Current state of the art in the application of laser technology in material processing

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ABSTRACT : *Laser processing technology is a processing technology that makes use of the characteristics of the laser beam interacting with matter to clean, cut, surface treatment, perforation and micromachining 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 the whole structural components are reviewed, and the influence laws of different process parameters on the quality of processing and forming are outlined. The working principles of laser cleaning, cutting, additive manufacturing and other laser processing processes are explained, the significant advantages and problems of laser processing technology over other technologies in the field of material parts are summarised, and an outlook for future development is given.*

KEYWORDS *- laser processing technology; aero structure parts; laser cleaning; working principle; optimization of processes*

I. INTRODUCTION

The rapid development of modern laser processing technology in aviation mechanical processing has given rise to many technologies, such as laser cleaning technology, laser drilling technology, laser additive manufacturing technology and so on. At the same time, aerospace structural parts processing future requirements for laser processing equipment is also 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.

Laser cleaning is the use of highly concentrated laser beam irradiation of the surface of the object, so that the dirt to be removed vibration, combustion, melting, evaporation, from the surface of the object to be detached from the process. Laser irradiation of the surface of the object will produce selective evaporation, rapid heating and cooling, plasma explosion and stripping removal and other effects. Laser cutting has the advantages of fast cutting speed, good seam quality, processing efficiency and so on, it is an advanced thermal cutting technology in the field of material processing. At the same time, as the core direction of the 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.

This paper takes different laser processing processes in nickel-based alloys, aluminium alloys, titanium alloys, strength steels and several other materials that are very widely used in the field of aerospace structural components as an entry point, reviews the research and application progress of typical laser processing processes in the field of aerospace structural components, and at the same time summarizes the current laser processing technology urgently needs to solve the problem, and puts forward the future direction of the development of laser processing technology in the field of aerospace structural components, with the aim of Provide reference for scholars to solve the laser technology problems on aerospace parts.

II. LASER CLEANING

2.1 Aluminium laser cleaning study

Aluminium alloy, as an important structural material for aircraft, is widely used in critical locations such as spacecraft skins, fuel tanks, propellers and landing gears. And aluminium alloy exposed to air for a period of time will form a layer of oxide film on its surface, which will affect the quality of weld seams and the tightness of the coating if it is not thoroughly removed before the structural parts are repainted and welded. There are many researches done on this issue.

Ren Yuan et al [3] found that laser cleaning can effectively remove impurities and oxides from the surface of aerospace aluminium alloy AA2024. The macroscopic morphology shows that there are many white oxides on the surface of the uncleaned aluminium alloy. When the laser energy density reaches 8.5 J/cm, white thermal oxidation spots appear on the surface of the aluminium alloy. Through analysis, the impact and vibration of the laser pulse do not remove the surface impurities due to the low laser energy density. When the energy density reaches 10.5J/cm, the heat input increases, the difference in thermal expansion coefficient between the contaminant and the substrate grows rapidly, the contaminant and oxide on the surface of the aerospace aluminium alloy expands rapidly, and after the shock and vibration of the pulsed laser, the contaminant is separated from the substrate, and the white oxide on the surface of the aluminium alloy is reduced. At the same time after laser cleaning, the residual tensile stress on the surface of the aluminium alloy increased significantly. The analysis of the structural changes on the surface of the aluminium alloy revealed that the oxide film on the surface of the aluminium alloy was cracked and thermally oxidised when the high-energy laser spot was irradiated onto the aluminium alloy substrate, at which time the residual stresses on the surface were restructured, resulting in residual tensile stresses.

Qiu Taiwen et al [4] used different pulse frequencies, widths and laser powers to carry out laser cleaning of epoxy basecoat on the surface of AA2024 aluminium alloy, and analysed the cleaning effect of different pulses of the laser by observing the morphology of the specimens after cleaning. It was proved that the best paint removal effect was achieved when the laser power was 500W, the pulse width was 60ns and the pulse frequency was 20kHz. After cleaning the specimen with the measured optimal parameters, the energy spectrometer analysis revealed that the oxygen content of the substrate surface was very close to that before cleaning, and its hardness was also very close to that before cleaning. The experiment shows that laser cleaning in the effective removal of paint at the same time did not destroy the workpiece surface oxide layer and its hardness, laser cleaning for alloy surface paint removal has great prospects for development.

