Current Applications of 3D Printing in Custom Automotive Tooling

Tianrun Bi

{bitianrun@dlmu.edu.cn}

Department of Mechanics, Dalian Maritime University, Dalian, 116000, China

Abstract. To adapt to the automotive industry's trends of personalization, small-batch production, and diverse product types, traditional tooling, due to long lead times, high costs, and insufficient flexibility, can no longer meet the demand. Additive manufacturing (3D printing) technology, with its advantages of rapid prototyping, design freedom, and integrated manufacturing, is driving innovation in the field of customized tooling. This report systematically reviews the current applications of this technology in automotive customized tooling, covering specific scenarios such as assembly fixtures, inspection tools, robot end effectors, molds, and auxiliary tools; analyzes the challenges currently faced in material performance, initial investment, process knowledge, and standardization; and looks ahead to future development trends such as new material development, hybrid manufacturing, digital-intelligent integration, and large-scale applications, aiming to provide theoretical and practical references for the further promotion of this technology.

Keywords: 3D printing, automotive manufacturing, customized tooling, additive manufacturing, smart manufacturing

1 Introduction

As the global automotive industry transitions toward personalized, customized, and flexible production models, traditional large-scale standardized manufacturing methods are undergoing profound changes. Market demand for diverse automotive products continues to grow, and the trend of small-batch, multi-variety production places higher demands on the responsiveness and adaptability of manufacturing systems.

In this context, production equipment, as a crucial part of manufacturing, directly impacts the efficiency and market competitiveness of automotive manufacturers through its development efficiency, cost controllability, and adaptability[1]. Therefore, exploring emerging technologies that can revolutionize the design and manufacture of tools and equipment has become an important topic in promoting the sustainable development of the automotive industry. Additive manufacturing technology, commonly known as 3D printing, has shown broad potential and innovative prospects in multiple industrial fields in recent years.

ICMEEA 2026, April 24-26, Singapore, Singapore

DOI 10.4108/eai.24-4-2026.2364914

This technology is based on a digital manufacturing process, eliminating the need for traditional molds and enabling rapid prototyping, which has earned it widespread recognition. In the field of automotive tooling, its application has expanded from initial prototype validation to the direct manufacture of auxiliary tools for production lines, such as assembly and inspection equipment, marking a significant shift from research and development support to a core manufacturing method.

Many global automotive companies and research institutions have actively explored the application of various 3D printing technologies such as Fused Deposition Modeling(FDM), Selective Laser Sintering(SLS), Stereolithography(SLA) and Selective Laser Melting(SLM) aiming to achieve lightweight, highly integrated, and customized tooling[2]. Practice has shown that 3D printing technology can effectively shorten tooling delivery cycles, reduce overall manufacturing costs, and significantly enhance design flexibility.

This paper aims to systematically evaluate the current application pathways of 3D printing technology in the field of customized automotive tooling, focusing on its specific application scenarios and technical characteristics in assembly jigs, quality inspection tools, adaptive robotic end effectors, as well as molds and auxiliary devices that meet specific production needs. Additionally, this paper will also discuss the challenges that limit the widespread adoption of this technology.

2 Current Applications of 3D Printing in Customized Automotive Tooling

Based on recent technological research achievements and industrial practices, additive manufacturing technology has demonstrated significant practical value and application depth in multiple specific stages of automotive process equipment.

2.1 Assembly Fixtures and Locators

In the field of assembly fixtures and locators, 3D printing technology has demonstrated the ability to systematically transform traditional manufacturing models. Its core lies in a digital, mold-free production approach that significantly enhances tooling responsiveness, lightweighting capabilities, and customization adaptability.

By convention, the fabrication of fixtures through traditional methodologies has involved a progression of machining operations followed by intricate assembly—durations extended often to several weeks comprise such undertakings. It is from recent instances that one observes 3D printing condensing this procedural continuum into timeframes measurable in mere days or fewer, production responsiveness thereby being considerably altered [3]. Manifested most distinctly within applications where structural intricacy proliferates are these disparities in approach. Approachable via techniques such as topology-driven model refinement and integrated formation of thin-walled entities, structures characterized by reduced mass and convoluted curvature have been rendered feasible; realization thereof with conventional paradigms remains largely impracticable.

