Preparation and the Mechanical and Tribological Properties of Laser Cladding Coating

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Abstract. Laser cladding of snsbcu based alloy coating on GCr15 steel substrate was carried out by using lam-400s powder feeding metal printer. The hardness, friction coefficient and microstructure of the coating were tested by Vickers hardness tester, friction and wear tester, metallographic microscope and scanning electron microscope. The effects of laser cladding parameters on the dilution ratio, hardness and friction coefficient of the sample were studied; With the increase of laser power, the hardness of the coating is improved, and the hardness distribution is more uniform; The friction coefficient of the coated sample decreases greatly compared with that of the substrate.

Keywords: laser cladding, orthogonal analysis, microstructure, friction and wear.

1. Introduction
Babbitt alloy is composed of soft matrix and hard point, which has good antifriction, wear resistance, compliance, embeddability and other excellent properties, so it is widely used in the field of industrial production. Babbitt alloys mainly include lead based and tin based alloys. Compared with tin based Babbitt alloys, the strength and hardness of lead-based Babbitt alloys are poor, and the lead element is toxic. Therefore, the application of tin based Babbitt alloys has been widely concerned and developed. Guo Zhengxing et al. [1] studied the arc spraying process of tin based Babbitt alloy coating, and found that the obtained coating had fine and uniform microstructure, better metallurgical bonding between the coating and the substrate, and significantly improved the wear resistance of the coating. Hao Yunbo et al. [2] used laser cladding technology to cladding tin-based Babbitt alloy on the surface of 20 steel substrate, and found that the microstructure size of the coating was smaller than that of the traditional casting process, and the microhardness was higher than that of the traditional casting process. Zhang Wei et al. [3] carried out laser remelting experiment on the surface of centrifugal casting layer of tin base Babbitt alloy of sliding bearing bush, and found that the average hardness of the remelted layer was 25% higher than that of centrifugal casting sample, and the defects of coarse compound, segregation and porosity of centrifugal casting Babbitt alloy were eliminated. Korea Chan kyu Kim et al. [4] studied the influence of laser cladding parameters on the low melting point alloy of Sn based Babbitt alloy, which shows that laser cladding technology is an effective improvement process.

Based on the advantages of laser cladding technology, such as high energy density, fast heating and cooling rate, small deformation of substrate, fine grain of coating and high bonding strength between coating and substrate, there are many researches on the properties of coating after laser cladding, but...
few researches on the effects of laser cladding parameters on the properties of coating. The effect of laser cladding parameters on the properties of the coating was studied.

2. Experimental materials and methods

2.1. Experimental materials
The substrate of laser cladding is 20 × ten × 10 mm GCr15 steel. Before cladding, the substrate was pretreated and polished with sandpaper until the roughness Ra = 0.2 μm. The oxide layer and impurities on the surface of the substrate were removed, and then cleaned and dried with anhydrous ethanol in an ultrasonic cleaner.

The alloy powder for cladding is composed of Sn based powder. The main composition of the powder is shown in Table 1. The powder was put into planetary ball mill and milled at the speed of 120r/min for 4H to make the powder mix evenly. In order to ensure the fluidity of the powder, the powder was screened to ensure that the particle size of the alloy powder was 100-200 mesh. Then the powder was dried in a vacuum dryer at 70°C for 300 min.

Table 1. main composition (wt%) of powder

| element | Sb | Cu | Fe | AS | Al | Sn |
|---------|----|----|----|----|----|----|
| Mass fraction | 11.2 | 5.8 | 0.03 | 0.002 | 0.001 | Bal. |

2.2. Experimental methods
The laser cladding experiment was carried out on GCr15 steel substrate by using lam-400s powder feeding metal printer. The shielding gas was high purity nitrogen, the powder feeding method was synchronous powder feeding, the spot diameter was 5mm, and the lap ratio was 50%. Laser power (800W, 900W, 1000W), scanning speed (300mm/min, 400mm/min, 500mm/min) and turntable speed (0.3, 0.4, 0.5) were selected as the research objects, and L9 (3^4) orthogonal table was used, as shown in Table 2. After cladding each sample, mark the sample (The subsequent sample numbers in this paper correspond to the serial numbers in Table 2).

