Application of laser 3D printing technology in rapid prototyping manufacturing

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ABSTRACT

3D printing technology has brought significant changes to traditional manufacturing industries and is crucial for the development of precision machinery, computers, CNC, lasers, new materials, and other fields. However, it still cannot completely replace traditional manufacturing industries. With the application of laser 3D printing technology in non-traditional industrial fields, this technology not only breaks through the limitations of traditional processing and manufacturing, but also improves the performance of traditional 3D printing technology and realizes characteristic manufacturing, and has been successfully applied in rapid manufacturing systems. This article takes various classifications of laser 3D printing technology as an example to illustrate its current status and application methods in the manufacturing field, and looks forward to its future development prospects in the field of rapid prototyping manufacturing.

Keywords: Laser 3D printing, laser, rapid prototyping, manufacturing field, non-traditional industrial field

1. INTRODUCTION

Laser 3D printing technology is an important research field in the field of laser science. Since the first laser instrument was introduced in the 1960s, research in this field has made rapid progress. Compared with traditional manufacturing methods, laser technology has the characteristics of high brightness, high directionality, and high coherence, which are of great significance to industry, scientific research, military medicine, and people's lives[1]. At present, laser processing technology has been integrated with various high-tech industries, especially in the rapid prototyping technology (3D printing) introduced by Western countries in the past decade, which has accelerated the rapid development of rapid manufacturing systems.

1.1 Processing after laser rapid prototyping completion

Laser rapid manufacturing technology (LRMT), also known as laser 3D printing or laser rapid prototyping, collects geometric and material structure information of objects and constructs digital models through methods such as solid-state inversion and computer-aided design. Subsequently, this information is input into the laser rapid prototyping system, where the computer processes the point cloud information of the 3D material to meet design standards, achieving rapid and accurate manufacturing of prototypes or components that traditional processing cannot produce[2]. This process involves seven stages: preprocessing, model construction, model approximation, forming direction selection, 3D model cutting, polishing, and surface strengthening. By slicing the source files of the component drawings, scanning point cloud information is formed under computer control. The materials are stacked layer by layer on the workbench and bonded together to obtain the complete prototype. Afterwards, peeling, curing, repairing, polishing, coating and other operations are carried out, and the strength is enhanced by quenching and sintering at high temperature[3]. Laser rapid manufacturing technology can be divided into two categories: rapid direct manufacturing of metal components and rapid prototyping product manufacturing. Compared with traditional technology, this technology can complete prototype construction in just a few hours to tens of hours, bringing changes and benefits to fields such as material manufacturing, metal processing, and manufacturing industry[4].

1.2 The development direction of laser rapid prototyping technology

The rapid progress of rapid manufacturing technology (LRPT) in modern laser technology demonstrates three characteristics of this technology: the continuous expansion of application scope, the continuous improvement of supporting software and hardware technologies, and the continuous emergence of newly developed laser rapid

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manufacturing technology[5]. In recent years, the development direction of LPRT technology has included three-dimensional photopolymerization modeling (SLA), selective laser sintering (SLS), laser lamination manufacturing (LOM), laser cladding forming (LCF), laser near forming (LENS), direct optical manufacturing (DLF), metal laser sintering (DMLS), and shape deposition manufacturing (SDM).

2. CATEGORY OF LASER RAPID PROTOTYPING TECHNOLOGY

2.1 Laser stereoscopic printing forming technology

Laser Stereoscopic Printing (SLA) is a pioneer in rapid prototyping technology and widely used in manufacturing. This technology uses photosensitive resin as the substrate and is cured layer by layer through computer-controlled ultraviolet laser scanning. Laser scanning triggers the photopolymerization reaction of a thin layer of resin, and after curing, the worktable moves. The new resin covers the cured layer and continues to scan, layer by layer bonding until the three-dimensional prototype is completed (Figure 1). This process is based on laser curing of a continuous thin layer of photosensitive polymer, ultimately generating precise three-dimensional construction products[6].

