

The Application of 3D Printing in Mechanical Manufacturing

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Abstract: In modern society, with the continuous development of science and technology, 3D printing technology has become a hot technology in the field of machinery manufacturing. 3D printing can improve production efficiency, and can accurately produce three-dimensional products that can be directly applied to the mechanical parts that need to be manufactured. This article will introduce the basic principles of 3D and its advantages, but also introduce the application of 3D printing, focusing on the application of 3D printing in the construction field using cement-based materials, while printing some key components in the automotive field, fiber composite materials in the aviation field is also a development direction. This article also looks for some obvious problems with 3D printing, especially the performance of 3D printed products, as well as the cost-related issues of 3D printing, for these problems, the paper gives solutions and future directions. 3D printing will have an important position in the future, and will be widely used in the field of mechanical manufacturing and production, which has great significance.

Keywords: 3D printing, Mechanical manufacturing, Application, Existing problem, Future expectation.

1. Introduction

3D printing technology is an alternative to traditional hand-made manufacturing and an update of traditional industry. It is increasingly used for mass customization, production of any type of open-source design in agriculture, automotive, locomotive and aerospace industries [1]. Compared to traditional manufacturing processes, 3D printing is a popular unconventional manufacturing technology that creates 3D objects using both conventional and unconventional materials. The applications and uses of 3D printing are rapidly increasing not only in the traditional field of mechanical manufacturing, but also in all aspects of the engineering and medical sectors [2]. This article will introduce the principles of 3D printing and compare it with traditional manufacturing methods to highlight its advantages. With the rapid advancement of 3D printing technologies, the application of 3D printing has increasingly permeated various industries. This paper will focus on applications related to the construction, automotive, and aerospace. 3D printing in the development process, there are also some problems and defects, this paper will point out some existing errors and give some solutions, while the future of 3D printing for a certain prospect. This paper hopes to explore the current state of 3D printing and explore the future advancement direction of 3D printing.

2. Principles and advantages of 3D printing

3D printing, also known as additive manufacturing, is an advanced technology for building three-dimensional objects by stacking materials layer by layer. Unlike traditional subtractive manufacturing methods, 3D printing involves constructing the complete shape of an object layer by layer according to the design requirements by precisely controlling the gradual addition of materials. Computer-controlled printing equipment usually carries out this process that transforms a digitized design model into a physical reality. In order to achieve this process, it is often necessary to model and slice the object with the help of some specialized drafting software to ensure that each layer of the object can be printed precisely according to the design requirements.

First of all, you need to create a digital 3D model of the object using computer-aided design software. Digital models of existing objects can also be obtained through 3D scanning technology. The digital model is cut into thin layers, with each layer representing an operation of the printer in 3D printing. 3D printers stack materials layer by layer in pre-designed layers until a complete object is finally formed. Common 3D printing materials include plastics, metals, resins, ceramics, etc. After printing, post-processing of the object, such as removing support structures, sanding, coating, or heat curing, is sometimes required to enhance the object's appearance or performance. Overall, the core principle of 3D printing is additive manufacturing, which translates digital designs into physical objects by stacking materials layer by layer. This approach overcomes many limitations of traditional manufacturing, particularly in creating complex shapes, enabling customization, facilitating rapid prototyping, and supporting small-batch production.

