Effect of laser deweighting on properties of ZL205A aluminum alloy

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Abstract. In this paper, a nanosecond fiber pulse laser is used to carry out the experimental study on laser weight removal of ZL205A aluminum alloy gyro rotor. By optimizing the process parameters of laser weight removal, better surface morphology was obtained. The effects of surface roughness, metallographic structure and hardness of samples before and after laser deweighting were analyzed. The experimental results show that the laser weight removal does not affect the matrix properties of ZL205A aluminum alloy. The laser de-weight technology is suitable for the balance of ZL205A aluminum alloy gyro rotor.

1. Introduction

Gyroscope is an important component widely used in aviation, navigation and spaceflight vehicles. The gyro rotor is the basic component of the gyroscope. Its balance accuracy will directly affect the accuracy, stability and service life of the gyroscope [1-2]. Therefore, precise de-balancing of gyro rotors is required. The traditional treatment method mainly uses an electric drill to remove the weight of the gyro rotor. It has many problems, such as low efficiency of gravity removal, repeated drilling and difficult to achieve accurate adjustment of the centroid. At the same time, there is mechanical stress when electric drill holes. This may cause axial wear [3], which requires new types of de-weighting technology. In recent years, laser technology has developed rapidly. It has the advantages of high de-weight precision, no contact during machining and no mechanical stress. This provides an effective method for laser de-gravity of gyro rotors [4-5].

For laser deweighting technology, Xue et al. [6] studied the influence of laser parameters on the quality of deweighting blind holes. A method of removing residue by laser secondary polishing is proposed. After laser polishing, there is no obvious residue and oxidation phenomenon after removing the blind hole. Zhang et al. [7] used laser de-gravity to remove the unbalanced mass of gyro flywheel rotor. They demonstrate that this method can achieve the dynamic balance of flexible supported rotors. Zhang et al. [8] carried out laser blind hole removal for flexible gyro. This improved the processing technology of flexible gyro. Its quality reliability and the qualified rate of finished products are improved. However, there are few researches on how to build the laser deweighting prototype, optimize the surface morphology of laser blind hole, and influence of laser deweighting on the performance of gyro rotor.
It is not enough to explore the effect of laser weight removal on the properties of metal matrices. In this paper, optical microscope, SEM scanning electron microscope, white light interferometer, metallographic microscope, micro Vickers hardness tester and other equipment are used to carry out the experimental study of laser deweighting process. The morphology, roughness, metallographic structure and hardness of the substrate after laser weight removal are analyzed. The experimental results show that the application of laser deweighting technology to ZL205A aluminum alloy gyro rotor is feasible.

2. Materials and methods

2.1. Sample preparation

ZL205A aluminum alloy was used as the material of gyro rotor in the experiment. To facilitate the study, two samples were cut from the gyro rotor by linear cutting method. Dimensions: 10mm x 10mm x 5mm. Among them, No.1 is the original matrix and No.2 is the laser deweighting sample. After laser deweighting, the surface morphology and roughness of the original matrix and laser deweighting sample were analyzed. Next, the sample was inlaid, ground, polished and prepared using 10% oxalic acid solution electrolytic erosion. Metallographic structure and micro Vickers hardness were detected. The effect of laser weight removal is shown in Figure 1.

2.2. Experimental method

The laser deweighting device is manufactured by Beijing Aerospace Control Instrument Research Institute. Among them, the laser wavelength of the pulsed fiber laser is 1064nm, the maximum average power is 30W, the pulse frequency is 2kHz-200kHz, and the scanning speed of the scanning system is 100mm/s~10000mm/s. In the experiment, an F-θ field lens was used with a focal length of 160mm and a focal spot diameter of 20μm. The z-axis lifting device can adjust the sample height and accurately adjust the laser focus position.

Olympus BX51 optical microscope was used to measure the surface topography of the substrate. The surface morphology of the matrix was measured by LEO-1450 scanning electron microscope (SEM). ZYGO Nexview white light interferometer was used to measure the roughness of the substrate surface. Sa is the mean value of the absolute value of the height difference of all points and Sq is the root mean square of the height of all points in the region. Olympus BX53M metallographic microscope was used to measure the matrix cross-section metallographic structure. Em-1500l Micro Vickers hardness tester was used to measure the hardness of matrix cross-section.

