection aims to identify and localize specific objects within an image as seen in Figure 2. This involves not only recognizing the object category (e.g., "person," "dog") but also pinpointing its bounding box (rectangular region) within the image. Advanced techniques like YOLO (You Only Look Once) leverage deep learning models to achieve real-time object detection, making them ideal for applications like self-driving cars and video surveillance systems. Object detection has a wide range of applications, including facial recognition systems that identify individuals in images or videos. It also plays a crucial role in autonomous vehicles, where object detection helps identify pedestrians, traffic signs, and other objects on the road for safe navigation.

Figure 2

Sample object detection results of different models (Borji et al., 2019)

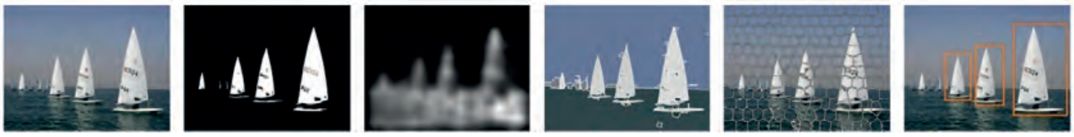


Image Segmentation

Image segmentation goes a step further than object detection as shown in figure 3. It aims to partition the entire image into meaningful regions, assigning each pixel to a specific category or object. This granular analysis allows for a more detailed understanding of the image content. Techniques like convolutional neural networks (CNNs) are employed for image segmentation, enabling tasks like medical image analysis where identifying and segmenting specific tissues or organs is crucial for diagnosis. Image segmentation finds application in various fields. In medical imaging, it helps in segmenting tumors in MRI scans for cancer diagnosis. In self-driving cars, it can be used to segment the road lane from the surrounding environment for improved navigation.

Figure 3

An image with detailed annotations from the Cityscapes dataset (Liu et al., 2019)

Speech-to-Text Conversion

Imagine seamlessly converting your spoken words into written text. Speech-to-text conversion, a cornerstone of applications like dictation software and voice assistants, relies heavily on pattern recognition. Speech signals are converted into a digital format and then analyzed using techniques like Hidden Markov Models (HMMs). HMMs capture the statistical patterns of speech sounds and their transitions, allowing the system to recognize words within a spoken utterance. Speech-to-text conversion has revolutionized accessibility, empowering individuals with disabilities to communicate more effectively. It also finds application in various industries, such as healthcare for dictation during medical transcriptions, and customer service for improved call center efficiency.

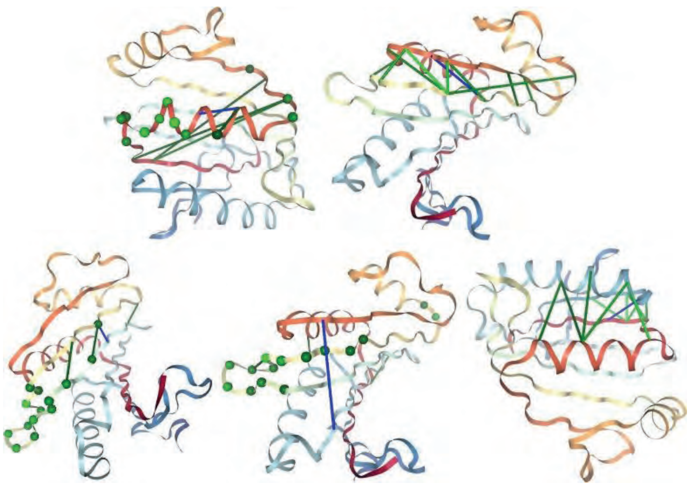
Language Recognition

In a multilingual world, language recognition empowers systems to understand the spoken language within an audio stream. Pattern recognition techniques analyze features like phonetics and prosody (speech rhythm and intonation) to identify the language being spoken. This identification is crucial for enabling real-time translation services or for content filtering based on language. Language recognition underpins real-time translation tools that allow for seamless communication across languages. It also plays a role in routing international customer service calls to agents who speak the caller's language.

Protein Structure Prediction

Proteins, the workhorses of the cell, perform a multitude of functions dictated by their intricate three-dimensional structures as seen in Figure 4. Pattern recognition plays a crucial role in protein structure prediction, a challenging yet vital task in bioinformatics. Techniques like homology modeling use known protein structures as templates to predict the structure of similar proteins based on sequence similarities. Additionally, machine learning algorithms are being trained on large datasets of protein sequences and structures to directly predict novel protein structures with high accuracy. Protein structure prediction offers insights into protein function, aiding drug discovery by identifying potential drug targets or designing novel drugs that interact with specific proteins. It also plays a role in understanding protein-protein interactions, crucial for various cellular processes.

Figure 4
Predicted protein pairs (Senior et al., 2020)



Gene Expression Analysis

Gene expression analysis aims to understand which genes are active (expressed) in a particular cell type or under specific conditions. Microarray and RNA-sequencing technologies generate vast amounts of data on gene expression levels. Pattern recognition techniques like clustering algorithms are used to identify groups of genes with similar expression patterns, potentially revealing co-regulated genes involved in specific biological pathways. Gene expression analysis helps identify genes associated with diseases, paving the way for personalized medicine. It also aids in understanding the mechanisms of drug action and in developing new biomarkers for disease diagnosis and prognosis.

Disease Diagnosis

Pattern recognition offers powerful tools for disease diagnosis in bioinformatics. Techniques like machine learning algorithms can be trained on medical data, encompassing patient records, genetic information, and medical images. These algorithms learn to identify patterns associated with specific diseases, allowing for more accurate diagnosis and risk prediction. Pattern recognition in bioinformatics can be used to analyze medical images for early detection of diseases like cancer. It also helps in analyzing genetic data to identify individuals with a predisposition to certain diseases, allowing for preventive measures.

Fraud Detection

Fraudulent activities, whether credit card transactions or financial transfers, often exhibit patterns that deviate from legitimate user behavior. Pattern recognition algorithms are employed to analyze vast amounts of transaction data. They learn the characteristics of typical transactions and then flag outliers that deviate significantly from these patterns, potentially indicating fraudulent activity. Techniques like k-Nearest Neighbors (kNN) can identify transactions that fall outside the usual spending patterns of a user. Additionally, clustering algorithms can be used to group similar transactions, highlighting transactions that fall outside established clusters and potentially indicating fraudulent rings.

Network Intrusion Detection

Network security hinges on the ability to identify and thwart malicious attempts to access or disrupt a computer network. Pattern recognition serves as a vital tool in network intrusion detection systems (NIDS). These systems analyze network traffic data, searching for patterns that deviate from normal network activity. These patterns might include unusual ports being accessed, suspicious data packets, or attempts to exploit known vulnerabilities. Machine learning algorithms trained on labeled data containing examples of normal and malicious network traffic can effectively identify anomalies. Additionally, techniques like Hidden Markov Models (HMMs) can be used to model the statistical patterns of normal network traffic and flag deviations that suggest potential intrusions.

Advanced Topics in Pattern Recognition

Active Learning in Pattern Recognition

Pattern recognition thrives on data, but not all data is created equal. Labeling data for supervised learning can be a time-consuming and expensive endeavor, especially for complex tasks. Here's where active learning steps in, offering a more efficient approach to data utilization in pattern recognition.

Active learning flips the script on traditional supervised learning. Instead of passively receiving labeled data, the learning algorithm actively participates in the labeling process. It employs a selection strategy to choose the most informative data points from a large unlabeled pool. These informative points are then presented to a human annotator for labeling, focusing the labeling effort on the data that will have the greatest impact on the model's learning.

By focusing on the most informative data points, active learning can significantly reduce the amount of data that needs to be labeled by humans, leading to significant cost and time savings.

Active learning strategies prioritize data points that the model is most uncertain about. This targeted learning approach can lead to faster improvement in model performance compared to random sampling of data for labeling.

Active learning can help mitigate bias in training data by strategically selecting data points that represent the diversity of the overall data distribution.

Active learning offers a strategic approach to data utilization in pattern recognition. By prioritizing the most informative data points for labeling, it reduces labeling costs, improves model performance, and mitigates bias. As active learning techniques continue to evolve, they will play an increasingly important role in empowering pattern recognition for various applications.

Pattern Recognition in Reinforcement Learning

Reinforcement learning deals with agents that learn through trial and error by interacting with their environment. While exploration is crucial, efficient learning hinges on recognizing patterns within the environment's feedback (rewards) to optimize actions.

Agents in reinforcement learning navigate through a series of states, taking actions that lead to new states and receiving rewards based on these transitions. Pattern recognition helps agents identify the relationships between states, actions, and rewards. By analyzing past interactions, the agent can learn to predict the consequences of taking specific actions in different states. Techniques like Markov Decision Processes (MDPs) model the environment as a set of states, actions, transitions, and rewards. Reinforcement learning algorithms leverage these models to learn the pattern of state transitions based on past experiences.

Rewards are the currency of reinforcement learning, guiding the agent toward optimal behavior. Pattern recognition empowers agents to learn the patterns within reward signals. By analyzing how rewards are distributed across different state-action combinations, the agent can identify actions that consistently lead to higher rewards and refine its decision-making strategy. Techniques like Q-learning utilize value functions that estimate the future rewards an agent can expect from taking a specific action in a particular state. Pattern recognition helps agents learn and update these value functions based on observed rewards, enabling them to prioritize actions with the highest expected future reward.

Real-world environments can be complex and dynamic, with intricate relationships between states, actions, and rewards. Advanced pattern recognition techniques like deep learning are increasingly being used in reinforcement learning. These deep learning models can extract complex patterns from high-dimensional data, such as visual inputs from cameras or sensor readings, allowing agents to navigate and make optimal decisions in these complex environments. Deep reinforcement learning with pattern recognition finds applications in robotics, where robots can learn to navigate and manipulate objects in dynamic environments. It also holds promise in game playing, where agents can learn complex strategies by identifying patterns in game states and their rewards.

Conclusion and Future Directions

Pattern recognition has emerged as a cornerstone of artificial intelligence, empowering machines to unlock the hidden patterns embedded within data. From categorizing images to deciphering human language, its applications permeate diverse domains, transforming the way we interact with technology and the world around us. This chapter has delved into the core concepts of pattern recognition, exploring its techniques, algorithms, and the vast array of applications it underpins.

As we look towards the future, pattern recognition is poised for continued evolution, driven by advancements in machine learning and data science. Here are some exciting directions shaping the future of this transformative field:

- Explainable AI (XAI): While pattern recognition algorithms excel at uncovering patterns, interpreting their decision-making processes remains a challenge. XAI techniques will be crucial for building trust and ensuring transparency in applications where understanding the "why" behind a decision is critical.
- Lifelong Learning: Real-world data streams are constantly evolving. Pattern recognition algorithms will need to adapt and learn continuously, incorporating new information and refining their understanding of patterns over time.
- Human-in-the-Loop Learning: The synergy between human expertise and machine learning capabilities holds immense potential. Future systems will likely leverage active learning and human-in-the-loop approaches to achieve superior pattern recognition with minimal human effort.
- Privacy-Preserving Pattern Recognition: As data privacy concerns rise, developing techniques for pattern recognition that operate on anonymized or privacy-preserving data will be essential.

In conclusion, pattern recognition has unveiled a world of possibilities, empowering us to extract knowledge and insights from ever-growing data. As the field continues to evolve, it holds the promise of shaping a future where intelligent systems can navigate complex environments, make informed decisions, and ultimately, collaborate with us to solve some of humanity's most pressing challenges.

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An Example in Innovative Engineering Education: Seydişehir Ahmet Cengiz Faculty of Engineering (SACMF)

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Introduction

Innovative engineering aims at the creative and effective application of engineering disciplines with constantly developing technological and scientific innovations. Blending the basic principles of engineering with the requirements of the modern age ensures that more efficient, sustainable, and beneficial solutions are produced for society. This approach, which pushes the boundaries of traditional engineering methods, allows the new generation of engineers to approach problems with a much broader perspective. At the same time, engineers should be aware of critical issues such as environmental sustainability, ethical responsibility, and social justice.

Innovative engineering education provides students with the ability to think analytically, solve problems, and produce innovative solutions while educating them as leaders of the future. Analytical thinking skills are vital for solving complex problems and making data-driven decisions. Problem-solving skills, on the other hand, help engineers creatively and effectively overcome the challenges they face in daily life. The ability to produce innovative solutions enables engineers to follow technological developments and turn these developments into practical applications.

The innovative engineering approach aims to expand the scope of engineering education and provide students with both technical and social competencies. This approach educates engineering students not only as individuals with knowledge and skills but also as leaders who will contribute to the development of society. In this way, the quality of the studies in the field of engineering increases and contributes to the increase of the welfare level of society.

One of the cornerstones of the innovative engineering approach is the hands-on training process called intern engineering education. This process is an educational model in which engineering students can apply their theoretical knowledge to real-world projects, gain sectoral experience, and develop their professional skills. Intern engineering education not only provides students with technical knowledge but also provides them with important competencies such as understanding the dynamics of the business world, teamwork, and leadership (Tom Gillpatrick,2020).

Intern Training

Intern practice in engineering education is a critical process that allows students to test their theoretical knowledge in real-world conditions and gain professional experience. This application allows students to develop the knowledge and skills they have acquired throughout the education process in line with the current needs in the sector. Intern engineering does not only provide students with technical competencies; It also helps to develop important professional traits such as work ethic, communication skills, teamwork, and leadership (internship-statistics, 2024).

Intern engineering applications accelerate the adaptation process of students to the workforce after graduation. Especially in a rapidly changing technological environment, the chance for engineer candidates to put theoretical training into practice is vital to stay relevant. Such experiences support both the personal and professional development of students while preparing them for the dynamics of the business world.

This process bridges the gap between the business world and academia, allowing students to focus not only on academic achievement but also on sectoral achievements. Intern engineering education facilitates the process of finding a job for students after graduation and creates a solid foundation for their careers.

In this context; It started to be implemented in the 2018-2019 Academic Year Spring Semester in the Department of Mechanical Engineering of Seydişehir Ahmet Cengiz Faculty of Engineering.

The model, for the first time in Turkey; An example was taken from Gaziantep University Faculty of Engineering, which started to implement in the 2012-2013 Academic Year Spring semester. The application was examined on site and detailed information about the implementation of the program was obtained. However, the most important problematic issue we saw in practice was that “all department students were subject to intern practice” This problem; There was no problem for Gaziantep at the beginning fact that it was an industrial city, and the program started to be implemented, but it was stated by the academicians who carried out the program that it became problematic in the following processes.

The Three Most Important Innovative Features of the Intern Application in Seydişehir Ahmet Cengiz Faculty of Engineering (SACMF) That Distinguish It from Others

Internship Training is an essential part of engineering education. Classical internship training “Internship training is essential for engineering education learning-based and practical application. However; Intern education is completely engineering formation education. More precisely, intern education for Engineers is the same as the internship of last year’s students in medical education and the internship of lawyers after graduation. Internship training continues without any changes to the SACMF.

“Intern Education in Engineering is Never Internship Training”

Optional ELECTIVE Only in SACMF, COMPULSORY for the Entire Department in the Related Departments of Others

When the student meets the necessary conditions, finds the company to be an intern of the student’s own volition, and submits it to the approval of the intern commission. If accepted, the student starts intern training. The school is not legally obliged to find an intern place. As an example, Tabo 1st and 2nd SACMF 2023-2024 Academic Year 4. Class 1st and 2nd-semester curricula are given. As can be seen from the curriculum, 1 course with the same credits and ECTS as the elective courses is installed in SACMF, the course is an elective, while it is mandatory for the entire department in related departments. In SACMF, the course is an elective, while it is mandatory for the entire department in related departments. The elective course groups. Project courses in the last year continued for Intern students and they could transform their theoretical knowledge into practical applications by combining both the academic background of the project instructor and the infrastructure of the experienced engineers in the workplace while choosing their subjects integrated with their workplaces and realizing their projects. This process allows students to both develop their professional skills and step into the business world in a more prepared way.

CONTINUOUS MONITORING differs from other applications with a "FULL CONTROL MECHANISM" without abuse.

There are two methods applied in SACMF. The first method; If the workplace is a corporate company such as ASELSAN, TAI, etc., attendance follow-up is followed without being officially left to the initiative. Therefore, there is no need for any special follow-up and abuse in corporate companies.

Second Method; If the company to be interned is not corporate and/or is a small-scale company (KOBİ, etc.); Here, they must take advantage of the "on-the-job training – 6 months" program carried out by the Ministry of Labor through İŞKUR, otherwise such non-institutional small companies are not accepted. The control of the personnel employed in the "On-the-Job Training" program is carried out by İŞKUR.

Companies other than these are not approved. Thanks to these methods, the student has the chance to continue his intern education not only in the city where he/she is educated but also in the city where he lives.

Tablo 1

SACMF Mechanical Engineering Department 2023-2024 4th Year Fall Semester Curriculum (Seydisehir Mechanical Engineering Page, 2024)

4th Year Fall Semester				
Course Code	**Course Name**	**T+U+L**	**Credit**	**ECTS**
0370020052	Organization internship in industry[4]	20 working days	0	5
0370020055	Design in Mechanical Engineering I[1,6,7]	3+1+0	3,5	9
TECHNICAL ELECTIVES I1				
0370020056	Quality Management Systems	3	3	4
0370020057	CNC Machine Tools			
0370020058	Thermal Turbomachinery			
0370020059	Mechatronic System Design			
0370020119	Material Characterization			
0370020031	Composite Materials I			
0370020136	**Workplace Training and Practices I[5]**			
TECHNICAL ELECTIVES II1				
0370020061	Material Inspections	3	3	4
0370020062	Transport Technique			
0370020063	Heating System Design			
0370020064	Energy Management			
0370020120	Powder Metallurgy			
0370020086	Hydraulic-Pneumatic Systems			
0370020137	**Workplace Training and Practices II[5]**			
TECHNICAL ELECTIVES III1				

0370020102	Sheet Metal Molding Technique	3	3	4
0370020069	Mechanical Behavior of Materials			
0370020121	Heat Treatments			
0370020083	Engineering Package Programs-I			
0370020138	**Workplace Training and Practices III[5]**			
TECHNICAL ELECTIVES IV1				
0370020070	Natural Gas and Applications	3	3	4
0370020071	Mechanical Vibrations			
0370020072	Hydraulic Machines			
0370020104	Plastic Molding			
0370020074	Material Selection			
0370020122	Casting Technology			
0370020139	**Workplace Training and Practices IV[5]**			
	TOTAL CREDITS/ECTS	**15+1+0**	**15,5**	**30**

Tablo 2

SACMF Mechanical Engineering Department 2023-2024 4th Year Spring Semester Curriculum ((Seydisehir Mechanical Engineering Page, 2024)

4th Year Spring Semester				
Course Code	**Course Name**	**T+U+L**	**Credit**	**ECTS**
0370020075	Design in Mechanical Engineering II[1,6,7]	3+1+0	4	6
TECHNICAL ELECTIVES V1				
0370020078	Refrigeration Technology	3+0+0	3	6
0370020079	Acoustics & Noise			
0370020080	Plastic Materials			
0370020081	Engine Dynamics			
0370020105	Machine Design			
0370020106	Industrial Product Design			
0370020116	Package Programs in Engineering-II			
0370020140	**Workplace Training and Practices V[5]**			
TECHNICAL ELECTIVES VI1				
0370020082	Solar Energy and Applications	3+0+0	3	6
0370020084	Standardization			
0370020085	Air Conditioning Design			
0370020107	Computer Aided Manufacturing			
0370020108	Alternative Energy Sources			
0370020109	Finite Element Analysis			
0370020103	Industrial Automation			
0370020143	Nano Materials			
0370020131	Computer-Aided Engineering Applications			
0370020141	**Workplace Training and Practices VI[5]**			
TECHNICAL ELECTIVES VII1				

0370020087	Composite Materials II	3+0+0	3	6
0370020088	Introduction to Robotics			
0370020089	Pumping Systems			
0370020090	Heat Exchangers			
0370020110	Drying Technique			
0370020130	Thermal Engines II			
0370020142	**Workplace Training and Practices VII[5]**			
	TECHNICAL ELECTIVES VIII1			
0370020150	Reverse Engineering	3+0+0	3	6
0370020149	Expert Witness Training			
0370020148	Welding Technology			
0370020147	Introduction to Nanotechnology			
0370020146	**Workplace Training and Practices VIII[5]**			
	TOTAL CREDITS/ECTS	**15+1+0**	**15,5**	**30**

[1] The exams of this course can be practiced.
[2] In this course, students will be given at least one experiment by the relevant instructor.
[3] In this course, students will be made to do at least one design project in which they will apply what is explained in the course.
[4] Internships will be held for at least 20 working days by the internship directive.
[5] Only graduate students can choose these courses.
[6] This course is offered only for students who have completed the normal education period and are in the position of graduates, and the other semester as well.
[7] The content of this course includes laboratory applications.
[8] These courses can only be offered for foreign students.

- **The Program has a FLEXIBLE Structure**

The curriculum is also composed of workplace training courses under the group of elective courses of both semesters in the final year. Thus, students who have completed their first-semester or second-semester courses can do their internship in the fall or spring semester of their last semester. At the same time, if there is a problem in the intern program, the student could return to normal formal elective courses at the school, for example, within 1-2 weeks, if he does not pass a certain period. During the COVID outbreak in 2019, students had the opportunity to return to their elective courses in distance education and did not lose a year thanks to this flexible structure. As can be seen from the curriculum in Tables 1 and 2, the basic backbone of engineering education has not been touched at all, and internships and projects remain unchanged.

Transcript of Social Responsibility Projects

Innovative engineering education not only focuses on technical skills but also emphasizes the responsibilities of engineers to society. Social responsibility projects allow students to develop environmental awareness, gain sensitivity to social problems, and produce sustainable solutions. These projects enable engineers to grow as ethical and socially sensitive individuals who can respond to the needs of society (Jessica Smith & Juan Lucena, 2018).

One of the problems that students face after graduation is the documentation of the social responsibility projects, they participate in during the education period. With this project;

All activities attended by the students are scored and a "social responsibility transcript" is created in the form of transcripts of the same courses each semester (Table 3). In addition to the diploma, Turkish and English (Shown in Table 4) transcripts signed by the supervisor, head of the department, and the dean are given together with the diploma. Some of the advantages of this most important system are;

- When they start their business life, they officially document their social activity activities, which are as important as their diploma grade.
- The most important element of student participation in social activities is ***volunteering***. This system supports ***voluntary participation***. Otherwise; Unfortunately, in the events that the administration and the course instructor participate in with the threat of attendance; Only the hall is filled, and the event is held, and a photo is taken and shared on social media with a pink painting. All these negativities are eliminated.

Activity scoring is like academic promotion criteria (in terms of form), each activity is scored differently. For example, activities carried out by community president, community member, participant, organizer, student clubs and organizations, community-oriented studies, degrees, and awards won at national and international levels, scientific activities, cultural, artistic, and sports activities, studies within the scope of the volunteering course, other social and cultural activities approved by the evaluation commission, etc. tasks are scored.

This application, which was initiated in Seydişehir Ahmet Cengiz Faculty of Engineering, was presented to the Management of the period 2 times in the academic board in 2016 and it was stated that it was very popular and that it would be nice to apply it to other faculties and departments. In the dean's briefings given to the management in the period after 2018, the subject was explained 2-3 times and received appreciation, and as in the previous period, the application recommendation was made by the management throughout the university. However; The program, the torch of which we lit, was implemented under the name of NESEF through the Necmettin Erbakan University student mobile application, albeit with a delay of 5-6 years. So; The Social Responsibility Project, which is a successful innovative approach of Seydişehir Ahmet Cengiz Faculty of Engineering, has found its way, albeit late.

