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Progress in the Application of Laser Processing Technology in the Field of Aerospace Materials

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ABSTRACT : *Laser processing technology is a processing technology that makes use of the characteristics of laser beam and material interaction to weld, surface treatment and micro-machining of materials. The research progress of different laser processing processes on typical structural component materials as well as the application progress and optimisation process on structural components as a whole are reviewed, and the influence laws of different process parameters on the quality of processing and shaping are outlined. The working principles of laser welding, cladding and other laser machining processes are explained, and the significant advantages and problems of laser machining technology over other technologies in the field of aerospace structural components are summarised, with an outlook for future development.*

KEYWORDS - *laser processing technology; aerostructure parts; laser welding; working principle; optimization of processes*

I. INTRODUCTION

As one of the symbols of scientific and technological progress in the 20th century, laser processing technology occupies an important position in the field of optoelectronic technology in modern information society. Meanwhile, as the core direction of laser industry, laser-based high-energy beam processing technology plays an indispensable role in the development of aviation equipment [1-2]. As an advanced processing means, laser technology plays an increasingly important role in the field of national construction and national defence. The advanced countries in the world have paid great attention to the development of laser technology and laser industry. The aerospace structural parts processing field is increasingly dependent on laser processing technology. With the development of aerospace structural components towards monolithic, topological and functional integration, laser processing technology will be widely used.

The rapid development of modern laser processing technology in aerospace mechanical processing has given rise to many technologies, such as laser welding technology, laser cladding technology and so on. Laser welding technology can be different material components welded together, welding interface beautiful and strong, suitable for welding aircraft shell and engine internal thin-walled components laser drilling technology makes the location of the processing hole more accurate, faster processing speed; laser cladding technology can be better repair of the alloy corrosion surface, to improve the alloy surface abrasion resistance and high temperature resistance. At the same time, aviation structural parts processing in the future on the laser processing equipment requirements are higher, need to have advanced intelligent manufacturing capabilities. Therefore, high-end laser processing equipment will become the core competitiveness of precision processing of aviation structural parts.

This paper takes different laser processing technology in nickel-based alloys, aluminium alloys, titanium alloys, strength steel and several other materials that are very widely used in the field of aerospace structural parts as the entry point, reviews the research and application progress of typical laser processing technology in the field of aerospace materials, and at the same time, summarizes the urgent problems of the current laser processing technology, and puts forward the direction of the development of the future of the laser processing technology in the field of aerospace materials, which is intended to provide a good opportunity for the The purpose of this paper is to provide reference for the scholars in solving the problems of laser technology on aerospace materials.

II. LASER WELDING

2.1 Laser welding study of nickel-based alloys

With the emergence of industrial gas turbines to meet the needs of high-load power generation and the requirement of long-term service of the material of the aircraft engine, the use of materials to have fatigue resistance, thermal fatigue, low coefficient of thermal expansion and other comprehensive performance. Nickel-based alloys is one of them, it has wear-resistant acid medium corrosion resistance, resistance to active gases, excellent performance, but also has a high strength, good plasticity, can be hot and cold deformation and processing of moulding and weldable characteristics, very suitable for aviation structural components.

Gao ZG [3] found that the boron concentration and weld profile in Inconel 718 nickel-based alloys have a great influence on the weld heat-affected zone (HAZ) intergranular liquefaction cracking. The crack length is shorter when the boron concentration in the material is low, with an overall parabolic shape at low power and monotonically decreasing at high laser power. Weld profile also plays an important role in grain boundary segregation, fully fused profile is energetically favourable to increase the resistance to HAZ intergranular liquefaction cracking, whereas partially fused profile not only did not reduce cracking but also reduced weldability.

Aina O J et al [4] conducted a pre-weld heat treatment process (FUMT) test on precipitation hardened nickel based high temperature alloy 738and compared the advantages and disadvantages with other different pre-weld heat treatment processes as shown in Table 1. Nickel-based high-temperature alloy 738 is often deployed in hot spots in aerospace engines and power generation turbines [5], where its performance is particularly critical. After automated laser welding of plates subjected to FUMT and another process, SHT pre-weld heat treatment, the total crack length of the FUMT specimens was about 70% lower than that of the SHT specimens.