Table 2. orthogonal experimental table

| Experiment number | Laser power/W | Scanning speed/(mm/min) | Turntable speed | Empty column |
|-------------------|---------------|-------------------------|-----------------|--------------|
| 1                 | 800           | 300                     | 0.3             | 1            |
| 2                 | 800           | 400                     | 0.4             | 2            |
| 3                 | 800           | 500                     | 0.5             | 3            |
| 4                 | 900           | 300                     | 0.4             | 3            |
| 5                 | 900           | 400                     | 0.5             | 1            |
| 6                 | 900           | 500                     | 0.3             | 2            |
| 7                 | 1000          | 300                     | 0.5             | 2            |
| 8                 | 1000          | 400                     | 0.3             | 3            |
| 9                 | 1000          | 500                     | 0.4             | 1            |

402mvd micro-Vickers hardness tester was used to test the hardness of the samples. The pressure was 50N and 15s. The measurement interval is 0.05mm. Ten points were selected on the surface of the laser cladding coating sample and the substrate surface to measure the hardness. The sample was ground flat with sandpaper, and dry sliding friction test was carried out on the sample by rtec mft-50 friction and wear tester at room temperature φ 25 mm GCr15, frequency of 4 Hz, stroke of 4.5 mm, applied load of 50 N and wear time of 30 min. the friction coefficient of the sample was measured.

The sample was corroded with 4% nitric acid alcohol solution. The microstructure of the coating was observed by dm2700m metallographic microscope and jsm-7610f scanning electron microscope; The phase of the cladding layer was analyzed by X-ray diffraction.
3. Experimental results and discussion

3.1. Effect of scanning speed on dilution ratio

The dilution ratio is the change of element composition in the cladding layer due to the diffusion of alloying elements from the base metal to the cladding layer due to the melting of the base metal in the laser cladding process. The main factor affecting the depth of cladding layer is scanning speed. The dilution ratio reflects the influence of process parameters on forming quality to a certain extent. The common calculation method is to calculate the geometric dimension of cladding layer. The formula is as follows:

$$\eta = \frac{h_2}{h_1+h_2} \times 100\%$$  \hspace{1cm} (1)

Where: $H_1$ is the height of cladding layer and $H_2$ is the depth of cladding layer.

It can be seen from Fig. 1 that when the scanning speed is 500mm/min, sample 3 is the lowest dilution rate; When the scanning speed is 400mm/min, the height and depth of the cladding layer of sample 2 are the maximum, and the cladding depth is high, which makes the surface hardness of the coating low and the flatness is poor; When the scanning speed is 300 mm/min, the sample 1 is the lowest, and the height of cladding layer is the lowest. It can be seen that the dilution rate decreases with the increase of scanning speed, because with the increase of scanning speed, the time of stay in the matrix area within unit time of laser head decreases, and the melting substrate depth decreases. When the dilution rate is too low, the bonding strength between the cladding layer and the substrate is low, and the cladding layer falls off easily. When the dilution rate is too high, there is a high metallurgical bond between the substrate and the cladding layer, and the melting phenomenon of the base metal is accompanied. However, when the dilution rate is too high, the substrate element over dilutes the cladding layer, so that the coating properties change, which leads to the mechanical properties of the coating. Therefore, it is necessary to control the dilution rate reasonably in order to obtain the coating with high performance.
3.2. Microstructure and phase analysis of samples

![Microstructure of sample 3](image1) ![Microstructure of sample 7](image2)

**Figure 2.** Metallographic diagram of the sample

The results are shown in Fig. 2 (a) (b). There are many rhombic massive precipitates in the two samples, which are evenly distributed in the dark tin based solid solution, and there are also small white particles, without obvious structural segregation (a). The grain size in the figure is larger than that in (b), and the grain size and distribution in (b) are more uniform. A lot of heat is produced in the process of laser cladding, and the heat is lost in a very short time, which increases the undercooling of the coating. With the increase of undercooling, a large number of nuclei will be produced, and the heat will lose rapidly in the process of nucleation growth, and the grain size will decrease, so as to achieve the goal of grain refinement. Most of the square precipitates are tin and antimony. Further combining with XRD analysis, it can be judged that the square precipitates are SnSb structure and the short rod structure is Cu₆Sn₅ structure.