"To be a Good Engineer; It is not enough to have technical equipment in the field, but also to have a sense of social responsibility"

Table 3

SACMF Social Responsibility Projects Scoring Criteria: A Sample Table

NEÜ SEYDİŞEHİR AHMET CENGİZ FACULTY OF ENGINEERING			
SOCIAL RESPONSIBILITY PROJECTS SCORING CRITERIA			
1. Program Organizations[1]	***Coordinator***	***Stuff***	***Participant***
a) Organization and preparation of programs such as Conferences, Seminars, Panels, Interviews and Festivals	*30*	*20*	*5*
b) Student workshops and special themed workshops	*30*	*20*	*5*

c) Organizational tasks in departmental programs	*20*	*10*	*5*
***2. Technical Activities*[2]**			
a) Designing and producing themed utility model projects (Energy, Environment, Society, Disadvantaged Groups, etc.)	*20*	*10*	*5*
b) Organization of technical trips carried out by communities	*20*	*10*	*5*
c) Faculty project working groups	*20*	*10*	*5*
***3. Social Activities*[3]**			
a) social responsibility projects (visits to the elderly, fight against addiction, relatives of martyrs, visits to veterans, etc.)	*15*	*10*	*5*
***4. Sports Activities*[4]**			
a) To engage in sports activities representing the faculty	*30*	*20*	*5*
b) Organizing tournaments between departments, classes, etc.	*15*	*10*	*5*
***5. Artistic Activities*[5]**			
a) Theater and cultural activities within the faculty (short film, themed music, etc.)	*20*	*10*	*5*
***6. Project Competitions*[6]**			
a) To participate in Tübitak project competitions	*40*	*30*	*20*
b) To participate in project competitions organized by other institutions (MEB, KOP, etc.)	*30*	*20*	*10*
c) Technical and social project competitions and debates within the Seydişehir Campus	*20*	*10*	*5*

Table 4

A Sample SACMF Social Responsibility Projects Transcript of A Student

NEU SEYDİŞEHİR AHMET CENGİZ FACULTY OF ENGINEERING			
SOCIAL RESPONSIBILITY TRANSCRIPT			
Student Name and Surname	A***** Y*****		
Student ID	1********		
Department/Program	Mechanical Engineering		
Semester	2017-2018 Spring		
Program Organizations[1]	**Coordinator**	**Official**	**Participant**
Kızılay Blood Donation Campaign	30		
2. Technical Activities[2]			
Eti A.S. Technical Visit		10	
Project Preparation Techniques Workshop			5
3. Social Activities[3]			
Visit to the Relatives of the Martyrs			5
4. Sports Activities4			
Inter-Faculty Football Tournament			5
5. Art Related Activities[5]			
30 August Art Gallery			5
6. Project Competitions[6]			
Participation in Electromobility Competitions			20

SUM	**30**	**10**	**40**
GRAND TOTAL UNITS			**80**
Supervisor **Head of** **Department** Signature Signature		**Dean** Signature	

Experimental Learning

Experimental learning is another important component of innovative engineering education. Supported by practical experiences such as laboratory work, workshop activities, and field applications, this educational model enables students to put their theoretical knowledge into practice. By taking an active role in projects, students develop their problem-solving skills and produce innovative solutions. In this way, they are ready for the challenges they will face in the industry when they graduate (Muhammad Khairuddin, 2023).

Normally; Although there is an opinion that engineering education is a practical education, it is obvious that it is not as it seems. Technical education and engineering education are often confused with each other. First, it is necessary to know the concepts well. The backbone of engineering education is basic sciences and is based on a theoretical infrastructure. However, the backbone of technical education is practice.

As mentioned above, many of the institutions that provide theoretical-based engineering education also bypass application-based education. When it comes to practice in engineering education; There is a need for laboratories where experimental applications of each department are made. When we look at the institutions that provide conventional engineering education, we see that there are almost no license-based laboratories, but there are advanced research centers with million-dollar test devices where graduate studies are carried out.

The fact that there are ***License-Oriented*** laboratories where the applications of each department can be made with a closed area of ***3,000 m²*** in Seydişehir Ahmet Cengiz Faculty of Engineering has created awareness both regionally and throughout Turkey as an approach.

"Experimental Learning in Engineering Education is Never the Same as Practical Training in Technical Education"

Central System Exams of Exam Application (ÖSYM, AÖF Etc.) Doing It In A Similar Way

Education is one of the most important processes for individuals to develop their talents, increase their knowledge, and grow as individuals who will contribute to society. The successful execution of this process depends not only on the quality of the education offered to the students but also on the examination systems that objectively evaluate their knowledge and skills. In Turkey, exams such as the Higher Education Institutions Exam (YKS) or the Public Personnel Selection Exam (KPSS) administered by ÖSYM (Measurement, Selection and Placement Center), known as central system exams, and exams organized by Anadolu University Open Education Faculty (AÖF) are evaluation tools that are carried out with the participation of large masses and have become one of the most important components of the education system.

"If you turn a blind eye to a cheating student, it means that every other student has a cheating right"

These exams are decisive for both students and educational institutions, ensuring a transparent, fair, and equitable evaluation of the educational process. One of the biggest advantages of centralized system exams is that all participants are subjected to the same questions under the same conditions and the exam is carried out according to a certain standard. This increases the comparability of the exam results and makes the results more reliable.

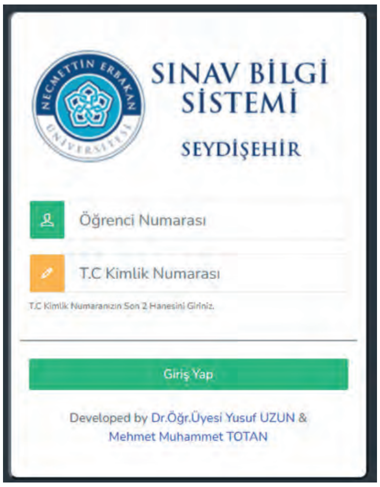
On the other hand, other exams administered in various educational institutions are often organized in a more flexible and open to inter-institutional differences compared to central system exams. This may raise questions about the reliability and fairness of the exam results. In this context, it is of great importance that the exam applications are carried out in a structure like the central system exams, in terms of increasing the quality of education, making the competition among students fairer, and reinforcing the trust in the exam processes in general.

In the SACMF, the potential effects and advantages of conducting exams like central system exams on the education system are discussed. In addition, the steps required for the implementation of this practice and how this process can increase the quality of education are emphasized.

With the support of the advisor faculty member at SACMF, software made by a Computer Department student has been developed. In this software; For each exam, the exam date, the number of students, the classes to be taken for the exam, and the list of proctors are entered into the system. When the program is run; Students are randomly assigned to classes and sequence numbers. The instructor in charge of the exam takes the class lists according to the class and sequence numbers and gives them to the invigilators on the exam day in return for their signatures and receives them in the exam coordination room at the end of the exam. Figure 1 shows the student interface of the exam information system.

Figure 1

Web interface of the exam information system for students (Exam Information System, 2024).



Creating an Online Student Recognition Card

The student recognition card can be used not only to understand the academic and personal characteristics of the students but also to evaluate their economic situation and provide scholarship opportunities. This innovative approach, which is planned at Seydişehir Ahmet Cengiz Faculty of Engineering, can be considered a step towards alleviating the financial difficulties that students may encounter in their education processes. The student recognition card developed for this purpose allows a more holistic assessment to be made by including the income status and financial needs of the students.

Assessment of the Economic Situation

The student recognition voucher can be used to ensure that scholarships and other financial support for students are distributed fairly and effectively. Data such as students' socio-economic status, family income levels, and scholarship needs are collected through this form and used in the evaluation of scholarship applications. Evaluating students with low economic status as a priority in this process both increases the motivation of the student and contributes to overcoming the financial obstacles they may encounter in the education process.

Scholarship Evaluation Criteria

The scholarship evaluation process begins with a detailed examination of the information obtained from the student recognition card. Here are some key factors to consider during this evaluation process:

Family Income

The total income level of the student's family plays an important role in determining the need for scholarships. In addition to family income, it is evaluated whether the student can afford the costs of education.

Other Scholarships and Supports

It is determined whether the student needs additional support by taking into account the scholarships and financial support he has already received.

Economic Obligations

Factors such as the number of dependents of the student's family and the financial obligations of the student are considered in the evaluation of the scholarship.

Interfaces and Application Process of the Student Recognition Card

The interfaces of the student recognition voucher program, which is planned to be implemented at Seydişehir Ahmet Cengiz Faculty of Engineering, aim to collect student information effectively and practically. Additionally, the data obtained through these interfaces allows for a quick and objective evaluation of scholarship applications.

Economic Situation

This tab, which includes questions about the student's economic status, allows you to enter detailed information about income status, current scholarships, and other sources of income in the family.

Academic and Personal Information

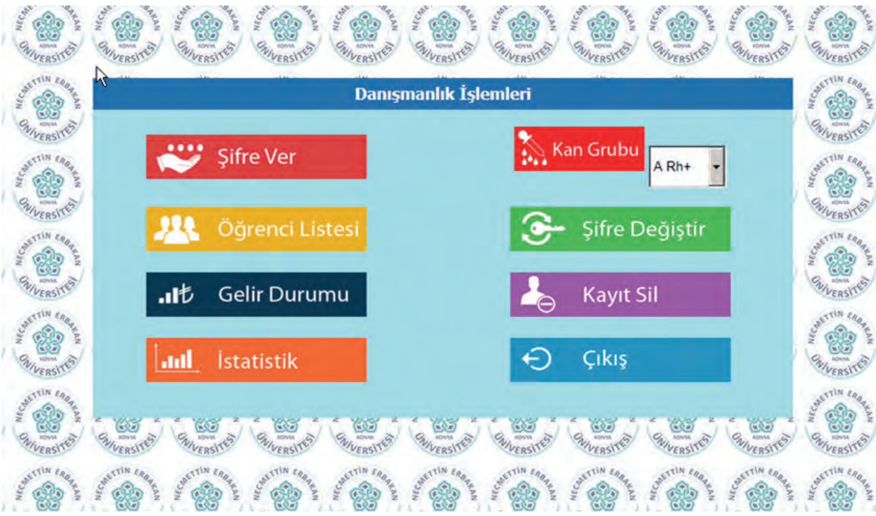
These sections, which also include students' academic achievements, interests, and career goals, help determine the needs of the student both in the scholarship application and in the academic process.

Designing the interfaces in a user-friendly and easy-to-understand way will contribute to the student's ability to fill in this information in a practical way and to speed up the data collection process.

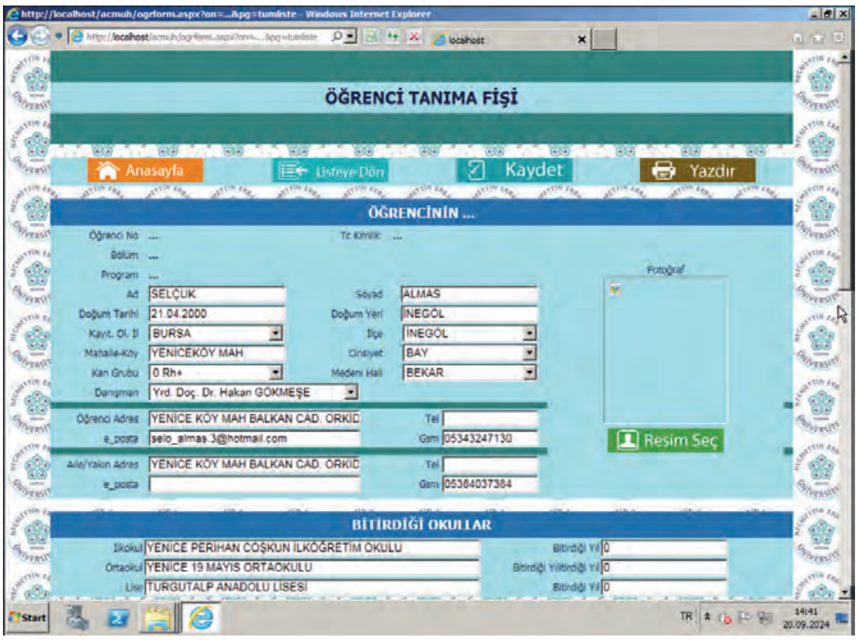
The use of the student recognition voucher for economic status makes an important contribution to making engineering education more accessible. Taking this information into account in the scholarship evaluation process allows students who are financially disadvantaged to be supported in their education process. The implementation of this practice at Seydişehir Ahmet Cengiz Faculty of Engineering can be considered an important step for students to continue their education more comfortably.

Figure 2

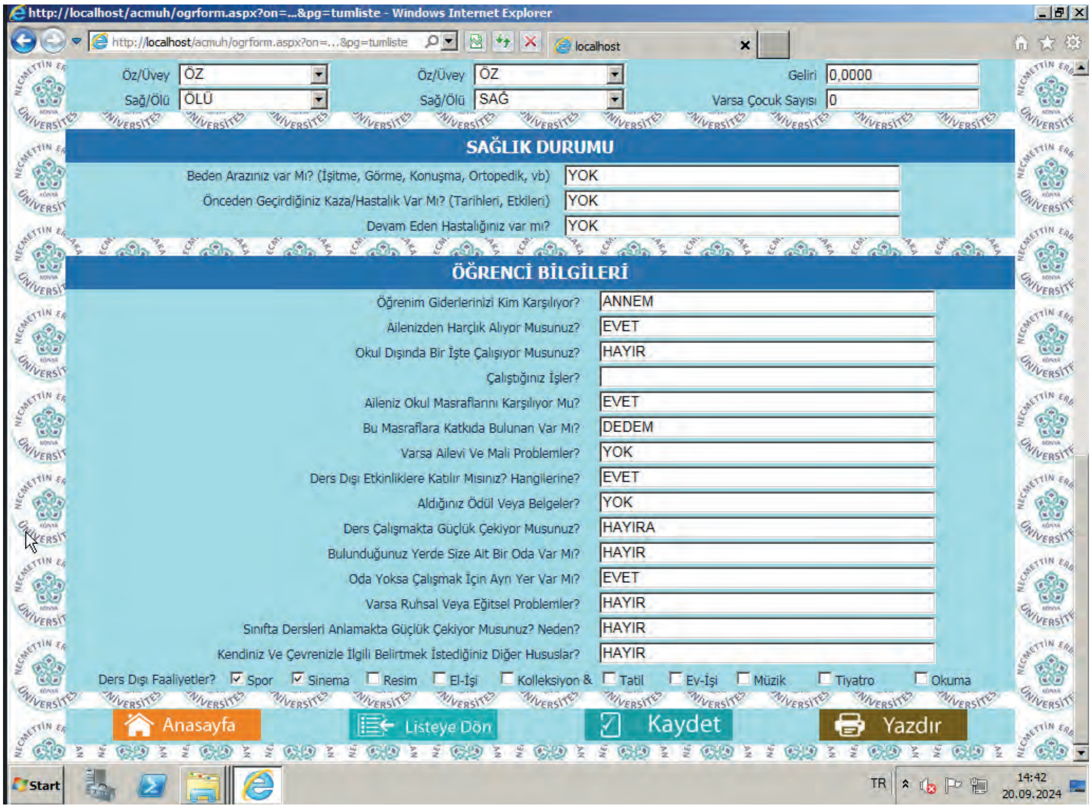
(a-e) *Student and Advisor Interfaces of Online Student Recognition Cards* (Information System for Students, 2024).



a)



b)


http://localhost/acmuh/ogrform.aspx?on=...&pg=tumliste - Windows Internet Explorer
Öz/Üvey ÖZ
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Sağ/Ölü SAĞ
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Varsa Çocuk Sayısı 0
SAĞLIK DURUMU
Beden Arazınız var Mı? (İşitme, Görme, Konuşma, Ortopedik, vb) YOK
Önceden Geçirdiğiniz Kaza/Hastalık Var Mı? (Tarihleri, Etkileri) YOK
Devam Eden Hastalığınız var mı? YOK
ÖĞRENCİ BİLGİLERİ
Öğrenim Giderlerinizi Kim Karşılıyor? ANNEM
Ailenizden Harçlık Alıyor Musunuz? EVET
Okul Dışında Bir İşte Çalışıyor Musunuz? HAYIR
Çalıştığınız İşler?
Aileniz Okul Masraflarını Karşılıyor Mu? EVET
Bu Masraflara Katkıda Bulunan Var Mı? DEDEM
Varsa Ailevi Ve Mali Problemler? YOK
Ders Dışı Etkinliklere Katılır Mısınız? Hangilerine? EVET
Aldığınız Ödül Veya Belgeler? YOK
Ders Çalışmakta Güçlük Çekiyor Musunuz? HAYIRA
Bulunduğunuz Yerde Size Ait Bir Oda Var Mı? HAYIR
Oda Yoksa Çalışmak İçin Ayrı Yer Var Mı? EVET
Varsa Ruhsal Veya Eğitsel Problemler? HAYIR
Sınıfta Dersleri Anlamakta Güçlük Çekiyor Musunuz? Neden? HAYIR
Kendiniz Ve Çevrenizle İlgili Belirtmek İstediğiniz Diğer Hususlar? HAYIR
Ders Dışı Faaliyetler? Spor Sinema Resim El-İşi Kolleksiyon & Tatil Ev-İşi Müzik Tiyatro Okuma
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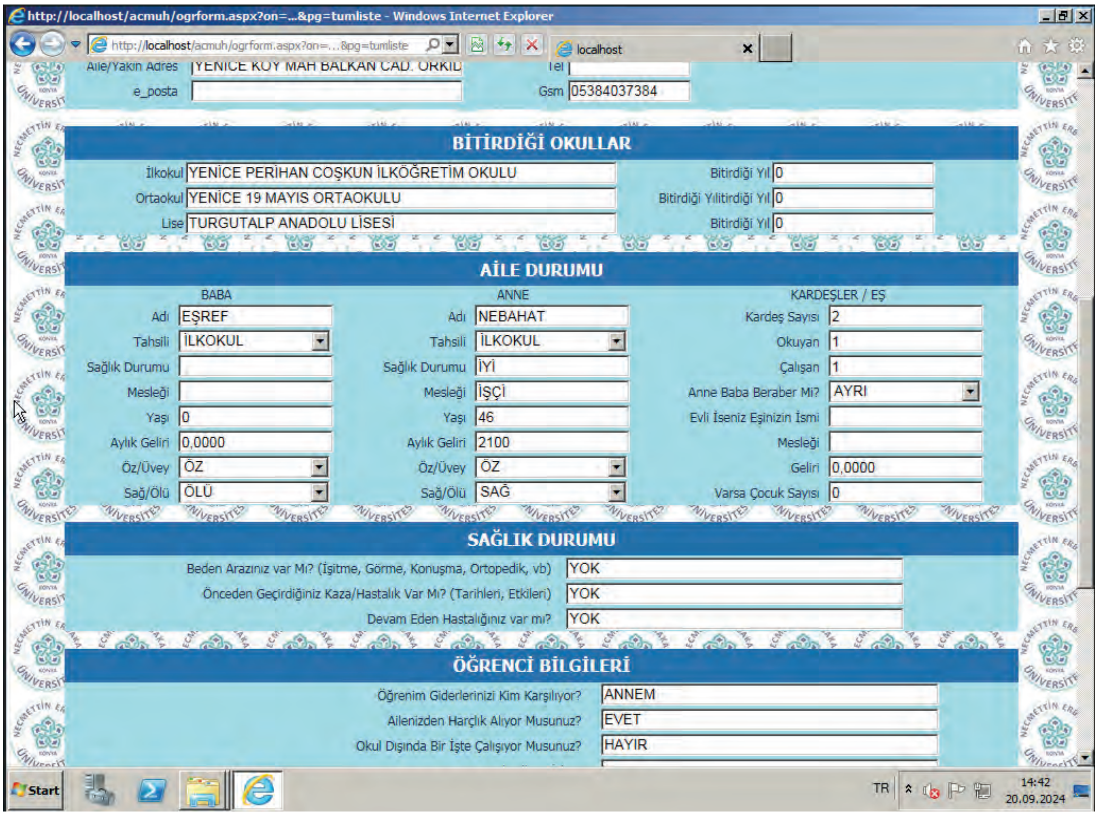
c)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BİTİRDİĞİ OKULLAR
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Ortaokul YENİCE 19 MAYIS ORTAOKULU
Bitirdiği Yılitirdiği Yıl 0
Lise TURGUTALP ANADOLU LİSESİ
Bitirdiği Yıl 0
AİLE DURUMU
BABA
Adı EŞREF
Tahsili İLKOKUL
Sağlık Durumu
Mesleği
Yaşı 0
Aylık Geliri 0,0000
Öz/Üvey ÖZ
Sağ/Ölü ÖLÜ
ANNE
Adı NEBAHAT
Tahsili İLKOKUL
Sağlık Durumu İYİ
Mesleği İŞÇİ
Yaşı 46
Aylık Geliri 2100
Öz/Üvey ÖZ
Sağ/Ölü SAĞ
KARDEŞLER / EŞ
Kardeş Sayısı 2
Okuyan 1
Çalışan 1
Anne Baba Beraber Mı? AYRI
Evli İseniz Eşinizin İsmi
Mesleği
Geliri 0,0000
Varsa Çocuk Sayısı 0
SAĞLIK DURUMU
Beden Arazınız var Mı? (İşitme, Görme, Konuşma, Ortopedik, vb) YOK
Önceden Geçirdiğiniz Kaza/Hastalık Var Mı? (Tarihleri, Etkileri) YOK
Devam Eden Hastalığınız var mı? YOK
ÖĞRENCİ BİLGİLERİ
Öğrenim Giderlerinizi Kim Karşılıyor? ANNEM
Ailenizden Harçlık Alıyor Musunuz? EVET
Okul Dışında Bir İşte Çalışıyor Musunuz? HAYIR
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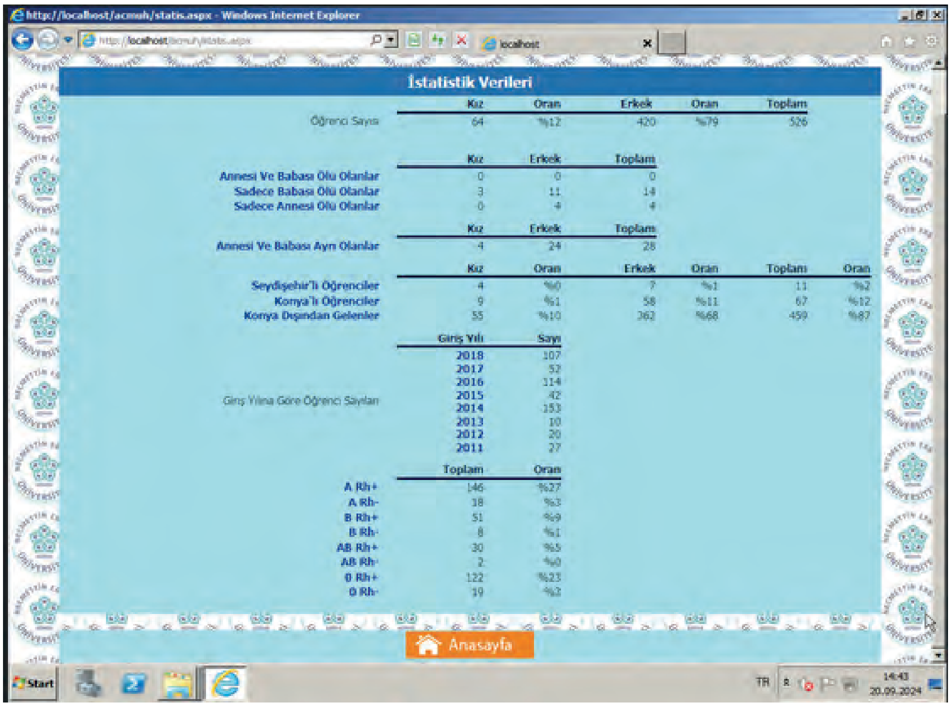

e)

Ensuring Sustainable Participation in Technical Competitions

Technological competitions offer an excellent platform for engineering students to showcase their innovative thinking and problem-solving abilities. Innovative engineering education provides students with the necessary support and guidance to ensure sustainable participation in these competitions. Thanks to these competitions, students develop their skills such as teamwork, project management, and time management, while at the same time having the opportunity to follow innovations and trends in the sector. Participation in such activities boosts students' self-confidence and helps them take an important step in their careers (Laura Green & Alex Martinez, 2023).

Sustainability in technical competitions is one of the most important factors that lead to success in undergraduate education. Experienced 3rd and 4th classroom students in the competition. Joining the students of the 1st and 2nd. Classroom students play an important role both in the master-apprentice relationship and in the continuation of institutional memory. The competition teams that make up at Seydişehir Ahmet Cengiz Faculty of Engineering usually consist of all classes and an ***Uninterrupted Memory*** is created between graduates and beginner students. These studies have led to successful results in competitions every period. Figures 2,3,4 and 5., we participated in the TÜBİTAK Electric Vehicles competition in 2016 and 2017, and the electric vehicle named ***HEDEF 2023*** and ***PARS*** are seen. The bodywork, chassis, and all kinds of parts of these vehicles, except for engines and electronic parts, are in Seydişehir Ahmet Cengiz Engineering Faculty Workshops; It was produced by ***Students of SACMF*** with the support of technical staff.

