

Study on Macromorphology and Microstructure of Laser Cladding NiCrBSi Alloy Cladding Layer

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Abstract

Laser cladding technology is an advanced surface modification technology that can achieve the coating, repair, and manufacturing of surfaces of metals, alloys, ceramics, and other materials. Laser cladding technology has the advantages of high efficiency, high accuracy, and the ability to achieve multi material composites, and is widely used in automotive, aerospace, shipbuilding, medical and other fields. However, there are also some problems with laser cladding technology, such as unstable weld pool morphology, uneven weld pool depth, and thermal stress, which limit its application range and the need to improve efficiency. Therefore, how to further improve the efficiency and quality of laser cladding technology has been an important research direction for researchers. Through nine orthogonal experiments without electromagnetic field, the effects of laser processing parameters, such as laser power, spot diameter, and scanning speed, on the quality of the cladding layer were studied. For melting height, scanning speed is the most significant influencing factor; For the melt width, the spot diameter is the most significant influencing factor; For the penetration depth, the laser power is the most significant factor. Through comprehensive comparison of subsequent morphology observation and mechanical property testing, it is concluded that laser power of 1500W, spot diameter of 3mm, and scanning speed of 4mm/s are the best process parameters, providing guidance for subsequent cladding experiments.

Keywords

Laser Cladding; Macro Morphology; Microstructure.

1. Introduction

As an efficient, precise, and flexible manufacturing technology, laser cladding technology is of great significance for promoting the transformation and upgrading of the manufacturing industry. Laser cladding technology can achieve surface modification and coating of materials, thereby improving the performance and function of materials. Using laser cladding technology can prepare materials with high strength, high hardness, high wear resistance, and high temperature resistance, which can greatly improve the service life and safety performance of products. In addition, laser cladding technology can also improve the lubricity, corrosion resistance, anti adhesion, and other properties of the material surface, further expanding its application fields. Laser cladding technology can also achieve customized preparation of materials, providing new ideas and ways for personalized customization of products. Therefore, laser cladding technology has an important application prospect and driving role in the field of manufacturing.

Nine sets of orthogonal experiments without auxiliary field were designed, and the optimal experimental parameters for cladding were determined through microstructure analysis: laser power, spot diameter, and scanning speed.

2. Experimental Design

2.1. Base Material

The base material of the large transmission gear repaired in this project is modulated 40Cr steel, which is used as the cladding base material. Its elemental composition is shown in Table 1. 40Cr steel is one of the most widely used metals in the mechanical manufacturing industry, with good low-temperature impact toughness and low notch sensitivity, so it is widely used in the manufacturing of medium and large gears [1-2]. However, its corrosion resistance and wear resistance are not good enough, and the working environment of large gears is relatively harsh, prone to defects such as wear, scuffing, and pitting. Moreover, large gears are expensive and costly, and replacing the entire gear due to minimal defects can cause a waste of resources. Therefore, in order to improve its working performance, it is also necessary to save costs and resources, The laser cladding process is used to repair the damaged gear or to cladding a coating with good mechanical properties on the working surface. Therefore, a base sample with a sample size of 70mm is selected for experimental verification $\times 15\text{mm} \times 15\text{mm}$.

Table 1. Element composition of 40Cr steel

composition	C	Si	Cr	Mn	Ni	P	S	Fe
Element content/%	0.37~0.44	0.17~0.37	0.80~1.10	0.50~0.80	≤ 0.30	≤ 0.04	≤ 0.03	Bal

2.2. Powder Material

In order to enhance the mechanical properties of the working surface of gears or repair damaged gears and achieve a strengthening effect, a self soluble alloy powder NiCrBSi with good wear resistance and corrosion resistance is selected. Its advantages are strong resistance to temperature, it is not easy to be oxidized, and it can still ensure good friction and wear performance in high temperature environments, and its cost is low [3]. The thermal expansion coefficient of alloy powder and substrate 40Cr steel is close, which can ensure that the powder and substrate can better fuse during the cladding process, and can reduce the thermal stress and cracks of the metal in the experiment [4]. The metal powder is a spherical particle powder with a particle size of 40-105 microns. Its morphology is shown in Figure 1, and the element content is shown in Table 2.

