ADDITIVE MANUFACTURING TECHNOLOGIES (3D PRINTING) IN MECHANICAL ENGINEERING

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Abstract: Additive manufacturing technologies, also known as 3D printing, have revolutionized the field of mechanical engineering by enabling the production of complex components with a high level of customization and efficiency. This article explores the applications of 3D printing in mechanical engineering, addressing the processes, materials used and the advantages of this technology over traditional manufacturing methods. By comparing the costs, precision and durability of 3D printed components, the paper highlights the benefits of this technology in the production of prototype parts and even small series production parts. Practical applications in industries such as automotive, aerospace and biomechanics are also discussed, demonstrating its significant impact on manufacturing and innovation processes. In conclusion, the potential of 3D printing to transform design and production in mechanical engineering is emphasized, given the technological developments and associated cost reduction.

Keywords: Additive Manufacturing, Complex Geometry, Selective Laser Sintering, Mechanical Prototype, Industrial Materials

1. INTRODUCTION

Additive manufacturing, also known as 3D printing, is a revolutionary production process that enables the creation of components through the successive addition of material layers. This technology has rapidly evolved and has become essential in the field of mechanical engineering, offering innovative solutions for prototyping, customized production, and waste reduction.[1, 2]

Over the years, additive manufacturing technologies have been successfully applied in industries such as aerospace, automotive, and medical sectors. These applications highlight their potential to transform traditional manufacturing processes by

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increasing flexibility and efficiency. The purpose of this paper is to analyze the main additive manufacturing technologies used in mechanical engineering, the methodologies involved, and their impact on production processes

Stereolithography (SLA) is one of the first developed additive manufacturing technologies, widely used due to its precision and high-quality surface finishes. The process involves using an ultraviolet laser to solidify a photopolymer liquid material layer by layer. With precise laser control, extremely fine details can be achieved, making SLA ideal for creating prototypes and complex parts. Advantages and limitations of SLA include:

- High precision: Fine details and smooth surfaces.
- Versatility: Excellent suitability for various industries, including dentistry and aerospace.
- High material costs: The resins used are more expensive compared to other materials.
- Fragility: Produced parts may have reduced mechanical strength'

FDM, also known as Fused Filament Fabrication, is one of the most popular additive manufacturing methods. The process involves extruding a filament of plastic material, which is then deposited layer by layer onto a platform. This technology is favored for its low costs and operational simplicity. Advantages and limitations of FDM include:

- Accessibility: Low costs for equipment and materials.
- Versatility: A wide range of available materials, including PLA, ABS, and nylon.
- Ease of use: Ideal for non-industrial and educational users.
- Surface quality: Layers may be visible, requiring post-processing.
- Lower precision: Compared to technologies like SLA.

SLS uses a laser to sinter fine layers of powder material, such as metals, polymers, or composites. This technology enables the manufacturing of complex parts without requiring support structures, making it ideal for industrial production. Advantages and limitations of SLS include:

- High mechanical strength: Produced parts are robust and durable.
- Geometric flexibility: Allows for the creation of complex shapes without significant limitations.
- Efficiency: Suitable for small to medium production runs.
- High costs: Both equipment and materials used are expensive.
- Post-processing: Cleaning parts to remove excess powder is necessary

Materials used in additive manufacturing include metals like titanium, aluminum, and stainless steel; polymers such as ABS, PLA, and nylon; and composites including carbon fiber-reinforced materials. Additive manufacturing offers several advantages, including flexibility in design, cost reduction for small series, and waste minimization. However, it also presents limitations, such as longer production times for large parts, high costs for certain materials, and inferior mechanical properties compared to traditionally manufactured parts.[3]

2. METHODOLOGY AND RESULTS

A case study will be analyzed, focusing on the use of Selective Laser Sintering (SLS) additive manufacturing technology for producing a complex mechanical prototype, a gear housing used in industrial applications. This part has a complex geometry, including internal cavities for lubrication and supports for fastening components, features that make it difficult to manufacture using traditional manufacturing methods.

The chosen gear housing for the case study is a mechanical component with a complex geometry, intended for specific industrial applications requiring both mechanical strength and operational efficiency. The part’s role is to protect and house the gear system, featuring a detailed structure to accommodate various components and ensure their proper installation.[4]

The part’s geometry is characterized by the presence of several internal cavities, essential for the efficient distribution of lubricant, which prevents premature wear and overheating during operation. These cavities are difficult to achieve using conventional methods such as casting or milling, which struggle with the precision and complexity of the internal forms. Additionally, the housing includes supports for mounting other components, which further complicates the manufacturing process.

