

Research on surface morphology and characteristics of top-hat fiber laser polishing aluminum alloy 5052

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Abstract. Aiming at the defects such as cracks in the polishing process of aluminum alloy 5052, the laser polishing of aluminum alloy 5052 was studied, and a new top-hat beam laser polishing method was proposed for aluminum alloy 5052. The energy distribution in the polishing process was well-distributed, which greatly improved the energy utilization efficiency and reduced the surface roughness. Confocal microscopy and SEM were used to obtain the microstructure and phase composition of the microstructures. The results showed that the surface roughness was considerably reduced to lengthen the service life of the aluminum alloy 5052 materials from an initial roughness of $S_a = 3.9 \mu\text{m}$ to $S_a = 1.32 \mu\text{m}$ after using top-hat fiber laser polishing.

Keywords: Aluminum alloy 5052, laser polishing, top-hot laser, surface roughness.

1. Introduction

Aluminum alloy 5052 is widely used in 3C electronics, aerospace, national defense industry, automobile, 5G communications and medical instruments and other industries. The product parts of aluminum alloy 5052 need polishing, about 30% of which also need polishing to sub-mirror or the highest level of mirror [1]. The essence of polishing is to smooth the surface morphology of parts and reduce the surface roughness to a certain degree. At present, the mainstream automatic polishing technology adopts the micro-reduction manufacturing technology, which can reduce the surface roughness by eliminating the crest or even the trough. Common polishing processes include magnetic grinding polishing, mechanical polishing, ultrasonic polishing, wheel polishing and chemical polishing, etc. There are some common or specific defects in the processing of metal parts by the above common polishing processes.

Some authors have investigated laser polishing metal surfaces [2,3], Zhou, Y.Q. et al [4]. conducted laser-polishing tests on H13 tool steel with different overlap percentages and improved the surface roughness by dual-Beam. More recently, Xiao h. b. et al [5] demonstrated Laser polishing of tool steel using a continuous-wave laser assisted by a steady magnetic field. Song Y et al. [6] used a CW laser with optimized irradiation to polish steel, achieving an effective surface roughness reduction. Schmidt, J. et al. [7] proposed a n Laser polishing of aluminum by remelting with high energy pulses. The method has been applied to different forging and casting aluminum alloy used laser system is an Nd: YAG Laser with maximum pulse energy of 65J. Rosa et al. [8] studied the methods and techniques for laser polishing, and laser polishing of ground aluminum surfaces with high energy continuous wave lase. Research shows that the effects of polished surface morphology and microstructure for 5A06 alloy under processing speed and spot distance were improved [9]. It can be seen from these researches that there are still some difficulty in polishing aluminum alloy. In this work, a flat-top laser polishing process and method for aluminum alloy 5052 are proposed.

2. Principle of flat top laser polishing

2.1. laser polishing Aluminum alloy

The original surface 3D morphology of the aluminum alloy surface is the undulating "hill" morphology. Top-tat laser polishing uses the laser beam with energy distribution along the predetermined scanning direction to melt the wave crest on the microscopic surface in the area where the laser interacts with the surface to form a molten pool. Through the tension formed on the surface of the molten pool, the melted wave crest is filled into the trough. The surface roughness after polishing is greatly reduced compared to the original surface. Method of laser polishing laser polishing aluminum alloy is shown in Figure 1.

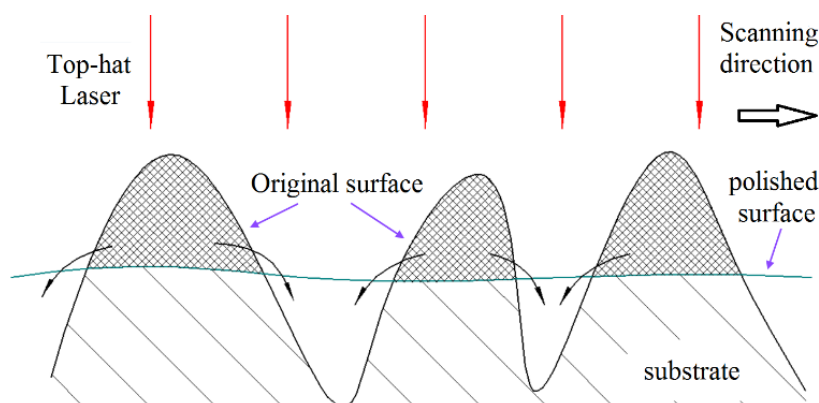


Figure 1. Method of laser polishing laser polishing Aluminum alloy.

