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Application of 3D Printing in Key Automotive Components

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Abstract. As the global automotive industry transitions towards low-carbon and high-performance development, 3D printing technology has gradually attracted the attention of both the academic and industrial sectors in the field of automotive manufacturing. This paper introduces the latest progress in the design, manufacturing, and optimization of 3D printing technology for key automotive components, with a focus on discussing its technological breakthroughs in lightweighting, function enhancement, and material innovation. By combining specific typical cases, it reveals the important contributions of 3D printing technology in weight reduction, efficiency improvement, and support for topological optimization. However, the large-scale application and production of 3D printing still face challenges such as high costs, material anisotropy, and bottlenecks in production efficiency. In the future, it is necessary to further promote the industrial application of this technology in the automotive field through means such as the combination of multiple materials and intelligent process control. This paper provides a technical reference for the in-depth research and industrial promotion of 3D printing technology in the automotive field.

Keywords: 3D printing, car, engine

1. Introduction

Key automotive components play a crucial role in aspects such as vehicle power and safety. The optimization of their performance and lightweight design are the keys to achieving energy conservation, emission reduction, and safe driving. Traditional manufacturing technologies (such as casting and forging) are limited by problems such as high mold costs and low design freedom, making it difficult to meet the processing requirements of the increasingly complex internal structures of automotive components. Against this backdrop, 3D printing technology, based on the manufacturing principle of "layer-by-layer stacking", provides a disruptive solution for the innovative design of key automotive components.

In recent years, the application of 3D printing technology in the automotive field has been continuously expanding, and it has gradually formed a high-efficiency production capacity. The Annual Review points out that the core advantage of 3D printing lies in "design-driven manufacturing", which can break through the geometric constraints of traditional subtractive manufacturing and plays a key role in the optimization of components such as exhaust pipelines and crankshafts [1].

Currently, the research on the application of 3D printing in automotive components mainly focuses on two aspects: Firstly, optimizing structural performance through multi-scale simulation. In automotive design and selection, 3D printing can achieve rapid prototyping and response. Secondly, exploring new material systems to adapt to extreme working conditions, providing more processing options for key parts of vehicles, such as engine mounts and pistons.

Although significant progress has been made in the application of 3D printing in key automotive components, it still faces three major challenges:

(1) Limitations of material performance: The fatigue strength of 3D printing materials may be inferior to that of traditional metal materials.

(2) Insufficiency of process economy: 3D printing equipment is still relatively expensive, and the processing efficiency of 3D printing is still not comparable to that of traditional processing. Its comprehensive cost is difficult to meet the requirements of large-scale mass production.

(3) Lack of a standardization system: Existing standards have not covered the performance evaluation of 3D printed parts. How to test key 3D printed automotive components, especially those affected by high temperature and heat, remains an aspect to be considered in the future.

This paper systematically reviews the research progress and engineering practices of 3D printing technology in key automotive components, analyzes the technical advantages and industrial bottlenecks of 3D printing through typical case studies, and proposes future development directions, providing a theoretical basis for the further establishment of the "process-structure-performance" correlation model and hybrid manufacturing strategy.

2. Application

2.1. Selection and verification

The lightweighting and integration of ductile iron engine blocks are the main directions of engine block design and production. Wang Jidong et al. explored and optimized the V-type 16-cylinder engine block of a certain manufacturer through reasonable 3D casting processes such as sand core splitting, gating system, and feeding system. As shown in Figure 1, the room-temperature yield strength and tensile strength reached 746MPa and 1027MPa, respectively, solving the problem of difficult forming of complex casting structures and making the production process more convenient and efficient [2].

3D printing can achieve complex combustion chamber geometries while providing precise tolerance and quality control. The IAV company conducted a design analysis and optimization of heavy-duty diesel engines using ASTM F1537 Alloy 2 and produced 3D printed pistons that can withstand 1900°F, creating great potential for further increasing the power density and thermal effect of heavy-duty engines [3]


(a) (b)

Figure 1. The physical entity of the casting after 3D casting process optimization [2]

2.2. Weight reduction and efficiency improvement

Additive manufacturing technology can achieve the lightweight design of components, thereby improving the overall performance of engines and vehicles. The BMW Company adopted the Selective Laser Melting (SLM) technology and applied Scalmalloy® (Al-Mg-Sc) high-strength aluminum alloy powder to the engine mount of the i8 hybrid sports car, reducing the weight of the mount by 44%. It also passed the 100,000-cycle vibration fatigue test (DIN 50100 standard), achieving a 30% increase in the stiffness-to-weight ratio and successfully realizing the lightweight transformation of the vehicle [4].

Traditional processing is often limited by molds and it is difficult to process structures such as porous or micro-channel structures. 3D printing, on the other hand, can achieve free forming through layer-by-layer stacking. General Motors (GM) used Electron Beam Melting (EBM) technology to manufacture fuel injectors with integrated micron-level cooling channels inside, increasing the fuel atomization efficiency by 20% and reducing emissions by 15% [5].