"Making the Technical and Social Activities of Students Sustainable in Engineering Education is Possible with the Synergy Between the Lower and Upper Classes"

These electric vehicles (Figures 2,3,4 and 5) are the best examples of sustainable participation and institutional memory (Web page of ***PARS*** and ***HEDEF 2023***, 2024).

Figure 2
The First Vehicle Produced by Seydişehir Faculty of Engineering Students and Participated In The Competition in 2016: ***HEDEF 2023***

Figure 3
HEDEF 2023 *in 2016 Tübitak Electromobility Competitions*

Figure 4
The Second Electric Vehicle Produced by Seydişehir Faculty of Engineering Students and Participated in The Competition in 2017: ***PARS***

Figure 5
PARS *in 2017 Tübitak Electromobility Competitions*

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Investigation of Innovative Design and Engineering Approaches in Industrial Design and Product Development in the Context of Usability, Form Creation and Manufacturability through Case Studies

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Selcuk University

To Cite This Chapter

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Introduction

Research Background

Project/Studio courses, which form the core of Industrial Design, directly simulate real-world engineering activities involved in designing, developing, or improving a product from the ground up. Through these courses, students face design and manufacturing challenges similar to those encountered in actual product design, development, and enhancement. As they work to resolve these issues, students are also introduced to innovative design and production tools, learning to use them under the guidance of the instructor.

In Industrial Design, the product design and development process involves several stages, arranged hierarchically. The challenges faced both in real-world scenarios and in Project/Studio courses, which simulate these situations, may occur at various stages of design and development. These challenges are influenced by the experience, skills, and technical capabilities of the designers or students involved.

This paper will first provide a brief overview of the stages involved in product design and development. It will then examine potential bottlenecks and issues that may arise at each stage. Afterward, it will explore how innovative design and engineering approaches can address these problems. Finally, the insights from the literature and findings of this study will be demonstrated through a case study to make the concepts more visually understandable.

Problem Definition

The design and development of a mass-produced industrial product from scratch, or the improvement of an existing product, involves multiple steps in a specific sequence. Throughout these steps, various design and production problems may arise due to numerous factors. Current design and engineering methodologies have emerged to tackle these issues. Introducing and discussing these modern approaches through case studies can offer valuable insights for overcoming potential design and engineering challenges.

Research Questions

The research questions are formulated based on the objectives outlined above. These questions guide the study and define its scope. The research questions are as follows:

- What are the stages involved in the design and development of mass-produced products from an Industrial Design perspective?
- What challenges are encountered in the Industrial Product Design and Development Process?
- What are the current design and engineering approaches that can address the challenges in the Product Design and Development Process?
- Can a case study analysis be conducted using modern Design and Engineering approaches?

Design and Development Stages of Industrial Products

From early design methodology research, design problems have been approached rationally, with multi-step models proposed to guide solutions (Curry, 2014). These staged models, which treat design as a series of processes, typically propose five or six iterative steps. Numerous stage-oriented design methodologies exist, each using different theories and terminology. The classical outline, proposed by Polya in 1957, is one of the most commonly followed frameworks:

- Understand the problem
- Develop a plan
- Implement the plan
- Review the results

Lawson and Dorst provide a more general version of the phased model, outlining design processes as follows:

- Define the problem
- Formulate the requirements
- Develop solutions

The American Institute of Architects also follows a similar model for its professional services:

- Pre-design review (Research/analysis)
- Initial design (Conceptualization)
- Refining and developing the concept (Testing/concept development)
- Structuring documentation (Finalizing the design solution)
- Signing the agreement
- Implementing the agreement
- Final implementation of the design

These phase-oriented methodologies, which treat design problems rationally in the same way as scientific and engineering disciplines, have faced significant criticism over time. Some of the founders of design theory rejected the predictive approach of these methods (Alexandre, 1971; Broadbent, 1973; Jones, 1977), arguing that they reduced the role of designers within the process.

Rittel was one of the critics of the rational approach, stating that "Design problems are inherently complex, and these complexities make the application of theoretical systems and scientific methods unsuitable in the design process" (Rittel, 1973). Dreyfus also suggested that "Complex problems question the significance of artificial intelligence in the design process" (Dreyfus, 1992).

In their 1973 study, Rittel and Webber defined these design problems as "Wicked Problems." The characteristics of wicked problems (also known as "complex problems resistant to solution") are as follows:

- Complex problems cannot be defined in a specific way.
- There is no definitive solution for complex problems.
- Solutions to complex problems are judged on "good-bad" terms rather than "right-wrong" terms.
- The solution to a complex problem cannot be tested immediately.
- There is only one opportunity to solve complex problems, making each attempt critical.
- Complex problems do not have predefined classifications of possible solutions.
- Each complex problem is unique, with no direct analogs.
- Complex problems may be related to one another.
- The contradictions within complex problems can be interpreted in various ways, with the solution process varying based on the interpretation.
- The problem-solver cannot afford to make mistakes, as they are fully responsible for the outcomes.

Considering the criticisms mentioned above, a revised stage model can be proposed for industrial design, both in academic project/studio courses and professional design services:

- Brief: In this phase, a design brief is provided, outlining the boundaries and objectives of the product design to ensure it meets the desired qualities.
- Market Research: This phase involves studying consumer habits, market needs, and industry requirements.
- Competitor Analysis: At this stage, existing market competitors are analyzed to identify key design issues, such as aesthetics, usability, ergonomics, and cost. Strategies for addressing design problems are formulated using design and engineering approaches.
- Sketching: In this phase, sketches are created to give the product the aesthetic and semantic qualities that will distinguish it from competitors. Sketching is a crucial step in product development, as it explores various design alternatives.
- Refining and Analyzing: Here, the design alternatives from the sketching phase are evaluated and refined based on formal and functional criteria. The best design alternative is selected, and its aesthetic, semantic, ergonomic, and functional

aspects are analyzed before producing technical drawings.

- Production Processes: In this phase, decisions are made regarding the materials and production methods to be used for the final product. A model is created, followed by a prototype, and if no significant issues are encountered, the product is prepared for mass production.

Problems That May Be Encountered in The Design and Development Stages of Industrial Products and Current Design and Engineering Approaches That Can be Used in Solving These Problems Through Case Studies

In the field of Industrial Design, examining current approaches to solving challenges encountered during product development and design processes—considering both design and engineering disciplines—can significantly enhance understanding of the subject. To demonstrate this, three products designed by Industrial Design student Melih Cura will be presented as case studies. These products were developed in the Industrial Design 3 course, led by Asst. Prof. Dr. Mahmut Celaleddin Kaleli, an industrial designer, during the fall semester of 2023 at the Faculty of Fine Arts, Selçuk University, Department of Industrial Design. The case analysis will be explored in parallel with the industrial design product development processes.

Figure 1

Electrical home appliances were designed by Melih Cura, an Industrial Design student under the direction of Dr. Celaleddin Kaleli at the Department of Industrial Design, Faculty of Fine Arts, Selçuk University in the fall semester of 2023 in accordance with the project brief.

1. Problems Encountered at the Brief Stage: In the professional environment, the brief provided by the employer to the industrial designer is typically prepared by the client or company. In an academic setting, however, the brief is given by an instructor who is an academic expert in industrial design, typically in the context of a Project/ Studio course. As a result, while there are similarities between the problems faced in both environments, there are also key differences. In the professional setting, employers

may not have a thorough understanding of the industrial design discipline, leading to expectations that may not be entirely appropriate or feasible within the professional context. On the other hand, in the academic environment, while the brief is provided by experienced academics, industrial design students may lack the necessary experience to fully comprehend and address the brief in detail. To address these issues, current studies on design briefing approaches (e.g., Engin Kapkın, 2010) can be analyzed. Briefs can be structured in a way that clearly expresses the expectations, desires, and concerns of both the receiving and giving parties, ensuring mutual understanding. Additionally, examining successful design briefs from similar projects may offer valuable insights. In the case study, a design brief was presented as the central theme, outlining the expectations, objectives, concerns, and boundaries necessary to achieve the desired product design qualities. For the Industrial Design 3 course brief at the start of the semester (included in the Appendix to maintain the article's flow), students were tasked with answering the question: "What kinds of products could be designed if a renowned company, which does not currently produce electrical household appliances, decided to enter the electrical kitchen appliance market?" Students were asked to select a company with a specific design philosophy and global recognition, and then identify three electrical kitchen appliances. Over the semester, they were required to design these three appliances in line with the chosen company's design philosophy.

Figure 2
Product examples of Alfa Romeo, the Italian automobile company selected for the desired company

2. Problems Encountered During the Market Research Phase: When designing an industrial product, particularly one that will be mass-produced, it is crucial that the product can succeed in the market and generate profits for both the operator and the manufacturer. A product's market success is directly tied to consumer satisfaction, which depends on a variety of factors, including the price/performance ratio, usefulness, ability to meet consumer expectations, and aesthetic and semantic qualities. Therefore, conducting thorough market research at the beginning of the design and development stages is essential. This includes researching consumer habits and expectations for both

global and local markets. However, several challenges may arise during this stage.

One of the primary difficulties is that consumer behaviors, expectations, and requirements vary greatly across different local markets. For instance, while consumers in Scandinavian countries may prefer aesthetic, minimalist designs that prioritize practicality, consumers in regions like the Middle East and India may favor more decorative, flashy products. This geographic diversity creates a dilemma: designing separate products for each market can significantly increase design and production costs. Therefore, it is vital to develop a product design with an optimal price/performance ratio that can meet the aesthetic preferences of various cultures.

To conduct effective market research in this context, a large number of data sets must be analyzed with minimal error. Traditional qualitative and quantitative research methods can be time-consuming and may not always yield accurate predictions. Here, the integration of artificial intelligence (AI) with traditional research methods could revolutionize data collection and analysis. AI can process larger data sets in shorter time frames, offering deeper insights by analyzing complex network structures rather than just surface-level data.

In the case study, the student utilized the ChatGPT AI engine to conduct market research, identifying gaps, trends, and customer preferences in both data collection and analysis. Based on the research, the decision was made to focus on the European market. Consumer trends in Europe indicated a demand for simple, user-friendly, and functional designs, leading to a design approach aligned with these preferences.

3. Problems Encountered During the Competitor Analysis and Market Research Phase: In the process of designing a new product or improving an existing one, it is essential to analyze the design issues of current products, such as aesthetics, materials, and usability, and develop strategies to address these challenges. Feedback from professional designers, combined with consumer reviews of existing products, can provide valuable insights that deepen the analysis for industrial designers and design students.

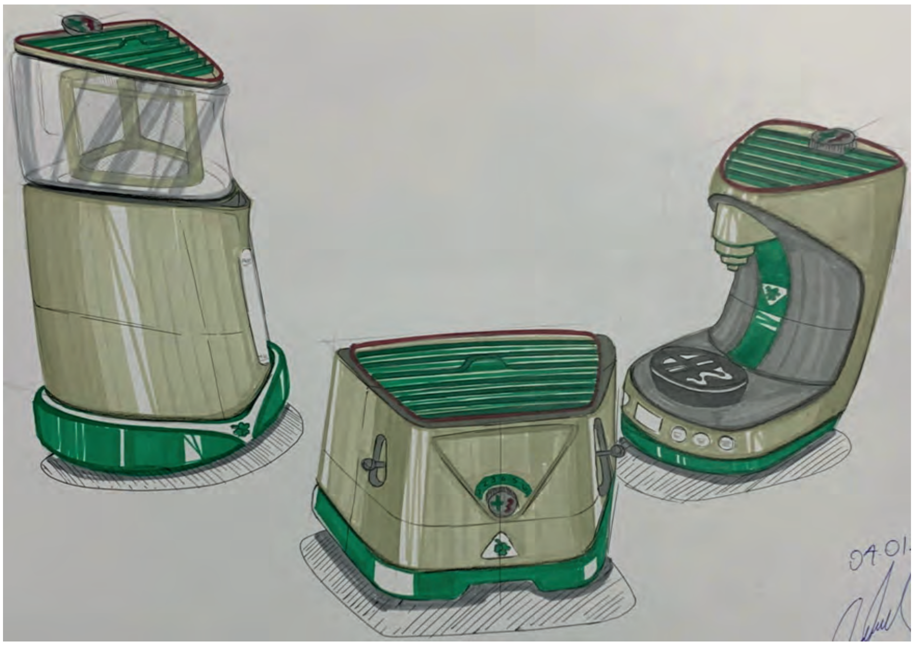
Artificial Intelligence (AI) tools can enhance this analysis by using Natural Language Processing (NLP) to conduct sentiment analysis on customer feedback, helping designers understand consumer emotions and preferences. In the case study, the student examined products like toasters and tea/coffee makers from various brands such as Philips, Kenwood, Arçelik, Arzum, and Karaca—brands that already manufacture electric kitchen appliances. By compiling and analyzing user reviews with the assistance of AI, the student was able to gain insights into consumer expectations and identify potential areas for improvement in terms of aesthetics and functionality.

4. Problems Encountered During the Sketching Phase**:** In industrial design, it is crucial to quickly generate design ideas and explore various alternatives. However, this speed cannot be achieved by relying solely on 3D computer-aided design (CAD) programs. As a result, industrial designers must often resort to freehand sketches. Creating and coloring these sketches presents its own set of challenges. For instance, it is important to avoid perspective errors to ensure accurate form creation before transitioning to 3D modeling in later stages. Moreover, to ensure the imagined form is understood clearly by other stakeholders, sketches must be accurate in terms of perspective, proportion, lighting, and shading. However, students, especially those who are still learning, often struggle to reach the required skill level in freehand drawing during their university education. Professional designers may also encounter difficulties at this stage. In the case study, the student worked closely with the instructor, making numerous sketches to

refine the final design. One of these sketches is presented below as an example.

Figure 3

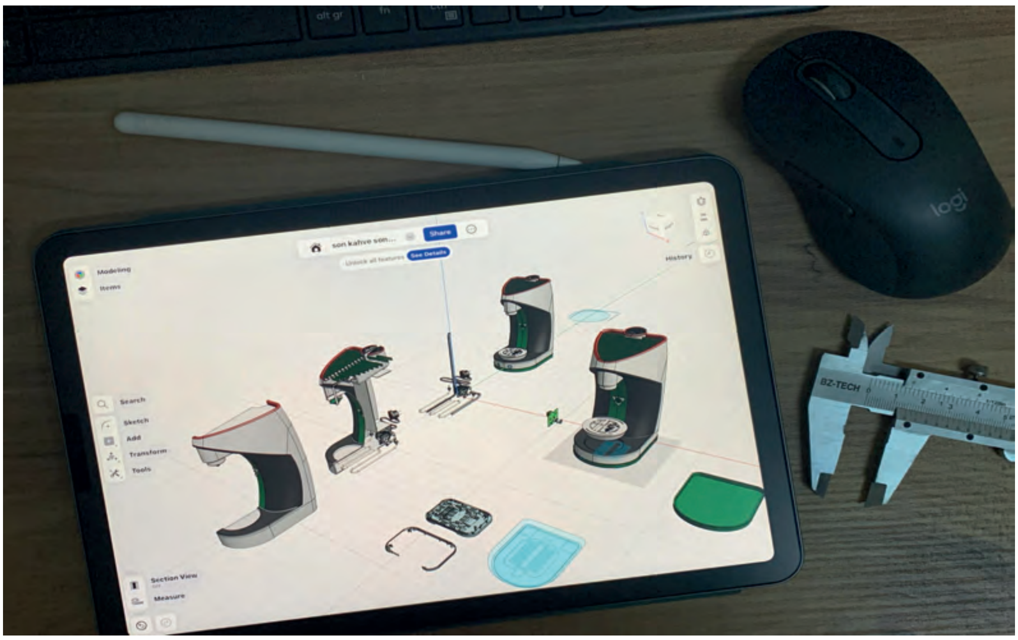
A sample of the works drawn in the sketching phase of the process to investigate form.



Current tablets are becoming increasingly powerful, with enhanced processing capabilities that enable them to incorporate artificial intelligence add-ons. These features allow tablets to detect and correct errors in perspective, proportion, and coloring in hand-drawn designs. Additionally, traditional methods that rely on high-cost materials—such as Japanese Bristol boards or heavyweight Shöller paper, along with premium markers for coloring—can be expensive for both professionals and design students. In contrast, modern graphic drawing tablets address this cost issue by providing an affordable alternative for digital drawing and design.

Figure 4

Shaper3d application example from the use of tablets in project development stages.



5. Problems Encountered During the Refinement and Analysis of Alternatives: At this stage, the final form of the product is developed. In this phase, current artificial intelligence algorithms, designed to address challenges in the maturation of the final industrial product design, can be extremely helpful. Visualization-focused AI tools, such as MidJourney and Vizcom, are commonly used to further develop product design and obtain early renderings. These AI models greatly assist designers in generating hybrid models of the alternatives considered in the previous stage. As the final step of this phase, the most suitable design alternative, after being filtered from various options, is modeled using three-dimensional computer-aided design (CAD) software. One of the main issues at this stage is that each CAD program comes with its strengths and weaknesses. For instance, while 3D Studio Max offers powerful tools for visualization and product animation, SolidWorks is more suitable for production processes. Similarly, Alias provides comprehensive tools for industrial design and production preparation, but mastering the program can take longer than other alternatives. To address this challenge, contemporary design and engineering approaches offer common interface tools that can convert the file extensions between these programs, embedded in the latest versions, making it easier for designers to switch between them. In the case study, the student used Rhinoceros 3D, a CAD program, to create the project drawings. For rendering, KeyShot was used, as it provides highly effective renderings in a shorter time by utilizing the microprocessor's power rather than relying on the graphics card. Additionally, AI-powered tools such as MidJourney and Vizcom, along with Photoshop's AI-supported plug-ins, were employed to enhance the use scenario. For example, these tools were used to place tea in the teapot, add smoke effects, and position the bread on the plate, making the presentation more realistic and visually compelling.

Figure 5

In order to convey the user experience of the designed products, artificial intelligence applications were used in the renderings that visualize the scenarios during use.

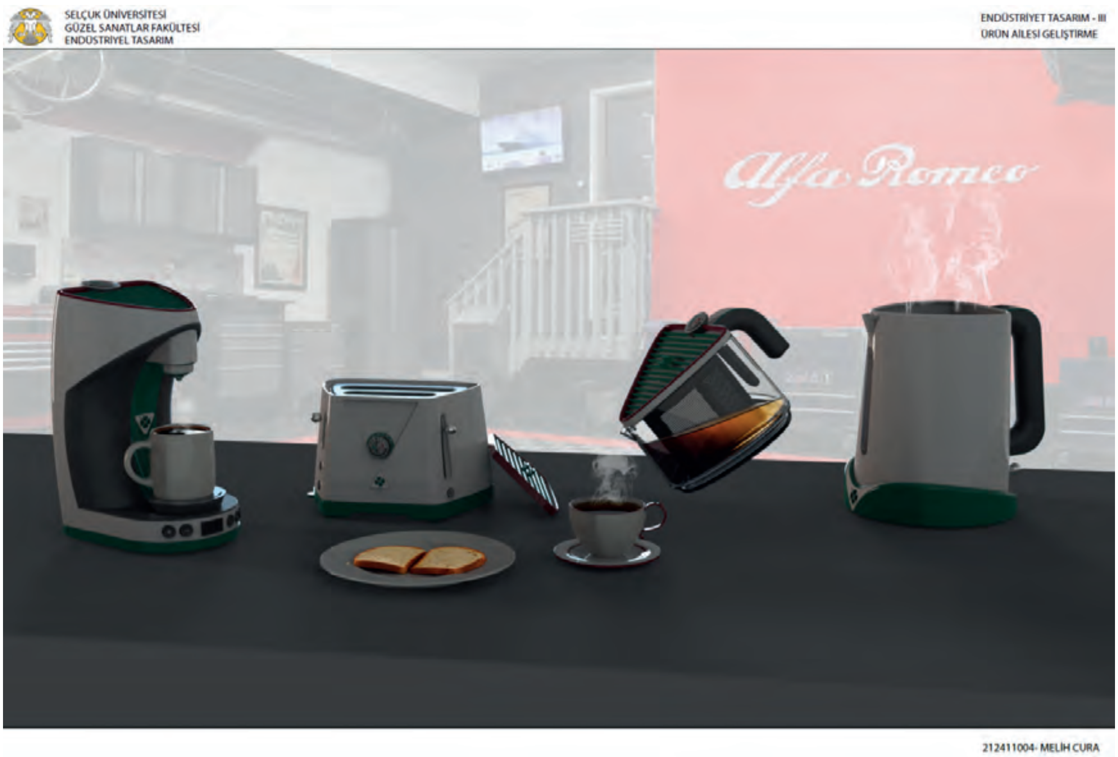


Figure 6

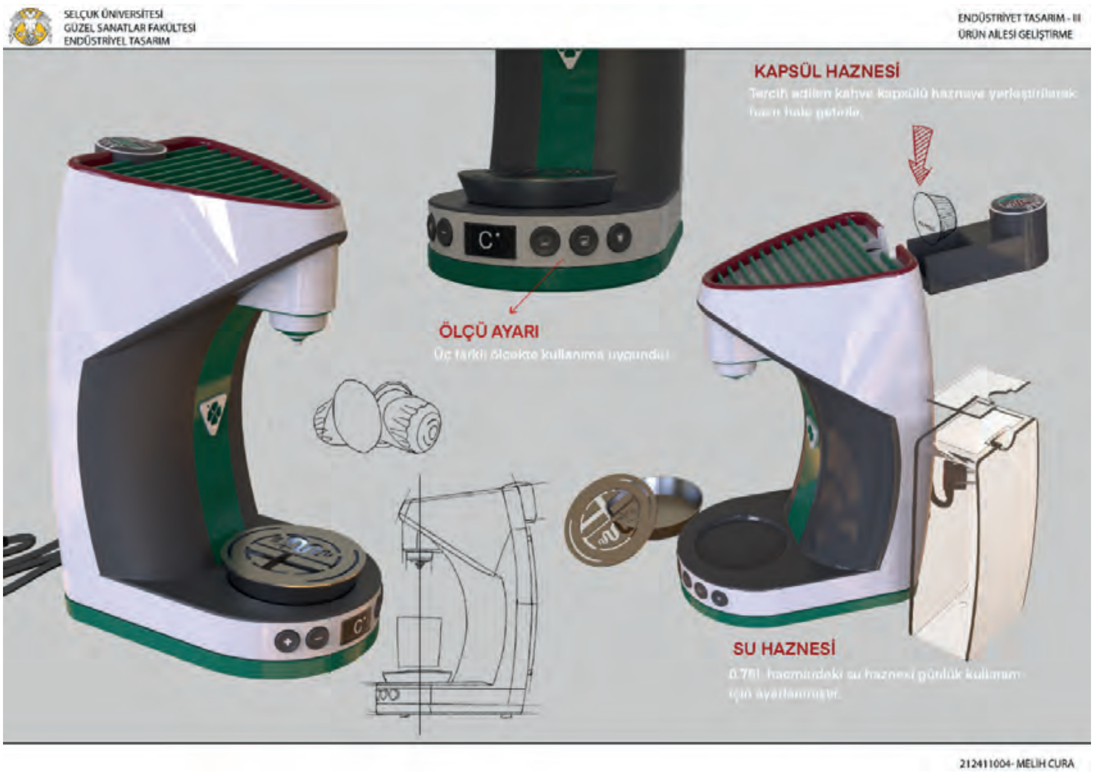
Details in toaster design that convey the user experience

Figure 7

Details conveying user experiences in the tea maker design.

Figure 8

Details in the coffee machine design that convey user experiences.



6. Problems Encountered at the Production Methods Stage: At this stage, decisions are made regarding the materials to be used, the corresponding production methods, the assembly processes, and the methods for combining the product parts. It is crucial to distinguish between production and assembly in this context. Production refers to the manufacturing of individual components or assemblies, while assembly is the process of putting these parts together to form the final product (Boothroyd et al., 2002). One challenge in this phase is that, due to the nature of industrial design, the selection of materials and the analysis of production methods are often postponed to later stages, which typically occur after the initial design phases.

