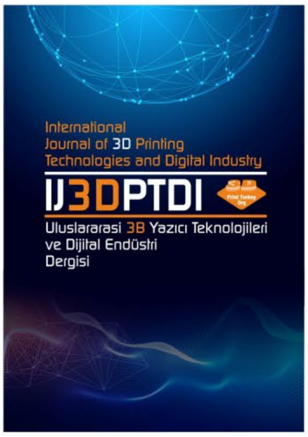

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DIGITAL INDUSTRIALIZATION IN THE TRANSITION TO 3D PRINTING TECHNOLOGY

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DIGITAL INDUSTRIALIZATION IN THE TRANSITION TO 3D PRINTING TECHNOLOGY

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ABSTRACT

In this article, details for the increasing properties with the help of 3D printer assisted technique of a material produced by classical sand mould casting method through a technological transformation were presented. At the same time, digital transformation studies were included with the development of online data monitoring systems in mass production. After the design studies were carried out with Solidworks, design verification research with computational fluid dynamics (CFD) and finite element analysis (FEA) have been realized. Solidification, filling-time-temperature analyses, and casting simulation studies of micro and macro shrinkage were carried out using the Anycasting simulation program. Then the intensive use of simulation techniques, the activities that would increase the quality of the product with 3D printers were detailed. The microstructure investigation, chemical analyses, and mechanical tests were performed to prove the positive effect of the 3D printing system. Surface morphology determination results showed that the better outcomes have been obtained from the 3D printing reinforced system. Finally, a unique data monitoring system that could communicate with production equipment for the first time in our country without the need for any external software and license, within the scope of digital industrialization system were explained. With the commissioning of the 3D system, 44.2% increase in efficiency and 33% improvement in quality rates were achieved. The biggest advantage of this system is that the total amount of energy consumed was reduced from 197 mJ to 81 mJ.

Keywords: 3D Printing, Digital Industrialization, Digital Transformation, Casting, Additive Manufacturing.

1. INTRODUCTION

Casting is a production method that allows the production of parts by solidifying the liquid metal in a mould. Sand mould casting, which is the oldest known casting method, is widely preferred due to its low production costs [1-6]. For this reason, it has become a necessity to carry out technological transformation and digitalization in quality improvement activities as well as cost reduction studies in casting process with the traditional sand mould method of materials with different structures and geometries [7-11].

Sintering is one of the methods developed as an alternative to the traditional casting method with a technological approach [12]. Sintering can generally be defined as the joining process performed at 2/3 of the melting temperature of the powder particles and at a rate of 0.8 times in general applications [13-14]. Sintering was initially considered under the science of powder metallurgy and was applied to metals with very high melting temperatures such as tungsten, molybdenum, vanadium. After being used in all kinds of metal applications with the advantages of working at lower temperatures, homogeneous structure, and high strength values, it was started to be applied to all ceramic, plastic and polymer materials and positive results were obtained [15-19].

Additive manufacturing, which has become one of the most up-to-date production methods of today, has also been developed by being inspired from the sintering technology [20]. 3D printers have been developed to serve this purpose and have started to be preferred in almost all sectors such as health, defence industry, automotive and aviation sectors [21].

Two types of raw materials for 3D printers are generally used on the application. PLA (Polylactic Acid) is an organic biopolymer and thermoplastic produced from corn starch and sugar cane. Therefore, it is not harmful to human health. However, ABS (Acrylonitrile Butadiene Styrene) is often used in industry for injection moulding and is widely used in toys, tools, sporting goods, etc. equipment is produced. In general, PLA should be the filament of choice if an easy printing experience is valued over engineering features [22-25]. The comparison of the PLA vs ABS is shown in the Figure 1.

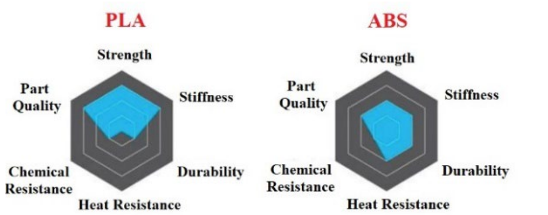


Figure 1. Comparison of PLA vs ABS [26].