Table 2. Element composition of NiCrBSi alloy powder

composition	C	Si	Cr	B	Ni	Al	Fe
Element content/%	0.5-1.0	2.0-3.0	9.0-12.0	1.0-2.5	Bal	2.0-5.0	≤ 10

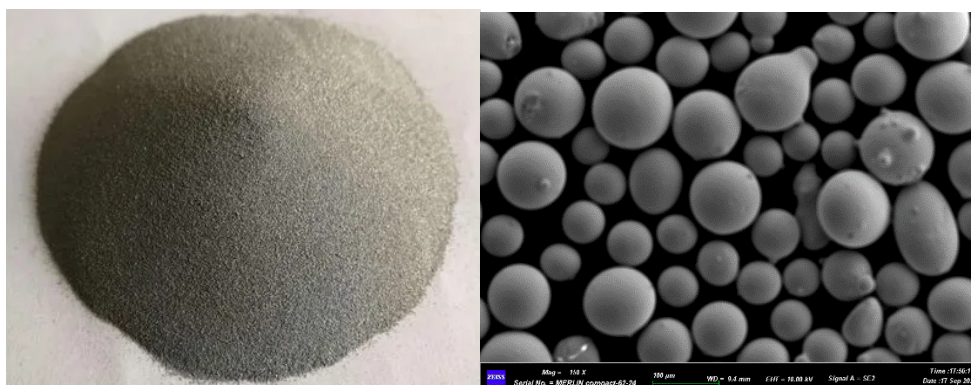


Fig 1. Morphology of NiCrBSi alloy powder

2.3. Experimental Scheme

The difference in laser power, scanning speed, and spot diameter will directly affect the performance of the cladding coating, and there are also mutual influencing factors among the three, which can couple and affect the coating performance. In this study, 9 orthogonal experiments were designed to investigate the effects of parameters on the coating from the perspective of changing laser power, spot, and scanning speed parameters. In order to study the effects of different laser power, spot diameter, and scanning speed on the preparation of NiCrBSi coatings on 40Cr substrate, the following research on the effects of different types and positions of auxiliary fields on the performance and quality of the coatings will be conducted.

According to the formula for specific energy E_s : $E_s=P/(Dv)$, three factors, namely, available power P , spot diameter D , and scanning speed v , are applied together to determine the quality and performance of the coating. Therefore, it is necessary to determine the optimal laser process parameters in the experiment, and guide subsequent experiments on the basis of that. Therefore, based on the existing data, nine orthogonal experiments have been designed with different values of power, spot diameter, and scanning speed, as shown in Table 3.

Table 3. Parameters of orthogonal experiment

Serial number	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9
Laser power (W)	1500	1500	1500	1700	1700	1700	1900	1900	1900
Spot diameter (mm)	3	4	5	3	4	5	3	4	5
Scanning speed (mm/s)	3	4	5	4	5	3	5	3	4

3. Experimental Results

3.1. Macro Morphology Analysis

As shown in Figure 2, the following nine images correspond to the cross-sectional morphology of the cladding layer of the test piece under the No.1 to No.9 laser parameters, respectively. From the figure, it can be seen that under different process parameters in nine groups of experiments, the metal powder and the experimental substrate have metallurgical bonding, and there are no obvious defects at the fusion lines of the weld pool and heat affected zone, which can clearly distinguish the weld pool, heat affected zone, and substrate. However, due to different laser parameters, there are different differences in the morphology between the nine groups of experiments. The specific values are shown in Table 4. Since the nine groups of experiments are all multi-channel cladding experiments, the width of the cladding layer is the total width, and the height and depth of the multi-channel cladding layer are not significantly different. Therefore, the average value of both parameters is taken as the final parameter of the experimental cladding layer for this group.

As shown in Figure 2. The depth of the cladding layer of ③, ⑤, and ⑦ is slightly smaller than that of others, because these three sets of scanning speeds are the fastest, resulting in too fast cooling of the molten pool, and too little absorption of laser energy per unit time between the powder and the substrate. Therefore, the degree of fusion between the powder and the substrate is relatively low, so the melting height of the cladding layer and the depth of the heat affected zone are relatively small. In addition, due to the different laser power and spot diameter in these three groups, the depth of the cladding layer is also different. As shown in ③, the small depth of the molten pool is due to the low laser power and fast scanning speed.

