Study on Laser Cladding Preparation of Bionic Surface of Cast Iron Brake Disc

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Abstract. The shellfish in nature was taken as the biological model, and the coupling design was carried out on the surface of grey cast iron. With the help of advanced laser cladding technology, the unit body was prepared on the surface of grey cast iron, so as to obtain the bionic samples of grey cast iron with high wear resistance and fatigue resistance. The composition, hardness distribution, morphology and phase of the unit were analyzed by micro-hardness tester, scanning electron microscopy (SEM) and XRD. Thermal fatigue test and friction and wear test were carried out on bionic and untreated grey cast iron samples. The effects on fatigue resistance and wear resistance of bionic laser cladding and grey cast iron were studied by comparing the experimental results. It was found that the laser cladding has a compact structure and a metallurgical bond with the substrate. The hardness of the unit is 2 times of that of the grey cast iron substrate. The thermal fatigue resistance of the material is improved by bionic laser cladding. The bionic laser cladding preparation can greatly improve the wear resistance of materials.

1. Introduction

Braking system is a key component of rail trains. The braking performance during high-speed driving directly affects driving safety [1-2]. Grey cast iron material is often used to manufacture brake discs. Strict requirements are put forward for the material of brake disc in practical applications, such as good wear resistance, good thermal fatigue resistance [3-4]. The pearl layer of shellfish is mainly composed of calcium carbonate material with high hardness and high strength, and a small amount of organic matter with low hardness and low strength. Carbonate in hard phase increases the fatigue resistance and wear resistance of shellfish, while organic matter in soft phase can buffer and weaken the stress imposed on shellfish, and greatly improve the fatigue resistance of shellfish [5]. The morphology, structure and materials of the body surface with excellent wear resistance and fatigue resistance were studied from the point of view of bionics, which provided ideas for the surface modification of grey iron brake disc materials. Units were fabricated by laser cladding. Comparing the bionic specimens with the untreated grey cast iron specimens, the thermal fatigue resistance and wear resistance of the specimens were studied. The effect of bionic laser cladding on the properties of grey cast iron was studied in order to develop new brake disc materials.

2. Experimental design and research methods

2.1. Materials and fabrication of laser cladding unit
Table 1 is the chemical composition of the substrate material; Inconel 625 alloy powder was used as cladding material. Its chemical composition was shown in Table 2. The particle size of the powder ranged from 33-61μm.

### Table 1. Chemical composition of substrate materials (wt%).

| Composition | C  | Si | Mn  | P  | S  | Cu | Cr | Fe |
|-------------|----|----|-----|----|----|----|----|----|
| Content     | 3.58 | 1.92 | 1.45 | 0.09 | 0.37 | 0.95 | 0.40 | Residue |

### Table 2. Chemical compositions of alloy powders (wt%).

| Composition | C  | Cr | Si | Nb | Mn | Mo | Fe | Ni |
|-------------|----|----|----|----|----|----|----|----|
| Content     | 0.02 | 23.1 | 0.10 | 3.40 | 0.18 | 9.10 | 0.40 | Residue |

In bionics, coupling body is a three-dimensional body with a certain shape, and the distribution in the surface of the substrate material is regular, its material composition and structure are different from that of the substrate [6]. The shape of the prepared unit is long stripe. The coupling body with U-shaped structure has stronger ability of eliminating stress concentration and restraining crack growth [7]. Therefore, it is necessary to choose U-shaped structure as the section structure of bionic element embedded in substrate as shown in Figure 1. W is the width of the unit body, and H is the height of the unit body. The grey cast iron brake disc is cut by a CNC WEDM Machines to obtain a grey cast iron sample measuring 25 mm × 25 mm × 6 mm. The surface of the sample is cut to produce a rectangular groove with a size of 1 mm × 0.4 mm, and the groove to groove spacing is 4 mm as shown in Figure 2.

In the experiment, the nickel-based alloy cladding powder was placed in the groove of the substrate by the preset powder method. The laser fabrication system consists of a laser generator and a processing operation platform with a laser wavelength of 1.06 um and a power of 800 W. Figure 3 is the physical picture of the bionic sample prepared by laser cladding in the experiment.

#### 2.2 Microhardness test and wear test

The hardness of the sample was measured by microhardness tester and the hardness distribution of the cladding layer was measured along the depth direction. The hardness was measured under load of 200 g and holding time of 10 s.

The bionic coupling sample prepared by laser cladding was fastened to a friction and wear tester. Before the test, it is necessary to select a pair of grinding discs that can produce good friction with the biomimetic specimens, the grinding disc material used in the test is H13 die steel, which has a hardness value of 48-55HRC and a diameter of 70mm. The friction test was carried out under the conditions of a load of 50 N, a rotational speed of 200 rpm and a wear time of 20 min. Before and after friction and wear, the bionic and untreated specimens should be weighed on an electronic balance with a precision of 0.1 mg.

#### 2.3 Thermal fatigue test

For bionic and untreated specimens, thermal fatigue tests were carried out using fatigue testing machine. The sample is heated to 600 ℃ by medium frequency induction furnace and kept for 75 s. The sample is cooled to 25℃ with tap water and kept for 5 s to complete such a heating-cooling process which is a
thermal cycle. When the number of cycles reaches a certain value, the thermal fatigue resistance of bionic specimens and untreated specimens is measured by observing the number of cracks on them. It was recorded when the crack spread to a length of 0.5 mm, which is a standard for recording cracks in this test.

