Effect of Co-based Alloy on Properties of Laser Cladding Layer

Y Yang, Z P Jiang, H Z Li
College of Mechanical Engineering, Qingdao University of Technology, Qingdao, China

Abstract. A large number of laser cladding experiments have been carried out using 20CrMnTi steel as substrate and Co-based alloy as cladding material. The influence of Co-based alloy on the laser cladding properties of 20CrMnTi steel was studied by analyzing the macroscopic and microscopic characteristics of cladding crack susceptibility, dilution rate, microstructure and friction and wear properties. The results show that the high-power laser cladding of Co-based material can obtain a flat defect-free cladding layer with compact structure and low crack susceptibility. A multi-layer cladding strategy with variable power can be used to fabricate thin wall structures without collapse Parts, the surface smooth without pores.

1. Introduction
Laser cladding technology is a new type of surface modification technology developed with the development of high-power lasers. It is the alloy powder is placed on the surface of the cladding substrate with different filler, the alloy powder is rapidly melted by laser as heat source, The surface of the substrate to form a coating with excellent performance, so as to achieve the purpose of strengthening the surface of the workpiece [1]. Laser cladding remanufacturing forming technology is in line with the national recycling economy and sustainable development strategy of green manufacturing technology, is also one of the state's key high-tech support [2-3]. 20CrMnTi is a kind of excellent carburizing steel with good hardenability, high impact toughness at low temperature and good fatigue resistance. It is widely used in industry [4-6], to study the material remanufacturing process has a certain practical significance.

A lot of researches have been done on laser cladding technology. Valsecchi [7] and so on using the optimal process parameters and argon protection conditions were prepared under the conditions of WC content of up to 85% of the Co-based cladding layer, to achieve a high surface hardness and low crack sensitivity combination. Farnia et al [8] prepared Co-based Stellite 6 coatings on low carbon steel substrates and studied the growth mechanism of the grains. The growth of grains in the Co-based cladding material was studied by the experiments of starting austenite Tissue grains. However, for 20CrMnTi steel materials, the laser cladding alloy powder research has not been reported. Which material is more suitable for 20CrMnTi laser cladding process, need further study and analysis. The influence of Co-based alloy on the laser cladding properties of 20CrMnTi steel was studied in this paper, which provided the basis for choosing suitable alloy powder for 20CrMnTi laser cladding process.

2. Laser cladding test
The carburized 20CrMnTi steel was used as the substrate, and the size was Φ170 mm × 10 mm. In order to ensure the consistency of the test and the actual parts of the state, the matrix sample carburizing quenching heat treatment, carburizing layer of effective hardened layer depth of 0.8 ~ 1.2
mm. Before the test, the substrate sample surface sanding to remove the surface oxide; use acetone to clean the residual stains after drying.

The main components and content (mass fraction,%) are: C 1.15, Mn 0.50, Mo 0.80 ~ 1.10, W 4.00, Fe 3.00, Co, Si 1.10, Ni 3.00, Cr 29, Co balance. The alloy powder was stored in a vacuum atmosphere before the test.

Laser DF4000-60 semiconductor laser was used in the experiment. Laser spot diameter was 4 mm. Powder feeder model SF02 carrier gas synchronous powder feeder, powder feeding gas and high purity nitrogen gas protection. The laser parameters were as follows: laser power 2800w, scanning speed 180, 360 and 540 mm/min; laser power 3500W, scan speed respectively, the parameters were as follows: single-channel cladding test, preset 2 mm alloy powder, 180, 360 and 540 mm / min. The laser power was 4200 w and the scanning speed was 180, 360 and 540 mm / min, respectively. The laser parameters were: laser power 3500 W, scanning speed 180 mm / min, powder feeder voltage 9 V, overlap rate of 33%, 50 m / min, % And 67% respectively. 1 set of multi-layer stacking cladding test, test parameters 1 to 10 layers, laser power 1500 w; 11 to 15 layers, laser power 800 w.

The surface quality, macroscopic crack and cross-sectional morphology of the cladding layer were observed by DTX stereomicroscope. The microstructure of the cladding layer was observed by using electronic metallographic microscope. The etchant was Nitro-hydrochloric acid. The hardness of the cladding layer was measured by FM-700 micro-hardness tester.

3. Test results and analysis

3.1. Cladding crack susceptibility

Crater at the topography shown in Figure 1. The research shows that the crater is jagged and the speed of arc welding at the end of the welding process is quicker to cool the molten pool and the metal can be crystallized in a very short time. But the liquid metal can not meet the need of final crystallization, Leading to cracks, so the crater cracks are hot cracks. The physical process of laser cladding and welding have certain similarities, all of which are heated and melted to form molten pool and then solidified. Therefore, the formation mechanism of the crack can be referred to the conclusion of welding process. From Figure 1, Which is in accordance with the character of crack in welding. The reason is the end stage of cladding, the laser beam disappears, the pool rapidly cools and the metal rapidly solidifies to form crater crack.