If looking for a part that is more resistant to impact and will be used for a long time, ABS should be chosen [27]. As seen in Figure 2, the surface quality and colour difference produced by PLA and ABS samples for the field application can be distinguished clearly. ABS can be easily dried with hot air (perfectly dry) sources. PLA reacts differently to moisture, in addition to bubbles or spurts from the nozzle, colour change and reduction in 3D written part properties can be seen [28-31].

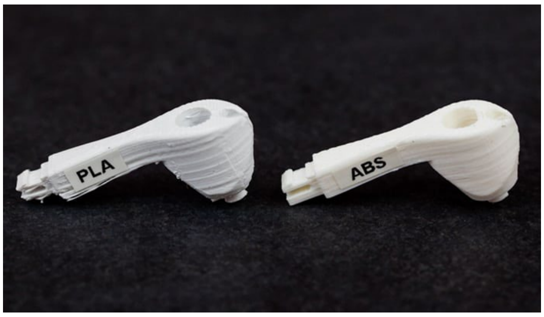


Figure 2. 3D printed samples appearance [26].

With the commissioning of 3D printers, studies on their adaptation to automation applications have increased and accordingly the concept of innovation has gained importance. In the Oslo Manual, innovation is defined as the whole of systematic studies of optimizing a process, increasing efficiency, implementing the logistics and assembly system [32]. Following the development of automation systems, digital transformation strategies dealing with production systems, software and robotic applications that can organize processes have a critical importance [33-35].

Digital transformation is defined as the process in which institutions and organizations integrate their technologies into their businesses to drive fundamental change [36]. The benefit it provides; increased productivity, greater business agility and ultimately unlocking new values for employees, customers, and shareholders [37]. Examples of digital transformations include the modernization of information technologies, such as the move to a cloud environment, remote readiness, re-skilling employees, implementing automation to accelerate customer support and service, and using artificial intelligence driven insights to increase sales efficiency [38]

In this study, it is aimed to share the data details of the research carried out with the help of 3D printers of the traditional sand mould casting system, product development, process optimization and digital transformation. In the first stage, the comparison of the redesign for the mould of a part produced with the traditional casting method with a 3D printer was presented in detail. In order to make the technological transformation data obtained in the first stage meaningful, the traceability of the products produced with the help of online data monitoring systems and 3D printers, the efficiency tracking, the digital transformation of the quality analysis data was mentioned in the second stage. Finally, the advantages of the developed 3D printer assisted product and improved online data system for the digital transformation were presented with details.

2. MATERIAL AND METHOD

2.1. Design

The initial designs of the specimen to be simulated, produced, tested, and characterized were drawn with the help of CAD (Computer Aided Design) by using AutoCAD program.

2D (two-dimensional) drawings provided the fundamentals for the design, as well as giving the designer an idea for 3D (three-dimensional) drawings. The 3D drawings were carried out via Solidworks 3D solid modelling and design software.

2.2. Simulation

In order to determine the mechanical strength of the material and to optimize the design according to the limit values, mechanical analyses were carried out by using FEA (Finite Elemental Analysis) method in the ANSYS simulation program. The strength values of the valve designed in FEA were determined according to the boundary conditions defined in the EN 1704 standard. The parts were handled with two different numerical methods, singular and assembled, and interpolation solution was realized with the Rayleigh-Ritz method.

CFD (Computational Fluid Dynamics) analyses were carried out by using ANSYS CFX module according to EN 12666 and EN 1074 standards. In CFD analysis, it was solved with the K-epsilon turbulence model, and improvements were made in the boundary layers and mesh by keeping the y+ value at 3 and below.

Anycasting simulation program was used to produce the product with suitable mechanical design under the right conditions and to determine the production parameters. The design was carried out with single runner feeding in the simulation program. However, the data were taken as CuSn10 material and casting temperature 1150 °C.