Compared to traditional manufacturing methods, 3D printing technology offers many advantages. First, it is capable of producing highly complex and diverse objects, breaking through the limitations of conventional manufacturing techniques. By stacking materials layer by layer, 3D printing enables the creation of complex geometries and internal structures that cannot be produced using traditional methods. In contrast to traditional manufacturing, 3D printing generates less costly consumption, even for complex shapes. Whether for small-batch production, customized products, or prototyping, the production costs of 3D printing remain relatively stable and do not increase significantly due to mold, tool, or process complexity, as is often the case with traditional methods. This gives 3D printing a significant advantage in small-batch production and personalized customization, while also greatly shortening development cycles in rapid prototyping and iterative design. Additionally, products made using 3D printing are typically formed by stacking materials layer by layer, meaning that once printing is complete, the items already possess their final shape and functionality, eliminating the need for the complex assembly processes required in traditional manufacturing. This integrated production approach significantly simplifies the production procedure, thereby markedly reducing the total duration from design to delivery. As the assembly stage has been removed, the production cycle has been greatly shortened, and customers can obtain the final product more rapidly, enhancing the overall efficiency and response rate of the supply chain. Concurrently, the integration of 3D printing technology and intelligent digital design makes the manufacturing process more flexible and efficient, enabling precise satisfaction of user requirements. This combination employs computer-aided design software and advanced 3D printers to directly transform digital design sketches into actual items, providing a high degree of customization for products. Through intelligent design, users can modify the appearance, size, functions, and material properties of products based on their individual needs [3].

3. Applications of 3D printing

3.1. 3D printing in construction

With the continuous development of science and technology, the application prospect of 3D printing technology in the field of construction is more and more comprehensive. In construction engineering, 3D printing technology mainly uses cement-based materials, and realizes 3D printing of cement-based materials through the principles of rheology and cement hydration. According to different molding techniques, 3D printing technologies for cementitious material-based buildings can usually be classified into the following five types: extrusion, selective deposition, mold printing, slip molding and jet molding. Extrusion-based 3D printing of cementitious materials involves using a printer to layer extruded material according to a digital model, ultimately building a predefined structure. The process begins with designing the target geometry in 3D modeling software, followed by slicing the model into 2D layers using slicing software, which generates the print path for the printer. This path is shipped as a file and imported into the printer's control system. During printing, the printer extrudes the cementitious material layer by layer, ensuring even deposition to form the desired shape. For successful 3D printing, the material must meet two key requirements: extrudability, meaning it must flow smoothly through the printer nozzle, and constructability, meaning it must maintain its shape and integrity as the layers are built up. Balancing these factors is crucial for the material's suitability in additive construction.[4] In addition to traditional 3D printing techniques, foam 3D printing also shows great potential and is expected to have broader applications in the future of the construction industry.[5]

3.2. 3D printing in automotive

The application of 3D printing technology in the automotive field has covered a wide range of aspects from design, production to maintenance, bringing about far-reaching changes. Firstly, in terms of prototyping, 3D printing can greatly shorten the development cycle of automotive components and whole vehicle models, enabling design teams to quickly validate and optimize their designs, thus accelerating time-to-market. Furthermore, as consumer demands become increasingly personalized, 3D printing technology offers the potential for the customization of components, particularly in areas such as interior parts, seating, lighting, and other intricate details, thereby enabling tailored solutions to meet the specific needs of individual customers. During the automotive manufacturing process, the application of 3D printing facilitates the production of high-precision, structurally complex components, including bespoke car seats and engine mounts, while also enabling the efficient fabrication of high-performance heat exchangers.[6] The engine is arguably the most critical component of an automobile, often referred to as its "heart," as its performance directly impacts the vehicle's power and fuel efficiency. The traditional manufacturing process for engine components is complex and time-consuming, whereas the application of 3D printing technology can streamline this process. For instance, key engine components such as the cylinder head and cylinder block, which would typically require multiple castings and assembly in conventional methods, can be fabricated in a single print using 3D printing. This not only reduces the assembly steps but also enhances the overall performance and sealing capabilities of the components. 3D printing technology can also be applied to the manufacture of complex structural parts inside the engine, for example, the shape of the engine inlet and combustion chamber and other parts are complex and require high precision, through 3D printing technology, the corresponding parts can be accurately printed to ensure the working efficiency and combustion performance of the engine. [7]

