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Laser Surface Cladding of Plastic-Molded Steel 718H by CoCrMo Alloy

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With the purpose of enhancing the surface properties of plastic-molded steel 718H, in this study, a wear-resistant CoMoCr alloy cladding layer was obtained using laser surface cladding technology. Laser surface cladding was carried out by melting the CoMoCr alloy powder (particle size 15-45 μm) supplied through a pneumatically driven powder delivery system with a 5-kW continuous wave (CW) CO_2 laser with the wavelength 10.6 μm. The microstructure, chemical composition, and wear resistance of the cladding coating were revealed by optical microscope (OM), scanning electron microscope(SEM), energy-dispersive x-ray analysis (EDX) and sliding wear machine. The microstructure of the cladding layer was found to consist of three zones: a top cladding zone mainly comprising CoMoCr; an internal zone comprising a cellular microstructure; and the interface zone which was a mixture of CoMoCr and 718H substrate. Compared to the 718H steel substrate with a microhardness of 345 Hv, the microhardness of the cladding coating showed a significant improvement, with its value increasing to 794 Hv. The wear results confirmed that the wear resistance was enhanced after laser cladding CoMoCr alloy powder.

Keywords CoMoCr alloy, laser cladding, wear resistance, 718H plastic-molded steel

1. Introduction

While many surface modification technologies can be employed enhance the corrosion and wear resistance of molded steel, laser cladding is found to be an attractive alternative to conventional techniques due to its excellent metallurgical bonding to the base material, resulting in uniform composition and coating thickness. Furthermore, the advantages of laser cladding include very low dilution and low-heat input to the component. Laser cladding of new components gives them improved surfaces with high resistance against wear, corrosion, and high temperatures. Therefore, laser cladding has been successfully employed to repair high-value metal parts subjected to aggressive conditions such as wear and corrosion and used, for example, in blades, valve seats, and molded steels (Ref 1-8).

Among the molded steels, plastic-molded steel is vital for the plastic processing industry. For the most ideal tooling and production economy, common demands on characteristics of tool materials for plastic-molding tools are high surface finish after polishing, corrosion resistance, wear resistance, high thermal conductivity, good machinability, and good surface finish after EDM or photo etching. Wear is a commonly encountered problem in plastic molds, especially in high productivity molds. Laser cladding is highly recommended for repairing and strengthening the molds, in view of its reliability and relatively low cost. Further improvement in wear resistance may be achieved by laser surface cladding via homogenization and refinement of the microstructure, and/or the formation of new alloys on the surface.

Cobalt base superalloys, because of their desirable combination of high rupture strength, wear resistance, and excellent hot corrosion resistance at high temperatures, have been widely used in industry for applications, such as vanes and combustor sections in many military and commercial aircraft turbine engines (Ref 3, 9-12).

In the present study, an attempt has been made to develop a wear-resistant CoMoCr alloy coating layer on the surface of 718H plastic-molded steel substrate. Detailed characterization of the clad layer was performed to reveal the microstructure and the chemical composition. Also, the performance of the wear resistance of the coating layer was evaluated and compared with the as-received plastic-molded 718H steel substrate.

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2. Experimental Procedure

The substrate was the plastic-molded steel 718H. The chemical composition of the 718H steel is 0.32-0.40 C, 0.20-0.80 Si, 1-1.50 Mn, 1.70-2 Cr, 0.25-0.4 Mo, 0.85-1.15 Ni, and Fe the balance. The plastic-molded steel 718H was subjected to the laser cladding using a high 5-kW continuous wave (CW) CO_2 laser (Qingdao Zhongfa Laser Technique Co., LTD). The powder was delivered straight to the melting pool. The chemical composition of the CoMoCr powder is 0.07 C, 20 Cr; 4.1 Si; 1.3 Fe; 30 Mo; and 1.5 Ni; with Co being the balance (all in wt.%). The parameters of the process were as follows: laser input 2-2.5 kW, scan rate 0.21 m/min, powder feeding rate 4 g/min, track thickness 1-1.5 mm, track width 3-3.5 mm. The subsequent laser tracks were overlapped by 25-40%.

