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Detection Technologies of Laser Thermal Processing Quality†

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The detection technology is valuable to the research and application of laser processing. The main test objects or content of three types of laser thermal processing (laser material removal, laser joining and laser surface modification of materials) is analyzed. The size precision, surface quality detection and the corresponding test equipment and methods are investigated. Some important instruments such as optical microscopy, acoustic microscopy, scanning electron microscopy, energy dispersive spectroscopy and X-ray diffraction, *etc*., especially their function and role in the laser processing are introduced. At last, some detection analysis works of laser processing in Anhui Jianzhu University are demonstrated.

Keywords: Laser thermal processing, Processing quality, Test content, Detection.

INTRODUCTION

Based on the mechanism of laser beam interaction with materials, laser processing can be divided into laser thermal processing and laser photochemical machining[1]. Laser thermal processing refers to the thermal effects of laser beam projected onto the material surface, which bring regional material melting, ablation, vaporization or internal organizational change, such as laser drilling, laser cutting, laser marking, laser welding, surface modification, laser heat-assisted machining and micro-processing. Laser thermal processing can be divided into laser material removal, laser materials joining and laser surface modification. The last type is more complex, among which laser transformation hardening material, laser re-melting and strengthening, laser alloying and strengthening, laser cladding, laser shock peening, laser cleaning belong to laser thermal effects. Laser materials processing is completed relies on some appropriate equipments. The processing quality is determined by the laser beam characteristics (including a laser light source, optical systems, laser control system), material properties, accuracy and precision of machine table, the environment and other factors[2].

Accurate and effective detection technology is the key factor to the quality of laser processing, which is to be adjusted and the process is optimized to provide technical information and to explore the mechanism of an important means of laser processing. In this paper, the detection projects in different types of laser processing are studied, as well as their effective detection methods and relative equipments.

Detection projects or contents analyses of laser thermal processing: Laser processing is a special material processing method and its detection is divided into the machining quality measurement and the machining process monitor. This article refers to the former, the study is mainly related to dimensional accuracy, surface roughness, material properties and other testing, which is according to the specific requirements in practical engineering processes and the laser material removal, laser material joining and laser surface modification is extended.

Removal of laser materials: Specific forms of laser material removal are laser drilling, laser cutting, laser marking, laser milling (laser ablation), laser surface modeling, *etc*. By laser changing materials or parts, the geometry shape, structure and function are achieved. The quality of laser material removal is mainly determined by the dimensional accuracy, such as dimensional error, shape and position errors and the surface roughness, hardness, strength, surface microstructure, as well as test the friction properties, corrosion resistance and other mechanical properties and optical, electromagnetic properties. It is necessarily to detect more for excellent mechanical properties or function of laser processing.

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In laser drilling, laser beam is repeated acting on a certain region of the material for through holes or blind holes. Testing contents of machining quality includes the aperture, depth, taper, roundness precision, the surface quality of holes' wall and bottom. There is no uniform standard of laser cutting quality, but mainly parameters are width, cutting surface roughness, the tilt angle of the cutting surface, heat affected zone, sticky residue, corrosion damage, *etc*.[2]. Laser marking make the surface colour chemical change or material vaporization, thereby leaving a variety of characters, symbols and patterns. Laser milling is a large-scale laser ablation, containing material vaporization, melting and solid block out. Besides geometry accuracy, surface quality including surface hardness, roughness, physical and chemical properties would be investigated in the research or production and these properties and microstructure of the machined surface and structure are related closely.

Joining of laser materials: The most common laser material joining is laser welding, which divided into heat conduction welding and deep penetration welding. The main detection content includes dimensional accuracy, thermal deformation, heat-affected zone, weld cross-section morphology, tissue components, the connection strength and *etc*.

Modification of laser surface: Laser surface modification of the thermal effect is mainly in three state follows, (1) heating: transformation hardening, annealing; (2) melting: remelting (fused), alloying, cladding, texturing, glazing (amorphous based) treatment; (3) vaporization: shock peening, cleaning, vapor deposition[3]. Laser texturing shapes material surface is more through both melting and vaporization in the authors' study. The main purpose of laser surface modification is expect to obtain better mechanical, physical and chemical properties, such as: the surface hardness, friction and wear properties, corrosion resistance, heat resistance, oxidation resistance, uniform internal stress, *etc*. Corresponding, the detection content is to test or observe these material properties and organizational structure, which including microstructure, surface morphology, structure, composition, *etc*.