![Composition map of sample 3](image3) ![Composition map of sample 7](image4)

**Figure 3.** XRD pattern of coating

The XRD pattern of Fig. 3 was obtained by phase test. It can be seen from the figure that the phase types of the coating are the same, which is mainly caused by the α-Sn, Cu₆Sn₅ and SnSb. The position of the diffraction peak is similar, which is due to the same kind of powder. When snsbcu based powder crystallizes, Cu₆Sn₅ phase is formed, followed by white block metal compound SnSb phase, and finally precipitates α-Sn matrix phase. Due to the high energy density of laser, the snsbcu based powder is
rapidly melted and then solidified with high temperature gradient during laser cladding. The solid solution of Sb and Cu elements in Sn matrix is too late to precipitate, which makes it difficult for SnSb phase to grow up, and then forms uniform, fine and dispersed hard phase supersaturated tin based solid solution.

3.3. Hardness of cladding layer

The average hardness comparison of sample 1, sample 4 and sample 7 is shown in Figure 4. Their hardness is 546.04hv, 644.67hv and 751.85hv respectively.

![Figure 4. Comparison of average hardness of samples under different laser power](image)

- Sample 1: 546.04hv
- Sample 4: 644.67hv
- Sample 7: 751.85hv

The laser power of sample 1 is 800W, that of sample 4 is 900W, and that of sample 7 is 1000W. Compared with other samples, the average hardness of sample 1 is the lowest. The main reason is that the laser power is too low and the powder is not completely melted, which leads to the low hardness of the sample. Through the laser cladding process, the hardness of the sample has been greatly improved, because the cladding coating has large undercooling in the solidification process, and the solidification time is short, and the grains are not easy to grow up, forming fine grains, which play a role in grain strengthening. In the process of non-equilibrium solidification, the high-density dislocation structure in the laser cladding coating plays a role of strengthening in place, which effectively improves the hardness of the cladding coating. In addition, the hard particles SnSb and Cu₆Sn₅ in the coating are strengthened by hardness. Therefore, when the laser power is 1000W, the hardness of the coating sample is the highest.

3.4. Friction and wear

Friction and wear experiments were carried out to obtain the friction coefficient at room temperature. As shown in Fig. 5, the friction coefficient values of each sample and the matrix at the initial stage of friction are quite different, and the friction coefficient of each sample tends to be stable at 600s. The average friction coefficients of sample 1, sample 4 and sample 7 are 0.3785, 0.3185 and 0.3143 respectively. The average friction coefficient of the substrate under dry friction is 0.4176, and the friction coefficient of the cladding coating sample is relative to that of the substrate. For example, in Fig. 6, the friction coefficient decreases obviously. SnSb and Cu₆Sn₅ crystal compounds are distributed on the soft matrix of the solid solution phase of the sample, and the hard points protruding from the surface play a supporting role, while the soft matrix has good plasticity and plays a role in reducing friction. Therefore, the friction coefficient of the coating sample is lower than that of the substrate.

Under the condition of dry friction, the wear phenomenon is slight because the overall hardness of the sample is high and the hard phase is not easy to fall off. The reasons for the fluctuation of friction
coefficient are as follows: during the dry friction test, the oxidation reaction takes place on the friction surface to a certain extent, the oxide film formed can reduce the friction with the friction pair, and the furrow formed by abrasive wear reduces the contact area between the ball and the coating. In addition, the accumulation of friction heat leads to the temperature rise of the friction surface, the softening of the soft matrix, the plastic deformation, the increase of the contact area between the ball and the sample, and the increase of the friction coefficient. Under the action of the above factors, the friction coefficient curve fluctuates with time.

