Characteristics, Connotation and Military Application of Additive Remanufacturing Technology

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Abstract: This paper analyzes the intelligent and digital trend of remanufacturing industry, discusses the connotation and characteristics of additive remanufacturing technology, compares and analyzes the application status and application technology of additive remanufacturing technology in China's military industry, points out that additive remanufacturing technology has broad application prospects in national defense science and technology, and brings higher military and economic benefits.

1. Introduction
Additive remanufacturing technology is a kind of rapid prototyping technology, also known as 3D printing technology and entity free manufacturing technology. It is an epoch-crossing technological innovation in the field of mechanical manufacturing industry in the past 30 years, which has brought a huge impact on modern society. Facing countries promote transformation and upgrading of traditional manufacturing and supporting the major strategic needs of the development of high-end manufacturing, increase material manufacturing as one of advanced remanufacturing technology is a very promising and multidisciplinary cross fusion innovation technology, is expected to boost the key basic parts, basic technology, basic material, basic manufacturing equipment research and development, In order to promote new energy vehicles, Marine engineering equipment, rail transit equipment, aerospace and other high-end equipment manufacturing bigger and stronger.
2. Characteristics and advantages of additive remanufacturing technology

2.1. The basic connotation of additive Remanufacturing
Digitalization and intellectualization are the development direction of remanufacturing industry. Additive remanufacturing is the frontier direction of remanufacturing technology. The additive remanufacturing technology is a digital rapid prototyping method driven by the 3D data model of the defect, through reverse modeling, discrete layering, filling path planning of the defect parts, and then layer by layer superposition, cumulative forming, and using intelligent control software and appropriate laser, arc, plasma and other energy beam additive process layer by layer stacking, using electric field, magnetic field, ultrasonic, flame, electrochemical energy and other energy to achieve size recovery and performance improvement in order to realize the remanufacturing process of mechanical parts [1-2]. Additive remanufacturing technology can maximize the added value contained in the damaged parts, and avoid the resource and energy consumption and environmental pollution in a series of processing, such as the direct recycling and reshaping of waste parts [2-3].

The inherent characteristics of additive remanufacturing technology make it suitable for the remanufacturing of asymmetric, curved surface and other complex structural parts. It can be used for the remanufacturing of equipment parts under multi-dimensional constraints on site, especially suitable for some occasions where rapid response is required and cost is not the main consideration, such as on-site repair of equipment parts, on-line remanufacturing of large parts or difficult to disassemble parts [3]. It has been widely used in vehicles, ships, heavy machinery, energy and chemical industry, aerospace and other fields [4].

2.2. Difference between additive remanufacturing and additive manufacturing
As shown in Table 1, compared with additive manufacturing, both of them process parts in the way of material stacking layer by layer [5]. Additive remanufacturing is an additive repair activity on the basis of damaged parts, which needs to meet the personalized repair needs of waste parts due to different failure forms, structures, performance requirements, etc., resulting in obvious differences from additive manufacturing process.

| Content                  | Additive manufacturing | Additive Remanufacturing |
|--------------------------|------------------------|--------------------------|
| Processing properties    | “creating something out of nothing” | “fix the broken one”    |
| Processing object        | Before service, the manufacturing process of new products | After service, the damaged parts are discarded and the invalid parts are treated |
| Processing conditions    | Carried out under factory conditions, it is less constrained. | Under site conditions, it is constrained by energy, atmosphere, materials, aging, assembly features and many other aspects. |
| Equipment required       | Adopt the three dimensional coordinate operation machine | Sometimes it is necessary to use intelligent robot for forming control |
| Technological process    | The same deposition process is used to process homogeneous materials generally. | Most of them belong to heterogeneous forming, and need to choose laser, plasma, arc and other deposition processes according to the forming materials and performance requirements. |
| Modeling process         | It can be formed directly by CAD model layering and path planning. | It needs to go through reverse modeling of defective parts, registration and comparison with standard CAD, remanufacturing modeling layering, path planning and so on. |
Remanufacturing belongs to advanced manufacturing and green manufacturing. Compared with additive manufacturing, additive remanufacturing is more diversified, personalized and complex in failure forms, matrix materials and performance requirements, which makes it more challenging. It is manifested in more complicated pre-processing, more complex forming process, more difficult quality control, more flexible manufacturing process, and less need for intelligent control. The accuracy and stability of the system put forward higher requirements [6-7]. Therefore, the technology content of the process is more high, and the advanced technology should be reflected.