2.3. Production

Due to its widespread use and low production cost, the materials were cast by sand mould casting method in accordance with DIN 1075 - 2.1050 standards. This standard defines the mechanical and metallurgical properties of tin bronzes. The most prominent feature of tin is that it increases the strength of the alloy. Tin bronzes are durable, hard and have very high ductility. Pump, turbine propellers, bearings operating at heavy load low rotational speed, worm and volute screw, worm gear and plain bearings.

In order to provide technological transformation with an innovative approach to the casting method, which became a traditional and outdated application, to ensure technological transformation, material production was carried out in the 3D printer. Zortrax M200 Plus model additive equipment was used for the 3D manufacturing stage as shown in the Figure 3.

Figure 3. 3D Additive manufacturing equipment.

2.4. Characterization

Chemical analysis of the casting material was carried out with Metavision 1008 brand spectrometer. The mechanical properties of the samples were determined by notch impact and tensile tests. The samples prepared for the notch impact test were tested with an OTTO WOLPERT WERKE PW 30/15 brand machine at a temperature of 25 °C, and the samples prepared for the tensile test were tested at room temperature with an OTTO WOLPERT U-40 type tensile device.

The samples, which were moulded into polyester moulds for microstructural analysis, were grinded and polished with the STRUERS Tegrapol-21 brand grinding and polishing device by turning 90° each time with 600 grades SiC sandpaper, 220 grade 9 µm, 3 µm and 1 µm felt and diamond pastes, respectively, and made ready for the etching process. Prepared samples for the microstructure analyses were etched with 15 g $FeCl_3$, 75 ml HCl, 25 ml HNO_3, 25 ml H_2O solution for 10 seconds. Then, the samples were investigated with a 1000 magnification NIKON ECLIPSE LV 150 optical microscope. The hardness values were tested at room temperature with an ALBERT GNEHM brand universal hardness measuring machine with Brinell tip.

2.5. Digital Transformation

The digital transformation studies were carried out to increase the operational efficiency during the production of materials by using 3D printers.

From additive manufacturing production lines; waste, failure rate, cycle time, instantaneous temperature, pressure, filament amount, raw material rate etc. A data collection and analysis system has been developed that can record and report the data, analyse this data, and monitor the production, and work in harmony with PLC. A data collection and analysis system has been developed that can record and report the data taken from the additive manufacturing production lines such as cycle time, instantaneous temperature, pressure, waste and failure ratio, filament amount, raw material usage etc. The developed system is a digital transformation software that is compatible with PLC (Programmable Logic Controller) and integrated to ERP (Enterprise Resource Planning) applications. Figure 4 illustrates the industrial automation pyramid for the digitalisation.

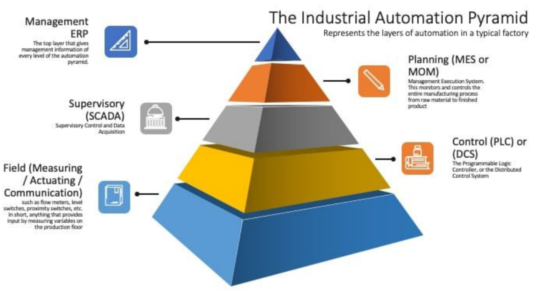


Figure 4. The industrial Automation Pyramid [38].

3. EXPERIMENTAL FINDINGS

The technical details targeted in the article for the CFD analyses in line with the requirements defined in the EN 1267 and EN 1074 standards are given in Table 1.

Table 1. Technical properties for CFD.

Properties	**Unit**	**Value**
Line Pressure	*Bar*	16
Fluid Velocity	*m/s*	5.0
Flow Coefficient	m^3/h	52000

The parameter that would support the velocity vector analysis of this system should be its characteristic behaviour under 16 bar pressure, and velocity vector analysis was carried out. Accordingly, when the disc was in the fully open position, the resistance of the disc and the body against flow could be characterized more clearly. Innovative design trials have been carried out to suit the desired conditions. Figure 5 shows the velocity vector analysis of the system under 5 m/s. According to the research in the literature, it has been determined that there are factors that disrupt laminar flows, sharp surface change, temperature change and material resistance in valve disc materials [39-41]. As a result of these evaluations, no problems were encountered in the CFD analysis of the disc material at a flow rate of 5 m/s, and it was observed that the flow lines were suitable in red and yellow colours.