After laser cladding, laser cladding 718H samples were mechanically cross sectioned, polished, and chemically etched for metallographic study. The microstructures of the clad layer (both the top surface and the cross section) were characterized by optical microscope (OM) and scanning electron microscopy (SEM). A detailed examination of the compositions present within the coating layer was carried out with energy dispersive x-ray (EDX) analysis. The hardness of the coating layer and the substrate were measured using a microhardness testing system. The data reported here are the statistic averages of at least three measurements. The applied load was 0.2 kg, with a holding time of 15 s.

Finally, the wear behaviour of the surface coating was compared to that of the as-received 718H steel substrate by abrasive wear testing using a dry sand/rubber wheel abrasion test equipment (TR-50: CETR, Inc.). The dry abrasion wear testing was performed using a rubber-wheel abrasion test equipment, which is a modified version of the ASTM G65 standard. In the dry abrasion wear test, the steel block with a coated surface was pressed against a rubber-lined wheel at a normal load of 30 N. The test time is 1 h, which is equal to a total wear length of approx. 6 km. The abrasive material used was quartz sand with the particle size of 0.1-0.3 μm. The particles are bulky and sharp in their shape, as the sand was obtained by crushing. After the test, the surface wear groove was revealed by SEM technique.

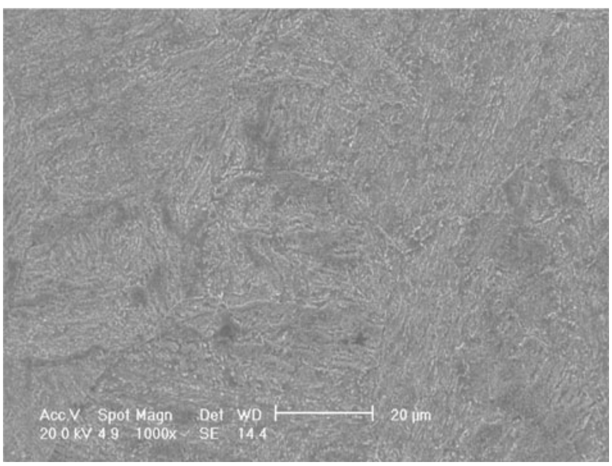

Fig. 1 Microstructure of the as-received 718H substrate

3. Results and Discussion

Figure 1 shows the microstructure of the plastic-molded 718H steel. The typical microstructure of 718H steel is uniform, pearlite sorbite, and light acicular bainitic ferrite.

Figure 2(a) shows a cross section of the CoMoCr alloy coatings. The layers, with an average thickness of about 0.6 mm, present a uniform appearance, and lack of adherence or the presence of defects is avoided. Figure 2(b) shows the interface between the coating and the substrate. A clear fusion line can be observed. The coating is metallurgically bonded to the substrate.

Quantitative analyses of chemical compositions in the cladding zone and in the interface were carried out using EDX at three different spots (the spots are shown in Fig. 2b). The chemical composition of the coating layer near the interface is shown in Table 1. The results show the average composition in the interface as 3.89% Cr, 71.09% Fe, 16.90%

Table 1 EDX results obtained from Fig. 2(b)

	Point		
Element	**1, wt.%**	**2, wt.%**	**3, wt.%**
Si K	0	2.11	1.84
Cr K	3.89	7.02	6.23
Fe K	71.09	26.78	27.85
Co K	16.90	41.47	42.29
Mo L	8.12	22.63	21.80