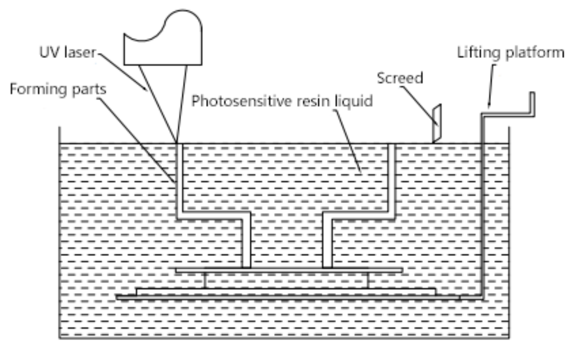

Figure 1. The forming principle of laser stereoscopic printing.

Stereoscopic printing machine, as a commercial rapid prototyping machine, integrates laser, lifting platform, storage cabinet, scanning mirror and computer control. Using ultraviolet laser and photosensitive polymer liquid, the contour of each layer is scanned at high speed through a positioning mirror (Figure 2). UV cured polymer surface, CNC command controlled laser scanning and lifting table movement, layer by layer cured to the set thickness. Scrape off excess polymer with a layer scraper and repeat this process until the prototype is completed[7]. This technology enables three-dimensional construction from liquid to solid state, quickly generating product prototypes.

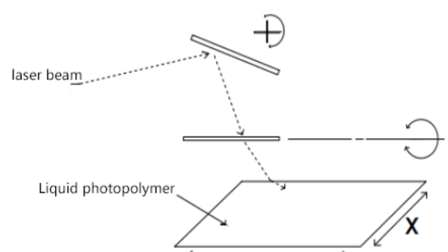

Figure 2. The laser scanning motion diagram.

2.2 Layered solid rapid prototyping technology

LOM technology, also known as layered solid manufacturing, is mature in the field of rapid prototyping. It is based on CAD model layering, laser cutting of adhesive film layers, layer by layer bonding and peeling off excess material to form a prototype. The process includes software layering, microcomputer controlled rotary cutting, hot pressing bonding, layer by layer reduction to the design height, and finally welding and cutting are completed (Figure 3). The product should be taken out, the waste is tapped and separated, the small cube is extracted from it, and the 3D prototype is obtained[8]. This technology is precise and efficient, achieving rapid conversion from design to physical object.

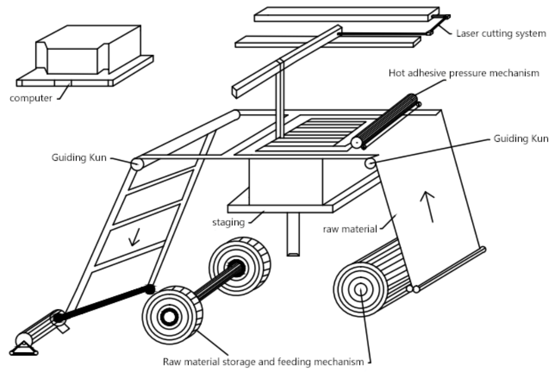

Figure 3. The principle of layered solid manufacturing system.

Layered 3D manufacturing technology differs from 3D printing technology in that it uses laser cutting of thin films instead of scanning cured resins, avoiding structural and stress changes, and improving accuracy and stability. This technology obtains cross-sectional profiles through data layering, without the need for full cross-sectional scanning and support, reducing costs and improving speed and efficiency (Figure 4). Common materials include metal foil, paper, plastic film, etc., which are suitable for the preparation of multi-layer curing systems[9].

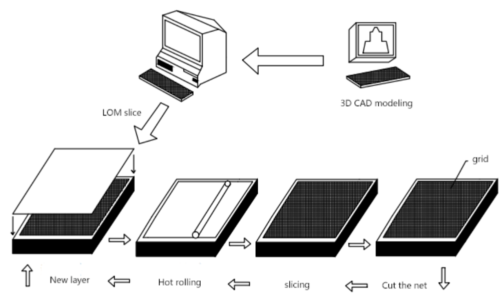

Figure 4. The process diagram of LOM rapid prototyping system.