2.2. Flat top laser beam shaping

It has the function of poleless adjustment of top-hat beam diameter by using Gaussian light conversion shaper to top-hat light, so as to realize the adjustment of energy density of flat-top beam. The Gaussian beam of the continuous laser, after passing through the collimator shown in Fig. 2, enters a 1-3 times non-polar beam shrinking mirror, which is intended to reduce the spot diameter to the range of the beam input of the three-dimensional galvanometer. Then, the Gaussian beam is converted into a flat-top beam by the DOE beam shaper, but the characteristics of the flat-top beam can only be fully reflected after the beam is focused on the workpiece surface through the three-dimensional galvanometer.

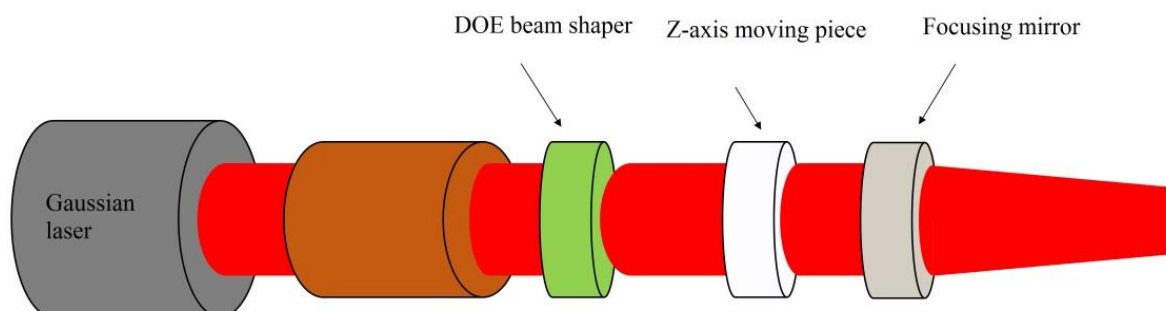
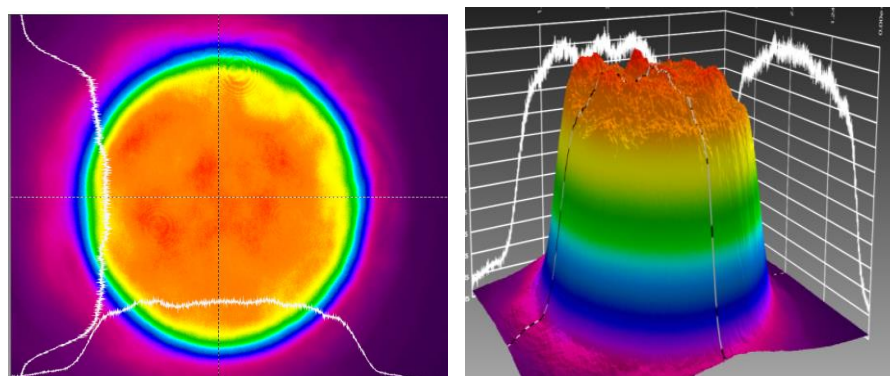


Figure 2. Schematic diagram of Gaussian light conversion shaping to top-hat light

The specification of DOE beam shaper determines the uniformity of energy density of flat top beam after focusing. At the same time, the spot diameter of the focused flat-top beam can be adjusted by adjusting the multiple of the shrinking mirror, and the energy density of the spot can be adjusted indirectly. Fig. 3 shows the two-dimensional and three-dimensional morphologies of the flat-top beam. The uniformity of the beam can reach 0.129, and the energy density distribution of the flat-top spot of the laser beam is very uniform. The beam distribution of top-hat laser is shown in Fig. 3. Parameters of top-hat beam is shouwn inTable 1.