As shown in Figure 2, the depth of the cladding layer in ④, ⑥, ⑧ is larger than that in other groups. The scanning speed of these three groups is slower, and the laser power is at a higher value. The metal powder absorbs more energy per unit time, the fusion pool and the metal

substrate are more fully mixed, the substrate melts more, and the depth of the cladding layer increases.

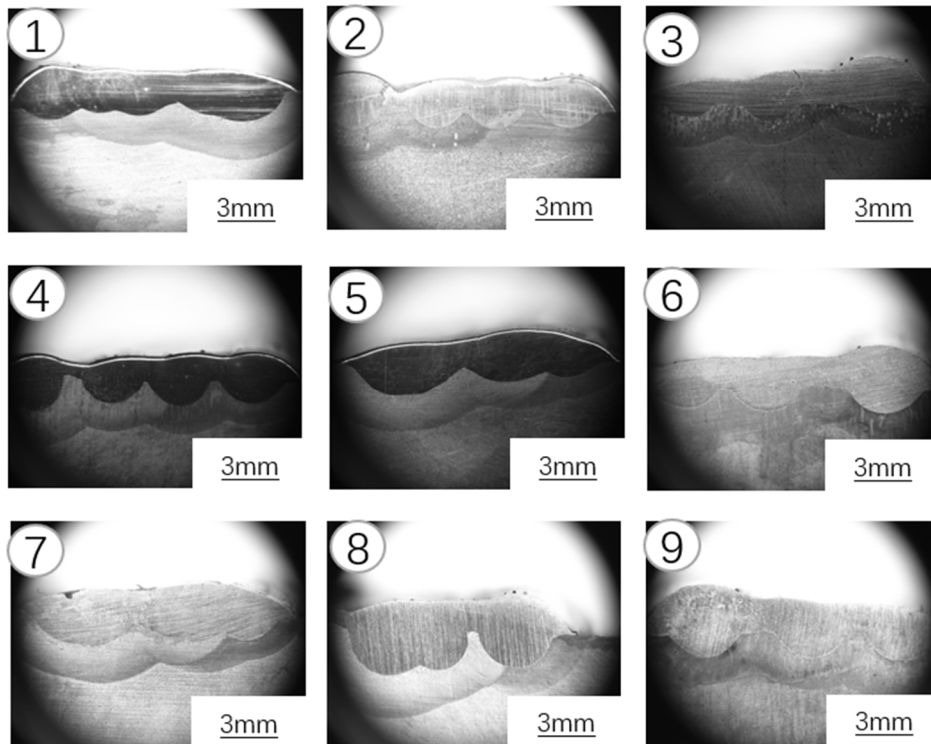


Fig 2. Optical microscope morphology number ① - ⑨ of cross section of cladding layer correspond to orthogonal experiment No. 1-No. 9 respectively

Table 4. Cladding Layer Data of Test Specimen

Serial number	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9
Melting height (mm)	0.73	1.02	0.78	0.72	0.71	0.88	0.72	0.92	1.07
Melting width (mm)	8.30	8.43	8.29	8.55	7.97	8.58	8.15	6.90	8.61
Penetrationdepth(mm)	0.66	0.52	0.61	0.87	0.69	0.83	0.83	1.22	0.73

3.2. Microstructure Analysis

As shown in Figure 3, during the laser cladding process, a molten pool is formed by direct laser irradiation on the preset powder, and the molten pool is connected to the substrate. The heat of the molten pool is transferred to a low energy substrate. At the junction of the molten pool and the substrate, the temperature gradient G is relatively large and the G/R is relatively small, so it is easy to form relatively coarse dendritic and columnar crystals at the bottom. At the top of the cladding layer, the heat is transferred from the top to the bottom, and the cooling rate in the molten pool is relatively small, the temperature gradient is relatively small, and the solidification rate is relatively slow against each other, resulting in an increase in the undercooling of the molten pool, Under the constraint of intergranular interaction, the main cellular crystals, dendrites, and some equiaxed.