2.3 Selective laser sintering technology

SLS technology is formed by laser sintered powder and layered based on CAD model. It incorporates sound, photoelectricity and temperature control, and the laser melts the powder into a three-dimensional prototype. In the process, after the powder is heated, a computer-controlled scanning platform is sintered layer by layer, and the process is repeated to form the powder layer by layer (Figure 5). Remove the residual powder and polish the finished product[10]. Similar to SLA, but with different materials. SLS is not limited by shape, no complex tools, fast molding, improve product competitiveness, usually 1-2 days to complete.

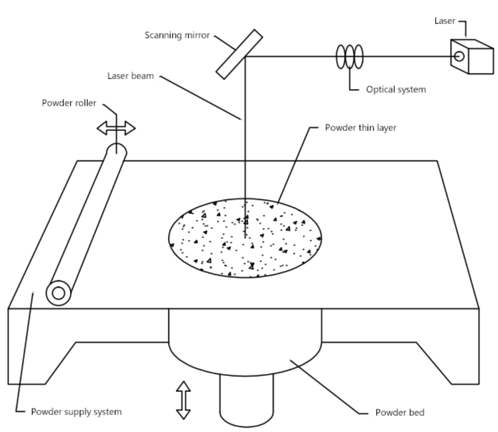

Figure 5. The SLS system schematic diagram.

2.4 Laser cladding rapid manufacturing technology

Laser coating rapid manufacturing technology combines rapid prototyping and laser cladding, such as LENS, DLF, etc., using CAD model stratification processing, through high-power laser scanning of the basic material to form a melt pool, and synchronized injection of metal powder to form a cladding layer. The numerical control platform controls the nozzle layer by layer scanning to realize the precise manufacturing of metal parts (Figure 6). Due to the rapid solidification characteristics of laser cladding, the metal parts produced by this technology have excellent performance and high quality strength[11].

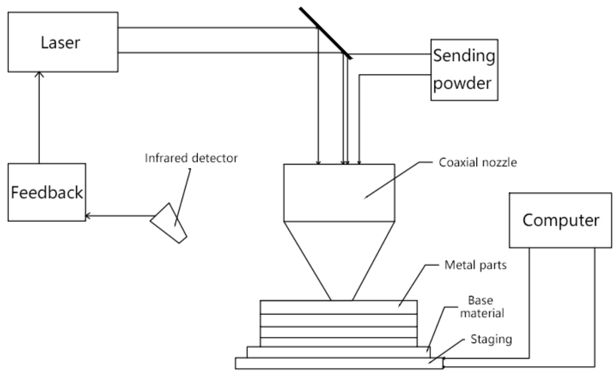

Figure 6. The principle of laser cladding rapid manufacturing technology.

Laser cladding direct manufacturing is superior to traditional manufacturing (Figure 7): (1) Efficient and flexible preparation of complex metal parts; (2) High efficiency and low cost, short cycle and high quality; (3) Enhanced design flexibility and broadened scope of technical application; (4) Suitable for a wide range of materials and improved material utilization; (5) Accelerated solidification and melting, conferring new characteristics, and compensating for manufacturing shortcomings[12].