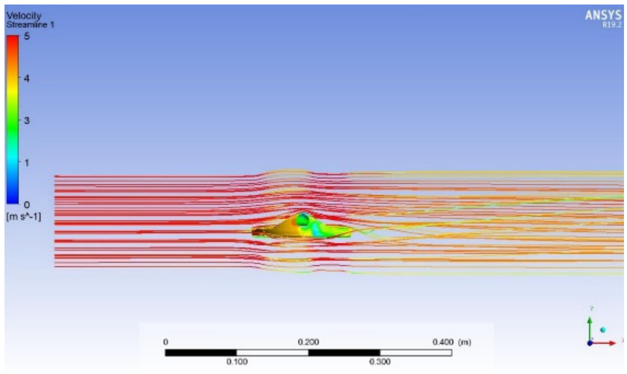


Figure 5. CFD analysis.

In order to increase the desired flow coefficient, in other words valve efficiency, various designs have been made in the disc geometry. The mechanical numerical analysis method was carried out by defining the boundary condition of ten percent of the nominal pressure for the disc materials, which were carried out by considering the yield strength values of 130 MPa. Accordingly, the mechanical analysis of the disc regarding to 18 bar, which corresponds to 1.1 times the maximum working pressure of 16 bar, is shown in Figure 6. The design developed to increase the mechanical strength of the disc exposed to the flow surface was defined by FEA and no red areas, which represent high stress zone encouraging plastic deformation, were observed.

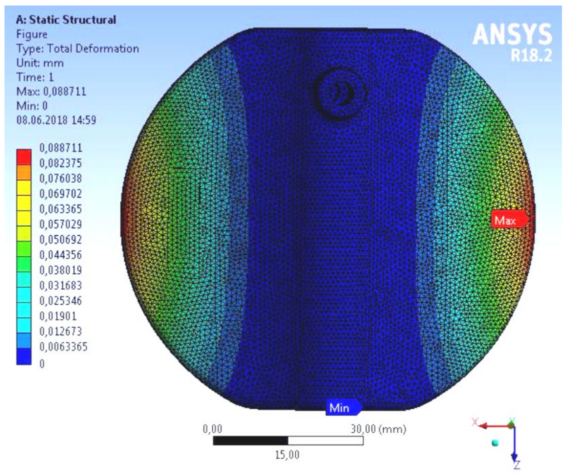


Figure 6. FEA analysis.

Anycasting simulation program was used to produce the specimen with suitable mechanical design under the right conditions and to determine the production parameters. The design was carried out single double runner feeding in the Anycasting simulation program. In the simulation, the data was taken as CuSn10 material and casting temperature at 1150 °C. According to the simulation data, the casting process took 19 seconds. Figure 7 illustrates the casting simulation by considering heating analyses.

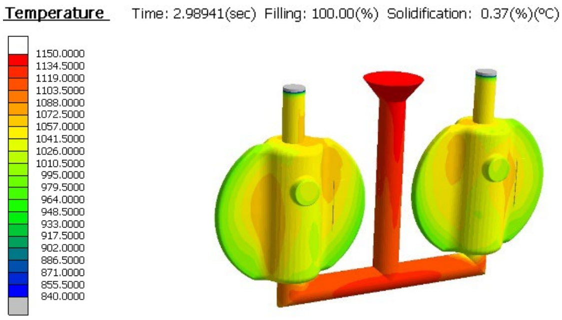


Figure 7. Casting simulation.

The chemical analysis, of the material known as CuSn10 and defined as Standard Alloy Number (C90700 / SAE 62, DIN 1075 - 2.1050, CC480K) was given in Table 2.

Table 2. Chemical analysis of the samples.