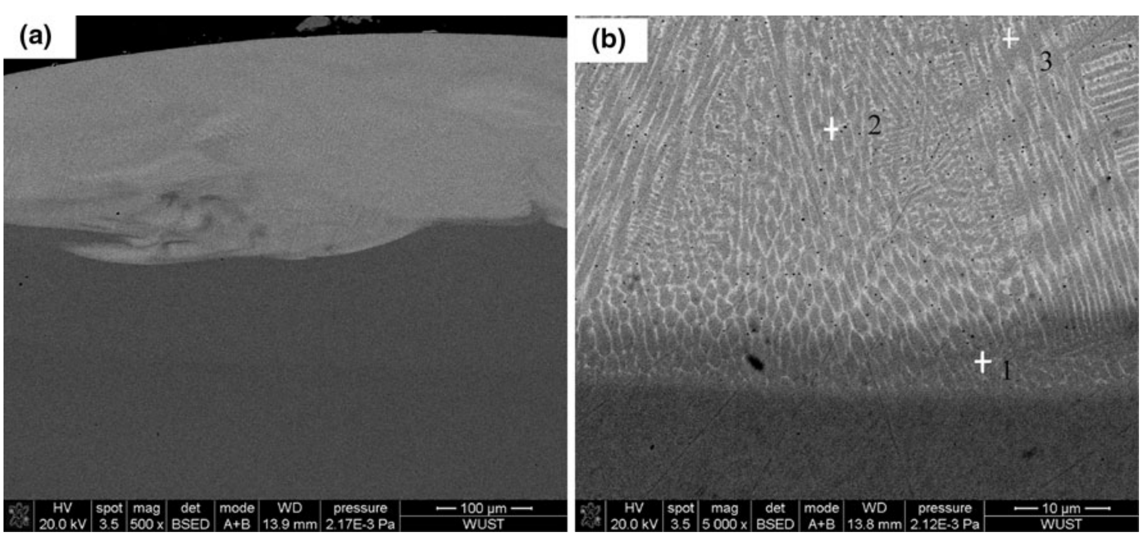

Fig. 2 (a) Transverse cross-sectional microstructures of the specimen cladded with one layer of powder; (b) interface between the coating and the substrate

