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Design a Space Frame Chassis for Light Weight Automobiles for Improved Safety and Reliability

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Abstract. Due to its high degree of freedom and strong flexibility, 3D printing technology is receiving increasing attention and emphasis in the automotive industry, especially in the field of vehicle lightweighting. This paper systematically elaborates on the actual role, materials used, and development trends of 3D printing technology in the field of vehicle lightweighting. By utilizing metal and composite materials collaboratively and optimizing the design and manufacturing of key components, 3D printing has achieved both lightweight and integration in automobiles. However, the anisotropy between different materials, the persistently high cost of large-scale production, and the lack of standardized systems remain major bottlenecks that restrict the large-scale application of 3D printing technology in the automotive sector. In the future, material integration, the development of artificial intelligence technologies, and breakthroughs in relevant standards will all drive the further application and advancement of 3D printing in the automotive field. This paper integrates current technological developments and industry practices to provide a theoretical reference and practical basis for the subsequent application of 3D printing in vehicle lightweighting.

Keywords: 3D printing, vehicle, lightweight

1. Introduction

The automobile chassis bears multiple responsibilities, such as power transmission and safety performance. Its performance optimization and lightweight design are key to achieving safe driving and energy conservation. Traditional chassis manufacturing technologies (such as casting, forging, and milling) are constrained by high mold costs, low design freedom, and severe pollution and waste, making them insufficient to meet the evolving needs of innovative chassis processing. The global automotive industry is investing heavily in additive manufacturing, with projections showing steady growth year by year [1]. Against this background, 3D printing technology, with its "layer-by-layer stacking" manufacturing principle, provides a disruptive solution for the innovative design and manufacturing of automotive chassis.

In recent years, the application of 3D printing in the automotive sector has continuously expanded and has shown considerable production benefits. Its core advantage lies in "design-driven manufacturing," which helps break the spatial limitations of traditional manufacturing methods and plays a key role in the layout and optimization of critical nodes on the chassis. For example, Zhang

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et al. used topology optimization design combined with the SLM (Selective Laser Melting) process to manufacture a chassis bracket, successfully achieving both weight reduction and stiffness improvement [2].

Currently, research on 3D-printed automotive chassis focuses primarily on two areas:First, structural design optimization through multi-scale simulation, offering rapid response and support for 3D-printed chassis. For example, Liu et al. combined multi-physics field simulation with 3D printing to verify the effectiveness of multi-scale topology optimization in enhancing mechanical performance and reducing weight [3];

Second, the exploration of extreme performance of various materials under specific working conditions, providing more feasible material choices for automotive chassis. For instance, Wang et al. evaluated the strength and durability of aluminum alloys and carbon fiber composites under the SLS process, finding that composites offer greater weight reduction potential while maintaining structural integrity [4].

However, despite notable progress in 3D-printed automotive chassis, three major challenges remain:

(1) Material performance: 3D-printed metals still lag behind traditional forged metals in terms of fatigue strength and ductility [5];

(2) Process cost: Equipment is expensive, powder material costs are high, and production cycles are long, making large-scale manufacturing difficult [6];

(3) Standards and systems: There is currently no unified and comprehensive standard for evaluating the performance of 3D-printed components in automotive environments, hindering engineering implementation [7].

This paper analyzes the technical advantages and industrial bottlenecks of 3D printing through typical case studies and proposes future development directions, providing theoretical support for the further application of 3D printing in the automotive field.