When the production methods for product designs developed in project/studio courses are decided, complications may arise. For example, some product components may not be removable from molds due to their organic or amorphous forms. Incompatibilities may emerge between the materials chosen for the product parts and the intended production methods. Additionally, it may become apparent that certain areas of the product exposed to force or stress could lack the necessary material properties to withstand cracking, stretching, fracture, or rupture due to stress, fatigue, or creep. Furthermore, combining parts produced via plastic injection molding without disrupting the aesthetics or integrity of the product can present challenges.

Given the unique nature of industrial design, especially in complex products incorporating various materials, it may be difficult or even impossible to apply traditional engineering processes. In contrast to engineering disciplines, where solutions are typically developed step-by-step—defining the problem, creating a solution, and testing and optimizing it (Türkücü & Börklü, 2017)—industrial design often requires a reverse engineering approach to solve production challenges. Reverse engineering allows designers to study existing solutions, redesign and develop these solutions, and then manufacture the improved designs (Türkücü & Börklü, 2017).

This reverse engineering approach was applied in the case study project designs. To analyze production methods for the completed designs, products with similar functional and geometric characteristics were disassembled. These disassembled products were studied to understand how the sub-parts were produced and assembled. This analysis informed the adaptation of the production methods for the new designs.

During this stage, discussions took place regarding the design of support walls, ribs, and other structural elements, especially in areas where material strength was insufficient. Issues such as how screw joints should be positioned and opened, and the optimal wall thicknesses for the parts, were carefully considered and adapted for the new product designs. To enhance the reverse engineering process, a 3D laser scanner—an advanced technique in reverse engineering—was employed. This technology allowed the creation of three-dimensional models of machine elements and micro-motors from the products. Compared to older photogrammetry methods, which used photographs and distances to detect images, 3D laser scanners offer a more efficient and data-rich approach (Herráez et al., 2016).

Figure 9

Cross-sections of the product designs were drawn to better understand the relationship between material and structure by making the invisible details of the product visible.

Figure 10
Assembly perspective drawing of the toaster design.

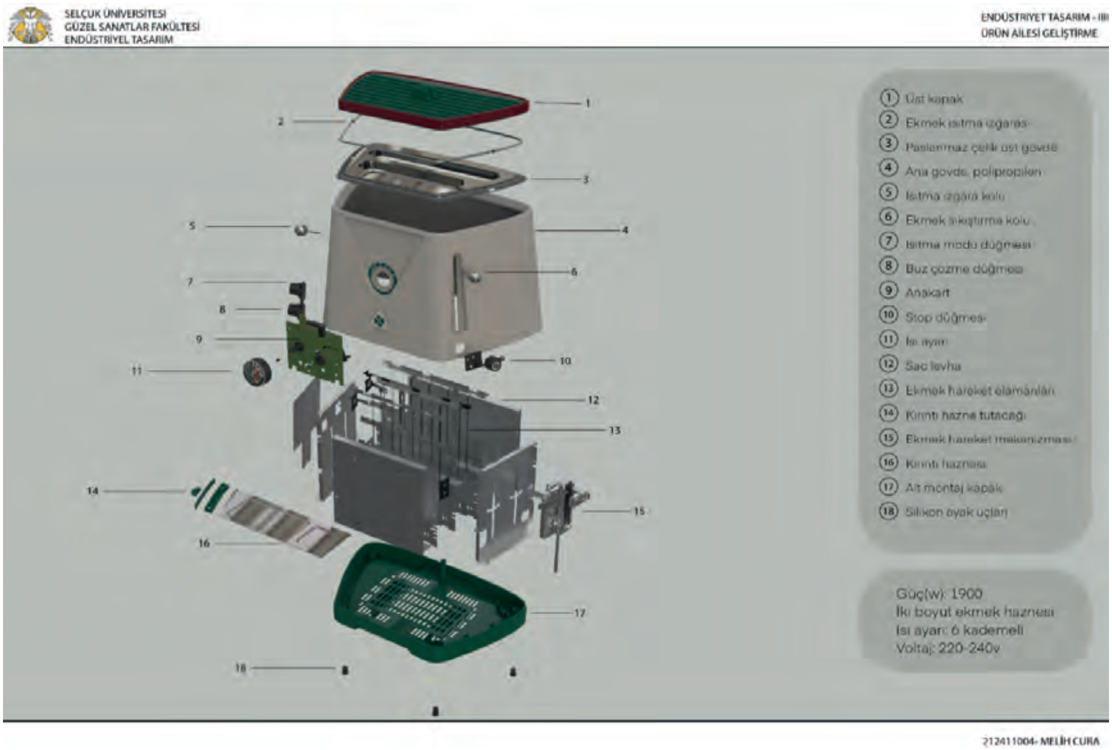


Figure 11
Assembly perspective drawing of the coffee machine design

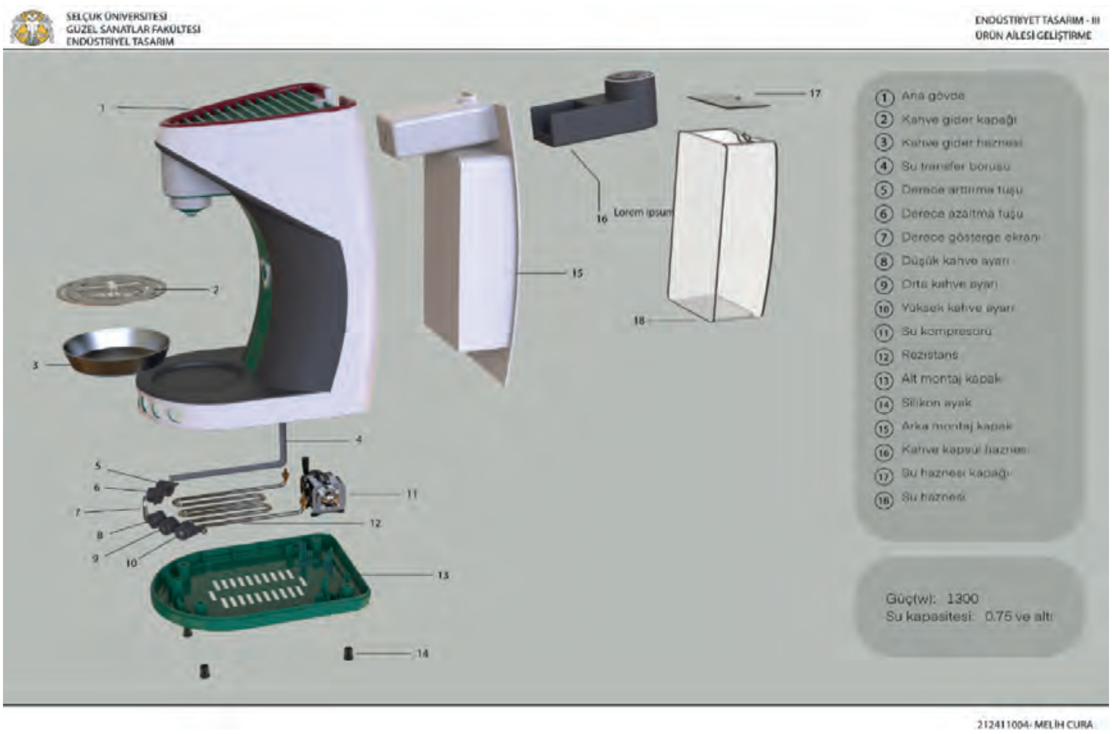


Figure 12
Assembly perspective drawing of the tea machine design.

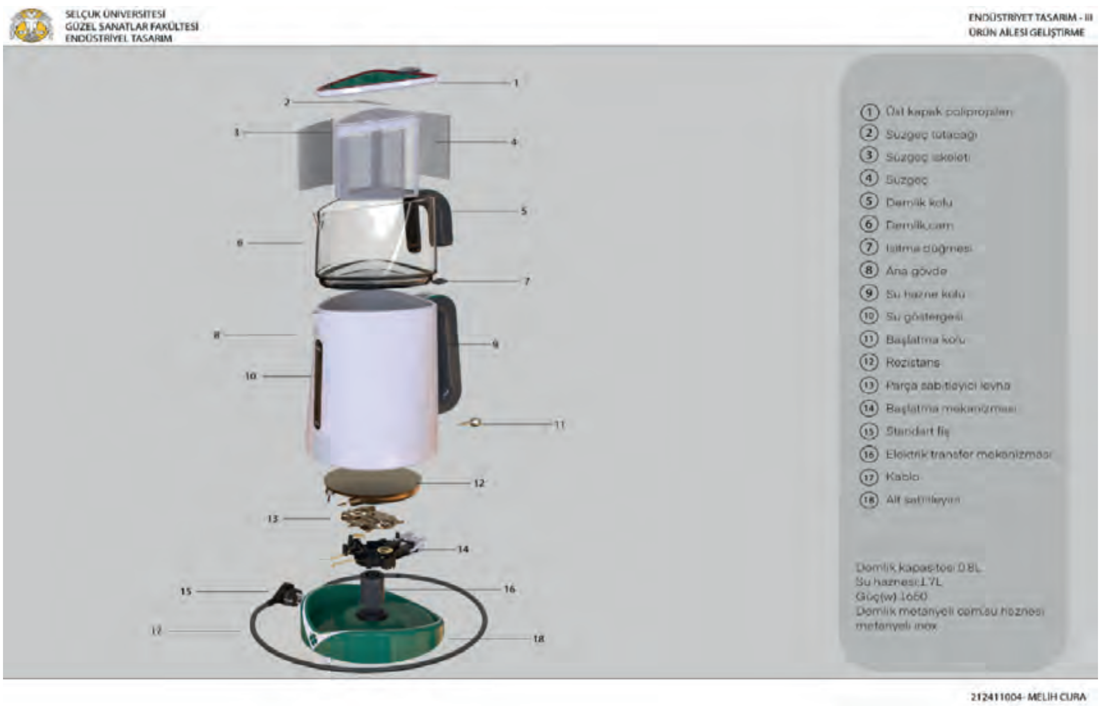


Figure 13
Technical drawing of toaster design.

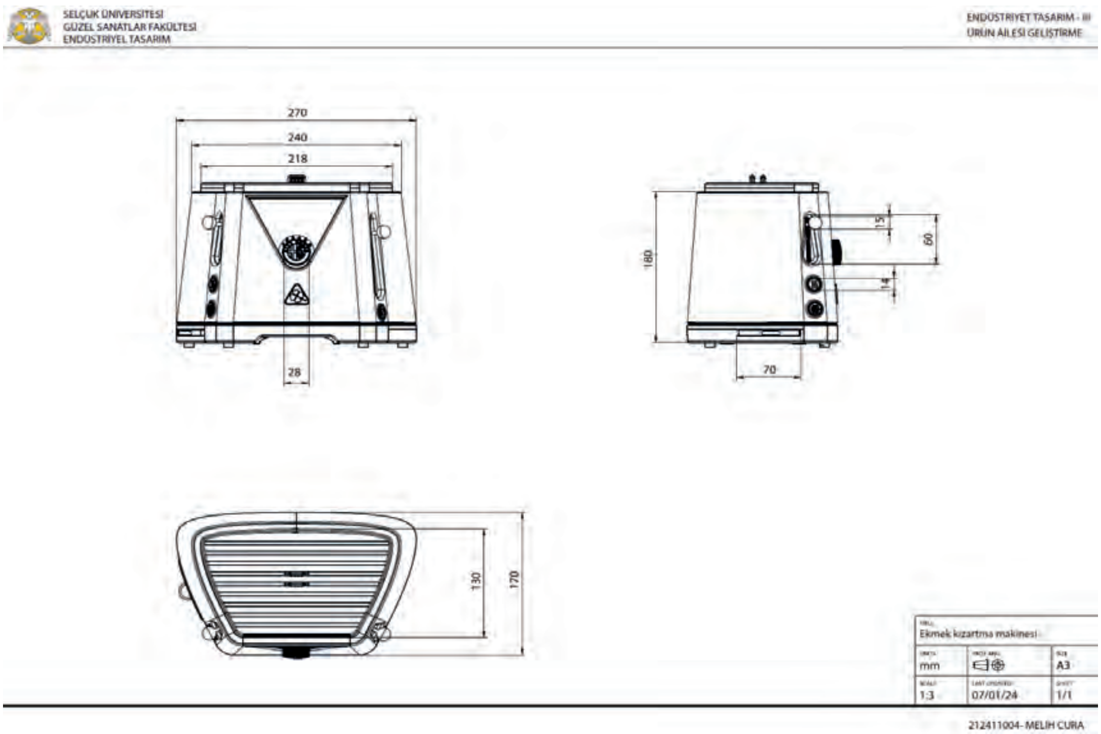


Figure 14
Technical drawing of the coffee machine design.

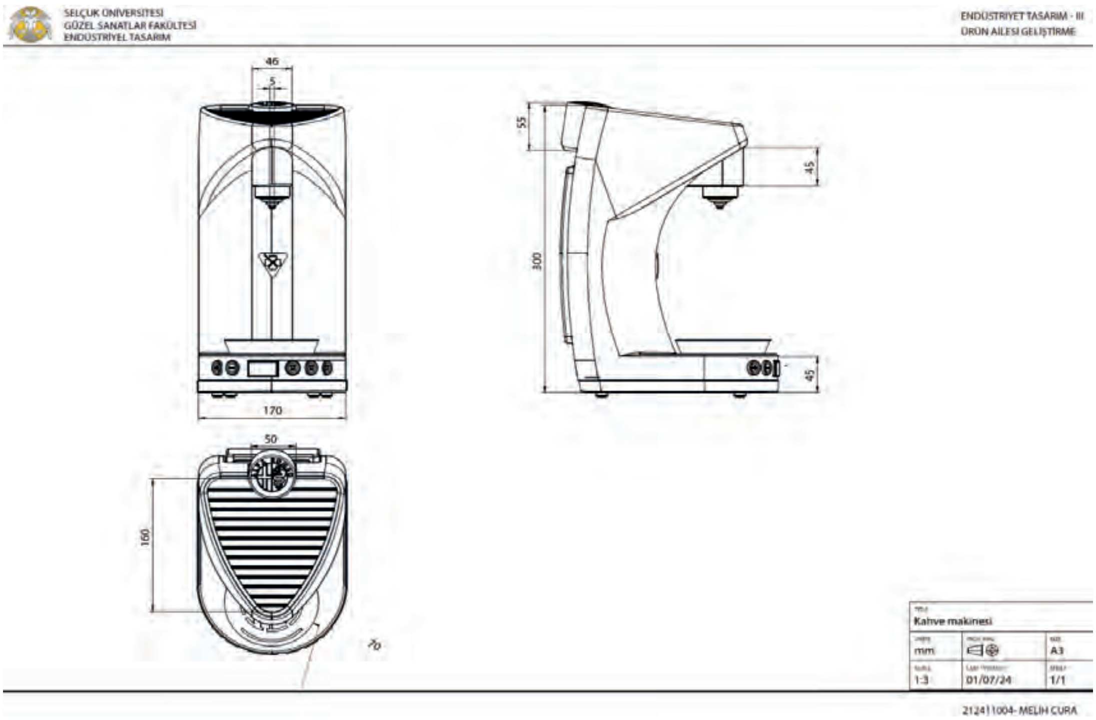
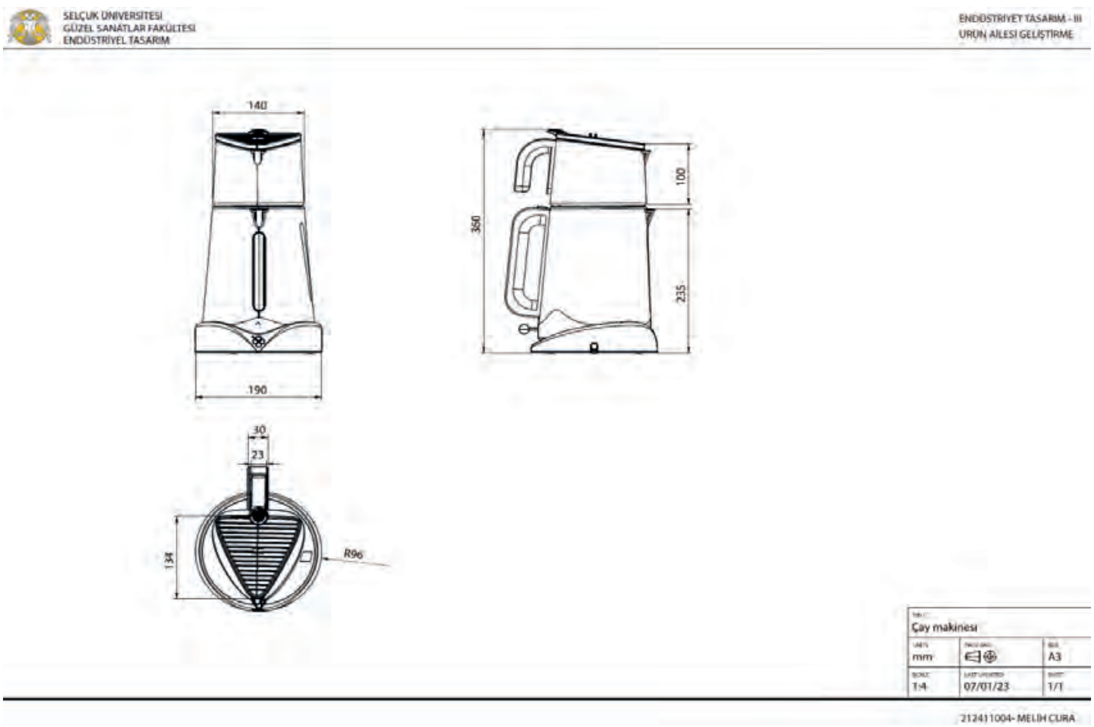


Figure 15
Technical drawing of the tea machine design.



The final step in the production phase of product design and development involves creating a physical model, followed by the production of a working prototype. For an industrial designer or an industrial design student, the ability to physically interact with the product they have designed—by walking around it, touching it, and holding it in their hands—is crucial for fully understanding its features, including both its strengths and weaknesses. While the design work for a project may be completed on two-dimensional planes, a design cannot be truly understood until it is manifested in three-dimensional space (Dunn, 2010). Unlike linear perspective drawings that provide a view from a single angle, a three-dimensional model allows for exploration from multiple perspectives, offering a more comprehensive understanding of the product's form (Spankle, 2012).

Creating a model or prototype is an essential part of the industrial design process, as it allows designers to identify potential issues and make corrections before the product enters production. This is especially important for identifying issues that might arise in application or manufacturing processes that may not be apparent in the initial design stage (Küçükerman, 1996). In the case study, the models for all three designed products were largely created using traditional methods to observe the outcomes of the model-making course conducted in the previous academic year and to continue the development of the student's skills in this area.

Traditional modeling methods were employed, with Styrofoam being cut to the appropriate dimensions using technical drawings. The pieces were glued together, and the final shaping was achieved through sanding.

To enhance the surface smoothness and structural integrity, wood and steel putties were applied. Once the structure was finalized, the surfaces were painted with water-based paints in the appropriate colors, and the main bodies of the models were completed by glazing. However, some small parts, such as emblems and covers, were deemed too complex for manual production and were fabricated using desktop 3D printing, which represents a current approach to production technology. The 3D models created in Rhino were exported in formats compatible with 3D printing (STL, 3MF), and small parts were printed, and then assembled with the rest of the model to complete the final prototype.

This approach to model-making balances traditional craftsmanship with modern technology, allowing the designer to develop their skills while also leveraging advanced production methods for complex components. While this process allows for a more accurate understanding of the design in its final form, challenges such as material limitations, precision of hand-made components, and time constraints in completing the model were encountered. However, the integration of 3D printing helped alleviate some of these issues by offering rapid prototyping for detailed and intricate parts.

Figure 16
Mock-ups of completed product designs.

Conclusion

The design, development, production, and delivery of a new product to the end user involves a series of meticulously planned processes and stages. These stages are structured in a hierarchical order, shaped and refined over time through the continuous advancements in both design and engineering disciplines.

This study explores the challenges that both designers and engineers may encounter throughout the entire product design process—from the conceptualization of an idea to the final product reaching the market—and examines the current developments in design and engineering that can assist in overcoming these challenges. The case study presented in this research, which uses the project/studio course as a simulation of real-life product design and development, offers a detailed exploration of these stages.

The analysis in this study demonstrates that introducing professional industrial designers, as well as industrial design students, to the latest advancements in technology and methodologies within both the engineering and design fields can significantly ease the problem-solving process in product design and development. It is anticipated that by staying updated with current developments in both design and engineering disciplines, designers and engineers can not only address challenges more effectively but also improve the efficiency of their work at every stage of the design process. By leveraging the latest technologies, tools, and methodologies, professionals can streamline workflows, reduce errors, and foster more innovative solutions. This ongoing engagement with new developments ensures that the design process remains agile, adaptive, and capable of producing high-quality products that meet both functional and aesthetic requirements, ultimately leading to better outcomes in product development. Furthermore, these advancements will lead to the creation of more successful product designs—both aesthetically appealing and functionally superior.

By integrating the latest tools and approaches, from artificial intelligence in market research to advanced 3D modeling and prototyping techniques, industrial designers can streamline their workflow, ensure higher-quality results, and minimize the risks associated with design flaws or production inefficiencies. Ultimately, this holistic approach to product design, supported by technological progress, will lead to the creation of innovative products that meet the needs of the market while overcoming the traditional limitations of both design and engineering.

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ANNEX-1

SELÇUK UNIVERSITY

FINE ARTS FACULTY DEPARTMENT OF INDUSTRIAL DESIGN

PROJECT BRIEF FOR INDUSTRIAL DESIGN III COURSE FALL SEMESTER 2023-2024

Project Topic:Kitchen appliance consisting of three electrical products to develop a product family.

Motivation for the Project: It is evaluated that consumers' purchasing decisions are influenced by the fact that the electrical household appliances to be used in the kitchen have similar formal and qualitative features with the other members of that product group and have the same brand identity. At this point, you are expected to choose three products that are related to each other as explained above, that will be used in the kitchen and that will work with electricity, and design them as different members of the same brand, but with similar formal and qualitative features, and come up with creative ideas. At this point, instead of creating your own brand identity, you are asked to choose an existing brand that does not produce kitchen products and adapt its design lines to the product you will design. At this point, some brands that you can choose to make your job easier are presented to you as follows, both as an option and as an example: Sony, Samsung, Cooler Master, Thermale Take, Braun, Nike, Adidas, Domyos, Ashley Furniture, Baker Furniture Apple, Xiaomi, Asus Tuf, Asus Rog Strix, Msi, Hegza Lighting, Logitech, Microsoft, Porche, Lego, K'nex, Ferrari...etc.

Attention Points:

- The products you will design are expected to have a strong formal and qualitative kinship with each other. Based on the concept of qualitative, a number of design trends (provided that they do not leave the brand identity) can be taken as a basis (Ex: Retro design, Bio Inspired Design, Inclusive Design, Futuristic Design, Othantik Design...)

- The products you will design are expected to be as distinct as possible from their prospective competitors in the market, both formally and qualitatively, and to acquire family-specific qualities among themselves.

- When working on the aesthetic and semantic qualities of the products we will design, special attention should be paid to ensure that their formal qualities do not cause new design problems and do not conflict with their functional qualities.

- For each three members of the product family you will design, studies should be carried out to identify design problems and to develop solutions for them from a design perspective. At this point, it should not be ignored that the design problem may be not only in function but also in form.

- In the final evaluation, the success achieved formally and functionally in the design of the product family, as well as the continuous effort shown during the process and the meticulousness and quality in the preparation of the visuals of the product design will be taken into consideration. I wish you success.