Application of this technologic method by an automotive manufacturer upon fixtures constructed for windshield wiper installation resulted in a reduction of total fixture weight reaching 40%,with the persistence of clamping rigidity unaltered, thereby making evident its advancement within the paradigm of high-strength, lightweight structural configuration [3]. Demonstration is given further by the technology's facilitation of integrative functional design—consolidation into singular entities being observed among components previously maintained as discrete, such assemblage permitting transaction-reduction during assembly procedure and exerting control over compounded errors emerging from multiple installations.

Within the domain of material systems can be identified nylon-centric composite substances—their ascendancy to mainstream status as non-metal tooling arises through empirically verified properties: pronounced toughness, resistance to attritional processes. Contrastingly, regions necessitating augmented strength, such as positioning constructs, increasingly witness incorporation of metal-based three-dimensional print-processing.

Such adaptation, it may be discerned, remains confined preferentially to production regimes typified by restricted batch amplitude, elevated configurational intricacy, and operational flexibility. Prospect of wide-ranging industrialization appears contingent on iterative refinement, equilibrium-achievement between aggregate expenditure, durability under prolonged loading, and stabilization at standardized practice levels [3].

2.2 Inspection and Measurement Fixtures (CMM Fixtures/Gauges)

3D printing enables mold-free, rapid, and customizable fabrication of automotive inspection fixtures [4]. Seen from recent instances, direct manufacturability is revealed as particularly appropriate for those dimensional inspection jigs with inherently intricate surface geometries. To this, precision-oriented positioning fixtures can also be added, whose production demands high configurability unattainable via traditional methods. This technology significantly shortens the development time of testing fixtures, which traditionally takes several weeks to manufacture. Concurrently, accommodation for singularized or micro-quantitative inspection requisitions has been supported.

Realization through metal-based 3D-printing paradigms furnishes opportunities by which conformally integrated cooling networks or mechanisms tasked with high-load positioning are manifold in mold insert manufacture, by which constancy throughout testing regimes is undergirded. Disclosed as preeminent within alternative domains, resin-centric 3D printing finds prevalent application in fabricating non-force-bearing apparatuses—optical examination frames and platforms configurable for sensor installation included—wherein diminution of fiscal outlay alongside alleviation of mass can be observed.

Amongst significant shifts shaping the trajectory of 3D-printed inspection fixture design, the pursuit of lightweighting emerges as an emblematic trend. A notable trend in this field is the redesign of typical structures, such as inspection brackets, using methods like topology optimization, thereby significantly reducing material consumption and overall mass. Adduced from empirical studies are cases involving utilization of hollow-core support architectures within custom-fabricated jigs produced via additive manufacturing modalities—circumstances under which quantifiable reductions surpassing 40% in raw input usage have occurred, whilst essential rigidity and the requisite precision necessary for metrological tasks remain unaffected throughout operational deployment. Detection of such outcomes reflects an incremental transformation underway in contemporary practice related to resource efficiency and structural innovativeness manifest in inspection toolfabrications enabled by advanced printing techniques.

Through the utilization of this methodology, observable are considerable reductions in fixture self-weight and optimizations in procedural assemblies, as well as notable advancements in metrological facilitation [4].

Taking a hydraulic hose inspection fixture as an example, 3D printing can produce fixtures with complex surfaces and intricate structures, achieving a forming accuracy of up to 0.08 millimeters, which meets the dimensional inspection requirements of automotive components [5]. Employed modularity in prescriptive design frameworks permits the conception and fabrication of discrete units characterized by heterogeneous functional intentions for inspection, realized through amalgamative strategies that allow diverse modules to be interconnected post-production. To less than forty percent relative to traditional machining paradigms, the total duration allotted to developing an entire fixture may thereby be diminished, a transformation evident in the acceleration and augmentation seen in both adaptability and efficiency pertinent to inspection fixture engineering [5].

Thus, 3D printing is particularly suitable for high-precision, iterative, and low-volume inspection needs.

2.3 Robotic End-of-Arm Tooling (EOAT)

The traditional manufacturing methods for robotic arm end-effectors face issues such as long development cycles and high costs for iterative modifications. Moreover, the rigidity constraints of conventional processes in terms of structural adaptability often limit the spatial freedom for innovative configurations. 3D printing technology supports a rapid prototyping iterative cycle of "design-print-test-optimize," significantly enhancing development efficiency and reducing testing costs associated with repeated adjustments. For example, in a textile sorting task performed by an industrial robot, using 3D-printed customized gripping components allows the entire process—from structural scheme design and multifunctional integration to performance validation—to be completed within a few hours. Practice has shown that this process can shorten the development cycle of robotic end-effectors by more than 70%, and due to reduced demand for traditional tooling and material waste, manufacturing costs can be lowered by up to 90%, while the grasping success rate increases to 99%. This case demonstrates the capability of 3D printing to support complex geometries and achieve integrated lightweight formation, which not only aids in functional verification but also accelerates the large-scale deployment of robotic end-effector components[6].