2. Space frame for vehicle load-bearing

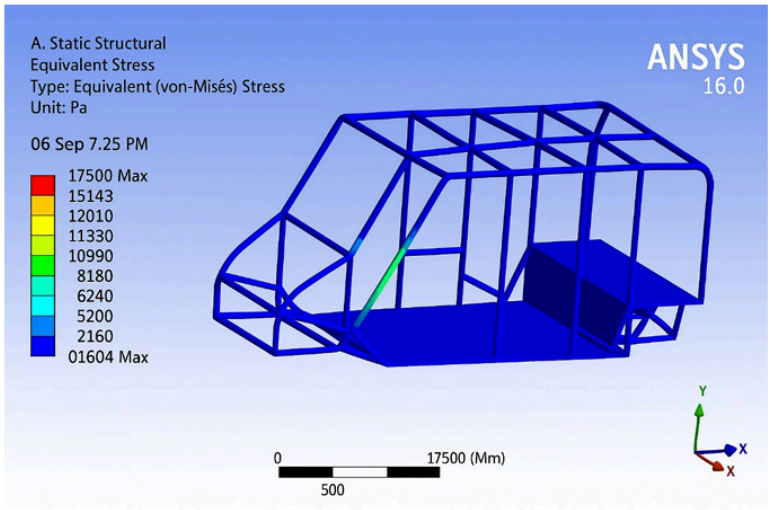


Figure 1. Static analysis model of the vehicle body structure

In traditional load-bearing body structures, issues such as high mass, high energy consumption, and complex manufacturing exist. Chala J. Bulgu et al. proposed replacing the main vehicle structure with a space frame and performed static, crash, and rollover simulations using ANSYS

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software, as shown in Figure 1. The results showed that the structure reduced overall vehicle mass by approximately 12% while ensuring torsional stiffness and reduced maximum stress in rollover analysis by 18%, significantly improving occupant safety [8]. The design advantages include simplicity, modular manufacturability, and suitability for electric vehicle platforms. However, the disadvantages lie in the high precision requirements for welding, and stress concentration at joints during actual manufacturing may shorten fatigue life.

3. Test results and discussions

3D printing is applied in different areas of automotive manufacturing depending on the characteristics of various materials. For instance, titanium alloy, due to its exceptional strength and torsional resistance, is frequently used for producing load-bearing structures. In contrast, aluminum alloy is favored for its lightweight and fatigue resistance properties, making it suitable for 3D printing of automotive frame shells. This aligns with existing research highlighting the metallurgical challenges in metal AM, such as porosity and anisotropy.

In conventional automotive frame manufacturing, typical issues include excessive weight, insufficient rigidity, and limited load capacity. Tamas Márkovits proposed the use of Ti6Al4V titanium alloy in 3D printing, accompanied by geometric shape validation, static load testing (Figure 2a), and dynamic performance testing (Figure 2b). The front rocker arm fabricated from this material achieved a 40% weight reduction per component and a threefold increase in stiffness and load capacity, significantly enhancing performance while supporting lightweight goals. However, the design still faced challenges such as reduced service life during testing and the complexity induced by high precision manufacturing requirements.

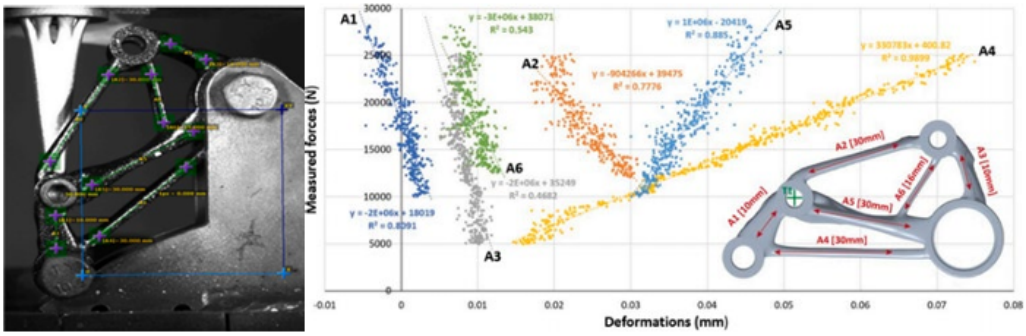


Figure 2. Application of 3D printed titanium alloy in automotive front rocker arms

Selective Laser Melting (SLM), a powder bed fusion metal additive manufacturing process, is another widely adopted technique in 3D printing. Keyi Liu proposed using SLM to fabricate aluminum alloy automotive shells by melting powder layer by layer using laser beam thermal energy. This method requires minimal support structures and avoids traditional grinding tools, effectively suppressing warping caused by thermal stress. Furthermore, YOLO and CNN-based artificial intelligence models were applied during the 3D printing process to detect and identify defects in real time (Figure 3) [9].

