Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/140/2025.21278

3D Printing Is Empowering the Automotive Industry

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Abstract: The present paper provides a comprehensive review of the application of 3D printing in the automotive industry, which is an emerging field with promising development prospects. Furthermore, this technology possesses exceptional characteristics that have the potential to revolutionize and steer the current automotive industry toward new horizons. This article provides a concise overview of the disparities between 3D printing and conventional manufacturing technologies, while also offering a succinct introduction to prevalent methodologies in 3D printing. This paper focuses on the application of 3D printing in four areas: automotive weight reduction, maintenance, manufacturing material diversification, and research and development. Additionally, it highlights that 3D printing technology faces challenges such as a lack of standardized specifications, limited theoretical models, and lengthy single-piece production cycles. This paper aims to provide the latest advancements and challenges in the application of 3D printing in the automotive industry, catering to the needs of researchers and practitioners in related fields, thus offering valuable support for their scholarly endeavors.

Keywords: Automobile industry, additive manufacturing, 3D printing, Industrial application

1. Introduction

In recent years, with the rapid development of 3D printing technology, its application has become increasingly widespread across various industries. In the automotive sector, traditional manufacturing methods are plagued by disadvantages such as long production cycles, complicated manufacturing processes, and high material wastage rates. As a result, automotive companies worldwide are exploring new manufacturing methods to address these issues. 3D printing, also known as Additive Manufacturing (AM), differs from traditional subtractive manufacturing techniques that rely on material removal to achieve the desired shape. AM works by reading the model slicing files provided by the user and depositing material layer by layer based on the coordinates outlined in these slicing files, ultimately creating the desired shape. Current mainstream 3D printing technologies include Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS), among others. Additionally, technologies such as Directed Energy Deposition (DED) and Lithography-based Ceramic Manufacturing (LCM) are also employed. These technologies have been applied to varying degrees within the automotive industry. For example, Italdesign utilized 3D printing to produce seats for the Climb-E concept car [1]. Honda used 3D printing to manufacture a

DOI: 10.54254/2755-2721/140/2025.21278

crankshaft that was 50% lighter in weight [2]. Local Motors produced the Olli, a small shuttle bus where 80% of its body components were 3D printed [3].

This paper aims to summarize the frontier applications of 3D printing technology in automotive design and manufacturing, as well as address the challenges encountered during its application. Through this paper, readers will gain a clearer understanding of how 3D printing is applied in automotive R&D, vehicle weight reduction, automotive repair, and material diversification in vehicle manufacturing. Furthermore, the paper discusses issues such as the high unit cost of large-scale production and lack of standardization, which still persist in the field. This will provide readers with a quick overview of the current state of 3D printing applications in the automotive industry.

2. Applications in automotive research and development

With the advancement of the automotive industry, issues such as design limitations, long development cycles, and high R&D costs in traditional automotive development processes have become increasingly evident [4]. As a result, major global automotive manufacturers are seeking solutions to address these challenges. In the prototype manufacturing stage of vehicle development, components used for validating design feasibility are typically low-volume parts with frequently changing shapes. Whether produced using mold manufacturing, machining, or manual methods, automotive manufacturers are required to invest substantial labor, time, and financial resources. By incorporating 3D printing technology into the prototype manufacturing process, automakers can leverage the advantages of 3D printing, such as no need for molds, rapid product iteration, lightweight design, and customization. This approach enables significant savings in both cost and time during product development, facilitates rapid responses to product design changes, and better meets prototype testing requirements [5].

During the early stages of automotive exterior design, automotive manufacturers' design teams often need to produce multiple scaled models of the vehicles they are designing. These models serve as a highly intuitive representation of their designs, enabling the team to observe and refine their work. Additionally, these models are used for aerodynamic testing to determine whether the design adheres to aerodynamic principles. When exterior design teams use Selective Laser Sintering (SLA) and material jetting technologies to create these scaled models, they can rapidly produce high-precision, smooth-surfaced vehicle models that are consistent with the design's appearance. This approach significantly reduces the time spent by the design team waiting for prototype models to be made, allowing them to quickly assess whether the latest design changes are suitable for the overall vehicle. Consequently, this increases the design team's efficiency and shortens the overall automotive development cycle [6].