Industrial Designer

Assistant Prof. Dr. M. Celaleddin Kaleli

Sheet Metal Formability and Formability Tests

Murat DİLMEÇ

Necmettin Erbakan University

Ahmet CAN

Necmettin Erbakan University

To Cite This Chapter

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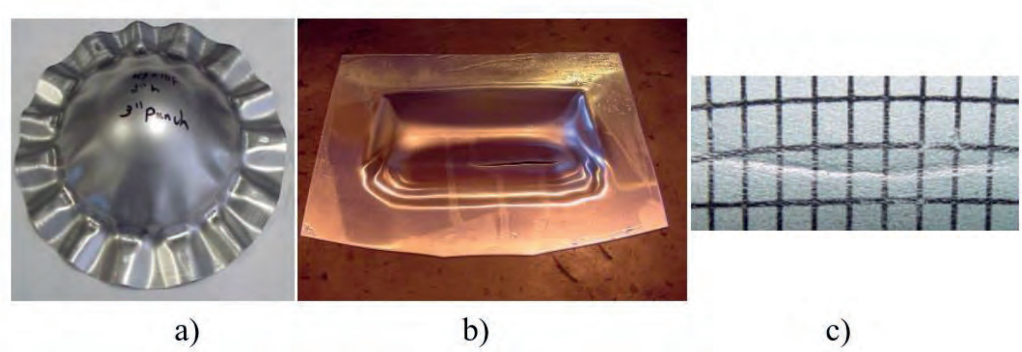
Introduction

While in the past years, sheet metal die manufacturing was done by trial and error method, today, with the development of technology, the process can be modeled and simulated in the computer environment using the finite element method (FEM), even before the forming process is carried out. As a result, defects that may arise can be predicted and precautions can be taken. As a result of basing the die design on scientific foundations, the number of trial and errors is reduced, saving time, labor and costs. In order for FEM analyzes to provide realistic results, it is very important to correctly determine the material and process parameters in the software. One of the most important of these parameters is the Forming Limit Curve (FLC) data, which is one of the most reliable tools that provide information about the limits to which sheet materials can deform. Sheet metal forming can be a simple bending process or a very complex forming process that is a combination of bending, stretching and deep drawing processes. Bending is the most common type of deformation and occurs in most forming operations. In the deep drawing process, the flow of the sheet metal into the die is controlled by a pressure plate and formed with the help of a male die. In the stretching process, the movement of the sheet metal towards the female die cavity is prevented by the pressure sheet (Marciniak et al., 2002).

Problems such as tearing, necking, wrinkling and springback may occur during sheet metal forming processes (Figure 1). The occurrence of any of these or a combination of these makes the sheet metal useless, and these defects are the factors that define the deformation limit. During the stretching process, the sheet thins first uniformly and then regionally, and a regional thinning band known as necking occurs in the sheet (Banabic et al., 2000).

Figure 1

Problems That May Occur in Sheet Metal Forming a) Wrinkling, b) Tearing,c) Regional Necking (Altan, 1998)

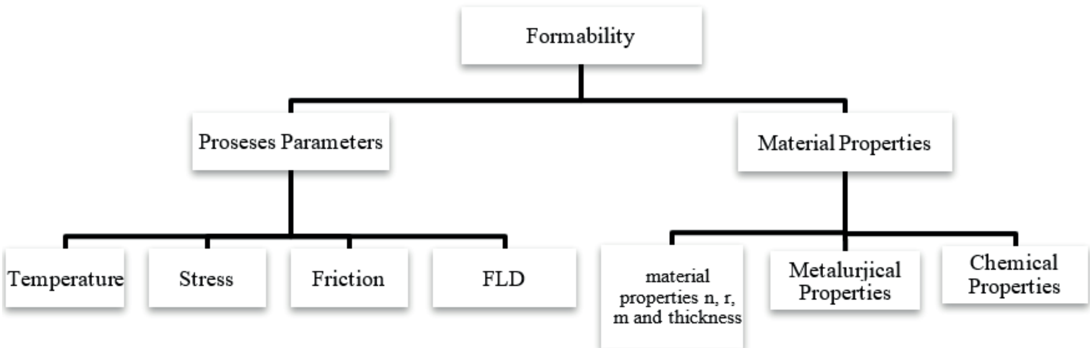


For successful forming, deformations must be uniform, a high deformation level must be achieved without damage, the shape of the part must remain the same when removed from the die, and its surface must be smooth (Taylor, 1988). The "formability" of sheet metals is; It is the ability of the sheet metal to take the desired shape without suffering damage such as tearing, regional necking and wrinkling during forming (Marciniak et al., 2002). Material properties and process parameters are the main factors that determine the formability of metals (Dieter, 1988). Figure 2 summarizes the parameters affecting the formability of sheet metals.

Many experiments have been developed by researchers to determine the formability of sheet metals. The important ones of these experiments are explained below.

Figure 2

Parameters Affecting the Formability of Sheet Metals (Önder, 2005)



Formability Tests

Simulation experiments to determine the formability of sheet materials, (Olsen, Erichsen, Swift Cup, Hecker, Fukui, etc.), Limiting Dome Height, mechanical experiments and experiments in which the forming limit curve (FLC) is created are used.

In simulation experiments,

- processes cannot be modeled exactly and therefore sufficient information about formability in real forming processes cannot be provided.
- In addition to the material quality, the size of the material, lubrication conditions, and the standard of the test equipment also greatly affect the results obtained.
- A feature such as the obtained limit drawing height can only be applied to a specific forming process and this feature does not provide information about die forming

These experiments are used to compare the formability of materials rather than obtaining a numerical value for formability. On the other hand, while mechanical properties obtained from experiments such as tensile tests reveal the forming behavior of the material, they do not provide information about formability. FLC is an effective tool that provides information about the limits to which the material can change shape (Theis, 1999) and will be examined in more detail below.

Forming Limit Curve

Sheet metals can only be formed up to certain limits without damage. Models have been developed to predict material behavior in forming operations. However, experimental data is needed for these models to give realistic results. For this purpose, the yield curve obtained by the tensile test must be introduced to the FEM program. By analyzing this information, the deformation status of each point in the part can be calculated. However, since sheet metal forming processes are complex, simple mechanical properties obtained from the tensile test are insufficient to determine whether the workpiece is damaged or not. In addition, it is absolutely necessary to introduce FSI data, which is one of the most important tools that provide information to what limits the material can change form, into the FEM program (Dieter, 1988; Lamberts, 2005).

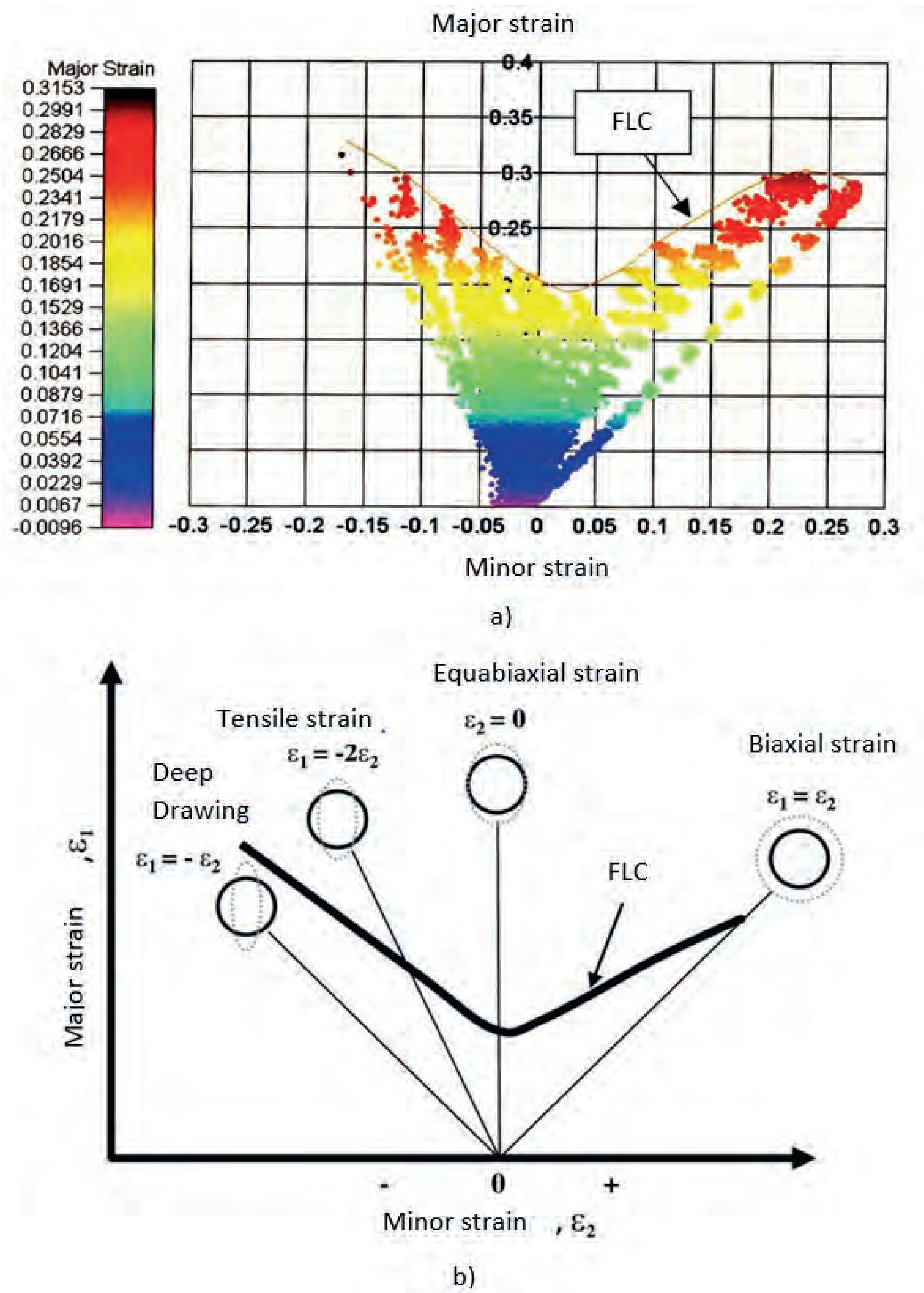
The sheet metal sample, whose surface is covered with circular or square grids, is formed until the beginning of necking or tearing with standard experiments, and the combinations of minor (small, ε_2) and major (large, ε_1) principal strain are measured in the grids that turn into ellipse or trapezoid form in this region. forming limit diagram (FLD) is formed by transferring it onto a diagram as shown in Figure 3a (ASTM E 2218 02). This diagram is not a simple fracture criterion and is obtained by using strain in all possible forming situations that the workpiece may encounter. These forming situations are deep drawing, uniaxial drawing, plane strain and biaxial stretching, as seen in Figure 3b. These situations are achieved by forming samples of different widths (Raghavan, 1995). In this way, by using the upper limit points of strain combinations obtained in a wide range from uniaxial tension to equal biaxial tension (equi-biaxial stress), FLC is obtained, a typical example of which is seen in Figure 3b.

Many of the typical FLCs consist of tear, necking, and safety data points (Smith & Lee, 1997). To stay on the safer side, in some studies, another curve called safe FLC is drawn at 10% below the FLC (Öztürk & Lee, 2005). To obtain reliable FLCs, the experiment must be stopped at the beginning of the sheet necking. The onset of necking is a phenomenon that occurs where the shape change becomes localized and can sometimes be seen, sometimes felt, and sometimes not even felt, depending on the damage mechanism of the material. However, it is very difficult to determine the onset of instability and experiments can often be stopped as soon as necking or tearing occurs. This situation is especially difficult for alloy aluminum, which tends to change rapidly in localized forming. In fact, in alloys with a brittle structure, the test can only be stopped in case of tearing (Smith & Lee, 1997).

In addition to providing information about the formability of materials, FLC is a proven and useful tool used in industry to avoid unsuccessful designs in part production (Stoughton & Zhu, 2004). As a result of forming, it can be determined whether the strain in the part remain in the safe zone and the appropriate process parameters (blank holder force, lubrication, etc.). Before die manufacturing, analyzes are made with FEM, estimated strain are calculated and compared with the FLC introduced to the FLC program. Thus, whether tearing will occur during forming or possible damage areas can be predicted. If the part is damaged, a damage-free production is attempted by changing the die design, process parameters, material or thickness. Wrinkling zones can also be predicted by introducing wrinkling limit curves in addition to FLC.

Figure 3

a) Obtaining FLC by Creating Different Strain, b) Typical FLC (Lamberts, 2005)



Theoretical Models Used to Determine Forming Limit Curves

Since obtaining FLCs experimentally is long and laborious, various studies have been conducted on their theoretical obtaining and models have been developed that vary depending on the definition of the error. The first theoretical FLC models were Hill regional necking and Swift diffuse necking models based on necking theory. In these theoretical models, the sheet is considered homogeneous. Later, a theoretical model was proposed by Marciniak and Kuczynski (1967) that takes into account the inhomogeneity of sheet materials, both geometrically and structurally. Stören-Rice proposed a vertex theory based on bifurcation theory to model regional necking under biaxial stretching (Jie, 2003; Paraianu et al., 2005; Banabic et al., 2007). Another theory in determining FLC is the ductile fracture criterion, which is based on calculating the energy stored by the sheet metal until it ruptures.

Experimental Determination of Forming Limit Curves

The results obtained above, it was decided to obtain FLCs experimentally in this study. FLCs consist of experimental gridding, forming and measuring stages. These stages are explained in detail below.

Grid Methods

Before the forming process is carried out in order to measure strain, circles, squares, etc. are drawn on samples of different widths. Small grids are created in this way. Measurement with grid analysis was first proposed by Keeler in 1965 (Keeler, 1968). Various shapes can be created on the sheet metal surface, as seen in Figure 4, with grid sizes ranging from 1.25 ~ 6 mm. When very small size grids are used, measurements can be made within the necked region. However, a small error in measurements will cause an even larger error in the strain value. If large grids are used, sufficient accuracy cannot be achieved and larger errors are made at a certain radius of curvature (Smith & Lee, 1997). In the ASTM E 2218 02 standard, it is stated that when the radius of curvature is 50 mm, the error caused by curvature is acceptable in grids up to 2.5 mm. For this reason, 2.5 mm grids are generally used.

When choosing the most appropriate method, care should be taken to ensure that the grids are not affected by shape change, that they resist process conditions such as friction and lubrication, and that the grids created by etching or carving do not affect the forming process by creating a notch effect. It is also important that the grids are obtained with high accuracy and resolution and that the method is cost-effective (Kim & Lee, 1996).

It was not deemed appropriate to use these methods in this study due to the fact that the grids created by the photochemical method can be removed even by rubbing, the laser engraving process is expensive, although good tolerances can be achieved in the electrochemical etching method, special equipment and chemicals are needed and the possibility of a notch effect. Instead, the Screen Printing method was determined as the most suitable method for gridding (Öztürk et al., 2009) because the created grids are not affected by shape changes, do not create a notch effect, and the method is simple to apply (Kari et al., 2008).

Figure 4
Commonly Used Grid Templates for Grid Analysis (Kim & Lee, 1996)

Forming Process

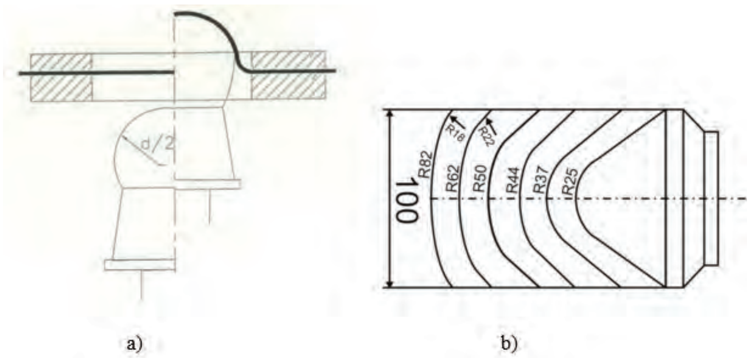
To create FLCs, researchers used different forming methods and various test samples (Lewison, 1999). While some researchers use the hydraulic inflation experiment with very low friction with elliptical dies with different ratios to obtain different strain states on the right side of the FLC, Holmberg et al. (2004) used tensile specimens of various widths for the left side of the diagram. Nowadays, out-of-plane and plane forming experiments using different stamp geometries, sample widths and lubricants are widely used to obtain the complete FLC (Lewison & Lee, 1999; ASTM E 2218-02).

Out-of-plane Forming Tests

In this type of experiments, the sheet material is formed with a spherical or hemispherical stamp. In these experiments, due to friction and curvature, larger strain are formed with additional bending strain that occur depending on the sheet thickness and radius of curvature. Therefore, the resulting forming limit depends on the tool geometries such as the stamping radius. (Raghavan, 1995).

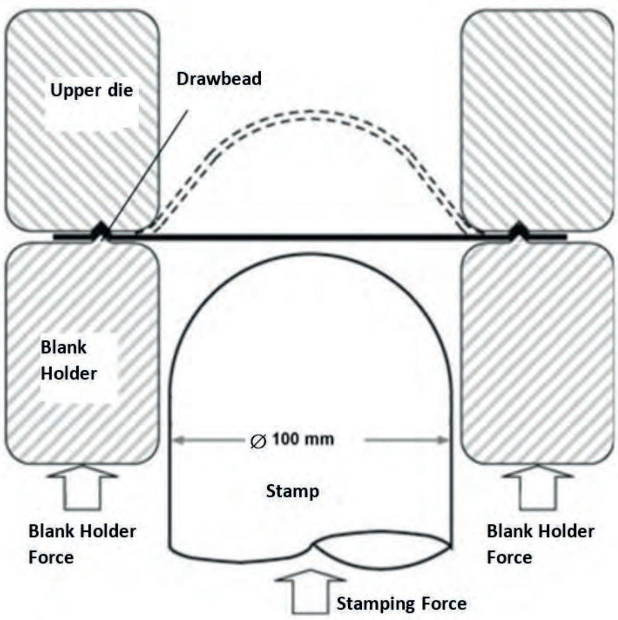
In the out-of-plane test, first proposed by Keeler and Backofen (1963), the sheet sample is locked between the pressure plate and the die, preventing the flow of the sheet into the die, and the sample is formed by stretching with a spherical stamp until damage occurs (Figure 5a.). Researchers have used different stamp forms and lubricants to obtain different strain states (Figure 5b.). However, in this experiment, only the right side of the FLC can be obtained and the stamp diameter changes the shape and level of the FLC.

Figure 5
Keeler's Suggested a) Experimental Set, b) Stamp Diameters (Keeler & Backofen, 1963)



Nakajima et al (1971), rectangular samples of different widths are locked with drain rods and formed with a 100 mm hemispherical stamp until the beginning of damage (Figure 6). Full FLC can be obtained using various sample widths and lubricants. The ratio of stamp radius to sheet thickness is greater than 15 to reduce the effect of bending stresses in the sample (Hosford & Duncan, 1999).

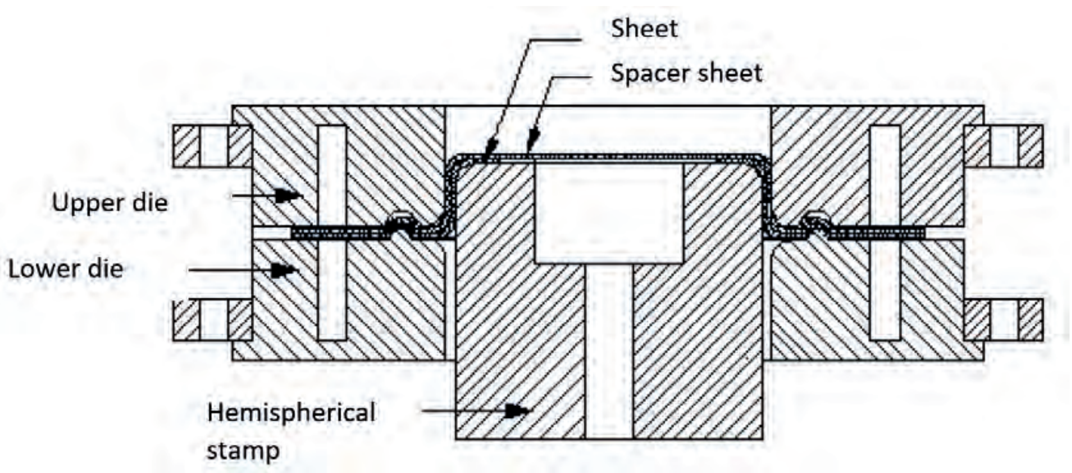
Figure 6
Nakajima Experiment Tool (Emilie et al., 2008)



In Plane Forming Tests

The most used plane forming experiment is the Marciniak test proposed by Marciniak and Kuczynski (1967). In this experiment, the samples are locked with the pressure plate and formed with a cylindrical stamp with a flat bottom and a gap in the middle until the beginning of the damage (Figure 7). In order to create a frictionless zone on the bottom surface and force tearing to this area, intermediate sheets with a circular hole in the middle were used between the sample and the stamp. Thus, the shape change occurs uniformly and proportionally in the plane of the sheet, without any bending or friction effects on the sample (Tadros & Mellor, 1978).

Figure 7
Marciniak Plane Forming Test (Öztürk, 2002)



Since the measured area is flat, measurement errors that may occur due to curvature are eliminated. In addition, due to the absence of bending strain, small strain are formed according to the Nakajima experiment. In their study, Moshksar and Mansorzadeh (2003) revealed that the FLC obtained from the Nakajima experiment was at a higher level than that obtained from the Marciniak experiment. In most plane forming methods, a limited number of strain paths can be obtained (Ghosh & Hecker, 1974). To overcome this disadvantage, Tadros and Mellor (1978), Gronostajski & Dolny (1980) and Raghavan (1995) modified the Marciniak test to obtain a wide range of FLCs by using test specimens of different geometry and width and spacer sheet. Holmberg et al. (2004) developed another planar experiment in which FLC was formed quickly and simply in a tensile tester. However, in this experiment, only the left side of the FLC can be obtained.

Although the Marciniak test has various advantages, the Nakajima test, which includes the bending stresses occurring in real forming processes and is performed according to the ISO 12004 2 standard, is widely used in determining FLCs (Hecker, 1975; ISO 12004-2). Therefore, the Nakajima experiment was used to determine FLCs in this study.

Grids of Measurement

In order to create FLCs, it is necessary to accurately measure the strain in the grids in the damage area after the forming process. To determine the boundary strain values, measurements are generally made from the tear or necking region or from the circumferentially opposite region to this region. Strain obtained from the damage area are called tears or necking, and those obtained from the opposite area are called the beginning of necking or safe (Smith, 1998).

Factors Affecting the Forming Limit Curve

The properties of sheet metals may vary depending on the material, alloying element, process, degree of heat treatment and cold forming (Taylor, 1993). Material defects or inhomogeneities such as thickness variation, porosity, roughness, and changes in plastic properties affect boundary strain (Bressan, 2008). Material properties that affect the strain distribution are hardening coefficient n, normal anisotropy r and strain rate sensitivity m. Achieving higher deformation levels depends on many factors such as material type and thickness t, alloying element, temperature, grain size and shape, microcomponents and uniformity (Taylor, 1988). Therefore, factors such as t, r, n, m, strain path, lubrication condition and inhomogeneity can affect the FLC level (Figure 8) (Djavanroodi & Derogar, 2010).

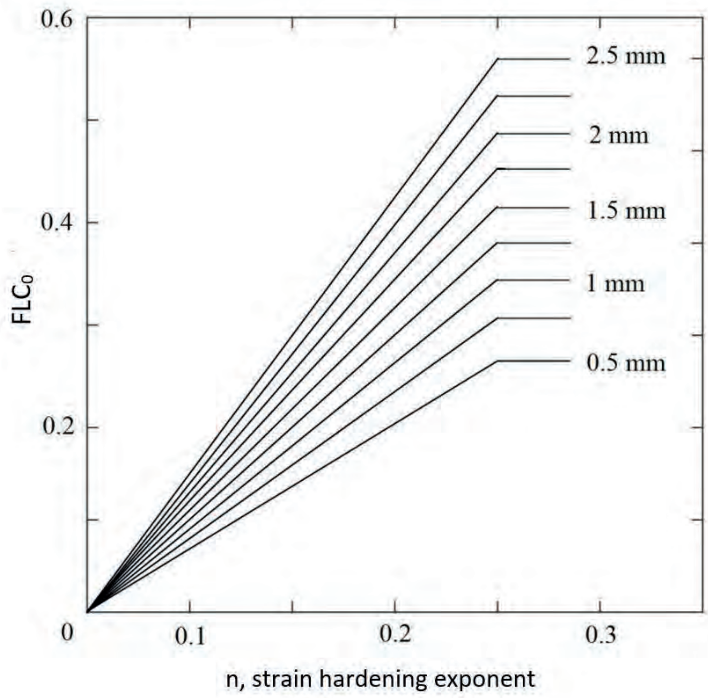
Sheet Thickness

In industry, a single FLC is often used for a given material. Using a single FLC for materials where sheet thickness affects FLC means that the formability of thicker sheets cannot be fully utilized, considering that formability increases with thickness. In addition, an incorrect limit will be determined for thinner sheets (Kleemola & Kumpulainen, 2003). It is generally believed that sheet thickness has a strong influence on formability and that thicker sheets have larger forming limits (Keeler, 1968; Lee & Hiam, 1978; Hosford & Caddell, 2007).