2.4 Molds and Casting Models

In the field of automotive molds and casting models, the introduction of 3D printing technology has brought transformative changes to rapid mold manufacturing, topology-optimized structures, and on-site repair interventions. For instance, in the practice of stamping mold repair, traditional repair processes often face issues such as long lead times for spare parts, insufficient dimensional tolerance control, and production losses caused by downtime[7]. By adopting 3D printing technology, replacement parts can be directly produced based on reverse-engineered models of damaged components, ensuring a high degree of fit and performance restoration with the original mold, thereby significantly reducing repair time and enhancing operational adaptability.

Moreover, this technology enables the integrated manufacturing of high-performance molds with complex conformal cooling channels. By optimizing the internal thermal management structure of the mold, it improves the production efficiency of casting or injection molding processes. For scenarios involving small-batch trials or customized mold requirements, additive manufacturing can complete mold production at lower cost and shorter lead times, markedly shortening the cycle from design to production, reducing entry barriers, and promoting the development of mold manufacturing toward modularity, reconfigurability, and digitalized control.

2.5 Auxiliary Tools and Protective Fixtures

In the field of automotive crash protection tools, 3D printing technology offers a degree of design freedom that is difficult to achieve with traditional methods and holds significant value for the development of lightweight structures and advanced crash protection systems. The research by Ahmed Saber and colleagues specifically demonstrates the potential of 3D printing in this area[8]. The study employed fused deposition modeling (FDM), using both carbon-fiber-reinforced polylactic acid (CFR-PLA) and its standard version to fabricate conical energy-absorbing boxes with varying wall thicknesses and tapers for crash testing. The results showed that the CFR-PLA energy-absorbing boxes achieved a specific energy absorption of 32.08 ± 0.19 kJ/kg and crash efficiency of 0.74 ± 0.03, meeting stringent vehicle safety testing standards. This highlights the advantage of 3D printing in achieving closed-loop optimization of 'material selection—structural design—performance realization.'

Compared with traditional manufacturing, 3D printing not only enables mold-free forming but also allows targeted reinforcement in areas prone to stress concentration during material deposition, thereby enhancing structural stability and dynamic impact resistance. The study quantified the effects of various design parameters through parametric design and variance analysis, revealing that wall thickness is the most significant factor influencing energy absorption performance, contributing 73.18% and 58.19% to energy absorption and crash force efficiency, respectively. The regression model based on the data predicted with an error of less than 4.97%, providing precise guidance for structural optimization. The final optimized CFR-PLA energy-absorbing boxes achieved a specific energy absorption of 31.53 kJ/kg and a crash efficiency of 0.81, significantly reducing weight while ensuring crashworthiness.

Overall, 3D printing technology eliminates the need for complex mold development, greatly shortening the development cycle of crash test tools and enabling more efficient and flexible development of customized protective devices for different vehicle models. This technology strongly supports innovative designs for critical safety structures such as front cushioning devices and door anti-collision beams.

3. Challenges and Limitations Faced

Although application advantages of notable magnitude in the realm of automotive tooling 3D printing have been exhibited, a multitude—comprising persistent structural impediments—continues to restrict mainstream integration. The primary challenge lies in the material properties. Currently, commonly used engineering plastics are still unable to fully replace metals in terms of load-bearing capacity, high-temperature resistance, and wear resistance, especially under conditions involving prolonged mechanical and thermal stress [9]. Quantitative discrepancies between plastic-based constructs and their metallic counterparts thus manifest as limitations on deployment possibilities.

From this instance, initial investment expenditures emerge subsequently as another restrictive vector: acquisition outlays demanded by industrial-tier additive manufacturing equipment, augmented further through ancillary post-processing apparatus and ongoing maintenance costs, constitute financial thresholds seldom surmounted with ease by small- or mid-sized operators [10]. The capital requirement demonstrated thereby erects a participation barrier whose consequences impact industry structure fundamentally.

Capabilities requisite among design professionals likewise appear underestimated: proficiency not merely confined to conventional modeling but exigent also of specialized knowledge regarding layer-wise fabrication philosophies must be evidenced. It can be seen from widespread practice that scarcity both in talent pools and institutional expertise continually afflicts sectors dependent upon nuanced design-for-additive-manufacturing paradigms.