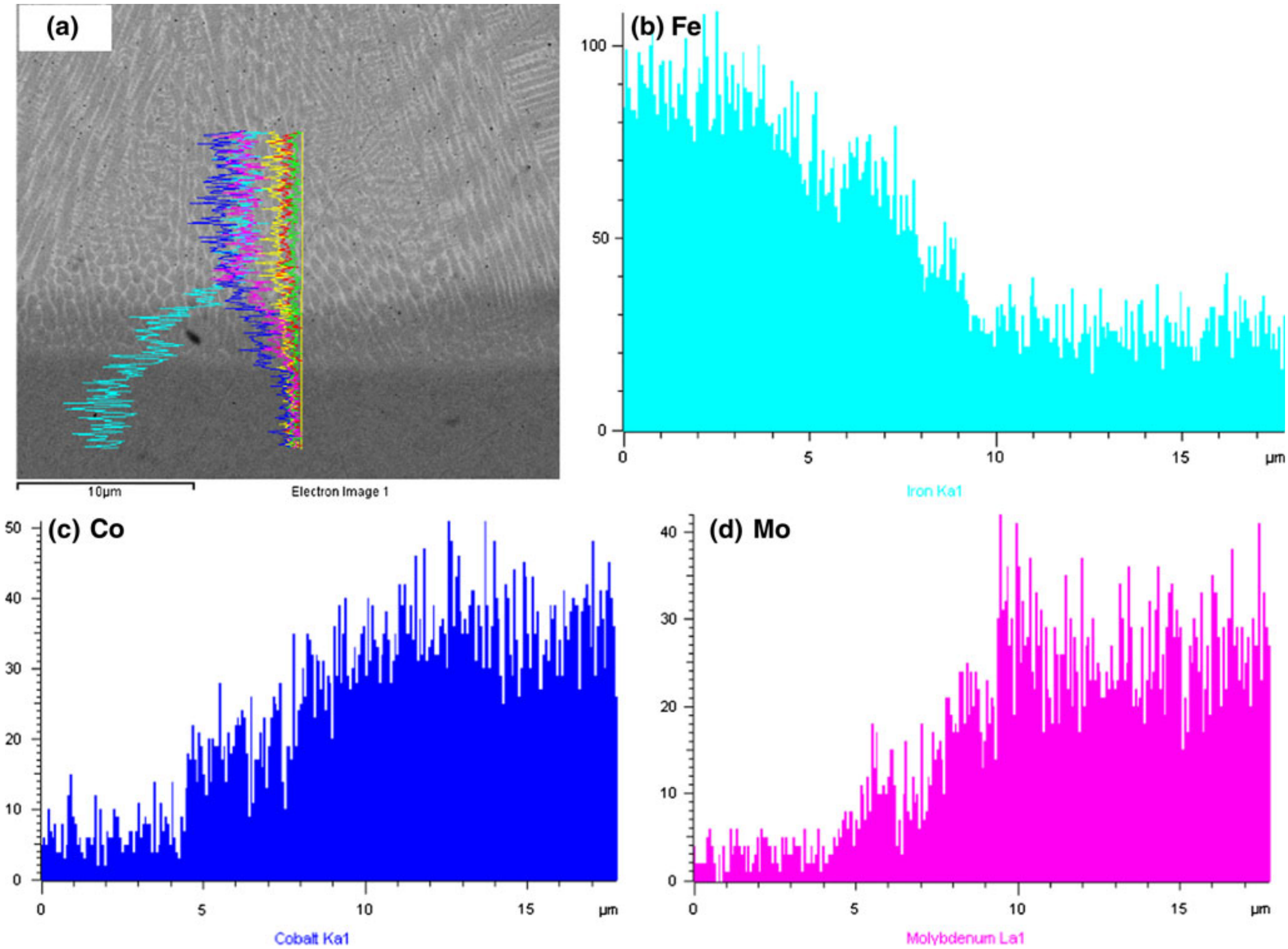

Fig. 3 (a) Line-scanning analysis for element Fe, Co, Mo diffusion near interface; line-scanning analysis for elements: (b) Fe, (c) Co, and (d) Mo

Co, and 8.12% Mo (wt.%); the average composition in white crystal as 2.11% Si, 7.02% Cr, 26.78% Fe, 41.47% Co, and 22.63% Mo (wt.%). The pot 3 has the average composition 1.84% Si, 6.23% Cr, 27.85% Fe, 42.29% Co, and 21.80% Mo (wt.%). The composition is similar to the composition to the initial powder. This indicates that the cladding process has been carried out with appropriate parameters which allows for the degree of dilution being appreciably controlled and avoiding major changes being induced in the alloy's initial chemical composition.

The distribution of elements Fe, Co, and Mo near coating/substrate interface was investigated by EDX, and the results are illustrated in Fig. 3. From the profiles, it is observed that the gradients of Co and Mo are much larger than those of the substrate. Significant Fe could be found in the substrate.

The scanning electron microscopy (SEM) analysis (Fig. 4) allows distinguishing of several regions in the microstructure of the cladding layer: the zone near the interface, Fig. 4(a-a1); the internal zone of the cladding, Fig. 4(b-b1); and the top surface cladding, Fig. 4(c-c1). Moreover, the higher magnification of the SEM enables us to observe more clearly the existence of a metallurgical bond between the clad and the substrate (Fig. 4a-a1). At the interface, a region of planar crystallization can be seen, with a thickness between 50 and 60 µm. This region is formed because the substrate at the interface acts as a heat sink, where the temperature gradient (G) is fairly high and the solidification velocity (V) is very slow. With a sufficiently high G/V ratio, planar crystallization is obtained (Ref 13, 14). Immediately above this region, a dendrite crystallization structure is observed, growth direction of which is perpendicular to the interface. Details of this dendrite structure are seen in the micrograph in Fig. 3(c). This zone is followed by a fine dendritic microstructure, situated in the central area of the laser track, which grows in the direction of the heat flow and turns appreciably finer from the interface to the top surface (Fig. 3c). This is due to the continuously decreasing value of G and the progressively increasing value of V.

The variations of microhardness along the depth of the cladding coatings and the 718H substrate are in Fig. 5. The hardness was relatively constant throughout the cladding coatings, showing a decrease both at the interface and at the 718H substrate. Throughout, the cladding coatings had a much higher microhardness than the substrate did, which may be mainly attributed to the formation of carbide and martensite hard phases in the cladding layers, as well as the solid solution strengthening in the supersaturated Fe, Co solid solution. In addition, the hardness of the coating also increased because of the fine microstructure introduced by laser rapid solidification