Element	Unit	Value
Cu	%	88.0-90.0
Sn	%	9.0-11.0
Zn	%	0.5 max.
Pn	%	1.0 max.
Ni	%	2.0 max.

The mechanical properties are given in Table 3 in order to define elastic and plastic limits of the materials.

Table 3. Mechanical properties of the materials.

Properties	Unit	Value
Yield Strength	*N/mm²*	120-140
Tensile Strength	*N/mm²*	240-260
Elongation	*%*	17-19
Charpy Impact Value	*Joule*	9-12
Hardness	*HB*	70-75

The casting process was carried out in accordance with the defined criteria, but the surface of the sample was not homogenous as seen in Figure 8.

Figure 8. Casted sample image

As the surface properties were far below the expectations, 3D printer was used for the production of the materials. The manufacturing was carried out with support angle 30°, nozzle diameter 0.4 mm, maximum wall thickness 3.13 mm. ABS was chosen as the filament material due to its high temperature and mechanical resistance. Additive manufacturing took 3 h 28 m and used 14.77 m (35 g) of ABS material. The details and final product image were shown in the Figure 9.

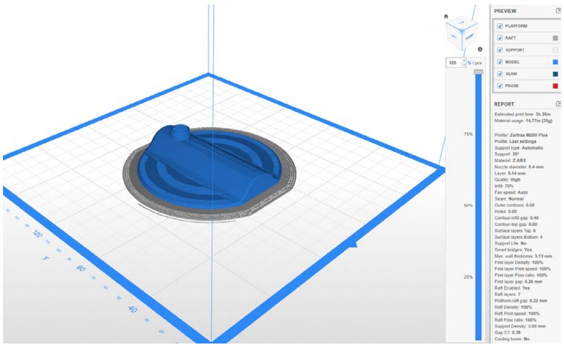


Figure 9. Additive manufacturing zone and layer parameters

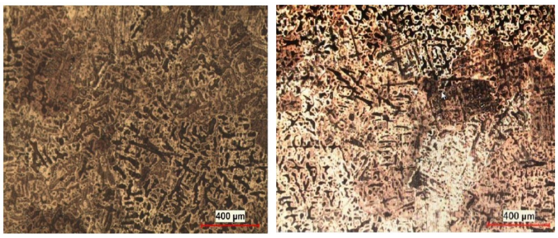
The visual of the mould model obtained from the 3D printer is shown in the Figure 10. As can be seen in this image, dimensional tolerances, and product quality display a high appearance.

Figure 10. Additive manufacturing mould.

Figure 11 illustrates the surface quality of the material produced by the 3D printer combination. The surface quality is quite high that does not include any cracks, porosities, fracture etc.

Figure 11. 3D moulded specimen

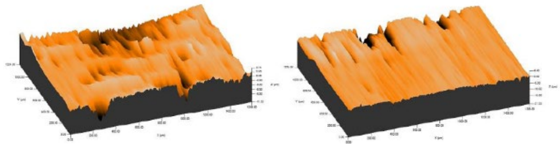
The determination of microcracks, porosities, inclusion, and any other defects were carried out by investigation of the microstructures. Figure 12 shows the microstructure comparison of cast and 3D printer supported samples. While no fracture and porosity were observed in both microstructures, the dendritic structure was more clearly observed in the products produced with the help of 3D printers. This homogeneity is due to the stable data of the 3D system.



(a) Casted (b) 3D printer assisted

Figure 12. Microstructure of the samples.

The product surfaces were compared according to the inside-out characterization methodology and this difference was clearly observed in Figure 13. The surface quality of the products produced with the help of 3D printers is more homogeneous and more stable.



(a) Casted (b) 3D printer assisted

Figure 13. Surface of the samples.

