Comparison of Microstructure and Properties between Co-based and Ni-based Gradient Wear-resistant Coating Obtained by Laser Cladding

Changchun Zhang, Xiaodong Zhang*, Hongxin Wang, Zhenbang Cheng
College of Mechanical and Vehicular Engineering, West Anhui University, Lu’an 237012, China.
E-mail address: 774359800@qq.com

Abstract: The alloy powder of St6, St12B was successively fused on the surface of 20CrMnMo steel, then the alloy powder of Co47+5%w(WC) and the alloy powder of Ni60+5%w(WC) was respectively fused on the earlier layer by laser cladding to fabricate the Co-based and the Ni-based gradient wear-resistant coatings with about 2.4mm thickness. The microstructures analysis and properties test of the two coatings were carried out. The results showed that the wear-resistant layer thickness of Co-based is greater than that of Ni-based, the microstructure of two gradient wear-resistant coatings are similar, such as the surface layer appeared the dense amorphous crystals, the transition layer appeared the large columnar crystals, and the bottom layer appeared the flat crystals and dendrites. The microhardness of Co-based wear-resistant layer reached 713HV0.1, and that of Ni-based wear-resistant layer reached 683HV0.1, the friction coefficient of Co-based wear-resistant layer reached 0.43, both of the wear resistance increased by 300% compared with the substrate.

1. Introduction
The heat treatment of 20CrMnMo steel with carburize, boron or nitride is fabricated the products such as manufacturing camshaft, gear, pin shaft, which were required to work in the scurviness conditions such as high temperature, high pressure and rough wear [1-3]. The laser cladding could produce excellent abrasion resistance, high temperature resistance and high - density metallurgical coating [4]. The gradient wear-resistant coating was obtained by laser cladding on the surface of 20CrMnMo/20CrMnMo steel surface can greatly improve the performance compared to the heat treatment processes such as carburizing, boron and nitriding [5] [6]. The Co-based and Ni-based alloy powder could significantly improve the wear resistance of coating which was fabricated by laser cladding, and owing to the advantages of prices and properties, many scholars are greatly concerning in the field of surface strengthening. X. M. Pan [7] fabricated the Ni/Co - based alloy composite coating on the 1Cr17Mn6Ni5N stainless steel surface by laser cladding, and found that the wear resistance of Co-based coating increased by 51%, when the wear resistance of Ni-based coating increased by 25%. D. Q. Dai [8] fabricated coatings on the 1Cr12MoV steel surface with Stellie6 and Ni60 alloy powder respectively by laser cladding, and found that hardness and wear resistance of the coating with Ni60 alloy powder are better than that of Stellie6 alloy powder. W. J. Han [9] prepared the Co-based alloy coating on the surface of Ni-based super-alloy by laser cladding technique. The results showed that the
surface of Co-based coating was smooth and crack-free, and the microhardness of the coating was about matrix hardness 3 times than that of the substrate. The performance difference of the Co-based and Ni-based high thickness gradient coatings by laser cladding was seldom studied.

In this paper, the high thickness Co-based and Ni-based wear-resistant coatings were fabricated with different kinds of alloy powder successively by laser cladding, and then the microstructure and property were compared and researched.

2. Experimental details

2.1 Materials

In this study, a die cast plates of 20CrMoMn steel was used as target for laser cladding, of which the size was 50mm×30mm×5mm. Their chemical composition is as follows: 0.17-0.23wt%C, 0.17-0.37wt%Si, 0.9-1.2wt%Mn, 1.1-1.4wt%Cr, 0.2-0.3wt%Mo, 0.03wt%Ni, 0.035wt%P, 0.035wt%Si, 0.03wt%Cu, and Fe in balance.

The composite powder of St6, St12B, Co47+5 vol%(WC) and Ni60+5 vol%(WC) was used as laser cladding material. The size of powder particle ranges from 45μm to 105μm.

2.2 Experimental setup and procedure

As shown in Figure 1, laser cladding experiments were conducted on the KUKA robot system, which matched HL4006D Nd: YAG laser, the type of powder feeding device was PFL- 2A, and the method of synchronous side-injection feeding powder with argon was used. The parameters: laser power: 800W, feeding rate: 4.75g/min, coke amount: 10mm, lap rate: 30%, scanning speed: 6mm/s. Finally, the 2.4mm thicknesses of Co-based and Ni-based coatings were obtained.

