Wear resistance of laser cladding and plasma spray welding layer on stainless steel surface

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The effect of coatings, which are formed with laser cladding and plasma spray welding on 1Cr18Ni9Ti base metal, on wear resistance is studied, A 5-kW transverse flowing CO_2 laser is used for cladding Co base alloy powder pre-placed on the substrate. Comparing with the plasma spray coatings, the spoiled rate of products with laser clad layers was lower and the rate of finished products was higher. Their microstructure is extremely fine. They have close texture and small size grain. Their dilution resulting from the compositions of the base metal and thermal effect on base metal are less. The hardness, toughness, and strength of the laser cladding layers are higher. Wear tests show that the laser layers have higher properties of anti-friction, anti-scour and high-temperature sliding strike. The wear resistance of laser clad layers are about one time higher than that of plasma spray welding layer.

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The main surfaces of many key parts are strengthened with bead welding or spray welding to improve the resistant to wear, corrosion, and fatigue nowadays[1]. As the importance control parts of the fluid, valves were used in various industries. Many high-parameter valves often ceased to be in force prematurely because their sealing surface worked under the condition of strong corrosion, high temperature and pressure, impact, abrasion, and wear. Compared with the conventional method of plasma spray welding, we have strengthened the sealing surface of high-parameter nuclear valves and petrochemical valves with laser cladding to improve the wear resistance of the sealing surface.

The base materials of specimens and valves were austenite stainless steel. Its chemical composition (wt.-%) is 0.12 C, 1 Si, 2 Mn, 8 Ni, 17 Cr, 1 Ti, and remain Fe. The coat material of laser cladding and plasma spray welding was a Co base alloy which was metallurgically prepared into alloy powder. Its chemical composition (wt.-%) is 0.8 C, 28 Cr, 6 W, $\leq$2.5 Fe, 4 Si, 3 B, remain Co. The particle size of the powder is $15-53$ μm. Two kinds of specimens were prepared for this investigation. The block specimens were $19\times15\times10$ mm^3, the dimensions of the ring specimens were $\phi38$ mm$\times\phi28$ mm$\times10$ mm. An HGL-90 type 5-kW transverse flowing CO_2 laser was used. The alloy powder, mixed with 2132 phenolic resin powder and alcohol, was pre-placed on the surface of the specimen, then the pre-placed layer and specimen were dried with stove. The thickness of the pre-placed layer was about 3 mm. Multi-scanning was conducted for block specimens, and the width of each overlapping region was 50% of the diameter of beam spot. The single-pass scanning was conducted for ring specimen. The parameters of cladding technology were laser power $P = 3.0-3.4$ kW, scanning speed $V = 8-12$ mm/s, and beam spot size $\Phi = 5$ mm. A domestic DP-500 type plasmatron with LFH type gun was used for plasma spray welding with powder supply. The thickness of spray welding layer was about 3 mm.

By using SX-40 type scanning electro-microscopes, we observed and examined the appearance of microstructure of welding layer; using a large MEF3 high-precision metallographic microscope, the microstructure and microhardness were examined; the composition of micro-region was examined using an E-9100 spectrometer; the phase structure was examined using an X-ray diffractometer.

By using ring-type mono-directional high-speed-sliding wear tester, we examined the wear resistance of the layers. The specimens (prepared as $19\times15\times10$ mm^3) blocks after plasma spray welding and laser cladding (six blocks for each kind) were abraded with the test specimens (GCr15, $\phi50$ mm). Each specimen was abraded, sliding in a mono-direction, the sum sequence was 10000 m, the rotating speed of the tester was 560 r/min, using 20# machinery oil as lubricant, the loads of the test were 200 and 300 N. The wearing value was carried out with weight by taking the mean value.

The resistance to high-temperature struck was examined on the abrasion tester of high-temperature strike. The specimen was prepared as $\phi30$ mm$\times\phi30$ mm$\times10$ mm ring with the surface polished and opposite strike hammer was prepared with the middle carbon steel, with the same size above. The specimens were high-frequency heated to $450-800$ °C. The specimen lubricated with machinery oil after each repeating. The repeating time of strike was 4 s, and the action time was 0.3 s. The strike force was 1.8×10^3 N, and the stamping stroke was 20 mm. The sliding speed of abrasion was 1.33 m/min. Before and after the test, the weight of the specimen was examined with the balance of precision 10^{-4} g. The abraded surface appearance was observed and filmed with a microscope.