![Figure 1. Crater morphology](image)

3.2. The dilution rate of the cladding layer

The cladding layer and the matrix material to form a good metallurgical bonding is to ensure that the cladding layer in use without cracking, shedding of the important conditions to ensure that the interface at the base material and cladding material melting, but the matrix material melting too much Resulting in the cladding layer and the matrix element mutual penetration, so that the performance of the cladding layer is affected. Using the simplified formula to calculate the cladding dilution rate, the formula is shown in the formula (1), and the physical quantities in the formula are shown in Figure 2.
The dilution rate of the laser cladding layer calculated by formula (1) is shown in Fig. 2. In the process of laser cladding, the energy is dissipated by the three methods of melting the cladding material, the heat transfer of the molten substrate and the substrate. According to the trend of the curve in the figure, it can be seen that the laser power is fixed and the scanning speed is increased, and the dilution rate of the cladding layer shows a decreasing trend. When the scanning speed is constant, the laser power increases and the dilution rate increases.

$$\eta = \frac{h}{H + h} \times 100\%$$

(1)

3.3. Microstructure of cladding layer

The surface quality and size of cladding layer prepared by laser cladding cannot directly meet the technical requirement of parts. After grinding, it is necessary to pay attention to the upper and middle parts of cladding layer in the study of cladding hardness. This part is the post-processing part of the surface. The data obtained by averaging the results of the microhardness measurements in the range of 1 mm to 2 mm from the upper surface of the laser clad layer on the single track were used as the hardness test results, hereinafter referred to as the effective hardness of the clad layer. Figure 3 shows the relationship between the microhardness of the cladding layer and the laser power and scanning velocity. When the scanning speed is the same, the effective hardness decreases as the laser power increases. The cladding microstructure under different process parameters is shown in Figure 4. The grain size increases with the increase of the laser power when the scanning velocity is fixed.

![Figure 2. Dilution rate of the cladding layer](image1)

![Figure 3. Hardness test of cladding layer](image2)

![Figure 4. Cladding layer microstructure](image3)
3.4. Friction and Wear Characteristics of Cladding Layer

Wear surface of the workpiece and the surface of the Si3N4 ceramic ball are not smooth, the friction coefficient at the front of the curve in Figure 5 rises rapidly at the beginning of the test. After 400 s, the sample into a more stable wear stage, two pairs of grinding surface tends to run, the friction factor in a certain range of fluctuations. The mean value of the friction coefficient of the Co-based material is 0.77 in the stable wear stage, 0.69 in the 20CrMnTi material, and 20CrMnTi in the abrasion resistance.

![Friction coefficients curve of the cladding materials](image)

**Figure 5.** Friction coefficients curve of the cladding materials

Co-based material and 20CrMnTi material before and after wear and tear compared to the weight loss shown in Table 1. The wear scar profile of the two materials is similar to that of the two materials, but there is a great difference in the wear depth. The maximum depth of wear trace of the Co-based material is 3.13 μm, and the grinding of 20CrMnTi material The maximum trace depth is 1.45 μm, and the trace of 20CrMnTi material is shallow. According to the studies have shown that by adding Y2O3, CeO2, La2o3, La2O3, and La2O3, WC and other strengthening phase can effectively improve the hardness and wear resistance of the alloy cladding layer.

| Sample wear (g) | Co-based cladding | 20CrMnTi |
|----------------|-------------------|----------|
| Before the test | 15.7867           | 19.4526  |
| After the test  | 15.7859           | 19.4523  |
| Sample wear     | 0.0008            | 0.0003   |

Table 1 Comparison of samples weightlessness before and after wear test

3.5. Multilayer laser cladding test

In the cladding process, the laser power to ensure the full melting of the material under the premise of gradual decline, you can avoid the phenomenon of burning collapse. As shown in Figure 6, the laser power was reduced to 800 W when the 11th layer was cladded. The surface of the prepared thin-walled structure was dense and free of hole defects, and the top Smooth without collapse.

![Thin-walled structure after multilayer cladding](image)

**Figure 6.** Thin-walled structure after multilayer cladding
4. Conclusion

(1) A large amount of laser cladding experiments were carried out using Co-based alloy powders, and the macroscopic and microscopic characteristics, such as crack sensitivity, dilution rate, microstructure and friction and wear properties, of Co-based cladding were studied. The multi-layer laser cladding experiment of thin-walled structural parts was carried out.

(2) High power laser cladding using semiconductor laser can make the thick Co-based cladding material melt and get a flat cladding surface. Co-based cladding has low crack susceptibility, only In the crater occasionally small cracks in the actual processing process should be taken to slow down the power or set the process board to avoid crack defects; Co-based materials need to add hard phase to enhance the wear resistance before they can be applied to the actual remanufacturing repair process in.

(3) The multi-layer cladding strategy with variable power can be used to prepare the non-collapsed thin-walled structural parts. During the cladding process, the laser power can be reduced by ensuring the material is fully melted.

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