3. Application of additive remanufacturing in military industry

The application of additive manufacturing technology in the field of military manufacturing is highly concerned by all countries. Because of its high flexibility and rapidity, it meets the requirements of rapid and accurate support in modern war. The U.S. military has always been a pioneer in the application of additive manufacturing technology. Many parts on F-22 and other fighters are produced by additive manufacturing technology, and a high flexibility field parts manufacturing system has been developed for battlefield use [7-9]. Using advanced additive remanufacturing technology to repair damaged equipment parts can improve the maintenance ability of equipment. In military applications, additive remanufacturing can be used to repair the damaged parts in war and normal service. The process is as follows: firstly, the damaged parts are scanned by 3D scanner to obtain the digital model of the damaged parts, and then the digital model is processed to generate the CAD model of the damaged parts, and the remanufacturing repair model is generated by comparing with the standard model; then the hierarchical path planning is carried out for the remanufacturing model, and finally the 3D printing system is used to process the damaged parts according to the planning path. The damaged parts are remanufactured and repaired [5-6].

The U.S. military is currently the biggest beneficiary of remanufacturing in the world. Since the 20th century, the US military has used various technologies to remanufacture bombers, Apache helicopters and tanks. If the damaged titanium alloy components of military helicopter are remanufactured and repaired, it can save us $20000-60000 compared with directly replacing new components. Another example is the remanufacturing and repairing of the engine fan protective cover of F119 fighter. Every year, tens of thousands of engine blades are repaired by laser cladding additive manufacturing technology, with considerable economic benefits. Using lens technology to repair a helicopter engine can save more than 100000 US dollars than using traditional methods. Because the wear resistance of the remanufactured part is better than that of the original material, the service life of the engine can be greatly extended. In terms of army equipment, the United States has built an ordnance repair system based on lens additive remanufacturing technology for the remanufacturing repair of Abrams M1 tank gas turbine engine parts, mainly including rotor, sealing runner, spacer compressor, guide vane, compressor stator, compressor vane, etc. After the system was put into operation, it saved us $6.3 million in military expenditure in 2002 alone. The rapid manufacturing and remanufacturing repair of machine guns and other parts of armed equipment has greatly improved the response speed and support level of rapid and accurate support of equipment [3-4].

At home, although additive manufacturing technology started late in China, the advantages of additive manufacturing technology in equipment parts maintenance support have been paid attention to from the beginning. At present, a series of achievements have been made in the research and application of additive remanufacturing repair of equipment parts in China. The rapid prototyping Laboratory of Shenyang Institute of automation, Chinese Academy of Sciences, cooperated with Qingdao Branch of Naval Aeronautical Engineering College to carry out the research on additive manufacturing technology of metal powder laser forming. At present, the technology has been successfully applied to the remanufacturing and repairing of engine turbine guide and ship propeller blade of a main combat aircraft. Continental Laser Technology Co., Ltd. in Shenyang adopted laser based additive manufacturing technology and plasma spraying technology to remanufacture and repair flue gas turbine blades, and achieved good results. The laboratory of Armored Forces Engineering College adopts laser cladding, arc cladding and plasma arc cladding additive manufacturing
technology, as well as thermal spraying, brush plating and other surface engineering technology to build a remanufacturing and repairing technology system of equipment parts in line with the characteristics of our army, which has produced huge economic and military benefits [5-8]. 3. Process flow of additive Remanufacturing.

4. Process flow of additive Remanufacturing

4.1. Remanufacturing process
Additive remanufacturing is a complex system engineering, which uses waste products as the production blank. The process includes recovery, disassembly, cleaning, detection, life assessment, repair, assembly and other processes. Among them, damage repair is the core process of remanufacturing, which relies on advanced remanufacturing technology to restore the dimension and service performance of parts [9].

The process of additive repair for volume damaged parts is usually as follows: firstly, the failure mechanism is analyzed according to the service performance requirements of the parts, the physical and chemical mechanical properties of the remanufactured parts are deduced, and then the microstructure and material composition of the parts to be repaired are determined, and the appropriate energy beam processing technology is selected. This is a reverse deduction process from the working performance of parts to physical and chemical mechanics, microstructure, material composition and additive processing technology [10].