(a) Two-dimensional display of top-hat beam (b) three-dimensional display of top-hat beam

Figure 3. Top-hat beam morphology and distribution

Table 1. Parameters of top-hat beam

Total energy	37737528506 cnts	X coordinate	2.9
Peak energy	16383 cnts	Y coordinate	2.49
The minimum energy	145 cnts	The top uniformity of cnts	0.127

3. Materials and Methods

3.1. Parameters of Dual-Beam Laser Polishing

Based on the preliminary research of our team [43], a top-hat beam polishing test platform consisting of a top-hat beam 3D galvanometer and a table was used. Using the polishing of the aluminum alloy part shown in Fig. 1 as an example, the infrared continuous laser with top-hat characteristics entered the 3D galvanometer of their respective front-focusing system. In the range of the 3D vibrating mirror machining, can be exposed. Parameters of the top-hat beam polishing are shown in Table3.

Table 2. Chemical elements content and physicochemical parameters of aluminum alloy5052

Chemical elements content								physicochemical parameters		
Fe	Si	Mn	Cr	Cu	Mg	Zn	AL	density	Melting point	Boiling point
0.4	0.25	0.1	0.15~0.35	0.1	2.2~2.8	0.2	left	2.7 (g/cm ³)	554 (°C)	2327 (2327°C)

3.2. Optimization of laser polishing process

Except the spot irradiation and scanning speed, the aluminum alloy 5052surface polishing strategy was like previous works, and the polishing parameters were optimized and given in Table 3.

Table 3. Optimized parameters of laser polishing in each group.

Factor name	Optimized Value or Feature
Polishing parameters	Wavelength: 1064 nm, Power: 200 W~400W, Step-over: 0.1 mm;
Roughness of initial state Sa (nm)	4920
Scanning speed (mm/s)	800 800 750 750 700 700 650 650 600
Top-hat beam profile	Between Medium and Ideal; beam quality M ₂ 1.3

4. Results and discussion

Figures 4 show 3D profiles of before and after polishing. The microstructures of the formed parts were dense, without macroscopic cracks and cavities, and their cell structures were at the submicron level, as can be seen from images taken by a high-power microscope. The initial aluminum alloy 5052 surface had roughness values of about 4μm, the polished surfaces had roughness values of from 3.9

μm to $1.32 \mu\text{m}$. Therefore, it can see that the surface roughness was considerably reduced after using top-hat fiber laser polishing.

