Remanufacturing of Parts Based on 3D Printing and Digital Modeling

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Abstract. This article explores the method of part remanufacturing using 3D printing and digital modeling, highlighting its significance in reducing economic losses, raw material waste, and promoting ecological protection and circular economy. It introduces the concept of remanufacturing as a high-tech repair technique that extends product life cycles, contrasting it with traditional recycling. The article outlines the types, benefits, and limitations of 3D printing technology, noting its suitability for small-scale and custom part production. It details the 3D modeling process, including model creation, slicing, layering, and post-processing, and explains the complex steps for item restoration, such as laser scanning and data pre-processing. Case studies illustrate 3D printing's application in automotive and aviation manufacturing, emphasizing the benefits of lightweight, integrated parts that eliminate assembly. Research on remanufacturing's environmental and economic impact, particularly in diesel engines and electric vehicle batteries, shows its potential to reduce energy use and emissions significantly. The essay also suggests research directions for 3D printing to enhance efficiency, lower costs, and improve material utilization. And proposes further study on 3D printing in mechanical maintenance and emphasizes the need for quality control and performance examining in remanufacturing processes. These innovations could lead to broader applications of remanufacturing technology, contributing to sustainable manufacturing and consumption patterns.

Keywords: 3D printing, Remanufacturing, Blade, Economy, Energy.

1 Introduction

In the modern era of rapid development of the manufacturing industry, the rate of equipment replacement and wear and tear has increased significantly. In the context of global warming, a difficult question is raised for the manufacturing industry - how to reduce greenhouse gas emissions. In terms of equipment loss, some scholars have put forward the concept of remanufacturing, which has been widely supported. Among them, the remanufacturing technology represented by 3D printing technology is becoming more and more sought after.

Remanufacturing and repairing damaged parts during the service process can restore their original shape and physical properties, which can not only greatly reduce

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the economic loss, but also reduce the waste of raw materials, and realize the green development concept of ecological environmental protection and circular economy. The following By remanufacturing and repairing the damaged parts in the service process, it can restore the original appearance shape and physical properties picture shows the abandoned machine tools in real life and the abandoned cars piled up in the dump. These discarded machines, whether remanufactured or broken down into base metals, produce a lot of polluting gases. In the context of carbon neutrality, the country has issued a series of policies to repair old equipment and bring it back into service. Among them, 3D printing, as a modern and emerging manufacturing method, has the advantages of low difficulty in operation, fast molding speed and strong flexibility. The low operational difficulty, rapid prototyping, and high flexibility of 3D printing make it an ideal technology for remanufacturing, enabling quick turnaround and customization for repaired parts. Compared with the traditional industrial large-scale manufacturing, 3D printing is more dominant in small-scale manufacturing. In traditional industries, the remanufacturing of non-standard parts is time-consuming due to limited storage capacity; however, 3D printing's flexibility significantly speeds up the production of these bespoke components.3d printing flexibility makes non-standard parts production speed greatly increased. The application of 3D printing technology in mechanical maintenance can better serve the needs, which is also the application prospect of 3d printing technology in remanufacturing [1][2].

2 Remanufacturing

2.1 The Concept of Remanufacturing

Unlike recycling, refabrication is a high-tech prosthetics aimed at extending the life of a product. Its essence is maintenance, but it realizes the industrial restoration with the manufacturing model as the core. Therefore, remanufacturing is a higher level of maintenance, which is very different from the traditional maintenance industry. The development of remanufacturing industry has also brought a new concept of "whole life cycle". In the concept of the whole life cycle, the life of the product that should be scrapped is not over, and it can be used again after remanufacturing, so the life cycle chain of the product is elongated for the manufacture, use, scrapping, remanufacturing, reuse, and scrapping of the product. The traditional product life cycle is generally divided into "manufacturing, use, scrap", and the life cycle of the product after remanufacturing becomes "manufacturing, use, scrap, remanufacturing, reuse, scrap". To a great extent, it extends the life of the product, reduces the replacement frequency of the product, and reduces the production cost of the enterprise.

2.2 The Development of Remanufacturing Industry

In 2005, The State Council of the People's Republic of China explicitly supported the development of the manufacturing industry in the "Several Opinions on Accelerating the Development of the Circular Economy". In May 2010 will focus on auto engine, transmission, generator and other parts remanufacturing, the auto parts remanufacturing pilot scope expanded to drive shaft, oil pump, water pump and other parts. At the same time, promote construction machinery, machine tools and other remanufacturing, large waste tire remanufacturing auto parts, construction machinery, machine tools and other specialized repair of the mass production process. nd ensure that it meets the original specifications and performance. This practice represents an advanced form of circular economy in action2. 3D printing brief introduction

3 A brief introduction to 3D printing

3.1 The Type of 3D Printing

3D printing technology is also called Additive Manufacturing (AM) according to the principle of molding technology can now be divided into Fused Deposition Modeling (FDM), Powder Bed Fusion (PBF), light curing molding (SLA), Direct Energy Deposition (DED), etc. The types used vary depending on the target and the material. 3D printing, which combines cutting-edge technologies in various fields such as digital modeling, materials science and information collection, is known as "the most iconic production tool of the third Industrial Revolution" and is gaining increasing attention in China.