Detection methods and equipments: The laser can almost machines all materials including metal, alloy, non-metallic materials. The processing quality is available by visual inspection and test equipment. The strength, hardness, surface roughness of laser thermal effect areas are the common detection parameters. Laser material joining strength can be performed by mechanical tests and the Vickers hardness, surface roughness are achieved by conventional apparatus. Micro hardness tester is used in precision testing for hardness and hardened layer depth of surface modification area or laser ablation heat affected zone. The friction properties of material surface are directly detected by use of friction test machine. Most conventional instruments could be used in laser cutting, welding, *etc*. of large-size boundary detection, the laser machining precision to micron level and below should be observed by microscope. Especially, observation and analysis on surface microstructure and organization, high-powered microscopes and specialized materials analytical instruments are essential. In addition, the conditions, methods and operation steps of detection must be considered. Direct detection in the laser processing is dangerous and for high precision researchers need to make a special specimen and scheme the testing work.

Light microscope is most up to 0.1 μ resolution. The width of the laser cutting, punching aperture, the heat-affected zone width, sticky residue, ripple, recast layer measurements are easy to get by the micro stage with the eye piece cross coordinate lines, where rotating stage is for angle measurements. In laser processing detection the identification and analysis of internal structure and tissue optical spectra of materials were tested and analyzed by light microscope with CCD and computer, which has image editing, output, storage, management and other functions. Binocular stereomicroscope can get perfect 3D image, has been widely used macroscopic surface observation, failure analysis, fracture analysis and other industrial field like laser welding, drilling, cladding, such as laser machining area detection of cracks, bubbles, *etc*. Laser scanning confuse microscope as the excitation light scanning device can also be used for surface analysis and microhardness analysis.

Scanning acoustic microscopy is a new non-destructive testing equipment, which uses high frequency focused ultrasound (typically a frequency of 10 MHz-2 GHz), the measured surface, sub-surface and within a certain depth of the fine structure for microscopic imaging[4]. It is can be used in laser cutting, welding, cladding and internal processing of materials (such as testing the new generation high-power interface). This microscopy can not only detect the parts the visual detection of the acoustic image, but also obtain the mechanical information[5].

Scanning electron microscope is the most important device in laser processing detection. It is directly carried out high resolution surface morphology, with image depth of field and varied from a few times to millions of times. Scanning electron microscope has a strong three-dimensional and can analyze the material composition and other information.

Energy dispersive spectrometer can detect materials' composition of the various micro-areas. X-Ray diffraction can get precise determination of the crystal structure of materials, texture and stress. The scanning electron microscope and X-ray diffraction or electron energy spectrometer combined as an electronic microprobe are more power for the analysis of material composition. Using the energy dispersive spectroscopy or X-ray diffraction is available for laser welding, laser surface modification and other complex processing, laser processing quality were detected to obtain the specific composition and structure and to understand the material processing mechanism.

Computer technologies in the detection analysis has been widely applied to the detection equipment available for result, especially in image processing or curve measurement and analysis of discrete data. Laser processing detection also needs its support.

Application research of laser processing detection technologies: In order to achieve accurate detection in actual testing, on one hand the high-precision instruments and advanced method must be considered, on the other hand it is necessary to consider testing equipments and conditions in research unit and convenient to carry out researches. According to references[6-10], the current detection methods relating to laser cutting, laser welding, laser drilling, laser shock processing, laser cladding, surface alloying are basically consistent with

those described above. This chapter presents some researches on laser processing detection technologies in Advanced Laser Manufacturing Research Centre of Anhui Jianzhu University.

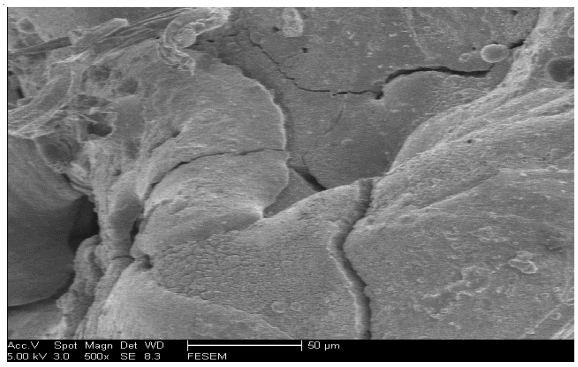
Laser transformation hardening: Lei *et al*.[11] conducted a laser transformation hardening test on raceway surface of GCrl5 steel bearing. The microhardness of the laser hardened region were measured after the samples being cut, polished and etched. Microhardness, depth and width of hardened zone were detected according to the hardness value, microstructure and morphology by an optical microscope and a scanning electron microscopy. Results of microstructure analysis have been showed the carbide distribution parameters.