In recent years, China has made progress in reverse modeling of defective parts, evaluation of weld bead, development of forming materials, remanufacturing of 3D volume damaged parts and automation. The intelligent deposition forming system of additive remanufacturing based on opto Mechatronics integrates materials science, information science, automation technology, mechanical engineering and other supporting technologies, which can meet the requirements of damaged parts due to failure forms, mechanical and electrical properties Due to different structure and performance requirements, diversified and personalized repair needs are generated, and large parts of several thousand grams to several tons are remanufactured at a lower cost [11].

4.2. Arc deposition forming technology
Arc additive remanufacturing is an advanced manufacturing technology based on the principle of discrete accumulation, which uses the arc as the energy carrying beam to heat and melt the metal wire. Driven by the path planning program generated by the defect data model, the point line surface body cumulative forming is used to restore the size, morphology and performance of the defect parts. At present, the research on arc deposition forming technology at home and abroad mainly focuses on the direct forming of parts, and the research on the remanufacturing and repairing of damaged parts is less. Scholars at home and abroad have carried out a lot of research work in the field of arc cladding additive repair manufacturing, mainly involving heat input and part precision control, part measurement modeling and repair program generation, process control, etc. the research foundation is gradually consolidated, and the technology development is increasingly mature [10-12].

4.3. Laser cladding technology
In recent years, laser additive remanufacturing technology is a new technology of parts repair and reconstruction, which has the characteristics of high precision, high intelligence, small thermal damage and low cost. It is widely used in many fields in China, especially for high value-added parts with local damage caused by wear, cracks and other reasons. Due to the metallurgical combination of cladding layer and substrate, laser cladding has obvious advantages in surface strengthening [10].

At present, the research of laser additive repair mainly focuses on the repair of titanium alloy, structural steel, austenitic stainless steel and other damaged parts. TC6 titanium alloy is widely used in the aviation field. TC6 titanium alloy structural parts are key load-bearing parts. There are surface corrosion, scratches, cracks and other defects in the process of use, but its price is expensive, the cost
of replacement repair is high, and the procurement cycle is long, which seriously affects the production efficiency [6]. Laser cladding remanufacturing technology has been widely used in aerospace, mining machinery, petroleum metallurgy and other industries. For example, in the field of aviation aircraft engine blade repair, marine ship engine crankshaft repair and reconstruction, mine scraper conveyor sprocket, hydraulic support hydraulic cylinder repair, agricultural field of agricultural tools repair, coating and so on. At present, remanufacturing repair based on laser cladding technology has been adopted in China, and good results have been achieved in the repair of aero-engine blades; for the repair of damaged crankshaft, the metallurgical bonding between the cladding layer and the matrix is good, and the hardness of the cladding layer is significantly better than that of the matrix. The surface strength and hardness of the repaired layer are higher than those of the original substrate.

5. Application cases of remanufacturing of military equipment repair additive

As shown in Table 2, additive remanufacturing technologies used in the field of military equipment repair are different according to their damage and characteristics. In addition to laser cladding welding, thermal spraying, 3D printing, etc.