Within the scope of digital transformation, for the first time in our country, an online data monitoring system, which can communicate with 3D printer benches without using any middleware and can operate without the need for an external software and license, has been implemented. This digital production management system is the summary definition of the automation system that aims to remove the data entry initiative of the personnel working in the production and to move the factories to higher levels in their 3D manufacturing sector with higher efficiency and competitive costs with the introduction of digital control systems. Topology optimization, within a design material distribution depending on specific load and boundary conditions, desired design and it is a design technique that enables to reach production. With the developed software topology, a system that can communicate between the machines in production in an integrated way without the need for any interface connection has been obtained. The topology algorithm was developed in Matlab environment, and Gekko optimization was used in the application of the topology phase. Figure 14 shows the topology of this system.

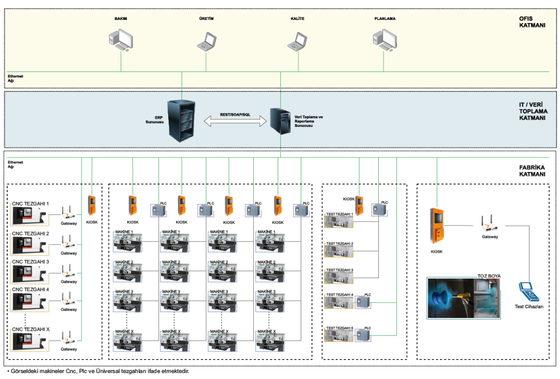


Figure 14. Topology of the digital transformation system.

Thanks to the developed digital system, in addition to production capacity and speed, productivity has increased significantly, standard products have been produced by reducing error rates, problems and malfunctions can be minimized. Moreover, quick solutions can be offered, general situation control might be made with detailed system analysis, and malfunctions can be made independently by the operator. Figure 15 shows the screenshot of the software system where the digital transformation was provided.

Figure 15. Digital transformation software system screenshot.

4. RESULTS

In this article, a detailed comparison of 3D printer systems for the development of traditional casting method and studies of digital conversion systems developed as a result of this comparison were presented.

Methodologies and measurement systems were implemented to increase energy, labour, process, and operational efficiencies by using natural resources efficiently, and this comparison was made according to more concrete data. Table 4 helps to understand this comparison by details.

Table 4. Comparison 3D method.

Parameters	Traditional Product	3D Printer
Material Type	*CuSn10*	*CuSn10*
Temperature (°C)	*1150*	*1150*
Quality Rate (%)	*67*	100
Efficiency (%)	*42.7*	*86.9*
Surface Quality (R_a)	*0.81*	*0.02*
Total Energy (mJ)	*197*	*81*

According to the online data monitoring results of the 3D printer system, it has been observed that it is 44.2% more efficient and 33% higher quality than the traditional casting method for the same material and at the same temperature. Total consumed energy for the production of 3D system is 81 mJ where the traditional casting method needs 197 mJ. A distinguished difference was observed between the surface qualities of the resulting products of these two systems. Surface roughness of the 3D printed system was measured as 0.02 ηm, moreover traditional casting method gives 0.81 ηm surface asperity value, that is 40 times higher than 3D printer method.

5. DISCUSSION

It has been determined that the data related to the digital transformation of 3D printers in businesses have not been discussed in detail from the design to the final product in previous studies. Moreover, all the details from design to production, from characterization to digital transformation were handled with data and this condition makes this study unique. Therefore, specific studies can be carried out for manufacturing sectors by considering the data given in this manuscript with details. Finally, with the digitalization of 3D printers, a significant increase in efficiency values was detected, and it is also quite effective in improving quality and reducing costs.

6. CONCLUSION

The motivation that started this work was to present its technological transformation with 3D printer systems to bring an alternative and innovative approach to the traditional casting method. However, it was to convey the details of the digital transformation in the new production method obtained to the readers with its data.

Today, it has become an inevitable reality to integrate all kinds of technological transformation with digital transformation in order to better demonstrate its success. In this study, savings in material, labour and time were achieved and detailed information about the academic and commercial studies of high-efficiency, low-cost products were given. The details of design development and process improvement studies, which are the two important points of reducing costs today, were given together and a privileged study was presented with a different approach. A synthesis of 3D printers, which is an important topic of today, and digital industry concepts, which is a popular topic, has been shared with the readers.

7. ACKNOWLEDGEMENT

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