3.2 Advantages and Disadvantages Of 3D Printing the Pros and Cons of 3D Printing

Traditional manufacturing parts need to repeat the manufacturing process of parts in the workshop, limited by the production time is not guaranteed, some special parts even need to spend a lot of time to call more than worth the loss. And the 3D printing technology that relies on digital modeling technology can be manufactured on the spot as long as there are model files, eliminating the tedious links in the middle, reducing the process of repeated manufacturing, and greatly reducing the time. With materials and 3D printers, you can start to work, which has the characteristics of fast molding speed that the traditional processing and manufacturing industry does not have.

The disadvantage of 3D printing is that the cost of 3D printers and materials is high. For example, in metal 3D printing, commonly used materials are titanium powder, aluminum alloy powder and stainless-steel powder, whose cost is generally 10 times that of ordinary metal materials. Some data indicate that metal powders used in 3D printing can constitute 20% to 30% of the product's total cost. In contrast, raw materials in traditional manufacturing only make up about 5% to 10% of the cost. Furthermore, 3D printing often concentrates materials in support structures, resulting in a lower overall utilization rate. The high cost determines that 3D printing technology is difficult to be competent for large-scale manufacturing, which is a user-oriented method to reduce time costs.

Nowadays, 3d printing technology has been able to avoid material waste caused by support through multi-axis processing and printing. How to reduce the cost of high-tech 3d printing tools is a promising research direction.

3.3 3D Modeling

There is many excellent modeling software on the market, such as 3DMAX, blender, Maya, SolidWorks, Catia, AutoCAD, etc. Engineers in the manufacturing industry often use SolidWorks, AutoCAD, etc. The advantage of this kind of modeling software is that it can design a model that meets the engineering needs with high accuracy and can be simulated. It is recommended to use this kind of software for the modeling of parts [3].

For parts manufacturing, there are 3 steps. First is Build model that use modeling software to build 3D model of the target according to the drawing. The second is Slice and layer that save the 3D model file as STL format and import it into the slice software for slice and layer. The finished step is post-processing that after the above process, you can get the molded part in the 3D printer. Some targets need support structures when printing, so these supports should be removed. In addition, there are problems with the surface finish of the printed molded parts and subsequent polishing is required [4].

For the restoration of the item, the steps will be more complicated. Take laser scanning, for example. Analyze the object and make a plan for scanning. Secondly In the process of reverse modeling, the point cloud data must be obtained first, which is usually completed by three-dimensional laser scanning. The 3D data of the scanned object surface is stored in the form of point cloud. After the scanning the scanned point cloud data cannot be used directly. It is necessary to pre-process it, including denoising, registration, splicing and other operations, in order to obtain an accurate and complete 3D model. The important step is establishing model, and the point cloud data are superimposed in order to view the corresponding relationship between the model and the point cloud. In this process, the model can be optimized and adjusted as needed to achieve the best results. The next step is to repeat the normal 3D printing steps.

3.4 Application of 3D Printing in the Field of Manufacturing

As early as the 1990s, 3D emerged and was applied to practical applications by engineers in various fields, as shown in Fig. 1, the first 3D printed concept car urbee. Since then, automobile companies have adopted 3D printing technology to build their own concept cars. 3D printing can make the printed parts reach the limit size of thin walls, sharp corners, overhangs, columns and other shapes that cannot be reached by the traditional way, so that product designers have more space to play.

With 3D printing technology, designers can more intuitively verify their design outcomes. Porsche's automotive engineers have printed an engine through 3D printing technology, as shown in Fig. 2. Compared with the traditional manufacturing before verification method, 3D printing technology can achieve higher accuracy, high replicability, fewer variables and so on. In the design process with fast iteration speed, if the idea can be verified, it will be of great help to the next design. China Aviation Group printed the fuel nozzle by 3D printing method, as shown in Fig. 3.

3D printing can print the parts of multiple components, which not only realizes the integration of the parts structure, but also avoids the problems of the connection structure inside the parts, and better gives play to the designer's imagination. The lightweight and assembly-free integration of parts can also bring some practical benefits to enterprises [5].

Fig. 1. A Concept Car Names Urbee [5].

Fig. 2. Porsche Integrated Engine [5].

Fig. 3. Avic 3d printed Fuel nozzle [5].