The manufacturing requirements for the part are clear and include the following objectives:

- Dimensional accuracy: The part must meet strict tolerances, particularly in areas where it integrates with other components, ensuring proper assembly and optimal system performance.
- Geometric complexity: The internal cavities and mounting supports require a technology capable of creating these features without compromising the structural integrity of the part.
- Weight reduction: Given the industrial applications, the part needs to be lightweight while still capable of withstanding the mechanical stresses encountered during operation.

These technical requirements align perfectly with the advantages of additive manufacturing technologies, particularly Selective Laser Sintering (SLS), which can produce complex and precise parts without the need for additional post-processing steps.

To produce the gear housing with its complex geometry, Selective Laser Sintering (SLS) technology was used. This is an additive manufacturing method where a high-precision laser melts and fuses fine material particles, such as nylon or various metal alloys, to build the part layer by layer. Compared to other 3D printing technologies, SLS stands out for its ability to create parts with superior mechanical strength, making it ideal for industrial applications.

The manufacturing process began with the creation of a digital model of the part using CAD (Computer-Aided Design) software. This model was then exported in a format compatible with the 3D printer used for the SLS process.

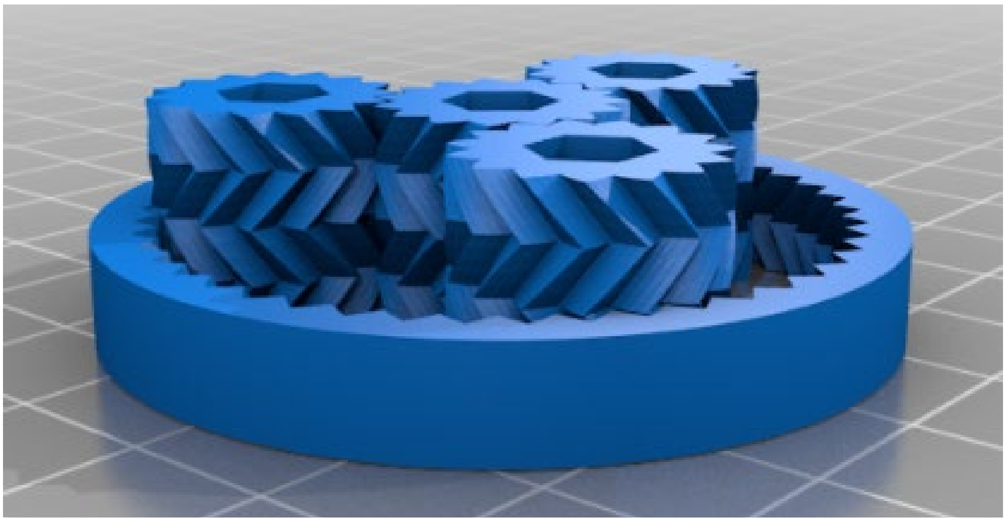

Fig.1 The digital model

Fig.2 The final piece.

During the process, a thin layer of powder material, typically nylon, was deposited onto the printing platform. A powerful laser then melted the powder particles, fusing them to create the first solid layer of the part. After the first layer solidified, another layer of powder was added, and the process was repeated until the entire part was complete.

It is a planetary gearset and functions like a cross between a needle bearing and a thrust bearing. No cage is required to keep the rollers in place, because their gearing keeps them perfectly spaced. The gears are all herringbone, which is why it cannot be disassembled and also why it can act as a thrust bearing.

A major advantage of the SLS process is that no external support material is required to support the part's geometry. The unused powder surrounding the part that is not melted by the laser acts as a support for the part's complex structures, including internal cavities. This makes the process more efficient and reduces the risk of defects that could occur during the production of complex parts.

Another important aspect of the SLS process is that the parts are made from high-quality material that offers excellent mechanical strength and durability, making them suitable for harsh industrial environments. After the printing is complete, the part can undergo a light finishing process, such as cleaning the unused powder and removing any surface imperfections.

Table 1. **Comparison of production costs for traditional methods and 3D printing**.

No.	Method	Cost per unit (USD)	Production time (hours)
1.	Casting	50	10
2.	3D printing (SLS)	30	5

In table 1 we presented the differences between the two method and it's results that the 3D printing it's much more efficient.

The additive manufacturing process using Selective Laser Sintering (SLS) technology brought several significant advantages compared to traditional manufacturing methods.

One of the greatest benefits of SLS technology is its ability to produce complex geometries, including internal cavities and support structures, features that cannot be efficiently achieved through traditional methods such as casting or milling.

In the case of the gear housing, these intricate details, which are essential for the performance of the part, were achieved with great precision without requiring costly or complicated additional processes.

Additionally, production time was significantly reduced. While traditional casting would require approximately 20 hours of production, using SLS technology, the production time was reduced to just 8 hours. This reduction in production time contributes not only to the efficiency of the process but also to the reduction of production costs, while simultaneously enabling rapid prototype production and quick design modifications if needed.