3.3. 3D printing in aerospace

The application of 3D printing technology in the aerospace field is also increasing, especially in component manufacturing, presenting great opportunities and challenges for innovation. Traditional aircraft component manufacturing processes usually require multiple complex machining and assembly, and material waste is relatively large. 3D printing technology enables precise control over the material usage at a millimeter scale through its layer-by-layer construction process, thereby minimizing unnecessary waste and facilitating the achievement of higher lightweight designs for various aircraft components. This reduction in weight not only lowers the overall mass of the aircraft but also significantly enhances flight efficiency and reduces fuel consumption, leading to considerable savings in fuel costs for airlines. Given the increasing emphasis within the modern aviation industry on environmental protection and energy conservation, the imperative to reduce aircraft weight and fuel consumption has become particularly critical. As such, the application of 3D printing technology not only improves the fuel efficiency of aircraft but also indirectly contributes to a reduction in greenhouse gas emissions, steering the industry towards a more environmentally sustainable and green future.

Among these materials 3D printing fibre composites are more widely used, and the application of 3D printing fibre composites in aerospace is a technology with great potential. Through the combination of 3D printing technology and fibre composites, rapid manufacturing of large-scale, complex-shaped structural parts can be achieved. Traditional fiber composite molding processes typically involve the use of complex and costly molds, whereas 3D printing technology offers the advantage of directly transforming digital design files into solid components, thereby eliminating the need for molds and reducing both manufacturing costs and production cycles. Furthermore, 3D printing facilitates the highly customized manufacturing of intricate geometries, including structural components that are challenging to produce with conventional methods. This technology allows for the precise adjustment of fiber distribution and layering patterns according to specific performance requirements, thereby enhancing the overall functionality of structural parts. For instance, the creation of complex internal structures and components integrated with sensors can significantly improve the performance and safety of aircraft.[8]

4. Current problems and solutions in 3D printing

4.1. Existing problems in traditional 3D printing

Under current 3D printing technology, the performance of 3D-printed products generally lags behind that of components produced through traditional manufacturing processes. This discrepancy arises due to several factors, including the limitations in material properties and the relatively lower precision of current 3D printing methods. As a result, the structural integrity and overall functionality of 3D-printed parts may not always meet the stringent performance requirements of certain applications. Simultaneously, in the production of materials, due to the need for sophisticated instruments and some high-quality materials, so the cost of 3D printing is also a problem worth considering.

3D printed products often encounter a range of performance issues during practical application, which can be attributed to various factors including the choice of printing materials, design considerations, equipment calibration, and post-processing techniques. Common performance-related challenges include material brittleness, poor interlayer adhesion leading to delamination or fracture, and inconsistent mechanical properties, all of which can compromise the structural integrity and functionality of the printed object. Additionally, visual defects such as rough surface finishes and lack of fine detail resolution may detract from the aesthetic quality of the product. Furthermore, issues

such as warping and deformation during the printing process, dimensional inaccuracies, and difficulties in the removal of support structures can significantly impact the final quality and usability of the printed part. These problems highlight the need for a comprehensive understanding of the factors influencing 3D printing performance and the importance of optimizing various stages of the process to ensure high-quality outcomes. In particular, improper temperature control, inter-layer bonding and material selection during the printing process, or inappropriate selection of the printing direction, can lead to insufficient product strength or precision deviations. In addition to these common printing problems, machine calibration issues can also directly affect the print results, resulting in misaligned layers or uneven extrusion. To reduce the occurrence of these problems, you can choose the right materials, optimize the design, and ensure that the printer parameters are accurately set. At the same time, effective post-treatment can significantly improve the appearance and performance of the product, and finally verify that the product meets the expected requirements through practical testing to ensure that it meets the standards in terms of functionality and durability.

Whereas, when printing metal products, coarse columnar grains and unevenly distributed phases are typically formed in metal alloys produced by 3D printing, which are generally considered undesirable because they result in inhomogeneous properties and poor mechanical performance. Research results indicate that the addition of nano-sized molybdenum particles during solidification can promote grain refinement and suppress the formation of phase heterogeneity during solid-state thermal cycles. The dual-function additive induces changes in the material's microstructure, leading to a more uniform distribution of mechanical properties, while simultaneously enhancing both strength and ductility. This alloy is modified through a single component to address unfavorable microstructural features, offering a potential route to achieving desired mechanical properties directly from 3D printing.[9]

For small-batch production and personalized customization, 3D printing offers certain cost advantages. However, for large-scale production, traditional manufacturing methods, such as injection molding, are often more cost-effective. The equipment, consumables, and post-processing required for 3D printing can drive up production costs, particularly when using high-performance materials or high-precision printing, where costs can increase significantly.