In addition, the industry lacks a unified standard system. The absence of certification procedures and performance benchmarks affects quality consistency and also poses uncertainties for the long-term reliability of the supply chain. Restrictions imposed through lack of accredited guidelines and empirical validation procedures derive, therefore, a landscape where scale-up ambitions remain preliminary.

Cumulatively, transitionary progress is hindered—from prototypic deployments toward comprehensive, volume-oriented production schemas—by confluence of technical, organizational, and infrastructural deficiencies elucidated herein.

4. Future Development Trends

In the field of automotive tooling, 3D printing technology is developing towards multidimensional integration and in-depth application. On one hand, evidenced through ongoing explorations involving emergent materialities—exemplified by high-performance composites, continuous fiber-reinforcement mediums, and application-specific metal powderates—the broadening of utilitarian frontiers under constraints such as heightened mechanical stresses or thermal exposures appears increasingly tenable. On the opposing axis, maturation characterizes hybridized manufacturing modalities; a synthesis wherein the complementarity between additive techniques and conventional subtractive paradigms typified by CNC machining becomes continuously accentuated. Through this amalgamation, an elevation manifests both in terms of metric precision, surface topological refinement, and geometrical intricacy observable in resultant tool constructs.

At the same time, digitalization and intelligent transformation will become central. The integration of artificial intelligence and digital twin technology can not only automate design optimization but also achieve adaptive control of production parameters and real-time feedback. Furthermore, with advancements in technology and cost optimization, 3D printing is expected to gradually expand from its current niche in small-batch customization to large-scale manufacturing scenarios. Consequently, the entrenchment of additive methodologies become integralized into the architecture of automotive production systems, its eventuality characterized by processual adaptability, operational fluidity, and analytical sophistication without recourse to external idiomatic descriptors.

5. Conclusion

3D printing technology has brought about a paradigm shift in customized tooling for the automotive industry. It not only enables rapid response, lightweight design, and functional integration of tooling through technological advancements, but also delivers significant economic value by shortening production cycles and reducing overall costs. Currently, this technology has proven its viability in applications such as assembly fixtures and inspection tools. While challenges remain in material properties and initial investment, continuous technological advancements and ecosystem development will inevitably elevate 3D printing from an "alternative" technology to an indispensable core manufacturing method in the automotive industry. This evolution will powerfully propel the automotive sector toward greater efficiency, flexibility, and intelligence.

References

[1] Jin, L., Du, P., Zhang, K., et al.: Current Application Status and Development Trends of Key Technologies in New Energy Vehicle Manufacturing. Automot. Electr. Equip. (12), pp. 78–80 (2025)

[2] Gao, Z., Zhao, X., Lü, H., et al.: Influence of 3D Printing Process Parameters on Tensile Properties of Composite Materials Driven by Multimodal Learning. J. Compos. Mater. (2025)

[3] Xie, W.: Application of 3D Printing Technology in Automotive Mechanical Manufacturing. Automot. Maint. Repair (Mainten. Ed.). (06), pp. 20–22 (2025)

[4] Zhang, D.: Application of 3D Printing Technology in Automotive R&D and Maintenance. Automot. Eng. (08), pp. 56–58 (2025)

[5] Wang, H.: Digital Design and Additive Manufacturing Enable New Pathways for Hydraulic Hose Inspection Fixture Development. Times Auto. (10), pp. 109–111 (2025)

[6] Fu, Q.: Research on Rapid Prototyping and Agile Verification Methods for Robot Gripping Devices Based on 3D Printing. Shenzhen Spec. Zone Sci. Technol. (05), pp. 62–65 (2025)

[7] Li, C.: Application of 3D Printing Technology in Automotive Stamping Die Maintenance. Die Mold Technol. (04), pp. 7–11 (2025)

[8] Saber, A., Güler, M. A., Acar, E., ElSayed, O. S., Aldallal, H., Alsadi, A., Aldousari, Y.: Crash Performance of Additively Manufactured Tapered Tube Crash Boxes: Influence of Material and Geometric Parameters. Designs. 9(3), p. 72 (2025)

[9] Li, E.: What are the limitations of 3D-printed automotive tooling? HT Tool and Die Co., Ltd. Blog [Online]. (2025)

[10] Callum, A.: Revolutionizing the Automotive Industry: The Current State and Future Potential of 3D Printing in Car Manufacturing. Adv. Automob. Eng. 12, p. 217 (2023)