| Adoption of Technology | Laser cladding welding | Thermal spraying | 3D printing |
|------------------------|------------------------|------------------|-------------|
| Military parts          | Some missile hook      | Piston rod of gas thruster in a certain type of aviation ejection device | Missile protective cover |
| Function of parts       | The important load-bearing parts in the front and rear actuating parts of aviation ejection device | The high temperature and high pressure gunpowder gas produced by the explosive bomb pushes the piston rod to move, so as to ensure the missile can eject smoothly from the beam | It can protect the electrical connector docking with the missile |
| Injury condition        | Superficial crack of missile hook | The residual gunpowder residue in the gas thruster was not removed in time, which corroded the chromium plating layer of the piston rod | In the process of repair, some of the caps were missing and cracked, so they could not be used any more. |
| Difficult to maintain   | The structure is complex, the cost of opening mold is high, and there is no need for mass production in the repair process. It is difficult to purchase equipment from abroad and the cost is high. | The bath solution used in the traditional chromium plating process pollutes the environment and is easy to cause the coating to be too thick and fall off. | There is no corresponding purchasing channel, it is mould pressing parts, the cost of re opening mould in the repair process is high, and there is no need for mass production. |
| Additive remanufacturing process | The cracks on the surface of the parts were removed by grinding, then laser cladding welding was carried out, and finally the surface of the parts was repaired. | The chromium layer on the surface of the part is removed, the corrosion pits on the substrate surface are removed by turning, then thermal spraying is carried out, and finally grinding to the specified size and surface roughness to complete the repair. | The 3D model of the part is established by surveying and mapping, and then the printing path is designed by slicing, and the additive processing of the plug is carried out by 3D printing. |
Additive remanufacturing repair technology also has important value in aircraft overhaul. The common failure modes of aircraft metal components can be divided into corrosion, wear, deformation, crack, etc., and the repair materials or surface coatings can be determined according to the repair objectives of component matrix materials and different failure modes [7-10]. At present, the types of advanced remanufacturing technologies entering the practical stage include: high speed arc spraying technology, micro nano plasma spraying technology, nano composite brush coating technology, micro nano surface damage self repairing technology, micro pulse cold welding technology of special surface, laser remanufacturing technology, rapid prototyping technology of remanufactured blank, cold spraying technology, special processing technology, etc. Additive remanufacturing technology can effectively solve the problems in the process of aviation product repair. Compared with the automotive industry, most Aerospace remanufacturing applications are more suitable for the current value proposition of additive manufacturing.

6. Prospect of additive remanufacturing technology

6.1. research on intensive design and preparation of additive remanufacturing materials
Due to the characteristics of various kinds and different materials of additive remanufacturing production objects, the damage of parts often has complexity, suddenness and randomness. Considering the timeliness and economy of rapid repair of damaged parts, it is difficult to ensure the complete homogeneous matching with the damaged parts in engineering practice. Therefore, based on the compatibility of materials and the interaction law of heterogeneous materials, it is necessary to carry out the research on the intensive design and preparation of additive remanufacturing materials, and it is necessary to use a few broad-spectrum intensive materials for additive remanufacturing of damaged parts of different materials.

6.2. Carry out precise support requirements
At present, the U.S. Army space and missile defense command and the Innovation Office of the future operations center of the Army Strategic Command have developed a 3D printer with low quality and low price for the battlefield personnel, which can be put in the backpack of the combat personnel and used in the battlefield.

6.3. Meet the needs of diversity of equipment parts
Improve the integration and automation of remanufacturing software system to improve the response speed of remanufacturing of damaged parts. At present, some companies have launched forward and backward hybrid design software, which is a step forward to high integration remanufacturing software system. At the same time, additive remanufacturing is developing in the direction of technology diversification and combination with other manufacturing technologies, so as to solve the problems of expensive laser 3D printing equipment, poor portability and low additive manufacturing accuracy.

6.4. Make full use of Internet of things and 5G Technology
Recently, the U.S. Army Research Laboratory and Purdue University have developed a new 3D printing technology, which can help soldiers deployed in different positions to remotely repair equipment (such as aircraft and automobile) parts, improve the efficiency of military equipment and greatly reduce maintenance costs [11-13]. At present, professional network 3D printing service platform has appeared in China, but the information about Remote 3D printing remanufacturing has not been reported.

Applying additive remanufacturing technology to the remanufacturing of damaged parts of military equipment can not only greatly save costs, save national defense expenditure and reduce the inventory of spare parts of military equipment, but also greatly improve the response speed of rapid and accurate support of damaged parts, promote the regeneration of combat effectiveness and improve the combat
readiness of the military. With the development and maturity of additive manufacturing technology, its application prospect in national defense science and technology will be broader, and it will bring higher military and economic benefits.

7. Conclusion
To sum up, this thesis is about the characteristics, connotation and military application of additive remanufacturing technology. The first part elaborates the characteristics and advantages of additive remanufacturing technology and exhibits the superiority of additive remanufacturing. The second part shows the application of additive remanufacturing in military industry from national analysis international aspects. The third part introduces the process flow of additive Remanufacturing. It includes remanufacturing process, arc deposition forming technology and laser cladding technology. The fourth part shows a number of application cases of remanufacturing of military equipment repair additive. In the end, the thesis looks forward to the prospect of additive remanufacturing technology.

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