4 Research Status

4.1 Development of Remanufacturing

Sutherland, J. W. et al., compared the energy intensity of manufacturing versus remanufacturing in diesel engines [6]. Nowadays, enterprises pay more and more attention to the impact of manufacturing on the environment, especially in the aspects of materials, energy and pollution gas emission. To compare remanufacturing with traditional manufacturing, a uniform quantitative standard is required Sutherland, J. W., et al. found that there was no good quantification of environmental performance in the aspect of remanufacturing, so their research team quantified and compared the environmental performance of diesel engine from the aspect of original manufacturing and remanufacturing. Firstly, they compared the energy intensity estimation of material extraction/refining, casting/manufacturing and remanufacturing, taking aluminum, cast iron and steel as examples. Through actual investigation, it is found that the energy required for remanufacturing is significantly lower than that for new manufacturing, for example, the remanufacturing energy of cast iron is only 0.56 to 7.0 MJ/kg of the manufacturing energy. The team then calculated the amount of energy contained in the original manufacturing and remanufacturing of various engine components. They found that remanufacturing the core parts of the engine can significantly reduce energy consumption. By remanufacturing the core parts of some parts, the effect of reusing the entire part can be achieved. For example, a six-cylinder diesel engine can avoid an additional 16,250 MJ of energy consumption.

Sutherland, J. W., and team highlight the potential of remanufacturing to reduce energy consumption and CO2 emissions and point out the challenges to realizing this potential. The findings suggest that the efficiency and environmental benefits of remanufacturing can be significantly improved by improving product design and recycling systems.

The Siqin Xiong team investigated the feasibility of remanufacturing used lithium-ion batteries for electric vehicles to address both the environmental threat posed by these batteries and the risk of future battery component supply [7]. The team evaluated the environmental impact and cost of remanufacturing batteries through quantitative analysis and compared it with using original materials for battery manufacturing. Using the Excel based EverBatt model, combined with the Battery Performance and Cost (BatPaC) model and the Environmental Impact of transport-related Facilities (GREET) model, the team found that the battery can reduce energy consumption and greenhouse gas emissions by 8.55% and 6.62%, respectively, during manufacturing. From a cost perspective, the savings in battery manufacturing amounted to about $1.87 per kilogram of battery cells. The study points out that remanufacturing can be profitable provided the recycling price of used batteries does not exceed $2.87 per kilogram.

4.2 Combined Application of Remanufacturing and 3D Printing

The application fields of 3D printing remanufacturing are very broad, including but not limited to manufacturing, medicine, ceramics, cultural relic restoration …….

At present, foreign countries have been able to repair the failed blade parts through laser cladding technology combined with adaptive grinding processing, and after repair, it still has good physical properties and a high degree of matching with the original parts. Because 3D printing technology spread late in China, and some domestic companies have not paid attention to the advantages of 3D printing. So domestic technical research in this area is relatively few, blade damage can only be sent to repair abroad, the cycle is long, the cost is high. What is more, it is necessary to replace the new mold, and the mold user fee is also very high. Through 3D printing technology can be a good solution to the above problems by avoiding the cost of mold opening and transportation. And the accuracy of the molding parts can meet the requirements. Fig. 4 is the flow chart of the core/shell integration technology proposed by Xi 'an Jiaotong University, which is realized by a light curing printer. For the broken blade in the previous page, some scholars have studied its repair methods. In this literature, the coordinate measuring machine was compared with 3D laser scanning technology. Because the measuring machine could not accurately detect the information of irregular jagged and pitted areas, 3D laser scanning technology was chosen to obtain the point cloud data of the broken blade. Fig. 5 is the registration diagram of the point cloud data obtained by the author. The diagram illustrates that the author selected an improved ICP algorithm, which reduced the registration time and enhanced efficiency. The author lofted the fractured blade from the fracture to form a complete 2D image of the blade according to the existing blade model and obtained the other half of the shape information of the fracture. Fig. 6 is the finite element simulation and mesh model of the blade defect model to be printed. The method proposed by the author is optimized in the digital part to reduce the time required for actual operation [8-11].

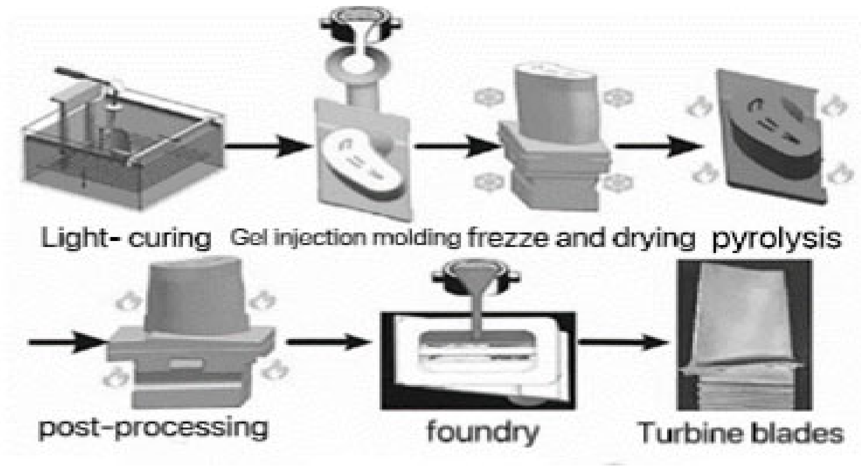

Fig. 4. Flow diagram of light-curing.one-piece blades [8].