2.4. Microstructure observation and phase analysis
Scanning electron microscope (SEM) is used to analyze the microstructure. The phase analysis of the biomimetic coupling sample was carried out using a DX-2700 X-ray diffractometer (XRD). This equipment can perform line scan energy spectrum analysis on the bonding area of the cladding layer and grey cast iron during the test. The energy spectrum test of this area needs to be used together with the scanning electron microscope.

3. Study on characteristics of laser cladding cast iron surface

3.1. Microstructure and morphology of cladding layer
Two of the units as shown in Figure 4. were observed by scanning electron microscopy (SEM). It is observed from the figure that the cladding layer has fine structure, which is the result of rapid heating and solidification in the laser solidification process. By observing the cross section of the cladding layer, it is found that there are no cracks and holes in the cladding layer, which indicates that the effect of laser cladding is very good.

3.2. Component analysis of cladding layer
The results of SEM micro-morphology and line scanning were shown in Figure 5. It shows that Ni and Co alloy elements in the cladding material can be well integrated into the substrate, and Fe and Cu elements in the substrate material can also be well integrated into the cladding layer, indicating that the cladding layer and the substrate have good metallurgical bonding.

Figure 4. Microstructure of the cross section of the cladding layer (5000 times).

Figure 5. SEM morphology and EDS analysis of cladding layer interface.
3.3. Phase analysis of cladding layer
The phase analysis of the cladding layer and the X-ray diffraction pattern results are shown in Figure 6. As can be seen from the figure, the main phases in the cladding layer are FeNi$_3$ and Cr$_2$Ni$_2$ compounds, Ni solid solution and Cr$_{23}$C$_6$, Cr$_7$C$_3$ and Cr$_6$B$_3$ strengthening phase. These substances are produced by thermochemical reaction of cladding material after heating during laser processing.

3.4. Microhardness
Figure 7. shows the hardness distribution curve of the cross section of the cladding layer. The hardness curve presents three steps, corresponding to the grey cast iron substrate (BS), the transition zone (TZ) and the cladding layer (CL). From BS, TZ to CL, the microhardness increases with the increase of the height of the cladding layer. This is mainly due to the dense structure of the cladding material after high energy density laser treatment. In addition, the presence of carbides and borides and other strengthening phases also plays a role in improving the hardness. It is found that the hardness of the cladding layer is about twice that of the substrate material.

4. Study on performance of bionic coupling brake disc material
4.1. Effect of thermal fatigue on hardness
The hardness change of the unit body and the substrate before and after the thermal fatigue test was compared and the microhardness change curve was obtained as shown in Figure 8. The substrate material has maximum decrease in hardness in the process of thermal fatigue test. The Ni-based alloy powder of the cladding layer has excellent high temperature resistance and oxidation resistance, so the cladding layer has minimum decrease in hardness.

4.2. Thermal fatigue resistance of bionic laser cladding materials
The curves of the number of cracks varying with the number of thermal cycles as shown in Figure 9. The results show that the thermal fatigue resistance of bionic specimens is stronger than that of untreated specimens. It is inferred that the thermal fatigue resistance of the material can be improved by bionic laser cladding. Figure.10(a) and Figure.10(b) are the morphologies of bionic specimens before and after thermal fatigue test respectively. Bionic cladding preparation can improve the hardness and strength of the material, make the crack not easy to generate inside, which also explains laser cladding preparation can improve the thermal fatigue resistance of materials from the structure. Compared with Figure.10(a), the grain of the material in Figure.10(b) is coarsened and the density is reduced. It shows that under the action of thermal cycling, the morphology of the material changes, resulting in a decrease in thermal fatigue resistance.
4.3. Wear resistance of biomimetic laser cladding samples

The wear resistance can be measured by calculating the wear amount. The formula for calculating the wear amount of the sample is as follows [8-9]:

\[ W = W_0 - W_1 \]  

Where: \( W \) is the amount of wear of the friction test specimen; \( W_0 \) is the quality of the sample before the friction test; \( W_1 \) is the mass of the sample after the friction test. Table 3 shows the wear amount after the sample wear test. It can be clearly seen from the table that the wear of the untreated sample after the friction and wear test is 1.4 times that of the bionic sample, indicating that its wear resistance is better than that of the untreated sample, further indicating that the laser bionic cladding preparation can significantly improve the wear resistance of the material.

Table 3. Test sample wear.

|                  | Biomimetic sample | Untreated sample |
|------------------|-------------------|------------------|
| \( W_0 \)(g)    | 42.2537           | 41.6153          |
| \( W_1 \)(g)    | 42.2522           | 41.6131          |
| \( W \)(g)      | 0.0015            | 0.0022           |

Figure 11(a) shows the wear morphology of the joint between the unit body and the grey cast iron substrate in the biomimetic sample. In comparison, the wear surface of the untreated sample shown in Figure 11(b) has more severe adhesive wear characteristics, the local surface material falls off, and there is obvious plastic deformation, and material transfer occurs.

5. Conclusions

(1) The laser cladding has a compact structure and a metallurgical bond with the substrate. The microhardness test results show that the hardness of the unit is 2 times of that of the grey cast iron substrate.
(2) The results of thermal fatigue test show that thermal fatigue coarsens the structure of the material. With the increase of the number of thermal fatigues, the decrease ratio of the hardness of the untreated sample and the increase rate of the crack are larger than that of the biomimetic sample, indicating that the thermal fatigue resistance of the biomimetic sample is better than that of the untreated sample.

(3) The friction and wear test results show that the wear volume of the untreated sample was 1.4 times that of the bionic sample, wear morphology of the bionic sample was better than that of the untreated sample, indicating that the bionic laser cladding preparation can greatly improve the wear resistance.

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