2.2 Research on laser welding of high strength steels

In the aerospace industry, high-strength steels are widely used in important components such as aircraft fuselages, engines, landing gears, etc., by virtue of their high strength, toughness, plasticity and reliability, as well as in structural parts of spacecraft such as rockets and satellites. The study of welding process of high strength steel is beneficial to its application in aerospace structural components.

Song Wei et al [6] found that when high strength steel is welded by laser welding, the HAZ austenite grain growth phenomenon is obvious. They obtained different line energies by changing the ratio of laser welding power and speed. By observing the grain growth of HAZ separately, it was found that the larger the line energy, the more obvious the grain growth. The reason was analysed as the heat input becomes larger when the line energy is large, resulting in a longer action time of HAZ in the temperature interval of austenite grain growth.

Wu Qiang et al [7] in laser welding of high strength galvanised steel found that the vaporisation of zinc leads to the destruction of the weld and the HAZ galvanised layer, and the reduction of the zinc content softens the HAZ. This can be effectively avoided by laser deep melting welding thanks to its fast heating and cooling rate and the generation of a certain amount of hardened tissue.

Dai Yibo et al [8] used annealing and tempering two pre-weld heat treatment methods on high-carbon and high-chromium martensitic 440C stainless steel, compared the two different pre-weld heat treatment methods on the weld zone and heat affected zone organisation. Both treatments form a good weld, but the two treatments have a more obvious effect on the organisation and properties of the weld heat-affected zone, and compared with annealing, the tempering treatment increases the hardness of the heat-affected zone joints by 35%, and the tensile strength of the joints is increased by 20%. It is worth mentioning that the hardness of the plate in annealed condition was increased by 60 per cent after the tempering treatment.

2.3 Laser welding study of 5052-H32 aluminium alloy

5052-H32 aluminium alloy has good forming and processing performance, corrosion resistance, weldability, used in the manufacture of aircraft fuel tanks, fuel pipes, etc. This alloy has high strength, especially fatigue strength, high plasticity and corrosion resistance, good weldability. It is mainly used on structural parts requiring high plasticity and good weldability.

ABIOYE T et al [9] successfully achieved pulsed laser welding of 0.6 mm thick alloy 5052-H32 commonly used in aerospace. In their study they found that macroscopically the weld width increases with increasing pulse laser current, pulse frequency and pulse width. At low pulse energy power and low average peak power, the welded joints showed dendritic organisation. Microscopically the results of elemental analyses showed that there was a loss of Mg in the welded joints. The content of Mg in the melted zone is significantly less compared to the base metal and filler metal i.e. the loss is more pronounced at higher heat input.

Zhang et al [10] used high welding speed, high energy density and small thermal deformation of 5052-H32 material welding, the study found that the laser power on the depth of fusion, weld thickness has the most obvious effect, the welding speed on the melt width has the most obvious effect, the formation of a good weld needs to be adjusted to the balance of power and speed. As for the problem of weld sagging during welding, the research team judged that the reason was the loss of Mg elements due to the instability of the joint molten pool, which led to the deterioration of the quality of the weld.

2.4 Research on laser welding of titanium and aluminium alloys

Laser welding technology with its excellent heat source performance, excellent deformation control and a wide range of material welding adaptability, in the welding of thin-walled high-precision components of the aero-engine unique advantages in the welding of aerospace high-temperature alloys, titanium alloys, titanium-aluminium intermetallic compounds, and other new materials welding has a greater prospect for development [11-12].

Airbus dual-beam dual-side synchronous laser welding process [13-15] applied to the A318 aluminium alloy aircraft fuselage two lower wall plate of the skin and truss welding in the formation of the overall fuselage wall plate, the weight of the aircraft fuselage to reduce the weight of about 20%, and improve the strength of about 20%.

U.S. Honeywell [16] has successfully applied laser welding technology to the Avro RJ regional jet series aircraft engine LF507 blade repair. Canada Liburdi Group of companies [17] using automatic wire laser welding equipment for blade repair, to achieve the RB211 engine high, medium and low pressure turbine blade repair.