2.3 Characterization

Cross-section Both of the Co-based and Ni-based gradient wear-resistant coatings were sectioned by wire-electrode cutting, mounted in bake lite, polished and etched using 5% Nital solution. The microstructure of the coating was analyzed by optical microscopy (OM). The microhardness measurement was conducted on the cross-sections of the melted zone and as-received using the Vickers Microindentor (HMT-3) with the loads of 100g applied for 10s. The tribological property was measured using a pin-on-disc wear tester (HT-1000) at room-temperature, sliding contact against the GCr15 steel ball (5 mm in diameter, 60–65HRC, and mass fraction: C:0.95%–1.1%, Si:0.15%–0.35%, Mn:0.5%, P:0.025%, Cr:1.3%–1.6%). The test was run at the constant normal load of 200N, the rotation speed and time were 200 r/min and 30min, respectively. The wear resistance was determined by measuring the mass loss and friction of the samples.
3. Results and discussion

3.1 Microstructure

As shown in Figure 2, the macro-morphology of the Co47+5%w(WC) (called as Co-based for short) and Ni60+5%w(WC) (called as Ni-based for short) gradient wear-resistant coatings. Two kinds of coatings thicknesses and the overall structures were similar, of which illustrated the macroscopic morphology of the coatings were affected by the technological parameters were greater than that of the powder types. Because the composition of Co-based powder is similar to St12B powder, that the elements diffusion level of between the wear-resisting layer and the transition layer is greater, so the wear-resisting layer thickness of Co-based was thicker than the Ni-based. Some distinct white bands were found in junction, which was attributed to the influence of the heating times and different powder between in the different melted layers.

![Figure 2 Macro-morphology of gradient wear-resistant coatings: (a) Co-based, (b) Ni-based.](image)

As shown in Figure 3(a), the crystals and the black hard phase were found in the wear-resistant layer, and the sizes of crystals were small and dense. When alloy powder was heated by laser irradiation, Co elements and most of the WC elements melt because of its high laser power. Due to the gravity, buoyancy, temperature gradient, and the role of liquid surface tension in the molten pool, the WC and Ni elements appear to spread quickly, and then form a strengthen phase. When the G/Vs [10] value of the wear-resistant layer was small, the dendritic orientation was mainly determined by the anisotropy of crystallography. Due to G value was very large, the crystals could crystallization but it was too late to grow, so the dense equiaxial crystals were formed.

As shown in Figure 3(b), the columnar crystals and a small amount of black reinforcement were discovered in the transition layer. As the decrease rate of V_S value was less than G value, G/V_S value was larger than the surface. Solidification crystallization process was close to equilibrium solidification, hence it developed well directional property and the good uniformity of columnar crystal. The occurrence of black hard phase was due to the diffusion of the WC and Ni elements in molten pool, and then a strengthen phase was formed.

As shown in Figure 3(c), the columnar crystals and some of the large dendrites were found in the bottom layer. Though G value was very small, V_S value tends to zero, so the G/V_S value was even larger, the solidification crystal orientation along the direction of heat flow form columnar crystal growth, and because of the G value was very small, and prompted some crystals to keep growing, and then the dendrites were formed.
As shown in Figure 4(a), the isometric crystals and more black-hard phase were found in the wear-resistant layer. The appearance of such isometric crystals was due to the small value of G/Vs; and when Ni based alloy powder was melted by laser beam, the diffusion degree of Ni-based powder with St12B was less than that of Co-based powder with St12B, so the dilution rate of WC was dropped off, and a lot of WC deposited near the wear-resistant layer.

As shown in Figure 4(b), the columnar crystals with a slightly larger size than the Co-based coating were found in the transition layer. The occurrence of columnar crystals was due to the decrease of the velocity of $V_S$ was smaller than that of $G$, and $G/V_S$ was larger than the surface, so the growth direction of the crystals was affected by the direction of the heat flow. The crystallization process was close to the equilibrium solidification. Because of the difference compositions of Ni-based powder and St12B powder, in the process of laser cladding, although the St12B appeared to melt, the diffusion of interlayer elements was low, and only the crystals were roughened.