Laser and chemical hybrid processing: The authors proposed a new method of laser and chemical hybrid etching of large-scale processing difficult-cut-materials first in China. On the support of the National Natural Science Foundation, W18Cr4V high-speed steel, Crl2 mold steel, Al_2O_3 ceramic materials and so on were machined successively by laser and chemical hybrid processing applied Nd: YAG laser and hydrochloric acid, nitric acid[12,13]. In this study a series of detection methods and apparatus are used and its results demonstrated that the hybrid processing can speed up the etching rate, significantly improve the surface quality and solve series questions of surface defects of recast layer, slag, micro-cracks and low dimensional accuracy. Fig. 1 are comparison photos of materials' morphology taken by scanning electron microscope after laser ablation solution and laser-chemical hybrid processing, respectively. Fig. 1a shows that there are many micron cracks and irregular slag on surface, while in Fig. 1b the surface is very smooth. Fig. 2 shows surface composition of high-speed steel which is detected by X-ray diffraction after oxygen-assisted laser ablation, mainly $FeCr_2O_4$, $FeWO_4$ and Fe_2O_3; Fig. 3 shows surface composition of W18Cr4V tested by the energy spectra after laser and HNO_3 solution hybrid processing.

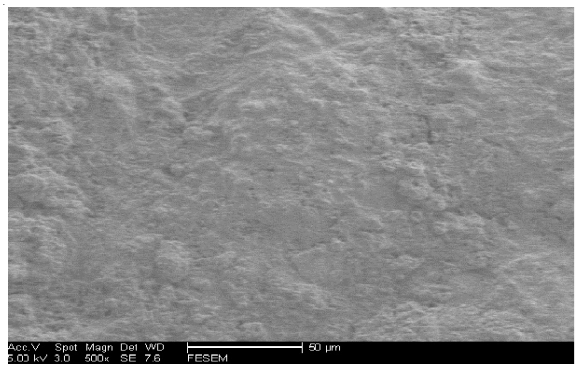
Laser surface texturing technology: The authors designed and manufactured laser texturing patterns of dot, grid, multi-point on surface of friction material QT600. The disk-shaped sample was textured dot and grid shape by laser in the head surface, then flat grinding was carried out with oil lubricated by using universal friction and wear testing machine. At last, the friction and wear results of the surface without laser texturing patterns were titled and analyzed. The volume of surface wear with laser texturing patterns is relatively small and surface abrasion resistance is significantly improved. According to the relationship between the friction torque and the load, the minimum value of surface friction coefficient is up to 0.1 and dot shape with the distribution rate of 10 % is more appropriate. In the study of friction and wear test, it was found that surface roughness tested by roughmeter were around 0.5 μm when they run in stable wear state for all laser textured surfaces. More achievement is published in reference[14].

Conclusion

The main contents relating to processing quality detection for laser materials removal, laser materials joining and laser surface modification are studied in the line of those thermal processing requires and characters. From two aspects of the dimensional accuracy and surface quality, the tests method



(a) surface morphology of laser ablation



(b) surface morphology of laser-chemical hybrid processing

Fig. 1. Materials' morphology taken by scanning electron microscope

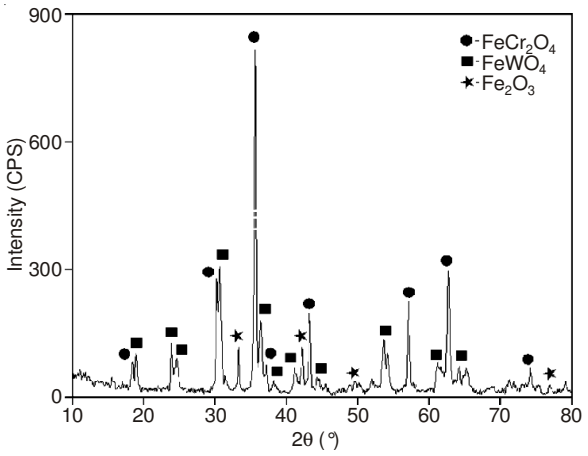


Fig. 2. Surface composition of high-speed steel which is detected by X-ray diffraction

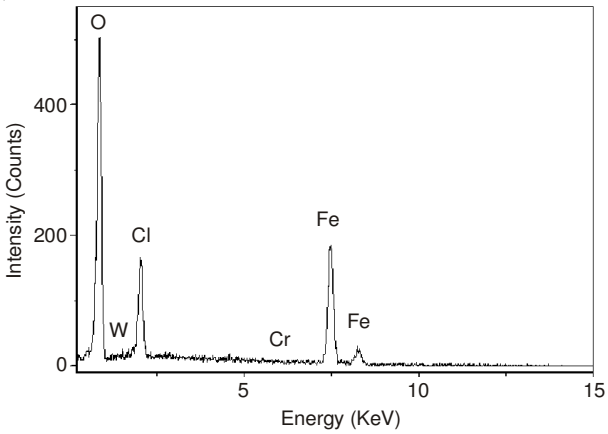


Fig. 3. Surface composition of W18Cr4V tested by the energy spectra

and testing apparatus are discussed, such as the function and role of the optical microscope, acoustic microscope, scanning electron microscopy, energy spectra and X-ray diffraction instrument. According to the previously proposed theories and methods, the typical detection methods and technologies are applied to laser transformation hardening, laser-chemical hybrid processing, laser surface texturing and other researches successfully.

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