In the manufacturing process of laser cladding, the cladding surface is relatively rough and cannot be directly applied to the actual working environment. Therefore, it is necessary to perform certain mechanical processing on the surface to remove the surface structure. Therefore, the actual working surface of the cladding part is the middle of the cladding layer, so

it is particularly important to study the microstructure and performance of the middle of the cladding layer.

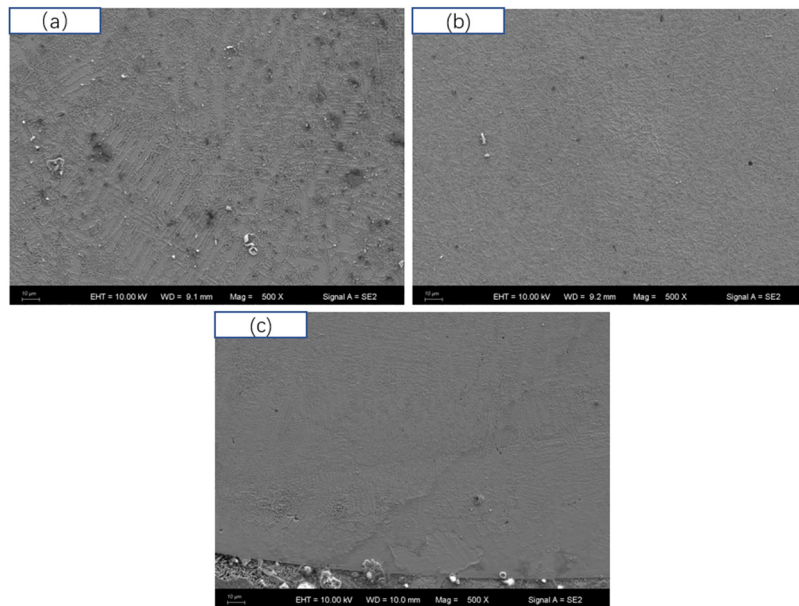


Fig 3. SEM diagram of microstructure at different parts of the cladding layer (a) upper part; (b) Middle; (c) At the fusion line