**Figure 5.** friction coefficient curve of matrix and sample

**Figure 6.** friction coefficient and sample comparison between matrix and sample
(a) And (b) is the surface topography of the sample, and (c) (d) is the element analysis of two points A and B in Figure B.

Figure 7. SEM of wear scar

As shown in Fig. 7(a) (b), the wear scar of the sample is shown by SEM. The wear mechanism of the coating is mainly abrasive wear. There are furrows and spalling in the wear marks. The matrix phase on the surface of the sample is composed of black tin based solution, and the dispersed massive precipitates and many white fine particles can be seen in the matrix phase. As shown in Fig. 7(c)(d), EDS analysis of the wear scar area shows that Sn and Sb are the main elements in the black part. Due to the influence of tin solid solution, the content of tin in the particles measured by energy spectrum analysis is high.

4. Conclusion

SnSbCu based coating was cladding on GCr15 substrate by laser cladding technology. Through orthogonal experiment, the following conclusions were obtained: in a certain range, with the increase of scanning speed, the depth of cladding layer decreased significantly, the melting area of substrate decreased significantly, so the dilution ratio decreased, so the quality of cladding layer was improved; With the increase of laser power, the input energy of the substrate increases, the area of the molten pool increases, the microstructure is refined, and the hardness of the coating is significantly higher than that of the substrate; Under the condition of dry friction, the friction coefficient of the substrate is 0.4176, and the minimum friction coefficient of the coating sample is 0.3143, which greatly reduces the friction coefficient. By comparison, it is found that the optimal laser cladding power parameters are: Power 1000W, scanning speed 300 mm / min and turntable speed 0.5.

Acknowledgments

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References

[1] Guo Zhengxing, he Yongyong, Lu Xinchun. Friction and wear behavior of Babbitt alloy ZSnSb8Cu4 [J]. Lubrication and sealing, 2014, 39 (07): 5 - 10.

[2] Hao Yunbo, Wang Jiang, Yang Ping, Wang Yuling, Liang Xudong, Gao Jiali. Microstructure and properties of laser cladding tin based Babbitt alloy [J]. China laser, 2020, 47 (08): 116 - 125.

[3] Zhang Wei. Study on Microstructure and hardness of tin based Babbitt alloy by laser remelting [J]. Hot working process, 2015, 44 (08): 32 - 34.

[4] Kim Chan Kyu, Choi Si Geun, Kim Jong Hyoung, et al. Characterization of surface modification by laser cladding using low melting point metal [J]. Journal of Industrial and Engineering Chemistry, 2020, 87 (prepublish).

[5] Xu Tongzhou, Zhang Chen, sun Changqing, Chen Haitao, Xu Ling, pan Xiuhong. Microstructure and mechanical properties of Ni / Sn based Babbitt alloy by laser cladding [J]. Progress in laser and optoelectronics, 2020, 57 (03): 155 - 162.

[6] Liu Yanhui, Chen Zhenyu, Zhou Xiyiing. Microstructure and properties of Laser Cladding Nickel Coating [J]. Mechanical engineering materials, 2010, 34 (04): 62 - 64.

[7] Materials Research; Researchers from Xi'an Jiao Tong University Describe Findings in Materials Research (Effect of laser remelting on tribological properties of Babbitt alloy) [J]. Journal of Technology, 2019.

[8] Yuquan Ni, Guangneng Dong, Zhe Tong. Effect of laser remelting on tribological properties of Babbitt alloy [J]. Materials Research Express, 2019, 6 (9): 096570 - 096570.

[9] Ni Yuquan, Zhang Hui, Dong Guangneng. Tribological performances of modified Babbitt alloy under different sliding modes [J]. J. Tribol, 2021.