Wang Kai et al [5] developed a new two-step non-destructive laser cleaning process using nanosecond pulsed laser cleaning of TB06-9 coating on the surface of aerospace 2A12 aluminium alloy. In the first step, a single laser cleaning was used, and the coating on the surface of the specimen was gradually reduced with the increase of laser power, thus exposing the oxide layer and the substrate. When the laser power is 40W, the oxide layer remains intact, and when the power is 45W, the oxide layer starts to show damage, which gradually increases with the increase of power. The optimised parameters for the first step were determined to be laser frequency of 20kHz, power of 40W, scanning speed of 1040mm/s and line spacing of 0.052mm. The second step was carried out on the basis of the first step for a number of times, and the optimised parameters were obtained to be laser frequency of 1000kHz, power of 80W, scanning speed of 690mm/s and line spacing of 0.0345mm. The surface of the two-step laser cleaned specimen is similar to the surface morphology of the original specimen, and the surface microhardness and tensile strength are basically consistent, which better protects the original mechanical properties of the material.

2.2 Research on laser cleaning of carbon fibre composites

Carbon fibre composite material is an important material for manufacturing aerospace vehicles, but the manufacturing technology is complex, the manufacturing quality requirements are strict, the manufacturing cost is higher, and the cleaning accuracy and efficiency requirements are also higher, so the traditional cleaning method has been poorly controllable, contaminated, and poorly adapted to the problem. Therefore environmentally friendly and efficient laser cleaning technology gradually began to be applied to the manufacturing process of aerospace materials to promote and facilitate the breakthrough of modern material preparation technology.

B. Rauh et al [6] studied the characterisation of aerospace carbon fibre composites (CFRP) before, during and after laser radiation to further understand the process of removal of silicones that make up the release agent residues. Since the laser energy in the wavelength range of 200-1000 nm cannot be absorbed by the silicone layer, a new laser cleaning process is proposed, i.e., the surface is cleaned with an ablative resin material to avoid the complete exposure of the carbon fibres, and the removal process is based on the stripping effect of the silicone. The contaminants were completely removed after treating the CFRP surface, but at the same time more carbon fibres were exposed. Under high magnification, the carbon fibres did not show any signs of damage, both presenting a smooth and clean surface and exposed fibre surface after the laser treatment, resulting in a joint strength 100% higher than the joint strength in the reference process. The new laser cleaning process has good generalisability on resin-surfaced CFRP materials and provides a new contaminant treatment technique to deal with different thicknesses of contaminants on the surface of aerospace carbon fibre composites.

Wang Hong'en et al [7] analysed the laser cleaning morphology of the material surface under different combinations of parameters, and analysed that the UV laser power and scanning speed have a great influence on the surface morphology of carbon fibre reinforced resin matrix composites after surface cleaning. At a laser frequency of 60 kHz and a scanning speed of 300 mm/s, the resin on the surface of the CFRP sheet and between the fibres was removed when the power was increased to 13.6 W. The laser frequency was adjusted to 30 kHz and the scanning speed was adjusted to 30 kHz. When the laser frequency is adjusted to 30kHz and the laser power is 13.6W, the residual resin on the surface layer of the material is more, and the cleaning effect becomes worse. However, when the scanning speed is increased to 500mm/s, the resin on the surface of the material and between the fibres is removed and the grooves and crevices on the surface of the material are distributed more evenly. The experimental results show that the laser cleaning effect is best when the laser frequency is 30kHz, the power is 13.6W, and the scanning speed is 500 mm/s. The laser cleaning effect is also better when the scanning speed is increased to 500 mm/s.