Another considerable advantage was the optimization of the part's weight. The adapted design for SLS production allowed for a weight reduction of approximately 15%. This improvement is particularly important for industrial applications, as a lighter part reduces energy consumption, thereby improving the performance of the system and contributing to its durability. Furthermore, weight reduction helps minimize wear and stress on moving components.

These benefits highlight the positive impact that SLS technology can have on manufacturing processes, demonstrating its efficiency and versatility, especially in the case of complex parts required in mechanical industries.

The choice of material for the additive manufacturing process is crucial to ensuring the performance and durability of the final part. For the gear housing prototypes produced through SLS technology, materials suitable for industrial requirements were used, offering an optimal combination of mechanical strength and durability.

Among the most commonly used materials are nylon (PA) and metal alloys, each of which has characteristics making it suitable for various industrial applications.

Nylon is a polymeric material with excellent mechanical properties, thermal stability, and wear resistance, making it ideal for parts that will be subjected to moderate mechanical stresses, such as gear housings.

Additionally, nylon is easy to process and can be used to produce parts with fine, complex details such as internal cavities needed for lubrication.

In some cases, for more stringent mechanical strength requirements, metal alloys, such as aluminum or stainless steel, may be used, providing additional resistance to high mechanical and thermal stresses. These materials are particularly used for parts that must withstand extreme operating conditions, such as components in industrial engines.

Additionally, depending on the specific requirements of the part, special polymers such as carbon fiber-reinforced nylon or heat-resistant nylon can be used. These materials are ideal for applications that require additional resistance to mechanical stress or extreme temperatures.

The choice of material depends on factors such as the environmental conditions in which the part will be used and the mechanical stresses it will undergo. By using the appropriate materials, the SLS process ensures the production of durable, reliable, and high-performance parts that meet the strict demands of the mechanical industry.

3. CONCLUSIONS

In conclusion, additive manufacturing technology, specifically Selective Laser Sintering (SLS), represents a revolution in the production process of complex mechanical parts, offering multiple advantages over traditional methods.

The use of this technology allowed for the creation of precise and efficient prototypes, such as the gear housing analyzed in this case study, which features complex geometry and details that are difficult to achieve using conventional methods like casting or milling.

The SLS technology has proven to meet the stringent requirements of the mechanical industry, including the creation of internal structures for lubrication and support for fastening components, which are essential for the part's performance in industrial applications.

One of the most important benefits of using SLS is the significant reduction in production time. While traditional manufacturing methods like casting would have required hours of work to produce a part, the SLS technology allows for the part to be created in a much shorter time, making prototypes easier to produce and modify.

This not only improves the efficiency of the manufacturing process but also contributes to cost reduction, which is crucial in an ever-changing industrial environment where speed and adaptability are key.

Another considerable advantage was the reduction in the part's weight. By using a design adapted and optimized for SLS, it was possible to achieve a significant decrease in the weight of the gear housing, which directly contributes to the improvement of the part's performance in industrial applications.

A lighter part means less energy consumption, less wear, and, ultimately, greater equipment durability. These improvements are not only economic but also ecological, as they contribute to reducing the carbon footprint of the production process.

The choice of the appropriate material was also a crucial factor in the success of this manufacturing method. The materials used in the SLS process, such as nylon or metal alloys, were selected based on the functional requirements of the part, ensuring that the parts were strong enough to withstand mechanical stresses and environmental conditions specific to the application.

This flexibility in material selection allows the manufacturing process to be adapted for a wide range of industrial applications.

Ultimately, the SLS technology offers multiple advantages for manufacturing complex mechanical parts, improving the efficiency of the production process, reducing costs, and optimizing the performance of the parts. These benefits, combined with the possibilities for customization and flexibility, make additive manufacturing a viable and promising option for the future of mechanical engineering.

REFERENCES

[1]. **Kurowski, P.,M.,** *Engineering Analysis with SOLIDWORKS® Simulation 2015*.

[2]. **Popescu, F. D., Radu, S.M., Andras, A., Kertesz, I.** *Infografică, modelare şi simulare asistată de calculator – format electronic*, Editura Universitas, Petroşani, 2020, ISBN 978-973-741-715-2

[3]. **Gibson, I., Rosen, D. W., & Stucker, B.** *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*, 2015.

[4]. **Murr, L. E., et al.** *Metal Fabrication by Additive Manufacturing: Examples of 3D-Printed Metals for Industrial Applications*. Journal of Materials Science & Technology, 28(1), 1-12, 2012.

[5]. Levy, G. N., Schindel, R., & Kruth, J. P**.** *Rapid Prototyping Technologies and Industrial Applications*. CIRP Annals, 52(2), pp. 589–609, 2003.

[6]. **3D Hubs. (n.d.).** *Selective Laser Sintering (SLS) Overview* [online]. Available at: https://www.3dhubs.com/knowledge-base/selective-laser-sintering-sls/