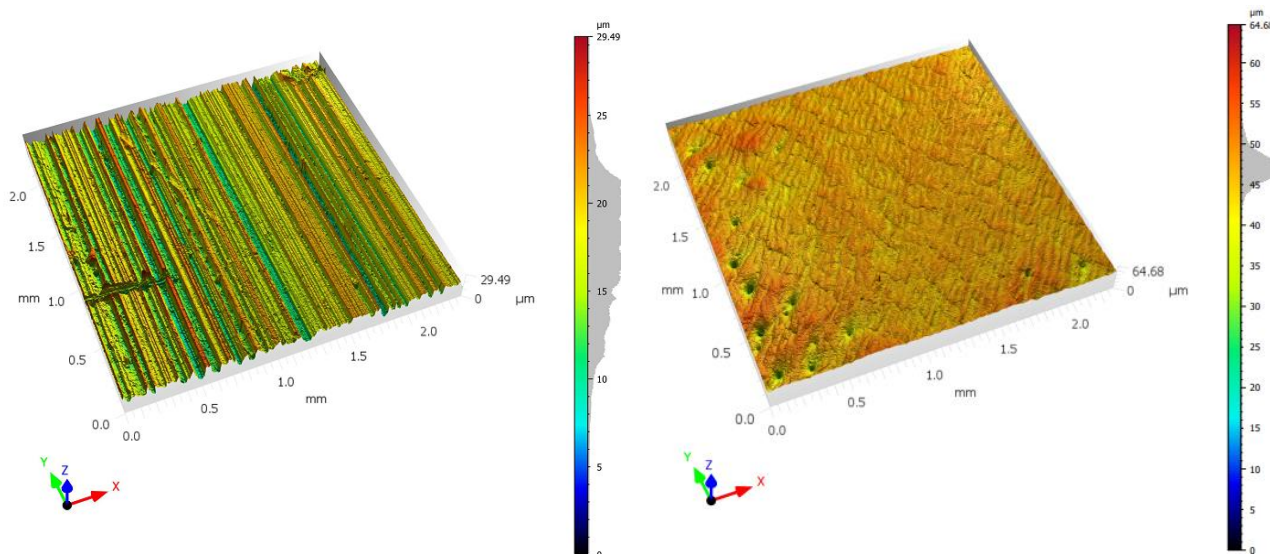


Figure 4. 3D profiles of aluminium alloy before and after polishing: (a) before polishing; (b) after polishing.

Photograph of aluminum alloy 5052 microporous is shown in Fig.5. SEM scanning of aluminum alloy 5052 microporous surface as shown in Fig.6, through microscope observation test, choosing the length of the surface of 2.2mm, and surface roughness changes by confocal microscope test, it can clearly see the polished surface roughness in $1\text{--}3\mu\text{m}$. The polishing quality by top-hat beam polishing surface is smooth and, with low thermal stress and thermal influence.

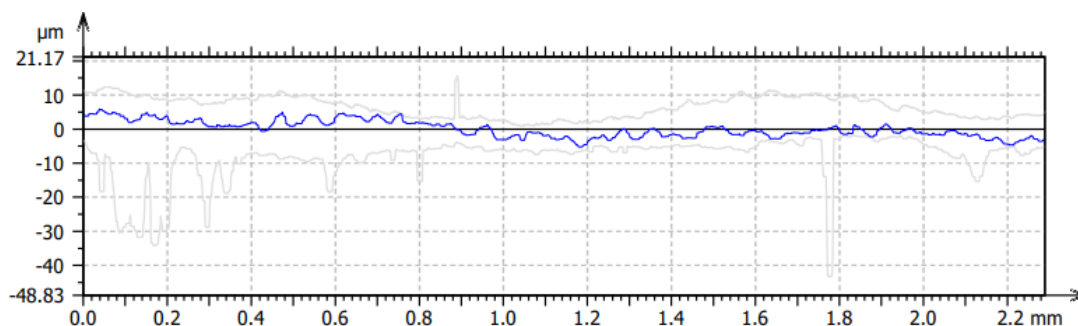


Figure 5. Roughness of the Aluminum alloy5052 after Laser polishing

When the laser polish power is small, the energy is not enough to melt the peak completely, resulting in different polishing effects at different positions. If the power is too high, the molten metal will flow and produce ripples. The generation of ripples is caused by the superposition of various forces on the aluminum alloy 5052 polished molten pool. The aluminum alloy surface roughness is small, the required polishing energy density is low, and ΔRa also decreases relatively small, but the polishing results will be better. At the same time, not only the surface roughness will affect the effect of laser micro-polishing, but also the aluminum alloy 5052 surface morphology will have a great impact on the laser micro-polishing.