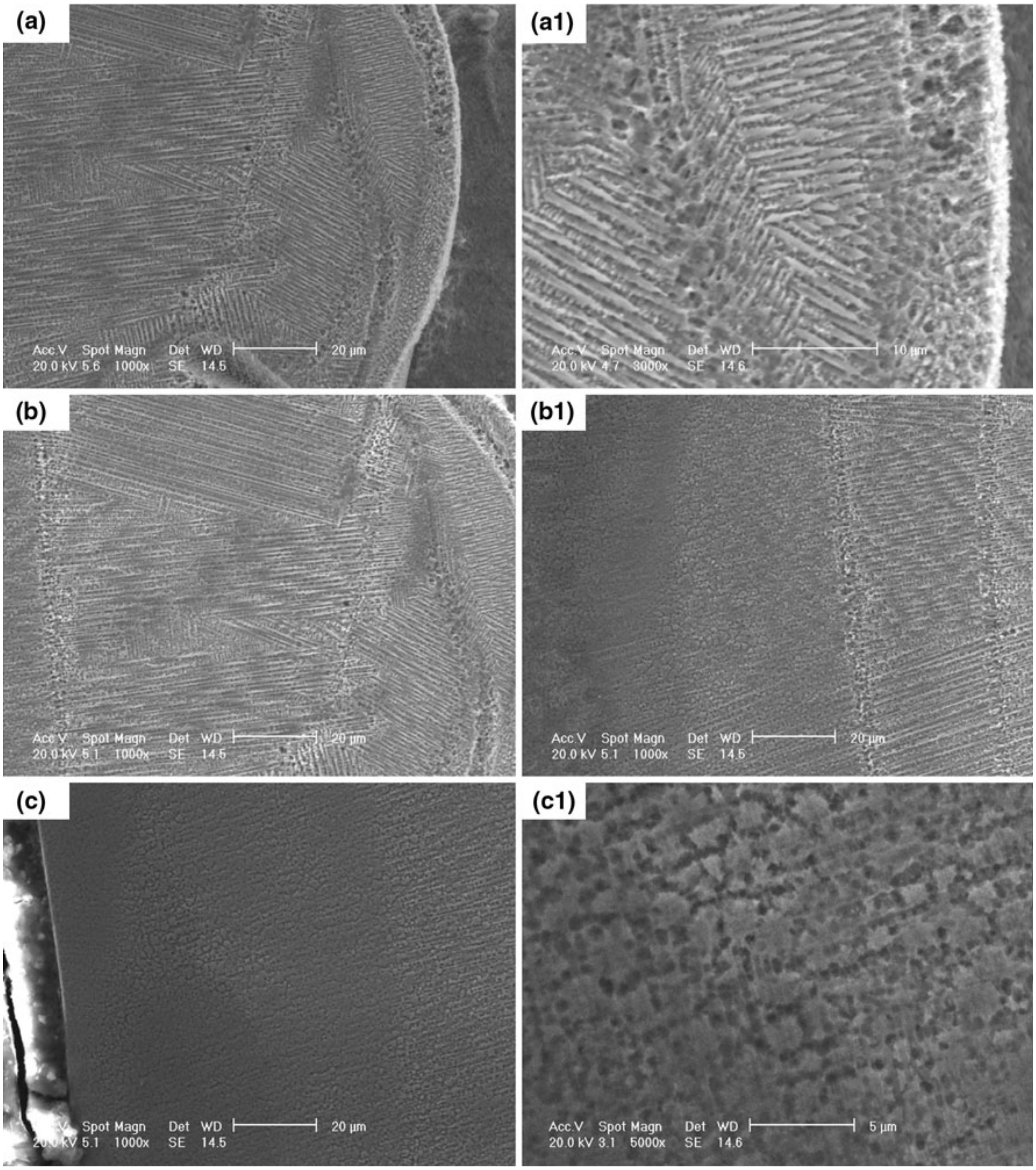

Fig. 4 Typical solidification structure observed: (a-a1) near the interface with the base metal; (b-b1) at the internal surface; and (c-c1) top surface coating

(RS) processing. The average value of the microhardness in the cladding coating was 789 Hv which was approx. 2.3 times of that of the 718H substrate (345 Hv).

To investigate the wear mechanism of materials, the morphologies of wear surfaces were observed with SEM. The results are shown in Fig. 6. The wear scars of both the substrate and the coating layer after block-on-wheel are shown in Fig. 6. The grooves and ploughing marks shown in Fig. 5(a) indicate that ploughing occurred on the CoMoCr alloy coating. Some pits were left on the worn surface, probably because of the pullout of the relatively smaller carbides. The coarse eutectic net, which was interlocked in the matrix, showed good resistance to ploughing and could be seen intact even after the tests. Ploughing dominated the volume loss of the coating layer, and caused considerable plastic deformation. The grooves shown in Fig. 6(b) were wide and deep, and ran through the whole length of the wear scar. Therefore, the 718H substrate shows lower wear resistance when compared with the coating layer. Because the hardness of the laser cladding layer is higher than those of the substrate, under the same wear conditions, the surface grooves of the cladding coating are smoother and shallower than those of the substrate. This indicates that the cladding layer is more wear resistant than the substrate.