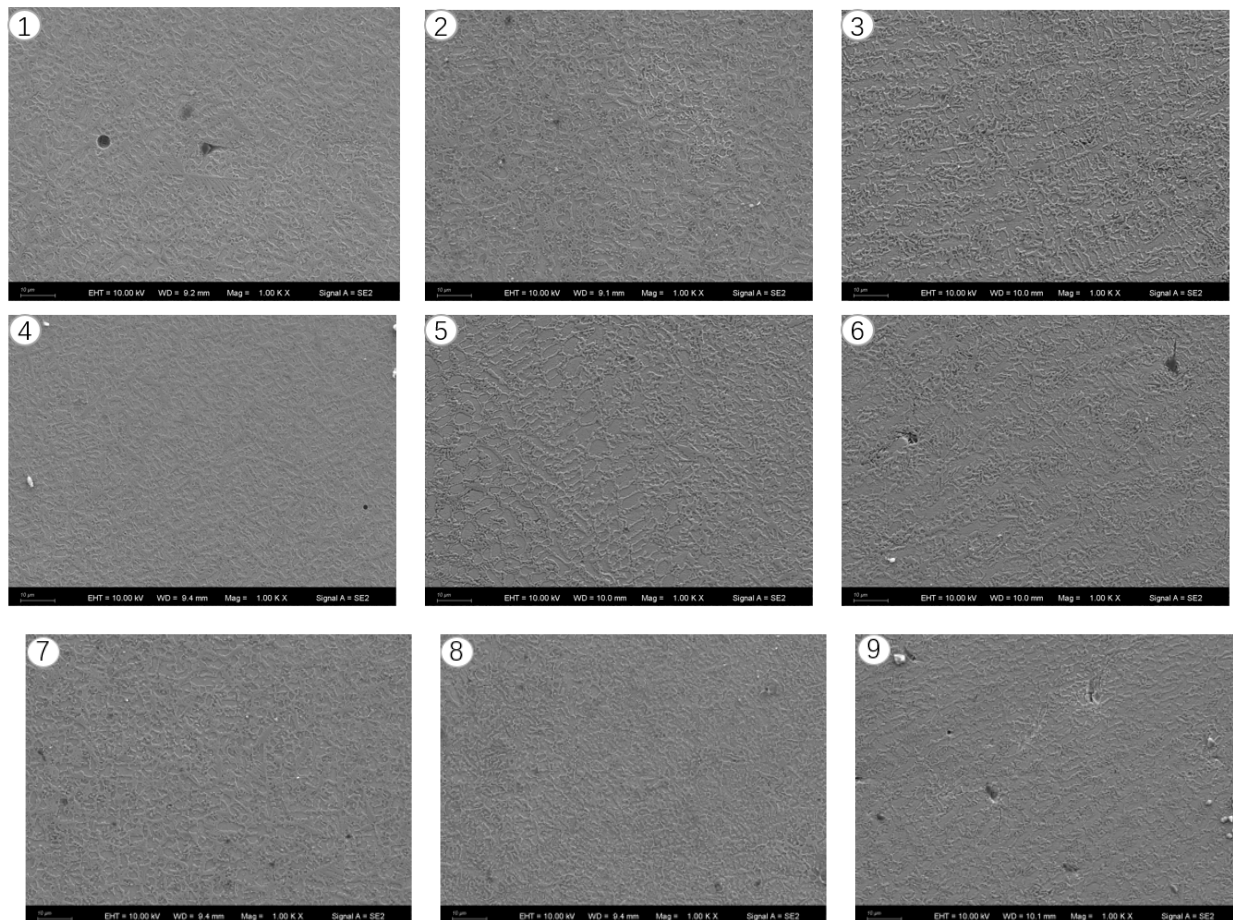


Fig 4. 8 SEM diagram number ① - ⑨ of microstructure of cladding layer correspond to orthogonal test No. 1-No. 9 respectively

As shown in Figure 4, ① - ⑨ are the SEM diagrams of the microstructure of the cladding layer in the orthogonal experiment No.1-No.9. From the diagram, it can be seen that most of the microstructure in the middle of the cladding layer is cellular crystals. As shown in Figure ①, ②, and ④, the laser power is not the highest, the energy absorbed during the deposition process is less, the solidification rate is faster, and the G/R value is relatively large. During the transformation of the molten pool from liquid phase to solid phase, cellular crystals and some equiaxed crystals are formed, The proportion of columnar crystals to dendritic crystals is small, while in other experiments, with the increase of laser power, the energy absorbed by the metal powder and the substrate increases, the crystallization rate slows down, and the solidification time increases. The proportion of columnar crystals to dendritic crystals increases. With the increase of scanning speed, the heat absorbed by the molten pool per unit time decreases, the solidification rate increases, the grain size is relatively small, and the dendritic growth direction is extremely irregular [5-8]. As the diameter of the light spot increases, the energy absorbed by the molten pool per unit area decreases, and larger areas of powder are irradiated by laser light. More volumes of powder absorb energy and melt, the width of the molten pool increases, and the contact surface between the molten pool and the substrate expands, which can better transfer heat from the molten pool to the substrate, leading to faster crystal crystallization speed, higher solidification rate, finer crystals, and a further increase in the proportion of dendrites [9].

4. Conclusion

This paper systematically studies the influence of laser processing parameters on the properties and morphology of the cladding layer on 40Cr substrate through orthogonal experiments. The conclusions are as follows:

- (1) The main process parameters that affect the morphology of the cladding layer are: laser power, spot diameter, and scanning speed. For melting height, scanning speed is the most significant influencing factor; For the melt width, the spot diameter is the most significant influencing factor; For the penetration depth, the laser power is the most significant factor.
- (2) In this chapter, nine groups of experimental workpieces were obtained through orthogonal experiments. Through comprehensive comparison between subsequent morphology observation and mechanical property testing, it was concluded that the optimal process parameters were No. 4: laser power 1500W, spot diameter 3mm, and scanning speed 4mm/s, providing guidance for subsequent multiple cladding experiments.

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