3. Results analysis

3.1. Laser deweighting experiment

The experiment was carried out under normal temperature and humidity. By optimizing laser parameters, such as laser power 27W, laser frequency 50kHz, scanning speed 1500mm/s, line spacing 0.02mm, the diameter of deweighting pits 1mm and scanning times 100 times, the depth of deweighting holes 1.5mm is achieved. The morphology of laser deweighting hole is shown in Figure 2.
Figure 2. Morphology of laser deweighting hole.
(a) remove the edge of the hole; (b) remove the bottom of the hole; (c) remove the sidewall of the hole.

To detect the influence of laser weight removal on the matrix properties, optical microscope, white light interferometer and other instruments were used to test the samples. The effects of laser deweighting on the surface morphology, roughness and microstructure of gyro rotor substrate were studied.

3.2. Analysis of matrix test results
Figure 3 shows the surface topography and roughness of No.1 and No.2 samples tested by optical microscope, SEM scanning electron microscope and white light interferometer. The surface of Sample No.1 has transverse stripes with equal spacing. This is the structure formed when the substrate is machined. The surface roughness Sa and Sq are 2.1μm and 2.44μm respectively. No.2 sample has concave and convex structure on the surface of the base after laser blind hole removal. It is produced by Gaussian laser deweighting. The surface roughness Sa and Sq of pits are 1.9μm and 2.49μm respectively. The surface roughness did not change significantly.

Figure 3. Surface morphology of samples No.1 and 2.
(a, d) Optical microscope test diagram; (b, e) SEM scanning electron microscope test diagram; (c, f) Test diagram of white light interferometer.

Figure 4 shows the metallographic structure of the surface layer, middle layer and bottom layer of cross-sections of No.1 and No.2 samples tested by metallographic microscope after polishing and acid etching. The microstructure of the samples in the three regions are matrix α (Al) + a large number of phase particles + gray-white precipitates at grain boundaries + black precipitates at grain boundaries + a small amount of bright white precipitates at grain boundaries. Stratified structure and fine grains were found in the surface layer. The results show that the laser deweighting does not change the metallographic structure of the material, which is the same as that of the original matrix.
Figure 4. Metallographic structure of cross-sections of No.1 and No.2 samples. (a, d) Typical surface tissue, 200X; (b, e) Typical structure of middle layer, 200X; (c, f) Typical tissue of bottom layer, 200X.

To detect the effect of laser weight removal on the micro Vickers hardness of matrix, the micro-Vickers hardness tester was used to test the hardness of No.1 and No.2 samples at different depths of the cross-section. Figure 5 shows the micro Vickers hardness curves of samples No.1 and No.2. The test results are shown in Table 1.

![Sample micro Vickers hardness chart.](image)

Table 1. Sample cross-section micro Vickers hardness test data table.

| No. | Indentation center distance from laser treatment layer position /μm | Micro Vickers hardness /HV (No.1) | Micro Vickers hardness /HV (No.2) |
|-----|---------------------------------------------------------------|----------------------------------|----------------------------------|
| 1   | 30                                                           | 134.41                           | 132.21                           |
| 2   | 200                                                          | 135.91                           | 132.21                           |
| 3   | 500                                                          | 142.43                           | 138.43                           |
| 4   | 750                                                          | 143.25                           | 140.12                           |
| 5   | 1000                                                         | 147.59                           | 140.24                           |
| 6   | 1250                                                         | 140.35                           | 142.21                           |
| 7   | 1470                                                         | 137.54                           | 136.55                           |
It can be seen from Table 1 that the cross-section microhardness of No.2 sample after laser weight removal is basically the same as that of the original matrix No.1 sample. No hardening layer was formed on the surface of No.2 sample after laser weight removal. This is consistent with the metallographic test results. Laser deweighting has no effect on micro Vickers hardness.

4. Conclusion
The dynamic balance of gyro rotor is balanced by laser deweighting technology, which has the advantages of non-contact, controllable surface topography and no mechanical stress. The surface roughness, metallographic structure and micro Vickers hardness of the substrate have no obvious changes after laser weight removal. Laser deweighting has no effect on the properties of gyro rotors. Laser de-weighting method is suitable for de-balancing gyro rotors.

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