III. LASER CUTTING AND LASER ADDITIVE MANUFACTURING

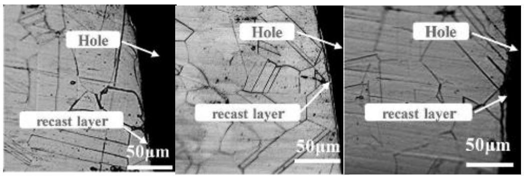
3.1 Visual in-situ measurement of laser perforated cooling holes

Sun, Weifang et al [8] proposed a vision-based in-situ measurement method for laser drilling hole dimensions for the measurement of critical parameters of aero-engine cooling holes. Combining DTCWT and local Gini index, the edge features can be extracted, and the key parameters of the holes are successfully calculated using the least squares method. However, the lens distortion leads to the experimental uncertainty still exists, and even if the distortion of the acquired image is corrected, the distortion is still an important factor affecting the measurement results, which is worthy of further study

3.2 Research on anti-splash process of laser perforation

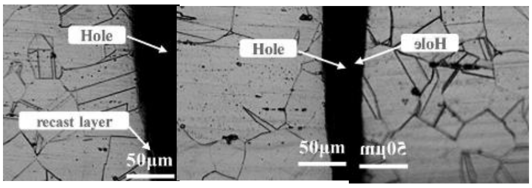
Laser perforation of metal materials, with the laser beam temperature increases, the metal from solid to liquid, the formation of molten pool; molten pool of liquid metal and then heated into the "boiling" state, and the "boiling" makes the internal pressure increases, bringing out the surrounding liquid metal, producing "Spatter". This affects the quality of the weld and contaminates and damages the lenses, so it is important to contain the spatter problem.

The anti-spatter composite coating ASCC developed by D.K.Y Low et al [9] was shown to be effective in preventing spattering during laser impact drilling of three aerospace materials, IN 100, Nimonic PK 33 and Alloy 263, as shown in Figs. 1 and 2. The spatter prevention mechanism of ASCC is based on the physical "shrinkage" principle. "principle. As a result of this contraction, the free space on the substrate surface is eliminated, and thus the high pressure from the auxiliary gas injection and the recoil pressure induced by the vapourisation cause a continuous spatter injection. In addition, due to the contraction, the jet angle of the substrate jet sparks becomes vertically orientated, effectively reducing splattering. This has been confirmed by high-speed imaging studies.



(a) IN100 (b) Nimonic PK 33 (c) Ar-assisted gas Nimonic 263 alloy substrate

Fig.1 typical SEM micrographs of laser drilled array holes at 2 mmhole pitch in uncoated



(a) IN100 (b) Nimonic PK 33 (c) Ar-assisted gas Nimonic 263 alloy substrate

Fig.2 typical SEM micrographs of laser drilled array holes at 2 mm holepitch in ASCC coated

3.3 Study of laser cutting of carbon fibres

Carbon fibre materials are widely used in aerospace and aviation fields due to their advantages such as good high temperature performance and high strength. Cutting operation cannot be avoided in material processing, but the traditional tool processing method is prone to produce defects such as fibre pulling out and tool wear. Thus, laser cutting, which is more efficient and better formed, began to gradually replace the traditional process.

Li Yongdu [10] used optimized laser process parameters for cutting carbon fiber composites, under the premise of ensuring maximum cutting efficiency, compared with the infrared light source, although the UV light source for cutting carbon fiber materials can be obtained when cutting samples of the heat-affected zone is smaller, but the UV light source due to its lower power, can not match the high cutting speed in fewer cuts makes the cutting efficiency is lower, therefore Therefore, UV light source is more suitable for applications with smaller demand but higher requirements on cutting quality.

Li Yuancheng [11] and others for laser cutting of carbon fibre reinforced resin matrix composites, the study found that the cutting quality along the fibre direction is significantly better than the vertical direction. The degree of thermal damage in cutting is related to process parameters such as cutting speed, laser power, pitch and scanning radius, which are determined by the pulse energy density and the degree of pulse aggregation.