Although there are many experimental (Charpentier, 1974; Raghavan, 1995; Kumar, 2002; Svensson, 2004; Narayanasamy & Narayanan, 2007) and theoretical studies (Rees 2001; Kim et al., 2003) in the literature on the effect of sheet thickness on the FLC level in steels. There have not been enough experimental studies for alloyed aluminum, except for a few alloys. In these studies, it is stated that the thickness effect is greater in steel, but this effect is less in aluminum and its alloys than in steel (Keeler & Brazier, 1977). While necking is more continuous in materials with high strain rate sensitivity, the neck area is sharper than steel for alloy aluminum with low m value. For this reason, it is stated that the thickness effect is less in materials with sharper necking, such as aluminum, than in steel (Nakajima et al. 1971; Smith and Lee, 1997; Hosford and Duncan, 1999), but this effect may be important in forming processes (Jalinier & Schmitt, 1982; Raghavan, 1995; Zadpoor et al., 2009).

Figure 8

Variation of FLC_0 for Steel as a Function of n and Thickness (Keeler ve Brazier, 1977)



Direction of Rolling

Normal anisotropy r is an indicator of the material's resistance to thinning and is defined as the ratio of the transverse true strain to the thickness true strain in the region of uniform elongation in the tensile test. If the r value is equal to 1, the material is isotropic, and if it is different from 1, the material is anisotropic. In addition, materials whose properties do not change depending on the direction are called planar isotropic, and those whose properties do not change are called planar anisotropic materials. Planar anisotropy is the indicator of the change of r value according to direction. Many of the sheet metals used in industry show different properties in different directions due to rolling (Marciniak et al., 2002; Kohara, 2005). For this reason, the placement of the sheet metal relative to the die can sometimes be important in forming processes (Rees, 2001).

Hospers (1977) and Banabic et al., (2000) state that r and n coefficients are significantly related to formability, and therefore to FLC. Raghavan (1995) states that although high r value generally increases drawability, this effect is not obvious in stretching processes. Story et al. (1993) experimentally examined the effect of rolling direction on FLC for Al 2008 T4 alloy aluminum. There are also studies in which the effect of rolling direction for Al 2024 T3 was obtained through tensile testing (Hatipoğlu, 2007).

Other Factors

As n and m values increase, the FLC level increases. The pre-stretching process also has a significant impact on FLC. The FLC level may increase or decrease depending on the direction of the pre-tensioning. While the FLC level tends to decrease when biaxial anterior strain is applied, it may increase when uniaxial anterior strain is applied (Graf & Hosford, 1993; Hosford and Caddell, 2007; Situ, 2008). In their study, Laukonis and Ghosh (1978) determined that, in the case of biaxial front strain, the SSI0 level changed significantly for steels, while it remained approximately the same for alloyed aluminums.

Inhomogeneity and defects have a great impact on the shape and level of the FLC, as they cause regional variations in thickness, composition and grain size (Marciniak et al., 2002; Hosford and Caddell, 2007). Grid size also has a significant impact on FLC. When the necking region is smaller than the grid size, lower strain will be obtained.

The friction coefficient also has a significant impact on FLC. In the ideal frictionless case, a more uniform strain distribution is obtained. However, compared to the frictional situation, major strain are smaller and minor strain are larger (Casari et al., 2006).

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Smart Trash Cans for a More Livable World

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Introduction

Substances that have become useless as a result of people's social and economic activities, have expired and need to be removed from the environment we live in, are generally called waste (Waste Management Regulation 2015, 2021). Waste and garbage are different concepts that should not be confused. Rubbish; It is the waste material that remains after materials such as paper, cardboard, glass, metal and plastic are separated and which cannot be recovered or recycled in any way. In other words, while garbage is a part that needs to be stored regularly or disposed of, waste is the part that needs to be separated from the materials it contains and subjected to recycling or recovery processes according to its characteristics, and can provide added value to the country's economy (İç Anadolu Hurda, 2018). Waste types are shown in Figure 1.

Figure 1
Waste Types

Within the scope of the Zero Waste Project of the Ministry of Environment and Urbanization, the color scale (https://ekolojist.net/tum-detaylari-ile-sifir-atik-projesi/) that institutions can use in their collection equipment and information posters according to the types of their waste is as follows (Figure 2) .

Figure 2
Colors of Waste Bins According to Waste Types

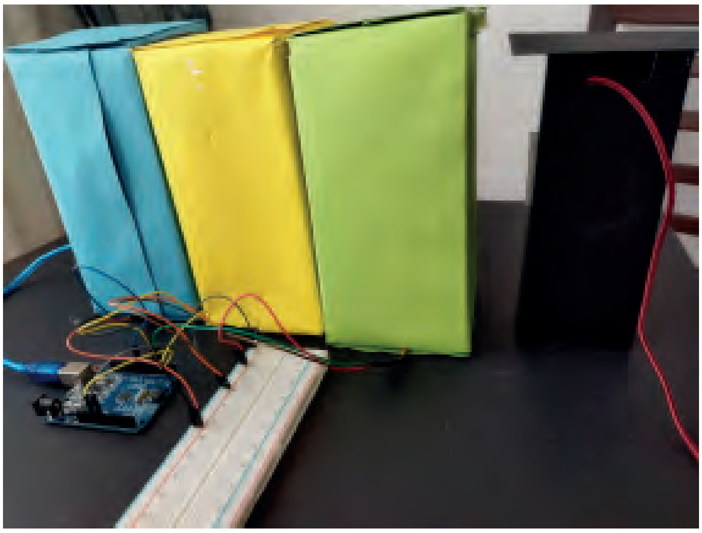
We call "recycling" when wastes that can be reused are converted into secondary raw materials through various physical and/or chemical processes and included in the production process again. The purpose of recycling is; It should be considered as preventing unnecessary use of resources and reducing the amount of waste by separating waste at the source. (Turkish Plastic Industrialists Research Development and Education Foundation Recycling Economic Enterprise, 2014). These products, collected and sorted for this purpose, are processed in recycling centers and made reusable. Separating the mixed wastes that come to these recycling centers (Figure 4) causes extra energy and time loss. This is because unconscious or irresponsible people do not use recycling bins correctly. In other words, it's like throwing paper where glass should be thrown, or glass where metal should be thrown. However, if the appropriate wastes are thrown into the correct bins as indicated in Figure 3, loss of time, energy waste, etc. will be prevented. We aimed to solve this problem in our project.

Figure 3
Garbage Separation Process

As mentioned above, waste bins are available in almost every city, but misuse is very common. The solution to this problem is, first of all, education to be given to individuals on this subject from an early age. However, our project will be a great solution for individuals whose education is insufficient, whose sense of responsibility and awareness is not developed, or who behave erroneously without realizing it. First of all, most people are curious about technology and different things. The use of artificial intelligence and cameras in our project will be interesting. Individuals' desire to use will increase. Depending on the type of garbage, the lid of the relevant box will be opened to ensure that the individual uses the correct waste bin, and in this way, positive behavior will be tried to be gained in the individual. And then these positive behaviors will become habits. The front and rear views of the working prototype of our project are shown in Figure 4 and Figure 5.

Figure 4
Working Prototype of Our Project / Front View

Figure 5
Working Prototype of Our Project / Rear View



The way our project works is as follows: When the individual comes in front of the camera, he is warned verbally and in writing and asked to show the camera the waste he wants to throw away. When the individual does this, the artificial intelligence, which has been previously trained on the types of garbage, determines the type of waste and accordingly, the servo motor on the lid of the relevant waste bin is activated and enables the lid of the bin to be opened. After the specified time, the lid closes again.

The purpose of the study is to recognize garbage with artificial intelligence, to open the lid of the relevant box according to the type of garbage and to ensure the correct behavior in individuals. Thanks to the cameras and artificial intelligence to be placed in the front of the recycling bins, garbage will be distinguished and only the lid of the bin that needs to be thrown away will be opened, depending on the type of garbage. Separating waste in advance prevents waste of time and energy. If we accept that these are millions of tons of waste, we think that by ensuring that the waste is pre-separated and delivered to these facilities, we will reduce the carbon footprint, save money by using the electrical energy and human labor used in these facilities more efficiently, and prevent harm to the environment.

We used electronic circuit boards, servo motors and cameras in the design of the study. As software, we used the Pictoblox program and its integrated Machine Learning Environment plug-in. We wrote the codes in Pictoblox. With the Machine Learning Environment plug-in, we enabled waste to be recognized by artificial intelligence. In other words, we have trained our machine.

Method

First of all, a literature review was conducted. Artificial intelligence technologies, their usage areas, applications related to image processing and machine learning have been researched. As 6th grade secondary school students, we use Mblock5 and Pictoblox in lessons. That's why we chose to use one of them and wrote the codes of the study with Pictoblox. We planned to use a local and national electronic circuit board, Deneyap card, in the study. We provided the experimental board, camera and other circuit elements. When we started working on the study, we learned that high-level languages such as Python were required to process images with the Deneyap card. We saw that the Deneyap Blok application does not include commands related to image processing from the camera. Unfortunately, we could not use this card in the study because the Deneyap card could not be introduced to Mblock5 and Pictoblox programs. We used Arduino Uno (Figure 6) instead. When we reached the authorized units regarding the Deneyap card, they stated that engineers were working to eliminate the deficiency in this regard.

Figure 2 shows 8 different colored boxes according to the types of waste. We thought that 3 waste bins would be sufficient to show how study works. We prepared three boxes in blue, yellow and green colors: paper, plastic and glass. We mounted a servo motor (Figure 7) on its covers. Servo motor is an electrical device used for precise control of angular rotation. The model used here can rotate 0-180 degrees. Camera (Figure 8) connection and circuit assembly were made, and a prototype model was prepared. on pictoblox

After machine learning was performed with the Machine Learning Environment plug-in (Figure 9), the codes were written (Figure 10) and loaded onto the Arduino card. Experiments were carried out and we tried to reach the most suitable result for our purpose. In addition, an animation was prepared regarding the operation of the study, thinking that it could be used for educational purposes (Figure 11). While the prototype is running, the animation also works synchronously. In our experiments, it was seen that the correct boxes were opened according to the type of waste. Our prototype was completed successfully.

Figure 6	**Figure 7**	**Figure 8**
Arduino Uno 	*Servo motor(Tower Pro SG90)* 	*Camera(Piranha 9635 Full HD 1080p)* 

We tried to make the prototype of the study feasible at the least cost.

Figure 9

Training Artificial Intelligence with Pictoblox Machine Learning Environment Plugin

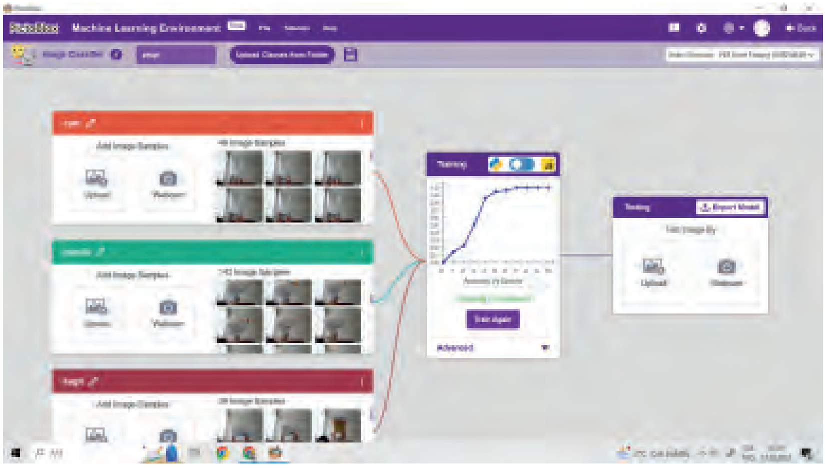
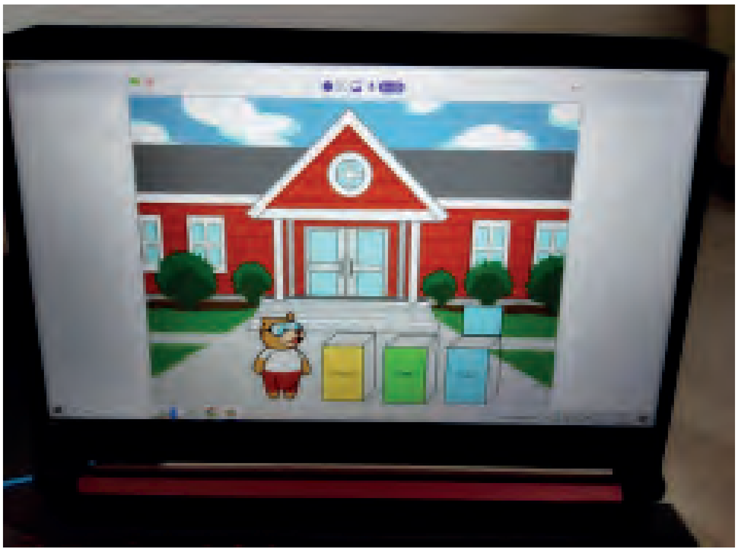


Figure 10

Codes Used in the study

Figure 11

Study Animation Screen



Work Timeline

Table 1

Work Timeline

Name of the activity	1.Month	2.Month	3.Month
Determining the Study Topic	X		
Literature Review	X	X	
Material Supply		X X	
Preparation of software and realization of Artificial Intelligence and Machine learning		X	X
Prototype Study to be done		X	X

Findings

The prototype of the study was tested and its operation was observed. During the study, artificial intelligence recognizes and distinguishes the types of garbage and opens the lid of the relevant box according to the type of garbage, directing people to the correct behavior. Study reached its goal and was successful.

Result and Discussion

Realizing the study idea will provide great savings in terms of economy and time. Its application is practical, economical and easy. It is a study with added commercial value.

In the literature review, it was seen that many studies have been carried out in different fields related to artificial intelligence and image processing. However, no study has been found like the one we used in the study. This study was developed by us as a completely original product.

Our target audience is primarily all individuals in society. Teaching individuals the right behavior is an important criterion for the development of society. If considered in a broad context; Based on the idea that the level of civilization of a society depends on the level of development of correct behavior of its members, we can say that the whole society is our target audience.

Suggestion

Companies dealing with recycling and manufacturing waste boxes can easily integrate the study into their products. We think that the study can be expanded and used in recycling studies in other countries in the future.

Risks that may arise during the implementation of this study in real life and solution suggestions against risks are presented in a table.

Table 2

Risk Analysis

Risks	Solution Suggestions
Since the study has a dispersed circuit structure in its current state, connections may be damaged over time and the study may become inoperable.	By placing the circuit elements in our prototype the study on a single printed circuit board, cable connections can be eliminated and thus connection-related problems can be eliminated.
The electronic circuit may become wet due to weather conditions or any other reason. It may damage the camera's components.	Into a waterproof transparent box can be placed.
For real life application Pictoblox's artificial intelligence feature may be insufficient.	In this case, more advanced programming languages and image processing methods can be used.

Intellectual product and patent application studies for the study have started, and if accepted, dissemination activities will be carried out at the level of municipalities and the Ministry of Environment and Urbanization.

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Investigation of The Effect of Cross-Section Geometry on Bending And Compression Behaviour of Glass Fiber Profile Composites

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Introduction

Nowadays, the decrease in natural resources has made it obligatory to use these resources economically. Especially in energy-consuming devices such as petrol, natural gas, and electricity, studies are continuing to reduce this consumption. In addition to this, the production of faster working devices to save time and the production of longer-lasting devices as well as factors such as cheaper production have accelerated these studies. In this direction, composite materials come to the fore. Composite materials produce combination properties of more than one material that cannot be obtained separately by fiber or matrix when they act alone.

Composite materials are both stronger and very light materials. They have features such as low density compared to metals, high surface quality, and corrosion resistance. Fiber-reinforced composites have been successfully used in various fields for many years. Glass fiber-reinforced plastic (GRP) composites have been the most widely used in the manufacture of composite materials. In recent years, glass fiber-reinforced plastic (GFRP) composite materials have developed faster than metals in structural applications. Due to their low density, high strength, and stiffness, their use as an alternative to metallic materials is becoming widespread.

For the safe application of composite materials in industry, a good statistical understanding of fatigue data is required. The statistical properties used usually depend on the usual distribution in mean strength. However, the Weibull distribution has more reliable values than other distributions in fatigue data evaluations in terms of variables in life and strength parameters. Composite materials have a wide range of applications and are used in various sectors.

When the macrostructure of composite materials is analyzed, their components can be selected and distinguished. Even though composite materials generally show heterogeneous properties, they are homogeneous to a lesser extent. Materials with different properties are used as reinforcement materials in composites. The main purpose of using reinforcing materials in composites is to meet the load acting on the material and to increase the strength of the matrix. The importance of the use of matrix in composite materials can be listed as protecting against external influences that may affect the brittle and fragile reinforcing elements, transmitting the load acting on the composite material to the reinforcing elements, and keeping the composite structure durable. In summary, for a material to be characterized as a composite; it must be a material that cannot be obtained ready-made in nature, brought together by a certain study, its components do not dissolve in each other and have properties that they cannot obtain alone.

With the reduced number of ester groups in a vinyl ester compared to polyester, the resin is less damaged by hydrolysis. For this reason, the material is sometimes used as a barrier or 'skin' coating for a polyester laminate that is to be submerged in water, for example in a boat hull. The cured molecular structure of vinyl ester also means that it tends to be stiffer than polyester, but to achieve these properties the resin usually needs to be cured at high temperatures. With the numerous production methods available, one of the most economical procedures with low energy impact is pultrusion. To understand pultrusion, it may be helpful to first understand extrusion. Extrusion involves forcing or pushing material through a mold to produce a component, applied within a closed volume. Similarly, pultrusion is a continuous process with an open-volume procedure that involves pulling material through a die with the help of a series of pulleys at the exit of a mold.

GFRP profiles exhibit stable mechanical properties but are susceptible to NUFD during manufacture, which adversely affects the local buckling capacity. Experimental and numerical analyses were performed on extruded GFRP profiles manufactured under three winding tension configurations, resulting in a 5% change in load capacity during bending (Songming vd., 2024). They report an experimental investigation on the effect of GFRP needles as a partial replacement of coarse aggregate in concrete on the shear behavior of large-scale reinforced concrete beams, where the presence of GFRP needles increases the total amount of material. The energy absorbed by RC beams is about 40% (Nie vd., 2020). They also worked on a new mechanical method to recycle GFRP waste by processing large fibers for concrete reinforcement. Among their results, a significant increase in the flexural strength and durability of concrete was noted (Fu vd., 2021).

They investigated the strength and ductility of column beams using FRP and concrete as a hybrid. To investigate the column beam behavior of concrete-filled pipes, they prepared specimens and performed experiments in different combinations. As a result, they obtained various performance improvements in concrete-filled elements (Mirmiran vd., 1999). They obtained a hybrid structure by filling the interior of the rectangular GRP element with concrete and using it as a column beam. They filled some elements and some partially with concrete and performed experiments by applying different eccentric loads to the prepared specimens. As a result of their studies, they obtained various graphs of the test specimens and made comparisons between filled profiles and partially filled profiles. As a result of the experiments, partially filled profile beams showed similar stiffness with filled profiles, but partially filled profiles fractured at lower values in bending tests (Fam vd., 2003).

They used profiles and polymer concrete as hybrid beams and performed bending tests on beams of different cross sections by theoretical modeling and experimental studies. They compared the load-deformation graphs of profile, polymer concrete, and hybrid beam finite element models. 8 The authors designed, manufactured, and tested hybrid rectangular beams and obtained the highest strength in hybrid beams (Ferreira vd., 2004). While investigating the flexural behavior of GRP beam designs, the allowable deflection amounts under working loads are taken into consideration instead of the maximum load they can withstand. In this study, the flexural behavior of GRP profiles was investigated analytically, experimentally, and numerically. Three-point bending tests were performed on the profiles and flexural strengths and shear moduli were obtained. These results were compared with the results calculated by finite element analyses (Neto & Rovere, 2006).

Material And Methods

Production of GRP Profiles

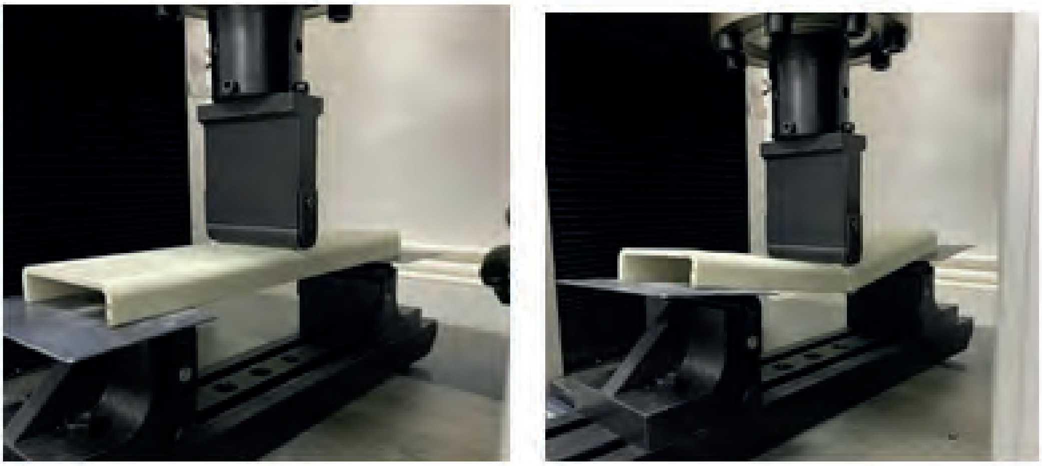
The samples used are produced by pultrusion method, as reinforcing elements, Şişecam 4800 tex yarns with uniform unwinding, good fiber distribution, very low static electrification, good resin absorption, fast wetting, and high mechanical performance are used. A mixture of orthophthalic polyester, isophthalic polyester, and vinyl ester resin is used as resin. The production process starts with the continuously wound glass fiber yarns being passed through the resin bath, resin impregnation, and heating. The resin-impregnated glass fiber yarns are then passed through the heated mold. While the resin is passed through the mold, it cures and solidifies. Cooling is applied to the profiles pulled from the mold using rotating rollers and after the profiles reach the desired length, they are cut with the help of cutters, and the process is completed.

Bending Test

The lengths of the profiles with cross-sectional areas of 330 mm^2 and 700 mm^2 were cut as 350 mm and bending tests were performed in two separate groups. In the experiment, the distance between the supports was set as 250 mm as standard according to the material wall thickness. The speed of the loading tip was set as 1 mm/min as specified in the standard. Before the start of the experiment, the center point of the specimens was determined and placed precisely in the test machine, and as soon as the loading tip touched the specimen, all data were reset and the experiments were started. The experiments continued until fracture occurred in all specimens and the necessary data files were obtained for plotting the experimental graphs in the Matlab program.

Figure 1

U profile specimen subjected to flexure test

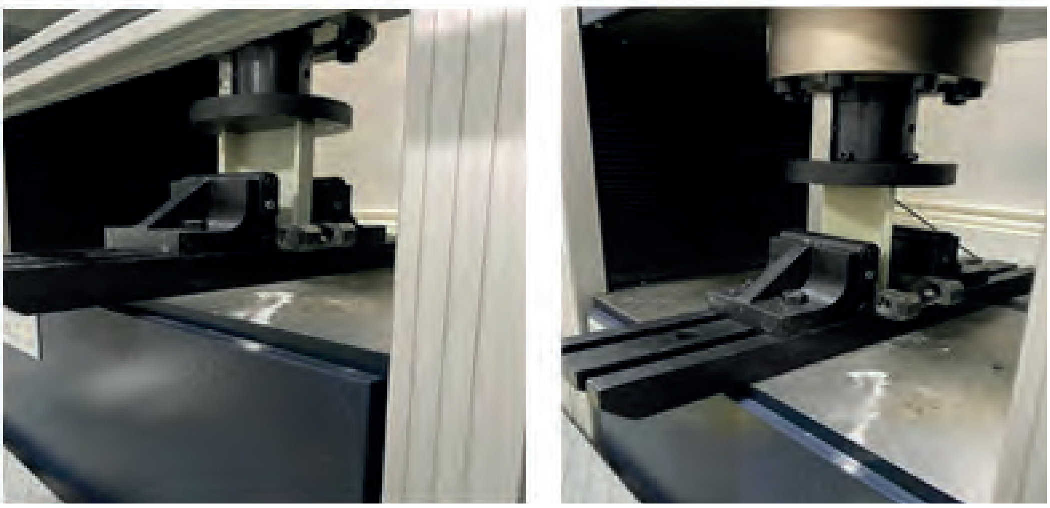


Compression Test

The lengths of the profiles with cross-sectional areas of 330 mm^2 and 700 mm^2 were cut as 150 mm and compression tests were performed in two separate groups. Before starting the test, a compression apparatus was prepared and the thin specimens were clamped between two supports to prevent the orientation of the thin specimens against bending. When the specimens were placed in the test device, they were adjusted to be centered. As soon as the end of the compression apparatus touched the specimen, all data were reset to zero, the loading speed was set to 5 mm/min and the experiments were started. The experiments continued until fracture occurred in all specimens and the necessary data files were taken for drawing the experimental graphs in the Matlab program.