As shown in Figure 4(c), the columnar crystals and some large dendrites were found in the bottom layer. Compared with Co-based coating, dendritic growth was less directional and less coarse-grained.

3.2 Microhardness
As shown in Figure 5, the surface hardness of Co-based gradient coating reached 732 HV$_{0.1}$. The analysis was based on the function of Co-based alloy and WC. However, the hardness was not increased in the place of 0.3-0.4mm, and the analysis thought that when the laser cladding conducted, there were the elements of transition layer and even bottom layer diffused to wear-resisting layer, which reduced the hardness of the place. And the surface hardness of the gradient coating which was obtained with Ni60 +5% (WC) powder by laser cladding reached 638 HV$_{0.1}$. The mutation point of microhardness emerged in place of 0.3mm in which is far from the surface, as the melting point of WC is considered to be higher than that of Ni60, that the unmelted WC was covered with the Ni60 and then a solid solution was formed.
The two kinds of powder could effectively improve the surface hardness of the gradient wear-resisting layer, and both of the gradient wear-resistant coatings had the characteristics of external hard and internal toughness.

3.3 Wear resistance
As shown in Figure 6, the average friction coefficient of substrate is 0.52, the average friction coefficient of Co-based gradient wear-resistant coating is 0.4, and the average friction coefficient of Ni-based gradient wear-resistant coating is 0.43. Because of different surface hardness of specimens causes the discrimination of the average friction coefficient, when the surface hardness was higher, the average friction coefficient was lower, and the wear resistance was better.

As shown in Figure 7, the wear amount of Co-based and Ni-based are 2mg, and then the substrate is 8mg, which increase by 300%, this demonstrates that the wear-resistant coating which is obtained with two kinds of powder by laser cladding could improve the wear resistance, because the time was shorter,
all while two different kinds of coating microhardness and friction coefficient but reflected on the same wear-resisting performance.

![Table]

| Samples condition | Wear quantity (mg) |
|-------------------|--------------------|
| Substrate         | 8 (mg)             |
| Co47+5% w(WC)     | 2 (mg)             |
| Ni60+5% w(WC)     | 2 (mg)             |

Figure 7 Wear quantity of gradient wear-resistant coatings

As shown in Figure 8 (a), the surface appears the reddish-brown oxide layer and furrows. In the friction process, the effect of high temperature and moisture in the air caused the oxidation reaction on the surface of 20CrMnMo steel to generate Fe₂O₃, the partially high Fe₂O₃ oxide came off to grind the substrate to make it appear furrows. As shown in Figure 8(b), the surface appears a large scale of flake wear bands and the white bright bands. In the friction process, the surface of GCr15 steel scraped against the wear-resistant layer as the hardness of wear-resistant layer was less than GCr15, and then the white bright bands produced. As shown in Figure 8(c), the surface appears a large scale of flake wear bands and the white bright bands, and the wear mechanism was similar to Figure 8(b).

![Images]

Figure 8 Wear morphologies of gradient wear-resistant coatings:
(a) Substrate, (b) Co-based, (c) Ni-based

4. Conclusion

The Co-based and Ni-based gradient wear-resistant coatings with about 2.4 mm thickness were prepared on the 20CrMnMo steel by laser cladding, the surface organization was densification and well-distributed, there was neither porosity nor crack. Then the metallurgical combination was found between the coating and substrate. In the microhardness test, the microhardness of Co-based and Ni-based gradient wear-resistant coating reached 713HV₀.₁ and 638HV₀.₁ respectively, and the hardness appeared continuously and slowly. In the friction and wear test, it was found that the Co-based and Ni-based gradient wear-resistant coatings could significantly improve wear resistance. In the friction process, because of the different hardness that the surface of the substrate was scratched by the abrasive parts and appeared Oxidative reaction, while both of the coatings scratched the abrasive parts.
Acknowledgements
This work was financially supported by the Natural Science Key Project of Anhui Province (No. KJ2010A329), the Natural Science Fund of Education Department of Anhui province (Grant Nos. KJ2016A745), and the Natural Science Research Project of West Anhui University (Grant Nos. WXZR2016066).

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