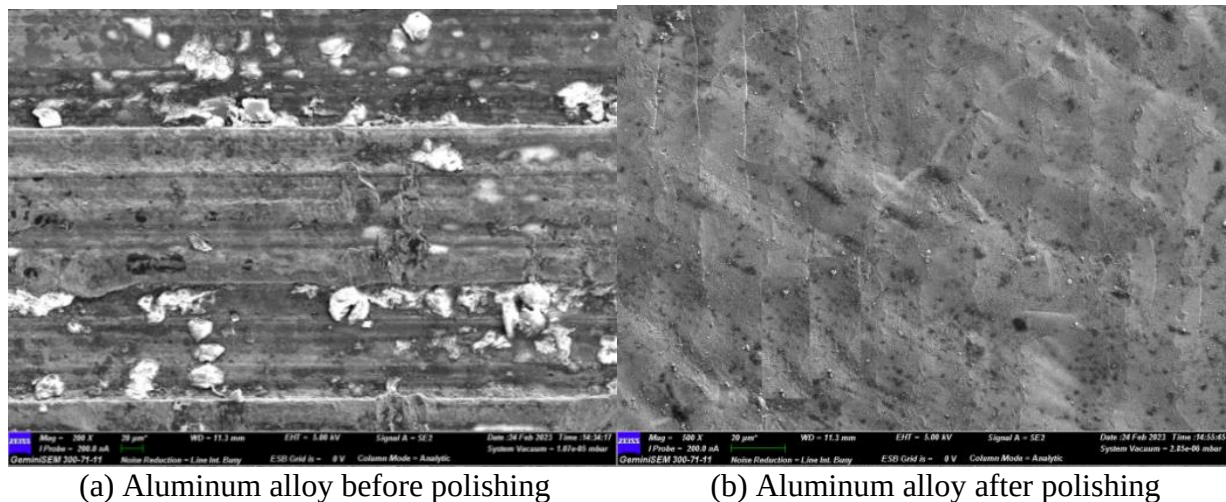


Figure 6. SEM scanning of aluminum alloy before and after polishing

5. Summary

Through the contrast analysis of polish aluminum ally 5052 and optimized with reasonable top-hat laser process parameters, the surface morphology of the material was measured and analyzed by microscope and SEM, the characteristic size and micro-morphology after processing were studied, the processing mechanism and the influence of different process parameters on the polish quality of aluminum alloy 5052 were analyzed.

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References

- [1] C Nüsser, Kumstel, J., Kiedrowski, T., Diatlov, A., & Willenborg, E. Process- and material-induced surface structures during laser polishing. *Advanced Engineering Materials*, 2015. 17 (3): 268 - 277.
- [2] Miller, J.D.; Tutunea-Fatan, O. R.; Bordatchev, E.V. Experimental analysis of laser and scanner control parameters during laser polishing of H13 steel. *Procedia Manuf.* 2017, 10:720 – 729.
- [3] Lee Seungjong, Ahmadi Zabihollah, Pegues Jonthan W, Mahjouri-Samani Masoud. Laser polishing for improving fatigue performance of additive manufactured Ti-6Al-4V parts. *Optics&Laser Technology*, 2021, 134. 106639.
- [4] Zhou, Y. Q, Zhao, Z. Y, Zhang, W, Xiao, H. B, Xu, X. M. Experiment Study of Rapid Laser Polishing of Freeform Steel Surface by Dual-Beam. *Coating* 2019, 9, 324 - 335.
- [5] Haibing Xiao, Yongquan Zhou, Mingjun Liu. Laser polishing of tool steel using a continuous-wave laser assisted by a steady magnetic field, *AIP Advance*, 2020 (10), 025319, 1 - 9.
- [6] Song Y, Wang H, Wang Q, et al. Research and Application of Laser Fine Surface Processing Technology: Cleaning and Polishing. *Aeronautical Manufacturing Technology*, 2018.
- [7] Schmidt, J., Scholz, R., Riegel, H. Laser polishing of aluminum by remelting with high energy pulses. *Material wissenschaft und werkstofftechnik*. 2015, 46 (7): 686 - 691.
- [8] Burzic, B., Hofele, M., Muerdter. S., Riegel, H. Laser polishing of ground aluminum surfaces with high energy continuous wave lase. *Journal of laser applications*, 2017, 29 (1): 011701.

- [9] Liu Bowen, Mi GY, Wang, CM. Study on the morphology and microstructure of 5A06 alloy by high-pulse-frequency pulsed laser micro polishing. Materials Chemistry and physics, 2020, 255: 123500.