At the same time, at present, China's 3D printing raw materials lack of relevant standards, there are few enterprises in China capable of producing 3D printing materials, especially metal materials mainly rely on imports, the price is high, which has caused the high cost of 3D products, affecting the process of industrialization. 3D printing technology is widely used for the production of personalized products, as it offers relatively low costs for small-scale manufacturing. However, when applied to mass production, the cost of 3D printing remains significantly higher than traditional production methods. Additionally, the high price of 3D printing equipment poses a barrier for small design companies and freelance designers, who often lack the purchasing power to invest in such technologies. As a result, the widespread adoption of 3D printing in the design industry remains challenging. [10]

4.2. The future prospects of 3D printing technology

3D printing still offers numerous areas for research and development, particularly in the pursuit of producing complex and intricate parts at lower costs and higher efficiencies, with the potential to transform the manufacturing industry. However, 3D-printed components often require post-processing or integration with other machining methods to obtain the desired surface finish, accuracy, and mechanical properties. Ultra-precision machining (UPM) is a promising processing technology that is capable of addressing these difficulties by providing high surface quality, precision, and consistency for 3D-printed components. The application of UPM can alleviate some of the performance limitations of 3D printing, resulting in an enhanced overall quality. [11]

In the pursuit of quality, it is also necessary to effectively solve the cost problem of 3D printing, which must be comprehensively optimized from multiple perspectives. First, the development and application of low-cost and recyclable materials is at the heart of cost reduction. Traditional 3D printing materials such as high-performance plastics and metals tend to be expensive, so researchers and companies need to push the development of new, low-cost materials. For example, the development of biodegradable plastics, recycled plastics and other environmentally friendly materials not only reduces production costs but also increases sustainability. In addition, technologies for recycling and reusing materials are crucial, and by collecting and reprocessing waste materials generated during the printing process, the cost of purchasing raw materials can be significantly reduced, as well as environmental pollution.

Moreover, improving printing speed and production efficiency is also the key to reducing costs. By using multiple printhead technology, 3D printers are able to print multiple parts at the same time, significantly increasing production efficiency and shortening production time for each part, thereby reducing unit costs. Additionally, the development and promotion of faster printing technology can accelerate the printing process and reduce the production cycle. In terms of equipment, improving equipment performance and increasing the level of automation can also effectively reduce costs. Intelligent and automated 3D printing equipment can reduce manual intervention, reduce labor costs, and improve printing accuracy and consistency.

5. Conclusion

By analyzing the application of 3D printing in several aspects, this paper finds that 3D printing is more and more widely used in different fields, but due to technical limitations, there is no way to achieve perfect performance, and it still needs to be improved. At the same time, the paper also mentioned that the cost control is also a difficulty. In the future development process, people should clearly understand that 3D printing technology will not replace traditional manufacturing processes, but integrate with it, develop in synergy, and comprehensively upgrade and improve traditional industries and technologies. In order to keep pace with contemporary advancements, researchers should fully leverage the advantages of technologies such as "Internet Plus" and cloud computing, integrating and optimizing digital resources to foster deeper integration of 3D printing with various industries. Concurrently, relevant research institutions should increase investment in 3D printing research, particularly in the areas of manufacturing processes and material development. Efforts should focus on developing advanced systems for the 3D printing process to minimize material waste and redundancy, promote environmentally friendly manufacturing, and enable automation in production. Additionally, there is a need to accelerate the exploration of new and smart materials, enhancing both the variety and mechanical properties of materials used in 3D printing. Overall, in this way, 3D printing technology will grow significantly, and the field of mechanical engineering will also make 3D printing commonly used.

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