In the design of automotive components, many structurally complex and innovative designs have previously been discarded due to the limitations of traditional manufacturing processes. However, with the introduction of 3D printing technology, many designs and shapes that were once constrained by manufacturing methods have become significantly easier to realize. This has provided automotive component designers with greater freedom during the design process, allowing them to experiment with bolder and more innovative ideas. Additionally, it has enabled the enhancement of the aesthetic and even artistic qualities of automotive parts [7].

3. Reducing vehicle weight

Currently, global warming has become an increasingly pressing issue. Without regulation of greenhouse gas emissions, global temperatures will continue to rise rapidly, leading to consequences such as rising sea levels, heightened flood risks, widespread animal fatalities, and more frequent extreme weather events. As one of the major sources of greenhouse gas emissions, the automotive

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sector must address the issue of reducing emissions, and a simple and effective approach is to reduce vehicle weight, thereby decreasing the amount of carbon dioxide produced through fuel combustion.

By leveraging the ability of 3D printing to create complex geometries, automotive manufacturers can optimize the internal support structures of vehicle bodies, shaping them in ways that better align with force distribution principles. This allows for the simplification of unnecessary supporting structures while ensuring that the required physical strength, stability, and balance of components are maintained, ultimately reducing material usage and lowering vehicle weight [8].

For components that do not demand specific strength and stiffness, such as automotive seats, employing 3D printing to create multi-layered structures can achieve weight reduction without compromising performance requirements. For instance, in 2020, Porsche utilized a 3D-printed sandwich structure for the base support of seats in their sports cars. This approach provided enhanced support rigidity and coverage while reducing seat weight through a unique internal structure, thereby offering an improved driving experience [9].

When designing specialized vehicles such as racing cars, which prioritize extreme weight reduction, vehicle engineers undoubtedly explore every possible avenue to minimize weight. However, due to the high costs and significant technical challenges associated with reducing the weight of the engine, attempting to lighten the engine is not an easy task. By utilizing 3D printing technology to produce engine components with specialized structures, weight reduction in the engine can be achieved more easily. For instance, Ryan et al. designed and 3D printed a special intake system with a conical-shaped cylinder and flow channels for a racing car engine, achieving a 22% reduction in the system's weight while simultaneously enhancing its performance [10]. This approach represents an innovative and highly significant new method for weight reduction in racing car engineering.

4. Applications in automotive repair

3D printing not only optimizes automotive design and manufacturing processes but also plays a crucial role in automotive repair and extending vehicle lifespan. In the current landscape of automotive parts manufacturing, the production of parts for repairs holds considerable importance. Typically, the production of these parts requires long lead times and high costs for mold development. Moreover, as the quantity of parts produced increases, the molds are prone to corrosion and cracking, necessitating regular surface repairs. When repairing molds, the use of Directed Energy Deposition (DED) technology allows the mold’s surface to be restored to the original mold’s level of functionality with a single repair. In contrast, using traditional Tungsten Inert Gas (TIG) welding for surface repair results in a mold lifespan that is only 12.5% to 29.2% of the original mold’s lifespan [11].

When the overall lifespan of the mold remains unchanged, the number of repairs required using DED technology is typically only one-fifth of that required with Tungsten Inert Gas (TIG) welding. This significantly reduces the time and cost associated with mold repairs, thus lowering the manufacturing cost of individual parts. Moreover, the lower frequency of repairs also minimizes the materials and energy consumed during the repair process, leading to a notable improvement in the environmental impact, particularly in terms of mineral extraction, ecological toxicity, carcinogens, and fossil fuel consumption [11]. When repairing imported or vintage vehicles, a common challenge arises due to the scarcity of specific replacement parts, which often results in extended repair times and increased difficulty, ultimately affecting the user experience. Utilizing 3D printing technology, repair personnel can quickly produce the required components. For instance, BMW employed 3D scanning and 3D printing technologies to restore a historically significant vintage BMW 507, formerly owned by Elvis Presley, in the absence of replacement parts [12]. This approach not only shortens repair time and enhances user satisfaction but also helps save the high costs associated with the manual fabrication of certain components.