The test result shows that the district of microstructure of laser cladding and plasma spray welded specimens could be divided into three parts: welding region, heat affected zone (HAZ), and substrate, as shown in Figs. 1 and 2. The microstructure of laser clad layer was fine and uniform: the micro-crystal particle size was determined to be $11-12$th grade, according to the standard YB27-77; the width of HAZ was $10-45$ μm. The microstructure of plasma spray welding layer was some what larger: the micro-crystal particle size was

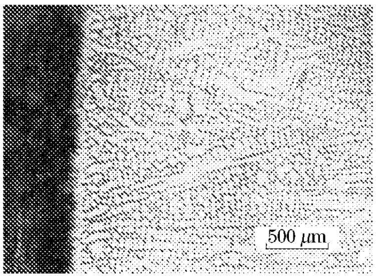

Fig. 1. Laser cladding layer and its combination region.

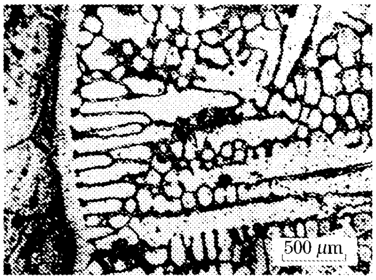

Fig. 2. Plasma spray welding layer and its combination region.

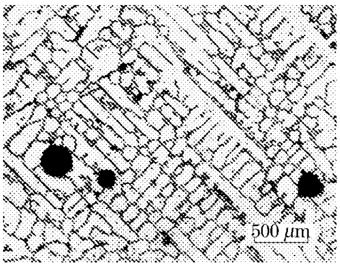

Fig. 3. Gas holes in the upper part of plasma-spray welding layer.

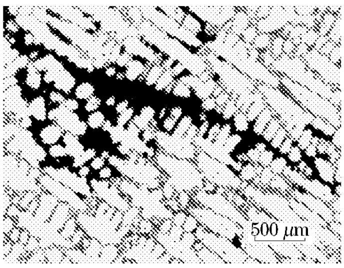

Fig. 4. Impurity in arborescent crystal of plasma welding layer.

9 – 10th grade; the width of HAZ was 120 – 160 μm. The rate of finished products without flaw of laser cladding reached to >95%, according to the quality of layer of 125 specimens which were dissected and analyzed. Cracks, gas holes, and impurities appeared in plasma spray welding layer, as shown in Figs. 3 and 4.

The average micro-hardness of laser clad layer was 740 – 860 HV but that of plasma-spray welding layer was 520 – 560 HV.

The average dilution rate of the three elements Ti, Fe, and Ni by substrate reached to 0.075, 8.58, and 1.385 (wt.-%) in laser clad layer, respectively, howewer in plasma-spray welding layer, the dilution rate of the above three elements reached to 0.83, 16.19, and 2.06 (wt.-%), respectively. For the three elements Co, Cr, and W in the layer defusing into substrate and HAZ, the loss rate of plasma spray welding layer was more serious than that of laser cladding layer, as shown in Figs. 5 and 6. The phase analysis showed various multi-elements co-crystalized chemical compounds, such as boride, chrome-x, and carbonide, had formed in both kinds of welding layers. And laser cladding layer had more complex phases.

The resistance to the wear of cladding and the welded layers was shown in Table 1. The resistance to the abrasion of the sliding strike at high temperature was shown in Table 2, the average abrasion value after 3000 times were obtained under the testing condition above mentioned, and the weight of the two kinds specimens was weighed after each 500 times.

The test showed that the abrasion value of laser cladding layer was one times less than that of the plasma spray welding layer after each recycle strike. The loss weights of these two kinds of specimens were 1.21 and 2.53 mg after 3000 strikes, respectively. The surface appearance of the tested specimens was shown in Figs. 7 and 8.

The test and application results showed that the laser cladding sealing surface had better performance of resistance to wear and longer work time than the surface treated with bead welding and spray welding.

From the above results, we have the following discussions:

(1) Compared with plasma spray welding layer, laser cladding layer was more fine and uniform in microstructure and more narrow in the width of HAZ. The reason is that it took a short time for scanning laser beam to heat and melt the coat and surface of substrate, while the over-cold degree was high during the rapid cooling-off,

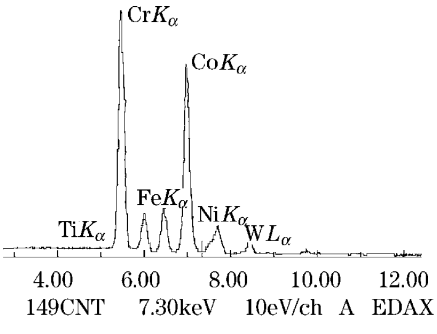

Fig. 5. EDAX energy spectrum analysis picture of laser cladding coat.