Domestic scholars for TA15 titanium alloy and TC4 titanium alloy laser welding has carried out a lot of research [18-20], laser welding has been applied to some models of aircraft in China's skin welding, ventral fin manufacturing, long truss T-joint welding. COMAC [21] dual-beam synchronous welding equipment, has been used for a domestic airliner. In addition, Beijing Aviation Manufacturing Engineering Research Institute has been laser welding technology applied to the engine titanium alloy load-bearing components of the manufacturing and maintenance optimization.

III. LASER CLADDING

3.1 Research on laser fusion coating of nickel-based alloys

Laser cladding uses a laser beam as a heat source to clad various types of high-performance alloys on the surface of nickel-based alloys to form a cladding coating, so that the two are melted and joined together to strengthen the existing metal surface and improve the performance of the substrate. After cladding treatment, the surface of the component material wear resistance, corrosion resistance and other properties will be greatly improved, not only to reduce production costs, improve efficiency, to meet the requirements of specific properties of the material surface, but also at the same time to reduce energy consumption.

Jon Lambarri et al [22] evaluated the applicability of laser cladding technology for the fabrication and repair of Inconel718 aerospace components. Multiple layers of coatings were deposited on an Inconel718 plate and the coatings were all deposited using a bi-directional strategy in which each layer was deposited in the same order as the previous layer. This strategy provided uniform and continuous deposition, while preliminary parameterisation was carried out in order to obtain well-formed laser-melted cladding layers.

The fracture zones of the four tensile specimens show that the fracture points of all four samples are in the middle region, so the results of the test are valid. The tested tensile properties of the samples extracted from the region near the coating wall (samples a and d) are very close to the tensile properties of the samples extracted from the centre of the deposited samples (samples b and c), which proves the homogeneity of the block coating.

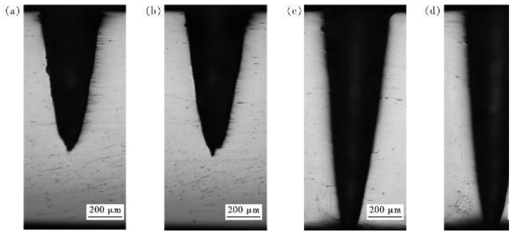

Fig.1 externaltopography of a stretched sample

Tensile tests on four fully aged specimens showed that the ultimate stress of the coating was about 1380 MPa, the yield stress was 1090 MPa, and the elongation was 13%, and the values exceeded the aerospace industry requirements: 1080 MPa for UTS, 0.2% YS for 870 MPa, and 2.5% elongation, and the specimens fully complied with the standards.

Wang Chuanyu et al [23] established a model of ultrasonic vibration-assisted laser melting coating IN718, and analysed the changes in its organisation and properties. It was found that the ultrasonic vibration transformed the columnar crystals of the melted coating into equiaxed crystals, and the composition of the organisation became more homogeneous. The maximum microhardness and average microhardness of the coating increased by 18.6% and 11.3%, respectively, and the wear volume decreased by 18.8%.

Wu Jun et al [24] to enhance the hardness and wear resistance of lnconel718 high temperature alloy, prepared TiC/Inconel718-based ceramic composite coatings, the use of high-energy laser cladding technology to explore the effect of different TiC content on the performance of composite coatings. In terms of hardness, with the increase of TiC content, more and more carbides were generated in the periphery due to the chemical replacement reaction, which enhanced the coating matrix and increased the hardness simultaneously. In terms of wear resistance, when the TiC content is relatively low, the most important wear mechanisms on the coating are abrasive wear and adhesive wear, and the mechanisms change to abrasive wear and oxidative wear after the TiC content is increased, which significantly improves the wear resistance of the coating.

3.2 Research on laser cladding of ultra-high strength steel with AISI420 stainless steel coating

As one of the commonly used structural materials in the aerospace industry, in order to improve the corrosion resistance and hardness of the surface of UHSS or to repair the worn surface, coatings are prepared on the surface of UHSS by means of laser cladding technology to enhance the properties of the material in order to prolong the life of the structural components.