Figure 2

U Profile and Angle Profile Specimen Tested in Compression

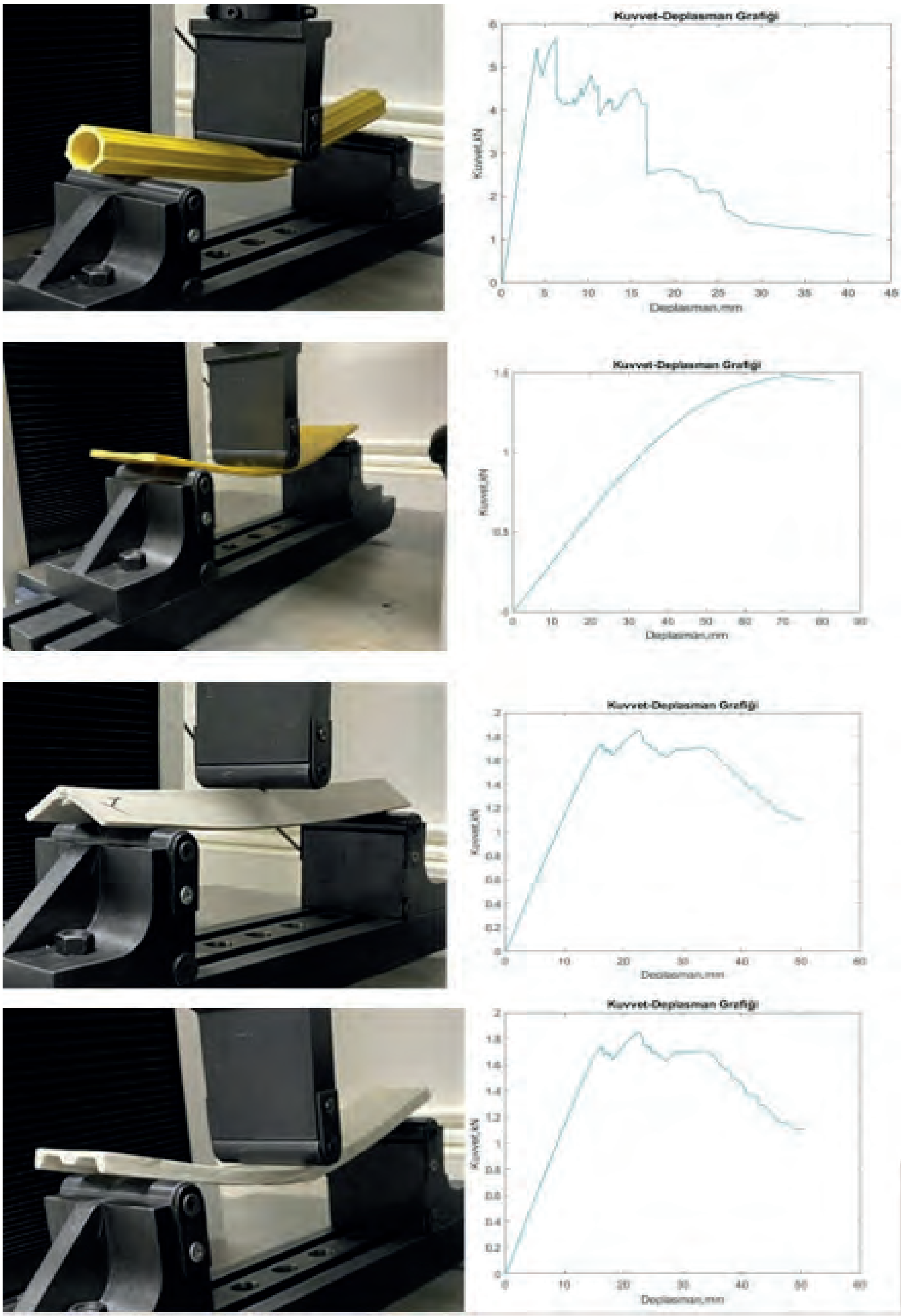


Test Results and Damage Images

Bending test GRP profiles with a cross-sectional area of 330 mm²

Figure 2

Bending test results of GRP profiles with a cross-sectional area of 330 mm²



When the serrated circular section profile, which is a special form of circular section profile, was subjected to a bending test, it showed a high bending performance, then deformed with superficial fiber breaks occurring in the cross-section-wall thickness, and the strength decreased up to 4 kN and withstood 15 mm bending by maintaining its strength due to the special profile shape feature and then destroyed. The strength of the material in terms of strength is important in the first fiber breaks and these values should be taken as strength values.

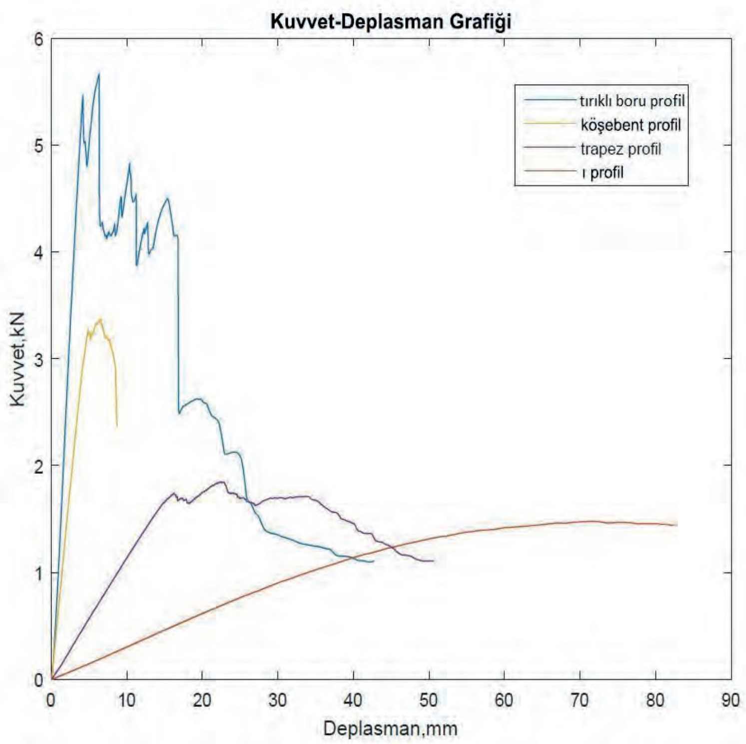
Since the I profile section specimen has very different dimensions in terms of moment of inertia, that is, its thickness is very thin compared to its height, it is destroyed in a very high displacement range at very low forces. Although it is extremely resistant to bending, it is clear that it will reach very high bending forces in the axis with a high moment of inertia.

The angle profile is a widely used structural geometry. The important thing in this profile is to load the material at the point where the cross-sectional density is, in this way, in our experiment, the material reached a force of 3.5 kN and a displacement of 4 mm. As can be seen from the graph, after these values, the edges of the gusset deformed through fiber separation from the midpoint and cross-sectional change. This section will have the highest flexural strength and the lowest displacement value only when used in this form.

The open ends of the trapezoidal profile specimen were brought to the support side and subjected to a bending test and with fiber breaks due to shrinkage in the sections forming the trapeze, it withstood a bending strength of 1.7 kN, a bending elasticity of 10 mm was provided in the first stage and the material was deformed with the first fiber breaks. The first fiber breaks occurred at the open ends of the trapeze.

Figure 3

330 mm2 cross-sectional area profiles bending test force-displacement graph combination



330 mm^2 cross-sectional area profiles' bending strength force-displacement graph shows two categories, pipe and angle profiles should be evaluated separately, and I and trapezoidal profiles should be evaluated separately. What is important here is low displacement and high bending forces. From this point of view, in terms of construction and cost, it is a scientific necessity to use circular section profiles in the first category and trapezoidal profiles in the second category, if possible, in terms of flexural strength.

Table 1
330 mm² cross-sectional area profiles moment of inertia and bending force/ displacement ratio chart

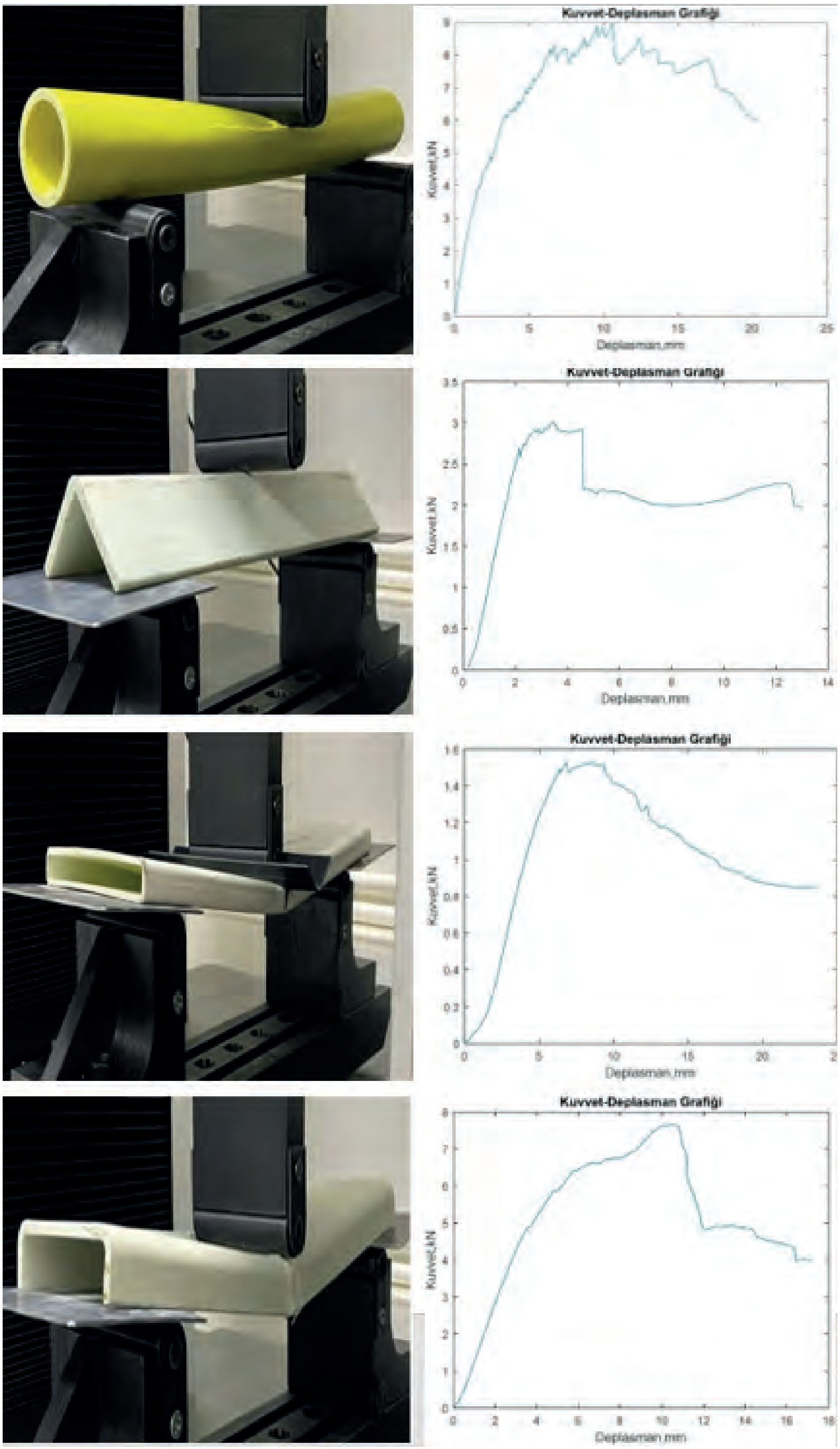
	I_x (mm⁴)	I_y (mm⁴)	Ixy (mm⁴)	Imax (mm⁴)	Imin (mm⁴)	Bending force (N)	Displacement (mm)	BF/D (N/mm)
I Profile	235340	470	0	235340	470	1500	71.9	20.86
Circular cross-section profile	36380	36380	0	36380	36380	5600	6.3	888.88
Trapezoidal Profile	2900	135510	0	135510	2290	1800	22.6	79.64
Angle Profile	39430	39430	23580	63010	15850	3400	6.5	523.07

When the principal moments of inertia are examined, it is important to load in the directions with high Imax values according to the profile sections in terms of section geometry, and balanced Imax Imin values in the circular section profile reveal that circular sections are preferred in bending strength. The cost factor must be taken into consideration here. In addition, the highest forces required per displacement are first in the circular section profile and then in the angle profile. Therefore, considering the construction requirements and cost, it is necessary to use a circular section profile first and then angle profile in terms of bending strength.

Bending test GRP profiles with a cross-sectional area of 700 mm²

The 5 mm wall thickness circular section profile has high bending strength and low displacement rates due to its geometrical characteristics. After the first superficial fiber fractures, it withstood a bending strength of 8 kN and then was severely damaged and deformed. The gusset profile was subjected to a bending test from the ridge area where the cross-sectional density was high and the first deformations around 2.5 kN were manifested by fiber separations in the form of delamination in the ridge area where the cross-sectional density was high and the material was destroyed without showing very high displacement. Box profile with cross-sectional area is a profile type selected quite differently in terms of principal moments of inertia. As can be seen in the graph, the flexural strength is quite low (1.5 kN) and the displacement is quite high according to this value. As it can be understood from the cross-section, it will have high bending strength and low displacement rate by using vertically rather than horizontally. U profiles have high bending strength and low displacement values due to their geometry. In the experiment, axial fiber separations around 5-6 kN and 4 mm displacement at the points where the cross-section continuity changes, fiber breaks around the force application point at the open ends of the U section, and delamination-like layer separations and deformation.

Figure 4
Bending test results of GRP profiles with a cross-sectional area of 700 mm²



As for the 330 mm² cross-sectional area profiles, in the combined graph, the tube and U-profile profiles carry close bending forces in almost the same displacement range. In both profiles, the first fractures occurred superficially and in areas where the material continuity was disturbed and according to the geometry of the force application end. In the gusset profile, deformation in the form of delamination was observed in the ridge area with relatively high bending strength, low deformation rate, and section density, while in the box profile, the applied force decreased and the displacement increased due to the excessive flexing of the section in the horizontal axis. Deformation in the form of fiber separation and rupture occurred at a high displacement rate of about 15 kN and 7 mm.

Figure 5

700 mm² cross-sectional area profiles bending test force-displacement graph combination

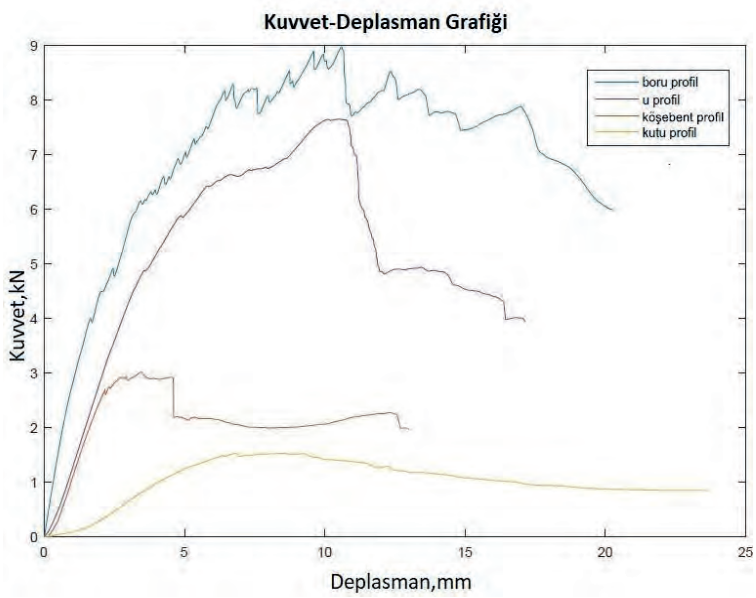


Table 2

700 mm² cross-sectional area profiles moment of inertia and bending force/displacement ratio chart

	I_x (mm⁴)	I_y (mm⁴)	Ixy (mm4)	Imax (mm4)	Imin (mm4)	Bending force (N)	Deplacement (mm)	BF/D (N/mm)
Circular section profile	181130	181130	0	181130	181130	8900	10	890
Box Profile	1090410	30050	0	1090410	30050	1500	6.9	217.39
U Profile	868330	30030	0	868330	30030	7800	10	780
Angle Profile	257090	257090	154720	411810	102370	3100	2.8	1107.14

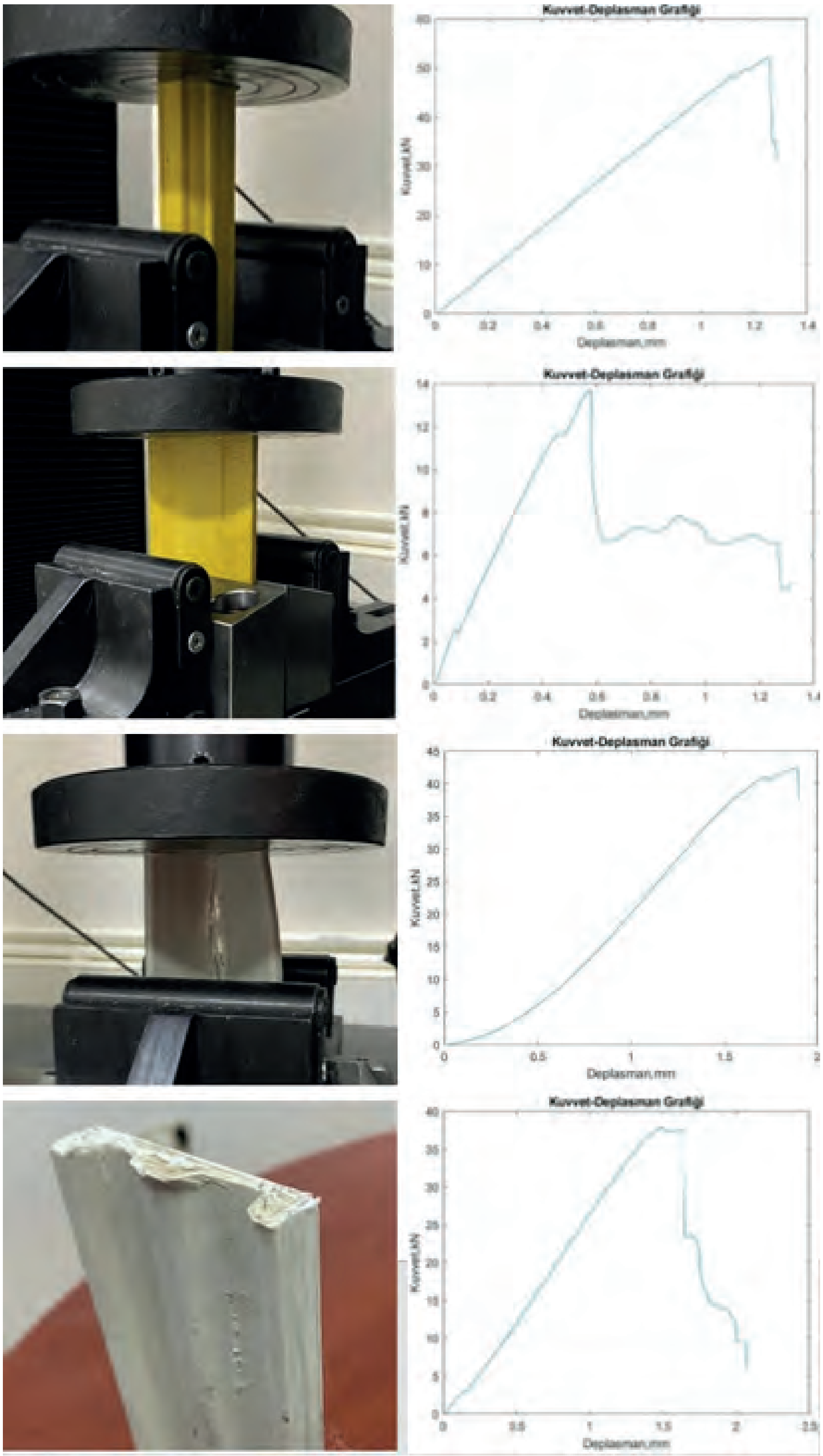
In terms of bending force, the required bending force per mm displacement is very similar for angle iron, circular section profile, and U profile with slight differences. One of these profiles can be selected in terms of construction and cost. When 330 mm² cross-sectional area profiles and 700 mm² cross-sectional area profiles are compared, the bending strength has increased with the increase in the wall thicknesses due to the increase in the cross-sectional areas in terms of angle iron and circular section profile, although the same test parameters are used. Interestingly, especially in the angle iron profile, this difference increased almost equivalently by a factor of two with a doubling of the cross-sectional area. Although 330 mm² and 700 mm² circular section profile section geometries are not the same, there is no significant change in flexural strength/ displacement ratios.

Compression test GRP profiles with a cross-sectional area of 330 mm²

Since the circular cross-section profile is serrated and material continuity is provided in composite materials, it was destroyed at high compressive strength and low displacement with the effect of serrated edges.

Figure 6

Compression test results of GRP profiles with a cross-sectional area of 330 mm²



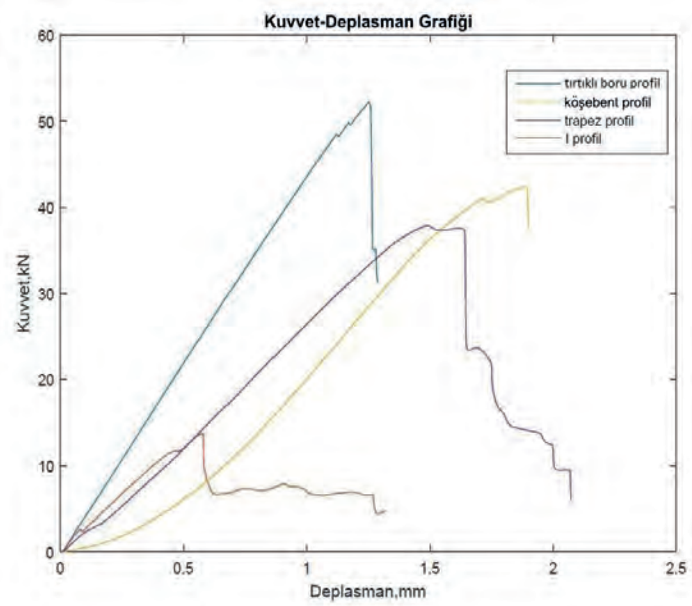
I profile was subjected to matrix/fiber separation around 2 kN with the effect of jaws and fiber separation starting from the edges reaching a value around 12 kN at low displacement values and the cross-sectional surface was destroyed around 14 kN.

The gusset profile buckled partially when the compression force was applied, then showed high compression strength in the very low displacement range and was destroyed by axial fiber separation in the middle region where the cross-section density was high.

The trapezoidal section was deformed in response to high compression force, especially at the point where the cross-section density in the middle region, again through axial load separation.

Figure 7

330 mm² cross-sectional area profiles compression test force-displacement graph combination



In the compression test, it can be said that the serrated circular cross-section profile is the most ideal profile geometry since it has the highest compression strength and the lowest displacement ratio. Then the trapezoidal profile has high compression and low displacement values in proportion to the size of the trapezoidal edges. Although the angle profile seems to be partially buckled, it is still the third profile geometry we would prefer. I profile is not an ideal section geometry since it has a very low displacement/compression ratio.