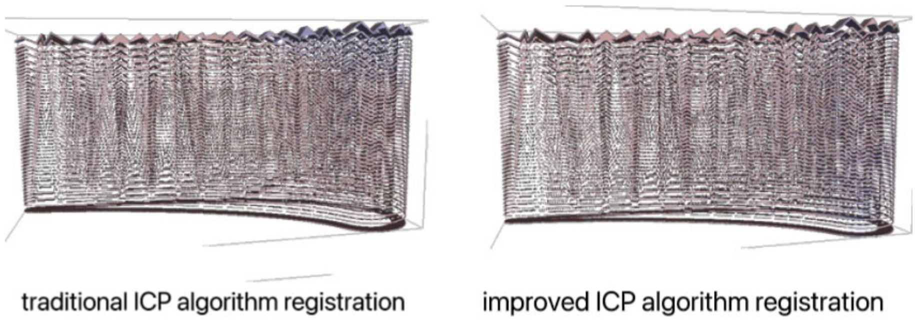

Fig. 5. Registration of point cloud data and mode [8].

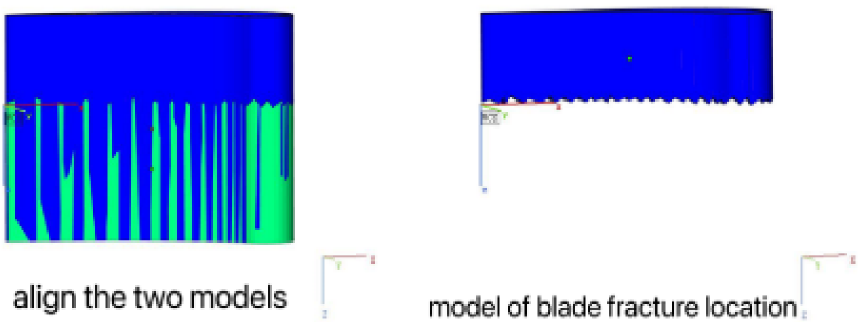

Fig. 6. Fracture part model solving [8].

5 Conclusion

This paper discusses the part remanufacturing method based on 3D printing and digital modeling technology, emphasizing the important role of remanufacturing in reducing economic losses, waste of raw materials, and promoting ecological environmental protection and circular economy. The concept of remanufacturing is introduced, which is different from the traditional recycling of waste materials, but a high-tech repair technology, which can extend the service life of products, and form the whole life cycle of "manufacture, use, scrap, remanufacture, reuse, and scrap".

The second part Outlines the types, advantages and disadvantages of 3D printing technology and its application in the manufacturing field. 3D printing technology shows great potential in small-scale manufacturing and non-standard parts production due to its advantages of easy operation, fast molding speed and strong flexibility. Although 3D printing technology has challenges in terms of cost and material utilization, it has made advances in multi-axis machining printing, which helps to reduce material waste. The process of 3D modeling is introduced in detail, including the steps of model building, slicing and layering, post-processing, etc., and the complex steps of item repair are explained, such as laser scanning, pre-processing, modeling and optimization. Through case analysis, the paper demonstrates the application of 3D printing technology in automobile manufacturing, aviation and other fields, and emphasizes the practical benefits brought by the lightweight nature of integrated parts and the elimination of assembly for enterprises.

The third part briefly describes the research status of remanufacturing technology, including a comparative study of the energy intensity of the remanufacturing of diesel engines, as well as the environmental and economic assessment of the remanufacturing of lithium-ion batteries for electric vehicles. These studies show that remanufacturing can significantly reduce energy consumption and greenhouse gas emissions and has good economic feasibility.

This paper points out the research direction of 3D printing technology to reduce costs, improve efficiency and material utilization, as well as the potential of developing process technologies to comprehensively recover multiple battery chemical components. In addition, further research on the application of 3D printing technology in mechanical maintenance is also proposed. And as well as an in-depth discussion of quality control and performance testing in the remanufacturing process. Through these studies and technological innovations, remanufacturing technology can be expected to achieve wider applications in the future and contribute to the realization of more sustainable manufacturing and consumption patterns.

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