Sun Shi Da[25] et al successfully clad AISI420 stainless steel powder coating on 300M ultra-high strength steel by laser cladding technique. The characteristics are as follows: no microcracks and high porosity in the cladding layer. Two distinct zones were observed: the cladding (C) zone and the overlap (OL) zone. the OL zone consists of a remelted cladding and a reaustenitised cladding. Among them, the delay time between the tracks in the C zone has a significant effect on the microstructure and hardness, and the evolution of microstructure is related to the changes in the sequence of quenching and tempering cycles during the austenite subcooling process.The martensitic start (Ms) and end (Mf) temperatures of AISI420 stainless steel are about 160°C and 25°C, respectively.In addition, Jiang Heming[26] et al. have also done a surface-coupled biomimetic using stainless steel as a base material research in laser cladding process.

3.3 Research on TC4 laser fusion coating

TC4 alloy has the advantages of high temperature resistance, corrosion resistance, low density, high strength, etc., and is widely used in the field of aerospace structural components. However, TC4 alloy has low hardness and poor abrasion resistance, and the surface modification of TC4 alloy by laser cladding technology can make up for its shortcomings in this aspect.

Luo Kuilin[27] et al combined with the repair needs of aero-engine large fan magazine TC4 titanium alloy static sub-blade, studied the laser fusion cladding repair process of the damaged blade, the fusion cladding layer composition, organisation, microhardness and mechanical properties of the analysis of the test, and Li Lian [28], Nie Pulin [29], et al. came to a similar conclusion: laser fusion cladding layer TC4 titanium alloy of the O, N, H elemental composition to meet the standard requirements. The laser cladding zone is a columnar crystal with the characteristics of the Weil's body organisation, the internal columnar crystal is a fine martensitic organisation, and the heat affected zone is a mixed organisation of columnar crystals and bimodal organisation, which gradually transitions to the bimodal organisation of the base material; the hardness of the laser cladding layer microhardness is 15% higher than that of the base material on average, and the transition is gentle; the results of the room-temperature tensile test, the high-temperature tensile test at 400°C, and the heat exposure test of the laser cladding TC4 samples are all higher than the base material specimens. The strength of the laser coated TC4 specimens is higher than that of the base material, and the elongation after fracture is slightly lower. The damaged blade is repaired by single-pass multilayer cladding process, and the test results show that the fan magazine meets the use standard.

Li Wentao[30] et al fused TC4 titanium alloy powder onto the substrate in a single pass, and analysed the microstructure and macroscopic dimensions after fusion, and found that: the fusion effect was good, and there were no cracks and porosity in the bonding area; the microstructure consisted of coarse columnar crystals growing epitaxially through several fusion layers; the fusion height increased with the increase of the powder feeding rate, and the scanning speed and laser power showed diametrically opposite effects on the fusion dimensions.

IV. CONCLUSION

Laser processing technology plays an increasingly important role in the field of aerospace structural components, which can improve the performance of the surface of structural components and increase the service life of structural components. At the present stage, many scholars have carried out a lot of research on the laser processing of several different aerospace structural materials and achieved results, the current status of the research in this area is summarised and prospects are as follows:

(1)Different laser welding process parameters have a large impact on the processing results. Changing the laser welding power, speed and time and other processing parameters have a large impact on the forming width and quality of the weld, as well as on the hardness and strength of the processed surface. Different weld profiles and pre-welding heat treatments also affect the generation of cracks. At this stage, the combination of laser welding process parameters on the post-welding quality of the influence of the law is not clear, need to be further in-depth study, optimise the process parameters, enhance the effect of surface strengthening.

(2)Laser cladding should not only pay attention to the powder feeding rate, scanning rate and other process parameters, but also more importantly, the selection of the cladding material on the substrate, the appropriate cladding material can better improve the surface properties of the substrate. However, the large-scale application is still limited and the problems of porosity and cracks in the cladding layer need to be solved urgently. Further hardware optimisation, cost reduction and process optimisation are required.

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