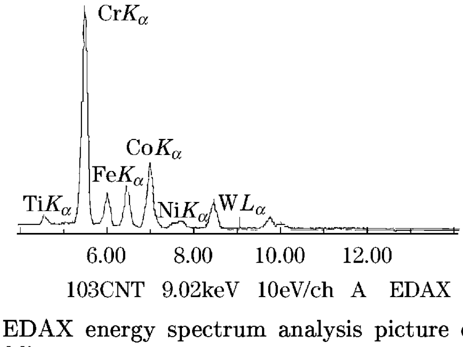

Fig. 6. EDAX energy spectrum analysis picture of plasma spray welding coat.

Table 1. Wear Examination Result

Test Load (N)	Specimen	Width of Abrasion Trace (mm)	Average Wearing Value (mg)
200	Laser Cladding	0.5	0.17
	Plasma Spray Welding	0.56	0.1775
300	Laser Cladding	0.574	0.22
	Plasma Spray Welding	1.1	0.48

Table 2. Examination Result of High Temperature Sliding Strike Abrasion under Temperature of 500°C

Recycle Strike Times	Average Abrasion Value (mg)	
	Laser Cladding	Plasma Spray Welding
500	0.23	0.62
1000	0.45	0.95
1500	0.72	1.47
2000	0.93	1.92
2500	1.08	2.21
3000	1.21	2.53

Fig. 7. Surface appearance of the laser cladding layer after 3000 times abrasion (20×).

Fig. 8. Surface appearance of the plasma spray welding layer after 3000 times abrasion (20×).

alloy elements in melting-pool could rapidly form various chemical compounds to increase the number of non-spontaneous host crystal and raise the rate of the host crystal forming. Thus, the fine and uniform microstructure could be obtained[3]. The fine structure could improve the combining force between the interface of crystalline grains and improve the strength, toughness, and the resistance to corrosion, wear, and abrasion.

(2) Because of the convective mass transferring in the melting pool formed by laser beam, the melting pool could be mixed enough and the gas and impurities in the pool could be separated out[2], which formed a fine layer and ensured the quality of the layer. But during the plasma spray welding, the welding powder was melted and accelerated by plasmas, then the melted powder was sprayed onto the surface of the substrate through the atmosphere, the spray-welding layer was mixed with gas. There always were gas holes and impurities among the large arborescent crystal in the upper part of the layer and the interface between layer and substrate, as shown in Figs. 3 and 4.

(3) The dilution rate of the laser cladding layer by the substrate was lower than that of the plasma spray welding layer. In addition, the diffusivity of effective elements designed and compounded formerly in the laser cladding layer was lower too. It is known that the change of the effective components in the layer would cause the change of microstructure and hardness, which led to the loss of the advantages of the original powder alloy. The preservation of the effective elements in the laser cladding layer, with the special action of the laser and the larger over-cold degree, made the layer have higher hardness, strength, and toughness[4]. Undoubtedly, all these could have a good effect on the resistance of the layer to wear.

(4) As shown in Figs. 7 and 8, the plasma spray welding layer of the tested specimens had more and larger spot-like stripping pit, and there were more and wider ploughing trenches. There was little adherent, thin scratches, and little deformation on both layers. The abrasion mechanism was synthetic action of adherent abrasion, abrasive grain abrasion, and fatigue abrasion.

From the result and analysis, the following conclusions can be reached:

(1) Comparing the technology of laser cladding with the conventional technology of plasma spray welding, as high power laser scanning, the rapid melting, and solidifications, the melting pool of coat material formed on the surface of the laser cladding layer which had fine microstructure, the gas holes were removed and the impurities were cleaved up, and solid solution combination was formed between the layer and the base. The dilution and diffusion rate of laser cladding layer components were lower, more chemical compounds were formed, the hardness, strength, and toughness was improved, and the quality of the layer was improved remarkably.

(2) The resistance to wear, abrasion, and high temperature sliding strike of laser cladding layer was better than that of the plasma spray welding layer. The abrasiveness was double improved.

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