Table 3

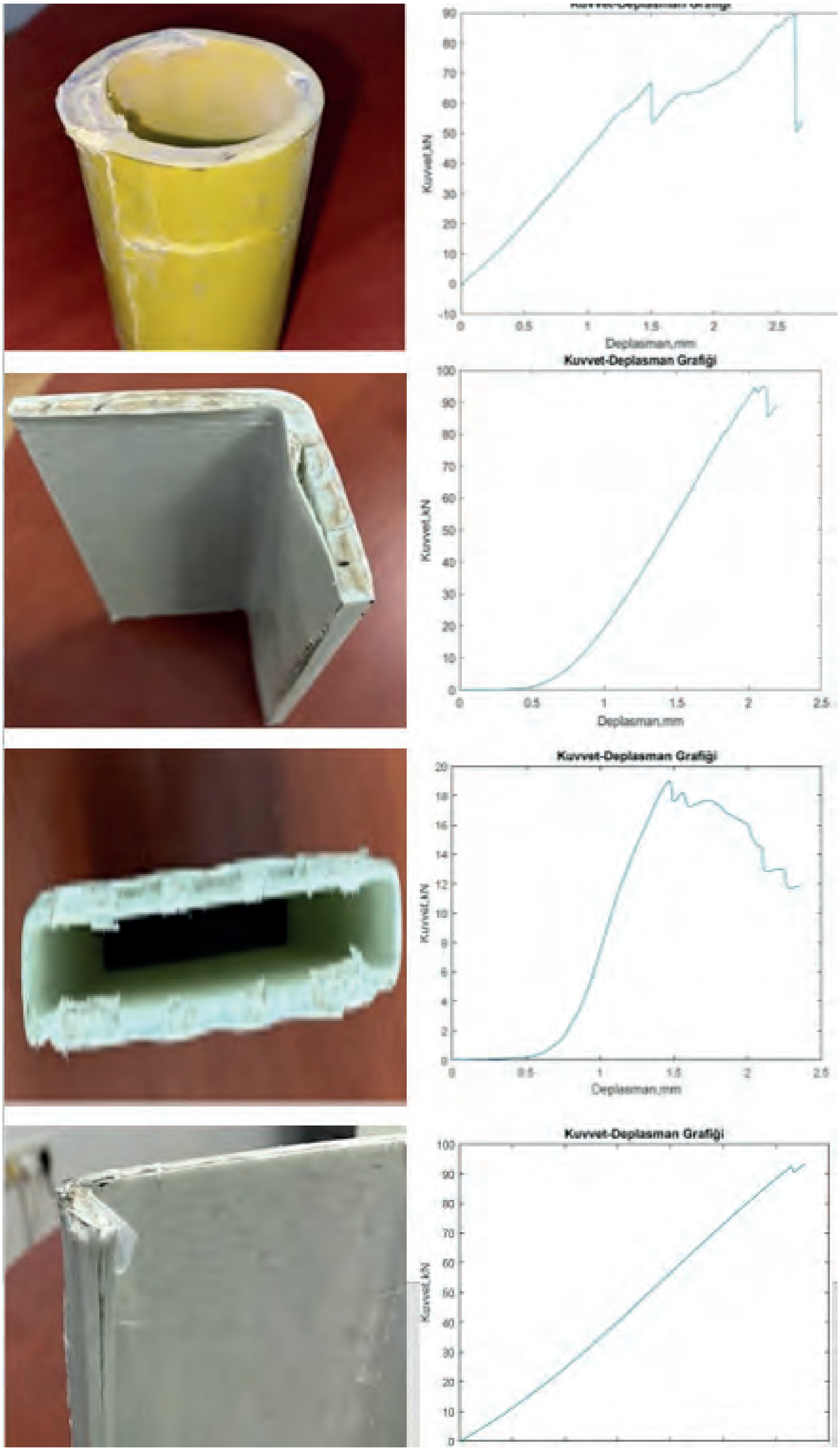
330 mm² cross-sectional area profiles compression force/displacement ratio chart

	Bending force (N)	Displacement (mm)	BF/D (N/mm)
Angle Profile	42300	1.8	23500
I Profile	13200	0.55	24000
Trapezoidal Profile	37500	1.4	26780
Serrated Circular section profile	52300	1.25	41840

In terms of compression strengths, the compression force required per mm displacement is very high in the serrated circular section profile, considering the construction and cost requirements, the serrated circular section profile should be selected first. In the trapezoidal profile and I profile, the ratios are very close and one of these two profiles can be selected as a second option.

Figure 8

Compression test results of GRP profiles with a cross-sectional area of 700 mm²



At a low displacement of 1.5 mm around a compressive force of about 70 kN in a circular cross-section profile, the material was deformed by axial and radial fiber separation. The subsequent destructions and high compressive forces are compressive forces caused by fiber crushing, they have no strength significance.

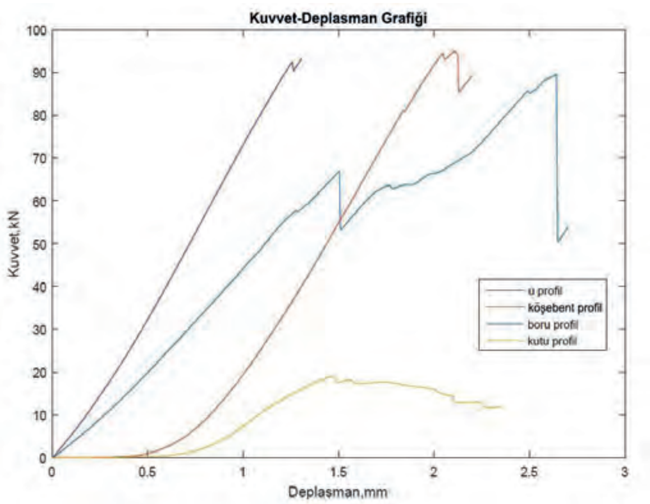
In the gusset section profile, the material was partially buckled, and then reached high compressive forces, especially with the contribution of the section density zone, and at low displacement values, the delamination-like axial layer was destroyed by fiber separation.

In the box section profile, after the jaw effect, the material was damaged in the form of axial fiber separation with a very high displacement/compression force ratio.

Due to the cross-sectional characteristics of the U profile, the displacement/compression force ratio is quite low. The material was damaged by sheet fiber separation from the open ends where the section discontinuity was found.

Figure 9

700 mm² cross-sectional area profiles compression test force-displacement graph combination



It is seen that the compression forces of the U profile and the angle profile with the highest compression force are the highest, but in the angle profile, it is seen that the displacement increases although the compression force of the material increases due to the effect of hard shear forces caused by the geometry of the compression head with partial buckling. In this case, the most ideal profile geometry is the U profile. Then comes the angle profile. A circular section profile can be preferred because it gives a lower displacement value despite high compression force. Since the width and width ratios of the box profile selected in our study are quite different, it is extremely unstable in terms of compression forces.

Table 4

700 mm² cross-sectional area profiles compression force/displacement ratio chart

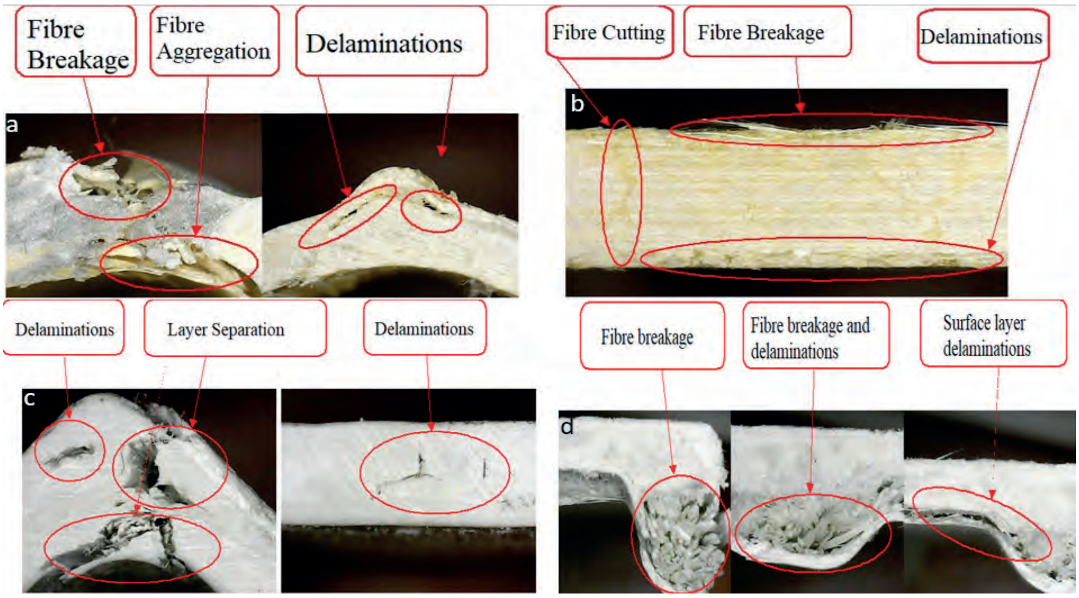
	Bending force (N)	Displacement (mm)	BF/D (N/mm)
Box Profile	19100	1.4	13640
Angle Profile	94500	2.1	45000
Circular section profile	68300	1.4	48780
U Profile	91300	1.3	70230

The most ideal profile with compression force per mm displacement is the U profile. Since the compression force/displacement ratios of the pipe and angle profile are very close to each other, there is no difference in preference if it is suitable in terms of construction and cost.

Microscope Images of Bending Test Damage Area

Figure 10

330 mm² cross-sectional area serrated circular section profile damage images



As can be seen in Figure (a), with the max. loading, breaks occurred in the outer fibers in the tensile direction and fiber aggregation occurred in the inner fibers due to compressive stresses. Geometrically, delaminations occurred at the points where knurled cross-sectional aggregation occurred.

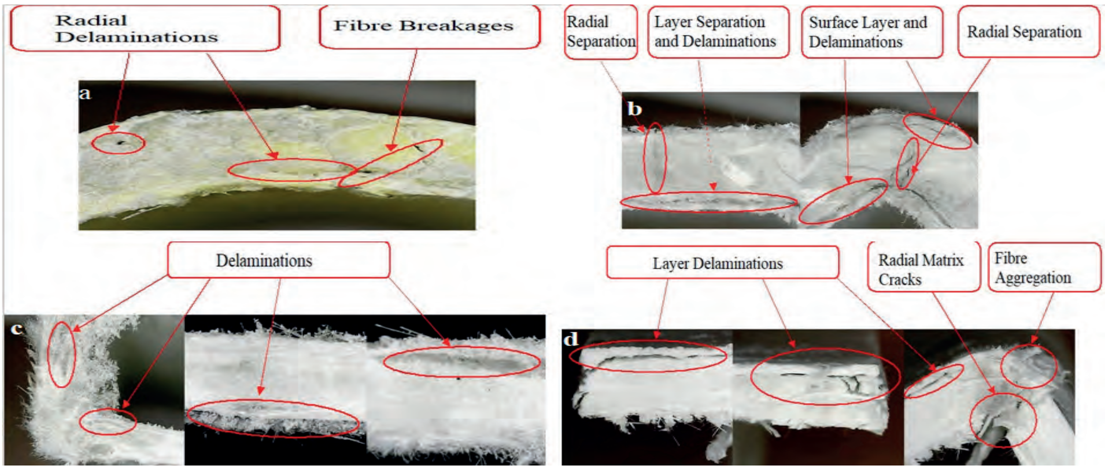
In the I profile in Figure (b) since bending stress was applied from the large surface, fiber breakage occurred in the tensile direction due to the cross-section geometry, fiber aggregation with partial delamination in the compression direction, and fiber shearing occurred due to shear stress caused by the material.

In the angular profile, axial fiber separations in the radial direction, partial delaminations, and serious delaminations in the axial direction at the angle joint point in the third axis due to the bending stress direction occurred in the regions where the section aggregation was the most intense (Figure c).

In the trapezoidal profile, serious fiber breakage and delaminations occurred due to shrinkage at the trapezoidal endpoints where the geometric continuity was broken, and delaminations occurred on the surfaces where the profile was in contact with the extrusion mold due to the deterioration of the resin/fiber ratio on the resin pledge (Figure d).

Figure 11

Damage images of FRP profiles with a cross-sectional area of 700 mm²



Since the circular cross-section profile has a clear circular cross-section without serrations, material production can be carried out more homogeneously. Again, delaminations and fiber breaks occurred in different directions in the axial direction with fiber breaks in the bending stress direction (Figure a).

In the gusset profile, delaminations and delaminations occurred on the surfaces close to the extrusion mold in the axial direction in the edge regions, delaminations in the radial direction, delaminations in the junction region where the cross-section is stacked, and radial delaminations caused by matrix cracking in the direction of bending stress (Figure b).

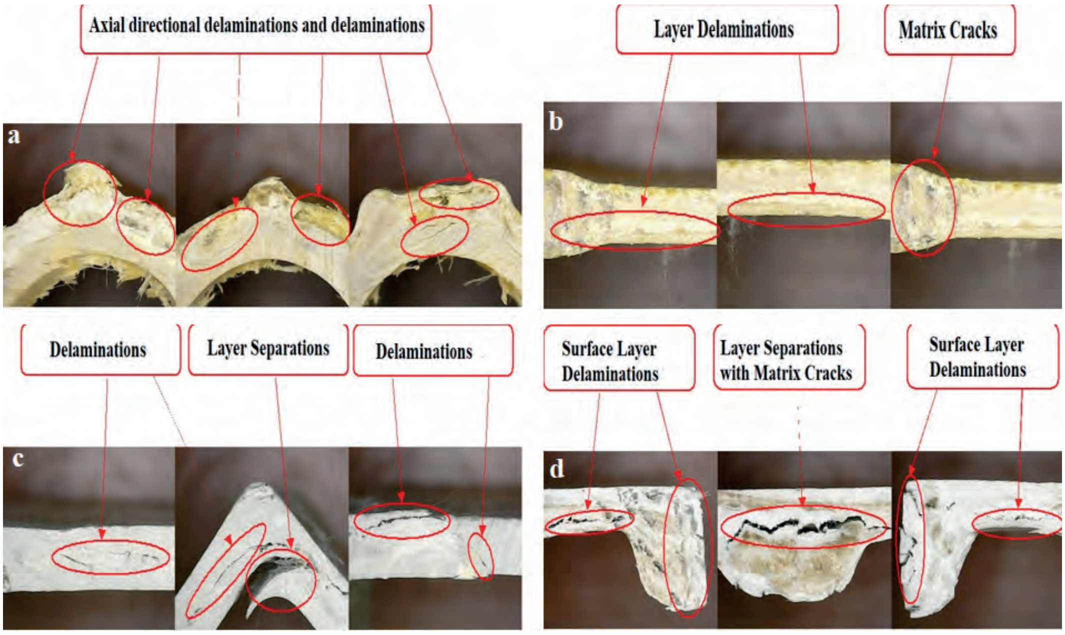
Since the box profile was selected as 130x16x2.5 mm, the bending stress was applied to the surface where the moment of inertia was small, and delaminations occurred partially within the wall thickness of the profile, especially in the areas close to the inner and outer mold surfaces, fiber breaks, and fiber agglomerations in the compression direction, especially in the areas with a thickness of 16 mm (Figure c).

In the U profile, fiber layer separations due to radial matrix cracking at the corner points where the material geometry continuity is disturbed, layer delaminations at the points close to the mold surfaces, and fiber breaks due to tensile and fiber agglomerations due to compression according to the bending methodology (Figure d).

Compression Test Damage Area Microscope Images

Figure 12

Damage images of GRP profiles with a cross-sectional area of 330 mm²



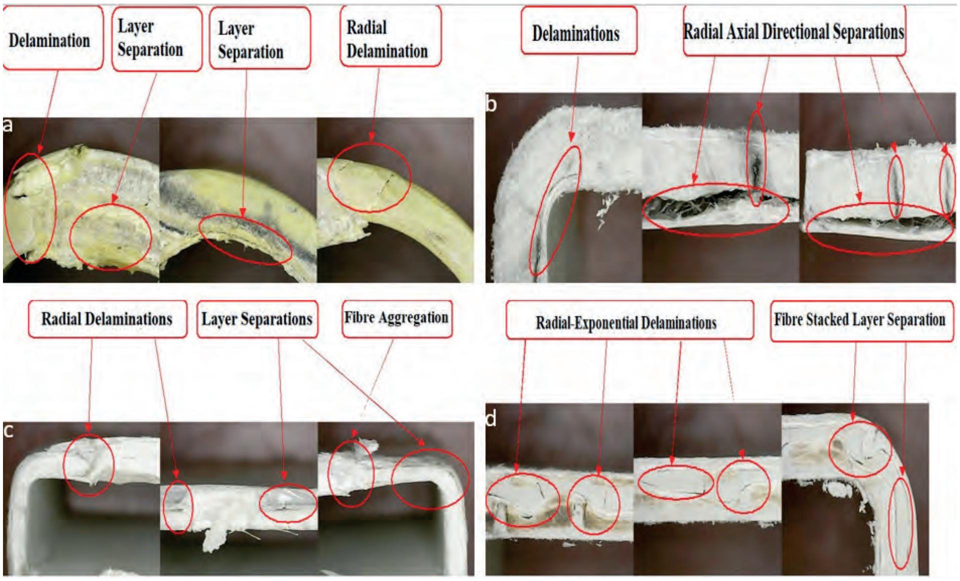
In the serrated circular cross-section pipe, it was observed that the serration regions were very suitable for delamination in the axial direction in the compression direction. This is due to the lack of continuity of the material in the circumferential direction. In extrusion manufacturing, the separations in the knurling regions caused delaminations of the fiber layers in the compression direction as a result of the disruption of the resin/fiber orientation. These delaminations also affect the natural circumferential cross-section of the pipe (Figure a).

In the I profile, matrix cracking and surface layer delaminations occurred in areas where geometric continuity was disturbed (Figure b).

In the gusset profile, delaminations caused by axial matrix cracking in the direction of compressive stress and delaminations occurred at the junction where the cross-sectional stacking occurred (Figure c).

In the trapezoidal profile, delaminations due to matrix cracking occurred at the points where the main section and trapezoidal edges were separated at the points where the material continuity was disrupted, and surface layer delaminations occurred at the points close to the extrusion mold (Figure d).

Figure 13
Damage images of FRP profiles with a cross-sectional area of 700 mm²



In the circular section profile, fiber agglomerations and partial delaminations occurred in the compression direction and partial delaminations occurred in the radial direction. Layer separations were observed on the inner surface of the pipe close to the mold surface. When the compression damage zone was examined, fiber breaks occurred in the circumferential direction approximately 20 mm from the compression surface. Fibre agglomeration occurred due to fiber breaks (Figure a).

In the gusset profile, delaminations caused by matrix delamination in the axial direction in the corner areas, and delaminations in both radial and axial directions in the gusset end areas (Figure b).

In the box profile, radial delaminations caused by fiber agglomeration, circumferential delaminations, and delamination-induced delaminations occurred at the mold edges in the fold areas (Figure c).

Radial axial delaminations in the circumferential direction in the U profile and delaminations caused by fiber agglomeration in the corner areas (Figure d).

Conclusions

In our study, the advantages and disadvantages of different cross-section geometries. In terms of bending and compression stresses in the polyester matrix, glass fiber profiles produced by the extrusion method in two different cross-section groups were tried to be explained. 330 mm² cross-sectional area profiles bending strength of the force-displacement graph of the force-displacement graph is examined, two categories are observed, pipe and angle profiles should be evaluated as separate categories, I and trapezoidal profiles should be evaluated separately. What is important here is low displacement and high bending forces. From this point of view, in terms of construction and cost, if possible, the use of circular section profiles in the first category and the use of trapezoidal profiles in the second category is a scientific necessity in terms of bending strength.

The circular section serrated profile withstood a bending force of 5700 N against a displacement of 8 mm, while the angle profile responded to the same displacement with a bending force of 3500 N. In the second category, the trapezoidal profile withstood a stress of 1800 N for a displacement of 18 mm, while the I profile responded with a force of 700 N for the same displacement, but since the I profile was loaded in the direction of low moment of inertia, it was deformed with a bending force of 1700 N for a displacement of 70 mm.

330 mm^2 GRP profiles are very advantageous against metals in terms of price and weight. In terms of strength, the circular section profile stands out with its resistance to bending and compression, in addition to this, when considered in terms of cost and usability, the most suitable section geometry in this grouping is the circular section profile. The circular section profile is 5 times lighter in comparison to its 30% price advantage. The circular and U profiles in this section group withstand a bending force of 8900 N for the circular section profile and 7800 N for the U profile against a displacement of 10 mm. In both profiles, the first fractures occurred superficially and in areas where the material continuity was disturbed according to the geometry of the force application end. The gusset and box profile withstood a bending force of 3100 N for the gusset profile and 1000 N for the box profile for a displacement of 2.8 mm.

In the gusset profile, relatively high bending strength, low displacement ratio, and deformation in the form of layer separations in the ridge region with section density were observed, while in the box profile, the applied force decreased and the displacement increased due to the excessive flexing of the section in the horizontal axis. When the bending force/displacement ratio is analyzed, the most advantageous section is the angle profile with a ratio of 1107. If it is suitable in terms of construction, the most suitable section in terms of strength is the angle iron profile.

In terms of cost; angle iron profile is 35% cheaper and 5.5 times lighter than metals.

In the compression test, a serrated circular cross-section profile is the most ideal profile geometry since it has the highest compression strength and the lowest displacement ratio. Then the trapezoidal profile has high compression and low displacement values in proportion to the size of the trapezoidal edges. Although the angle profile seems to be partially buckled, it is still the third profile geometry we would prefer. I profile is not an ideal section geometry since it has a very low displacement/compression ratio.

When evaluated in terms of strength, the use of a serrated circular cross-section profile is a scientific necessity. The biggest reason for preference is that it is lighter for a 30% price advantage.

The compression forces of the U profile and angle profile were found to be the highest. In this case, the most ideal profile geometry is the U profile. The compression force/displacement ratio of the U profile is 70230 N/mm. Then comes the angle iron and circular section profile. The compression ratio/displacement ratio of both profiles is equal to each other, the construction requirement is the factor of preference here. Since the width and width ratios of the box profile selected in our study are quite different, it is extremely flimsy in terms of compression forces. The most suitable profile section in terms of cost is the angle profile. When the damage zone images are examined, it is necessary to evaluate these sections in detail as a result of serious delamination in the axial direction due to disruption of material continuity in serrated circular and trapezoidal profiles with a cross-sectional area of 330 mm^2. In all of the profiles with both cross-sectional areas, serious delaminations due to matrix separation occur on the mold contact surfaces due to the decrease in resin viscosity when the fibers contaminated with polyester resin enter the heated extrusion mold. This is the biggest disadvantage of GRP profiles produced by the extrusion method. The solution to this problem is to change the fiber feeding angle and algorithm.

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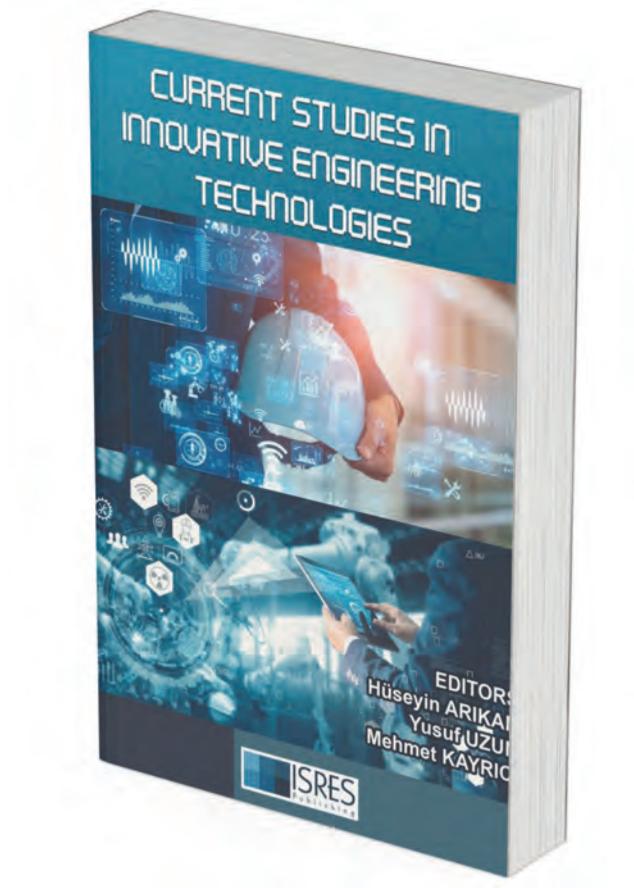

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