2.3. Performance verification

3D printing technology is of great significance for the pollution-free production of efficiently designed catalytic converters. SaeedHajimirzaee et al. increased the conversion rates of CH4 and NMHC from 24% and 38% to 31% and 45%, respectively, through the ceramic 3D printed DOC catalytic converter, making it commercially feasible [6].

3D printing can break through the dependence on tools and molds in traditional processing and achieve rapid response to processed products according to the requirements of users. The Ferrari F1 team used metal 3D printing to manufacture customized piston heads, optimizing the shape of the combustion chamber according to the characteristics of the race track and shortening the lap time by 0.3 seconds [7].

3. Materials

3.1. Metals

Using Inconel 718 superalloy, a turbine housing was manufactured by Laser Powder Bed Fusion (LPBF) with an integrated double-helix cooling channel inside (the cross-sectional area of the channel was optimized to 1/3 of that of traditional casting). During the process, the turbine response speed increased by 12%, helping the team reduce power attenuation on high-temperature race tracks (such as the Bahrain Grand Prix) [8].

3.2. Composites

3D printed composites can achieve lightweighting and a high strength-to-weight ratio, which is of great significance for improving the safety performance of key automotive components. The brake calipers of the Bugatti Chiron use a 3D printed titanium alloy and carbon fiber composite structure, reducing the weight by 40% and increasing the heat resistance to 1200°C, effectively ensuring the safety of the vehicle during braking [9].

3D printed composites can realize the structural upgrade of key components through topological structures. Boeing and Audi launched a cooperation project. By developing a Continuous Fiber Reinforced Thermoplastic Composite (CFRTP) door frame, it is 30% lighter than the aluminum component and has passed the collision test (FMVSS standard), achieving directional enhancement of mechanical properties [10].

3.3. Ceramic materials

3D printed ceramic materials can achieve the on-demand distribution of material properties and enhance the environmental tolerance of materials. When developing gas turbine blades, the Siemens Group used ceramics as gradient materials, which can effectively improve the high-temperature resistance and impact resistance of the blades [11].

4. Prospects

4.1. Advantages and disadvantages

3D printing technology has brought great creativity to the automotive industry. It can achieve a high degree of design freedom, support topological optimization and functional integration, with a material utilization rate of >95%, reduce waste, and support multi-material composite printing.

However, 3D printing technology still has significant bottlenecks in industrialization:

(1) In terms of economy, the costs of equipment and materials are high, and the economy of large-scale mass production is insufficient.

(2) In terms of production efficiency, the printing speed is relatively slow, making it difficult to match the rhythm of traditional production lines, and the post-processing process is complex.

4.2. Future development trends

After years of development, 3D printing has established a relatively complete processing system, but there is still great room for development in the future:

Firstly, 3D printing needs to focus on multi-material composites and functional gradient manufacturing. In the future, 3D printing will break through the limitations of single materials. Through the coordinated printing of multiple nozzles, it will achieve composite structures of metals, ceramics, and polymers, solving problems such as stress concentration and shortened service life caused by sudden changes in material properties of traditional components, and meeting the comprehensive requirements of key automotive components for high-temperature resistance, high strength, and lightweighting.

Secondly, 3D printing needs to be integrated with intelligent processes. In the future, 3D printing will be combined with artificial intelligence, digital twin, and real-time monitoring and other means to achieve dynamic control of the printing process.

Subsequently, 3D printing can be combined with traditional processes. Combining 3D printing with casting, machining, and other means can effectively balance costs and performance.

Finally, with the popularization of electric vehicles, 3D printing will focus on empowering electric motors and power hybrid systems, promoting the deep integration of 3D printing and sustainable development, breaking through the current efficiency bottleneck in the industrial field, promoting the transformation of the technology from prototype manufacturing to mass production, and establishing a full-process standard system covering design, manufacturing, and inspection [12].

5. Conclusion

3D printing technology has brought a disruptive innovation to the manufacturing of key automotive components. Its core value is reflected in three aspects: Firstly, through topological optimization and lattice structure design, it achieves the lightweighting of components and path optimization. Secondly, 3D printing supports the integrated forming of complex functional structures, which can significantly improve the efficiency of thermal management. Finally, it enables small-batch customized production, enhancing the adaptability to specific needs.

However, the industrialization of 3D printing technology still faces significant bottlenecks: (1) 3D printing has insufficient cost-effectiveness and requires further technological upgrades and industrial iterations; (2) 3D printing also has disadvantages in terms of material performance and requires the development of optimization algorithms for the manufacturing strategy of key components; (3) In terms of production efficiency, 3D printing is far inferior to the widely used subtractive manufacturing currently.

In the future, 3D printing will focus on process innovation to reduce production costs, develop new materials to improve the properties of components; (3) establish a standardized process system to monitor the production process. In addition, it can also be integrated with means such as digital twins and machine learning to achieve adaptive control of process parameters and further improve the 3D printing process.

In conclusion, 3D printing is reshaping the entire automotive industry, but further development still depends on the collaborative innovation of the entire industry.

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