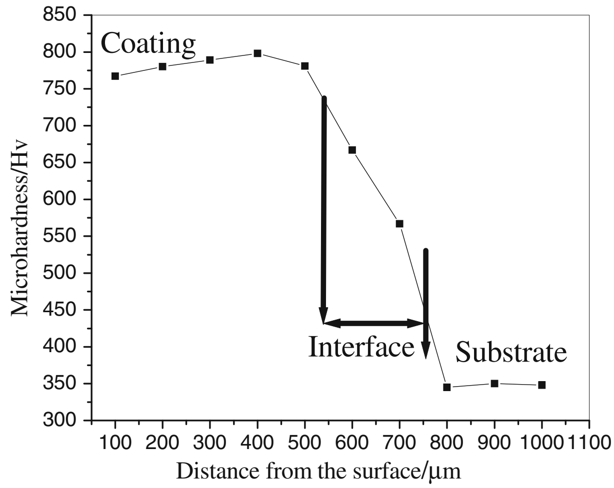

Fig. 5 Microhardness distribution along the depth of the cladding coatings on 718H alloy

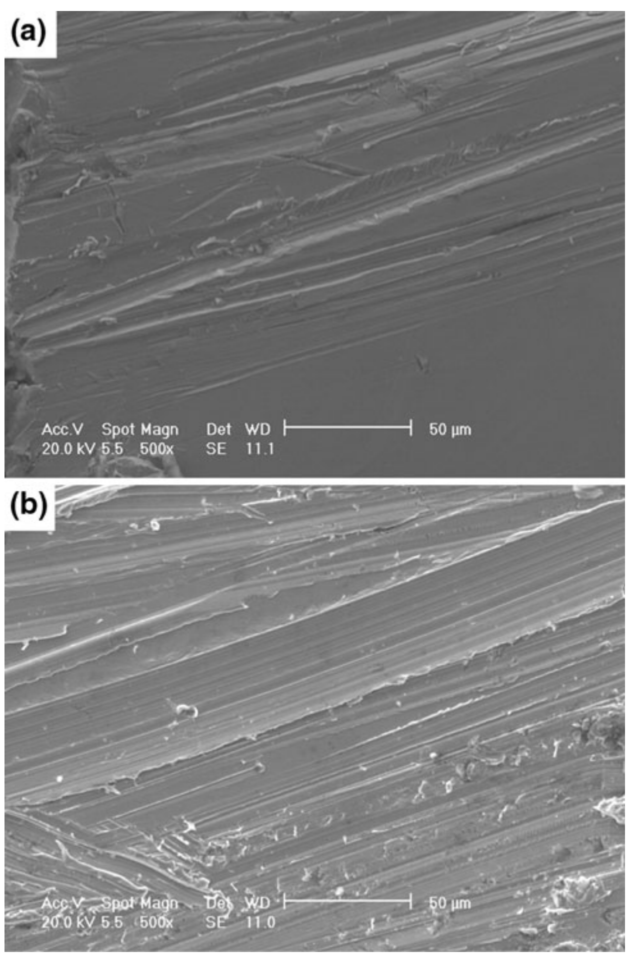

Fig. 6 The wear scars after the sliding wear tests of (a) cladding layer; and (b) 718H substrate

4. Conclusions

Laser surface cladding is suitable for plastic-molded 718H steel reparation. It has been demonstrated that homogeneous and continuous coatings, free of defects and with perfect adherence, can be obtained. Surface analysis showed a similar composition to the initial powders, indicating that the cladding process was carried out with the appropriate parameters which minimize the dilution from the base steel.

The microstructure of the CoMoCr alloy was formed by a cellular-dendritic zone composed of fine dendrites. The CoMoCr alloy cladding layer showed greater wear resistance than the untreated 718H substrate because of its dense network of carbides which effectively support the load applied during the test.

Acknowledgments

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