3.4 Laser cutting studies on aluminium alloys

Aluminium alloys are widely used in aerospace structures because of their high strength, light weight and excellent welding performance. Traditional cutting methods are mainly organic processing and wire cutting, but in this process, aluminium alloy is prone to deformation, so it is not suitable for aluminium alloy thin plate cutting. Laser cutting has become the main means in the cutting industry because of its advantages of good flexibility, precision and efficiency.

Wang Jiasheng [12] and others found that when cutting 6061 aluminium alloy when the laser cutting speed is too low, the amount of material melting at the kerf is too much and slag is formed at the bottom. As the cutting speed increases, the quality of the cut seam is improved, but the cutting speed is too large will lead to a decrease in the amount of material melted at the cut seam, the roughness increases, after the study: when the cutting speed reaches 120mm/s, the quality of the cut seam is the highest.

Wang Limin [13] and others found that the auxiliary air pressure, laser power, the amount of defocus and other parameters on the 15mm thick 2A12 aluminium alloy laser cutting efficiency and cutting quality has a significant impact. For example, the speed interval for obtaining better cut quality is much wider when taking positive defocus than negative defocus, which is more suitable for cutting 15 mm thick aluminium alloy.

3.5laser additive manufacturing

In the field of aerospace structural components, high strength alloys represented by aluminium, titanium alloys and heat-resistant alloys represented by nickel-based alloys have become one of the important materials in laser additive manufacturing with their excellent physical and chemical properties.

The world's first use of laser additive manufacturing technology to achieve aerospace structural components installed application of the U.S. AeroMet company through the technology has been manufactured products are: F-22 fighter joints, F-18 fighter connecting rings and landing gear connecting rods and so on. Laser additive manufacturing of F-22 fighter jet joints and landing gear connecting rod fatigue life are beyond the design requirements, the performance has been greatly improved [14-15]. AeroMet and Boeing, Knoxheed Martin and Northrop Grumman and other aircraft manufacturers, the use of laser fused deposition technology to produce a variety of aircraft sub-bearing titanium alloy components, the overall performance is comparable to forgings, static and static. Comprehensive performance is comparable with forgings, static strength and fatigue strength also meets the requirements of aircraft use [16].

Laser additive manufacturing technology can be more convenient to produce complex configuration parts, greatly broaden the innovative thinking of aircraft structural designers, can give full play to the infinite design flexibility of aircraft structural parts, design a more direct force transfer, higher load-bearing efficiency, lighter complex aircraft structural parts programme [17]. Airbus used laser additive manufacturing technology to manufacture aircraft Ti-6Al-4V bracket, compared with the traditional processing method weight reduction of about 30%. The manufacturing of airliner hatch latch shafts was also developed to consolidate 10 parts into 1 part to achieve weight and cost reduction. We also completed the manufacture of cabin bionic bulkhead parts using SLM technology. In a domestic model of civil aircraft, SLM formed titanium alloy hatch structure parts have also achieved the installed flight, weight reduction of about 20%. Beijing University of Aeronautics and Astronautics, academician Wang Huaming's team [18] developed and applied laser additive manufacturing of titanium alloy large-size metal components for aviation.

IV. CONCLUSION

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

(1) laser cleaning through the control of process parameters, two-step non-destructive method of cleaning process to achieve the desired cleaning effect. For laser perforation, a cooling hole in-situ measurement method and anti-splash process have been researched, which greatly improves the working efficiency and forming quality. However, the requirements for environmental conditions are high, increasing production costs, thus making the equipment relatively limited in the field of application. This is all to start from the equipment, update and optimise the hardware.

(2) Laser additive manufacturing technology is mainly used in the optimisation of the entire aircraft structural components, without reducing the strength of the premise of redesigning the structure to achieve the effect of lightweight and cost reduction. Restricted by technical problems, resulting in laser additive manufacturing forming efficiency is low, the need for further development and optimisation of the process.

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