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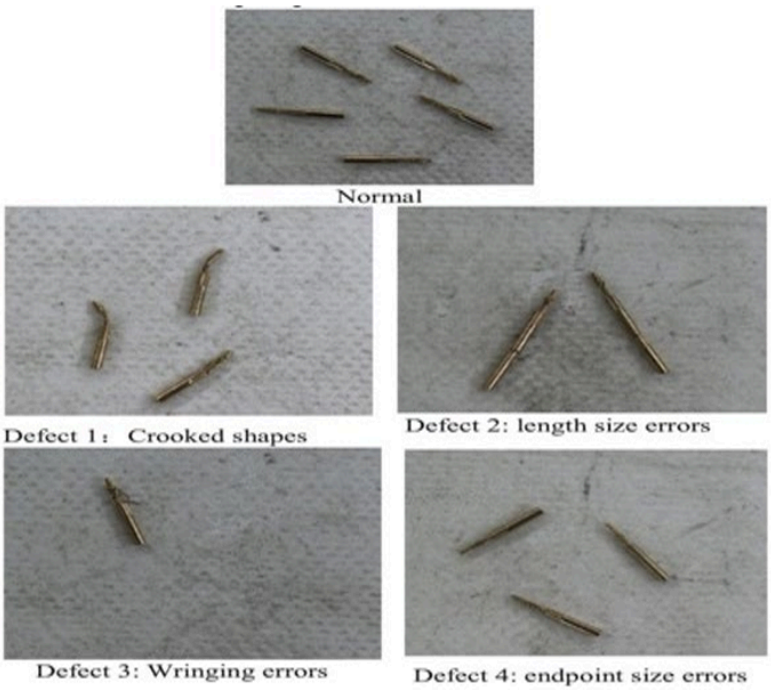


Figure 3. Application of AI in defect detection during SLM 3D printing process

SLM technology holds unique advantages in manufacturing complex, lightweight, high-performance components such as brake systems. Although aluminum alloy parts printed by SLM demonstrate substantial weight reduction and improved fatigue strength, their stiffness and strength may be inferior to steel. However, these mechanical properties can be improved through appropriate post-processing.

4. Conclusion

The discussed case studies involving titanium and aluminum alloys demonstrate the substantial impact of 3D printing in automotive component manufacturing. These technologies show that:

1. 3D printing can use identical materials to those in traditional manufacturing while achieving both weight reduction and performance enhancement;

2. Customization through additive manufacturing allows the production of complex, precise components tailored to specific vehicle requirements.

However, several limitations remain:

Achieving ideal performance often requires extremely precise control over the manufacturing process;

High costs associated with equipment, labor, and workspace currently hinder large-scale deployment;

The mechanical strength of certain 3D printed materials still lags behind traditional materials in some applications.

Looking forward, 3D printing is expected to transform automotive parts manufacturing by reducing costs and developing new manufacturing methods to improve performance. Although 3D printing may reduce material waste, energy consumption and equipment amortization remain non-negligible. Simultaneously, integrating artificial intelligence into the manufacturing process can enhance defect detection, boost accuracy and efficiency, and accelerate production timelines. The

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synergy between AI and 3D printing will likely spur innovation across the automotive sector and support the transition toward future smart cities.

In summary, while 3D printing is poised to significantly promote innovation in the automotive manufacturing industry, its advancement still requires support from policy, investment, and complementary technological development. Recent developments in AI-driven defect recognition systems show promise in online quality assurance for AM.

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