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5. Material diversification

Different materials possess distinct physical and chemical properties. For example, cobalt alloys are characterized by high strength, excellent corrosion resistance, and good thermal stability, while ceramics exhibit superior wear resistance, electrical insulation, and excellent dimensional stability. If these materials can be widely applied in the automotive industry and their properties are properly utilized, they could undoubtedly enhance vehicle performance in various aspects. However, due to the differing processing methods and technological requirements associated with each material, integrating them into a cohesive manufacturing process remains a significant challenge. Consequently, the selection of diverse materials for automotive production based on the specific physical and chemical requirements of different components is still a difficult task. With the use of 3D printing technology, automotive manufacturers can directly print these materials from their particulate form into the required shapes, bypassing the complex and varied traditional manufacturing processes. This significantly reduces the difficulty of utilizing multiple materials in automotive production, making it possible to flexibly select materials based on the performance requirements of individual automotive components. For instance, Stambach has used Lithography-based Ceramic Manufacturing (LCM) technology to 3D print exhaust gas deflectors and exhaust valves made from zirconium oxide, which possess a low elastic modulus, high strength, wear resistance, and deformation coefficients comparable to steel [13]. Additionally, the use of Selective Laser Sintering (SLS) technology to print flexible components such as air conditioning ducts and bellows from nylon provides excellent examples of how 3D printing with specialized materials can be applied to automotive component manufacturing [14].

6. Current limitations and challenges

Undoubtedly, 3D printing technology has the potential to bring about significant transformation in the automotive industry, with vast prospects for development. However, current 3D printing technologies still face numerous limitations that need to be addressed. For example, the implementation of universal industry standards for 3D printers, requiring all manufacturers to adhere to the same specifications, could resolve the issue of inconsistent print quality and performance. At present, different 3D printer manufacturers produce machines that follow independent standards, resulting in variations in the final products—whether in terms of quality or performance—when the same model and process parameters are used on different machines [14].

Currently, there is limited understanding of the specific impact that different process parameters have on the mechanical properties and geometric accuracy of 3D-printed products. This lack of clarity forces users to repeatedly test various parameters until the desired product is achieved, leading to a significant waste of time and resources. By establishing theoretical models, it would be possible to understand the specific effects of these parameters and calculate the optimal settings to produce the desired result, thus eliminating the time and resource waste associated with trial-and-error processes [15].

Additionally, 3D printing faces challenges in large-scale production due to the high cost per unit and extended production time. This significantly limits the widespread adoption of 3D printing in the automotive industry, making it suitable only for small-scale and experimental production where time and cost advantages are more apparent. Once the issues related to time and cost are resolved, 3D printing is expected to be widely applicable in the production of standard automotive components. This would greatly enhance production line flexibility, allowing for rapid adjustments in response to product changes, and significantly improving overall production efficiency.

7. Conclusion

3D printing is increasingly integrated into various aspects of the automotive industry, driving transformative changes within the sector. By leveraging the unique capabilities of 3D printing, automotive manufacturers can address several challenges such as long development and manufacturing timelines, high costs, and limited design freedom, thus advancing the industry toward greater efficiency and cost-effectiveness.

This paper provides an overview of the recent applications of 3D printing in the automotive industry, focusing on four key areas: automotive R&D, vehicle weight reduction, automotive repair, and the diversification of automotive manufacturing materials. At the same time, it outlines the current limitations of 3D printing in the automotive sector, including the lack of industry standards, insufficient theoretical models, high unit production costs, and lengthy manufacturing times. Through reading this paper, researchers can quickly gain insights into the current state of 3D printing technology in these areas and the challenges it faces, thus facilitating further research based on existing findings. Additionally, automotive engineers can draw inspiration from the case studies presented to innovate in design and manufacturing processes, identifying more effective solutions to existing problems.

As a groundbreaking manufacturing technology, 3D printing offers high design flexibility, shorter production times, and reduced material waste. By applying these advantages to automotive design, validation, and the manufacturing of complex components, the full potential of 3D printing can make future automotive designs more flexible and adaptable. The vehicle development and validation processes will become more cost-effective and efficient, while complex components will be easier to produce. Furthermore, once the current shortcomings of 3D printing, as outlined in this paper, are addressed, automotive 3D-printed parts will exhibit controllable quality, with more standardized and reliable printing parameters. This will further promote the large-scale adoption of 3D printing in vehicle manufacturing, enhancing the overall flexibility of production lines.

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