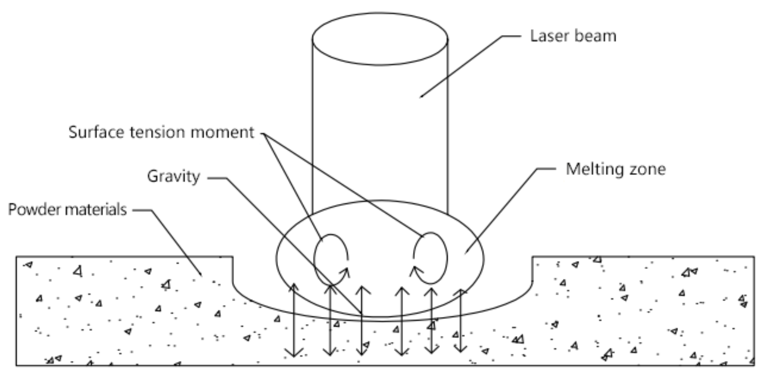

Figure 7. The melting process of powder materials under the action of laser

3. THE MAIN APPLICATION AREAS OF LASER RAPID PROTOTYPING TECHNOLOGY

Laser rapid prototyping technology has been extensively infiltrated into various industries such as jewelry, sculpture, archaeology, home appliances, light industry, film and television, military, medicine, architecture, art, machinery manufacturing, aerospace, and continues to expand its application scope with technological innovations[13]. Its application highlights include, firstly, industrial design and innovation: The technology enables designers to rapidly verify ideas, directly produce physical models, shorten the research and development cycle, reduce costs, and enhance the competitiveness of enterprises[14]; secondly, mechanical manufacturing: It is particularly suitable for the efficient production of small batches or complex parts. For instance, RP technology for small batch production within a single piece or 50 pieces is low-cost and fast[15]; thirdly, mold manufacturing innovation: Combined with traditional mold manufacturing, it can achieve rapid direct or indirect mold manufacturing, shorten the development cycle, and improve efficiency[16]; fourthly, medical application: Based on medical image data, it can manufacture human organ models to assist medical teaching and surgical planning[17]; fifthly, culture and art: It demonstrates unique value in the fields of cultural relic reproduction, digital sculpture, and artistic creation[18]. Sixthly, aerospace: It supports the rapid construction of high-precision, streamlined complex models and provides accurate models for aerodynamic experiments[19]; seventhly, home appliance industry: It integrates into the research and development process of many renowned enterprises, promotes product innovation, and achieves significant economic benefits[20]; eighthly, conceptual model and testing: As a creative communication medium, it optimizes product design and is used in stress-strain experimental analysis to ensure product quality[21]; ninthly, rapid mold manufacturing: Combined with electrode grinding, investment casting, and other technologies, it significantly reduces the cost and time of mold manufacturing[22]. Despite the current challenges such as precision, energy consumption, and institutional clarity, its development potential is immense. In conclusion, laser rapid prototyping technology, with its distinctive advantages, is gradually emerging as an important force driving innovation in multiple fields, and its future application prospects are vast.

4. DEVELOPMENT TREND

Laser rapid prototyping technology has broad prospects and can be applied to high-strength metal manufacturing, improving product performance, promoting material commercialization and innovative process design in the future. Especially in the medical field, such as SLM 3D printed dentures in stomatology, show great potential[23]. The technology produces high quality dentures with 80-120W laser power, 300 mm/s-500 mm/s scanning speed, accurate to 0.04 mm spacing (Figure 8). Key indicators such as inner crown wall thickness (0.3 mm-0.5 mm) directly affect clinical applicability. Follow-up treatments such as sanding and sandblasting ensure smooth surface. The study showed that the 0.4 mm wall thickness denture has excellent strength and comfort, demonstrating the successful application of SLM in the medical field.

Figure 8. The denture model made by laser rapid manufacturing technology.

5. CONCLUSION

Laser rapid prototyping as a new industry technology, with its advantages of layered design and integrated manufacturing, since human invention has become a hot spot in the field of manufacturing technology research. More than ten years have passed, the breakthrough of the concept of "prototype" marks that laser rapid prototyping technology has been developing rapidly in the direction of industrial manufacturing. Laser rapid prototyping technology has already achieved deep commercialization and marketization, and its application scope has gradually become clear in social production practice, and has also been recognized by the academic community and accepted by the industry. With the continuous emergence of new materials and new technologies, the change of laser rapid prototyping technology will also accelerate and intensify, and the actual parts manufacturing industry in the future will be more impacted and affected, which has a great role in promoting the development of the entire manufacturing industry.

REFERENCES

[1] "Laser 3D printing of carbon fiber parts," Reinforced Plastics, 65(1), 30 (2021).

[2] Li, B., Qi, W. and Wu, Q., "Research progress of carbon materials in the field of three-dimensional printing polymer nanocomposites," Nanotechnology Reviews, 11(1), 1193-1208 (2022).

[3] Necati, U., Adem, Ç. and Kubilay, A., "Machinability of 3D printed metallic materials fabricated by selective laser melting and electron beam melting: A review," Journal of Manufacturing Processes, 80414-457 (2022).

[4] Tyznik, C., Lamport, A. Z., Sorli, J., et al., "Laser printed metal halide perovskites," Journal of Physics Materials, (2020).
[5] Zhou, L., Miller, J., Vezza, J., et al., "Additive manufacturing: a comprehensive review," Sensors, 24(9), (2024).
[6] Preethi, L., Ram, S. M., Suresh, B., et al., "Additive manufacturing technologies with emphasis on stereolithography 3D printing in pharmaceutical and medical applications: A review," International Journal of Pharmaceutics: X, 5, 100159 (2023).
[7] Luna, A. J., Cho, H., Son, K., et al., "Assessment of temperature effects on photopolymer resin dental prosthetics fabricated by stereolithography using optical coherence tomography," Optics and Laser Technology, 179, 111248 (2024).
[8] Mahale, R. S., Shamanth, V., Hemanth, K., et al., "Processes and applications of metal additive manufacturing," Materials Today: Proceedings, 54(P2), 228-233 (2022).
[9] Kumar, A., Dixit, R. A. and Sreenivasa, S., "Mechanical properties of additively manufactured polymeric composites using sheet lamination technique and fused deposition modeling: A review," Polymers for Advanced Technologies, 35(4), (2024).
[10] Han, W., Kong, L. and Xu, M., "Advances in selective laser sintering of polymers," International Journal of Extreme Manufacturing, 4(4), 042002 (2022).
[11] Samuel, S., Bathusile, M., Paul, L., et al., "In-situ production of WC-Ni using a laser cladding technique," MATEC Web of Conferences, 370, (2022).
[12] Fang, T., Huang, F., Qian, X., et al., "The microstructure and properties of laser-cladded Ni-based and Co-based alloys on 316L stainless steel," Metals, 14(6), 698-698 (2024).
[13] Bulut, H., Murat, K., Süleyman, U., et al., "An overview of various additive manufacturing technologies and materials for electrochemical energy conversion applications," ACS omega, 7(45), 40638-40658 (2022).
[14] Kladovasilakis, N., Pechlivani, M. E., Sfampa, K. I., et al., "Metal 3D-printed bioinspired lattice elevator braking pads for enhanced dynamic friction performance," Materials, 17(11), (2024).
[15] Han, P., Torabnia, S., Riyad, F. M., et al., "Effect of laser heating on mechanical strength of carbon fiber-reinforced nylon in fused filament fabrication," The International Journal of Advanced Manufacturing Technology, 133(11-12), 6139-6146 (2024).
[16] Alessio, F., Alessio, M., Vedani, M., et al., "Novel concepts for the design of moulds and equipment for expanded polymer bead foams," Progress in Additive Manufacturing, 1-8 (2020) (preprint).
[17] Ananth, K. P. and Jayram, N. D., "A comprehensive review of 3D printing techniques for biomaterial-based scaffold fabrication in bone tissue engineering," Annals of 3D Printed Medicine, 13, 100141 (2024).
[18] Wilson, P. F., Donnelly, M., King, E., Williams, M. A. and Cooley, A. E., "Reverse-engineering history: re-presenting the chichester tablet using laser scanning and 3D printing," Studies in Conservation, 68(8), 773-783 (2023).
[19] Chen, Y., Qian, H., Pappas, J., et al., "Laser direct fabrication and characterization of 3d lattice structures using continuous carbon fiber thermoset composites," The International Journal of Advanced Manufacturing Technology, 133(11-12), 5585-5594 (2024).
[20] Jung, H. J. and Min, S. P., "Fabrication of a conductive pattern on a photo-polymerized structure using direct laser sintering," Applied Sciences, 12(21), 11003 (2022).
[21] Ramos, D. L.O., de Faria, L. V., et al., "Electrochemical platform produced by 3D printing for analysis of small volumes using different electrode materials," Talanta, 265, 124832 (2023).
[22] Petr, R. and Tomáš, S., "Thermal conductive composites for FDM 3D printing: A review, opportunities and obstacles, future directions," Journal of Manufacturing Processes, 83, 677 (2022).
[23] Boontherawara, P., Chaijareenont, P. and Angkasith, P., "Comparing the trueness of 3D printing and conventional casting for the fabrication of removable partial denture metal frameworks for patients with different palatal vault depths: An in vitro study," The Journal of prosthetic dentistry, 132(2), 434.e1-434.e6 (2024).