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Wear and corrosion resistance of laser remelted and plasma sprayed Ni and Cr coatings on copper①

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Abstract: Nickel and chromium coatings were produced on the copper sheet using plasma spraying and laser remelting. The sliding wear test was achieved on a block-on-ring tester and the corrosion test was carried out in an acidic atmosphere. The corrosive behaviors of both coatings and original copper samples were investigated by using an impedance comparison method. The experimental results show that the nickel and chromium coatings display better wear resistance and corrosion resistance relative to the original pure copper sample. The wear resistance of the coatings is 8 - 12 times as large as original samples, and the wear resistance of laser remelted samples is better than that of plasma sprayed ones. The corrosion resistance of laser remelted nickel and chromium samples is better than that of plasma sprayed samples respectively. The corrosion rate of chromium coatings is less than that of nickel coatings, and the laser remelted Cr coating exhibits the least corrosion rate.

Key words: corrosion; wear; laser remelting; plasma spraying
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1 INTRODUCTION

Copper and its alloys have been widely used as electrical contact materials because of their good conductivity. However, some disadvantages exist for copper, such as poor wear resistance and corrosion resistance. In order to enhance the mechanical strength and wear resistance of copper, some elements, such as Cr, Ni, Zr, Nb, were alloyed[1, 2]. However, the establishment of high strength and high hardness is dependent on sacrificing conductivity. If the alloy coating forms on the surface of copper, it is possible that the loss of the conductivity can be reduced to the smallest when the wear resistance is improved.

Many electrical contact problems are caused by surface contamination, especially the oxidation of contact metals which causes the degradation of electrical conductance, resulting in basbar joints heating under normal operating condition[3, 4]. Coating of electrical contact materials with different metals is one of the most common commercial practices used to prevent ambient corrosion and to improve the stability of the connection[5]. Cr and Ni coatings have been used to prevent oxidation of the superconductor joints at high current[6]. The plasma sprayed and laser remelted coatings are usually used to improve the mechanical and chemical behavior of metallic materials surface[7, 8]. Laser surface treatment has been successfully applied to improve the wear resistance and corrosion resistance of ferrous alloys[9, 10], aluminum alloys[11, 12] and other nonferrous alloys[13-15]. However, laser cladding of copper is quite scarce because of its very high reflectivity to light wave of CO_2 laser.

Usually, atmospheric corrosion test is based on surface observation method. This method is subjective in nature, and so an objective approach is proposed. The proposed method is based on the principle that if the sample surfaces are corroded and produce corrosion deposit on the samples, their contact resistance will increase. Hence, if joining two corroded samples together, and then measuring the contact resistance of joint, the variation of contact resistance will denote their corrosion degree.

The present study concerns with the cladding of Cr and Ni on the copper samples using a CO_2 laser. The microstructure, wear resistance and corrosion resistance of the cladding are investigated.

2 EXPERIMENTAL

The substrate material was pure copper plate (TU2). The samples were machined to the rectangular plates of 150 mm × 25 mm × 3 mm. After sand blasting, the samples were sprayed using a METCO 3MB plasma spray installation. The sprayed powders were Ni and Cr powder and the sprayed area was 25 mm × 25 mm. The thickness of the chromium and nickel coatings was 250 μm. Laser remelting was

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conducted using a 5 kW continuous wave CO_2 laser. During the processing of laser scanning, the laser power was 3.5 kW and the laser beam diameter was 1.5 mm. The samples were scanned at a speed of 10 mm/s with overlap interval of 0.5 mm. Helium gas was used to prevent oxidation of the samples, the pressure of which was 0.02 MPa.

The designation of samples resulted from different treatment conditions were designated as shown in Table 1.

Table 1 Designation of samples under different treatment condition

Sample designation	Treatment condition
P-Ni	Plasma sprayed Ni coating
L-Ni	Laser remelted Ni coating
P-Cr	Plasma sprayed Cr coating
L-Cr	Laser remelted Cr coating
Origin	Original copper

The sliding wear test was carried out using a block-on-ring apparatus (as shown in Fig. 1) under the condition of oil lubrication. The upper sample was a block with the laser-melted layer that was used as the worn face. It was machined to sizes of 12 mm in length, 3 mm in width and 6 mm in height. The lower sample was a ring made of low carbon steel containing 0.2% C. It was 40 mm in outer diameter and 10 mm in width, with a surface roughness of 0.8 μm. The lubricant was $10^{\#}$ engine oil and it was dropped at the rate of one drop per 15 s. A normal load of 100 N was used. The rotational speed of the ring was 200 r/min and the total wear distance was 5 000 m. Before the test, the samples were polished by sand paper to surface roughness of 1.6 μm. The mass loss of the block was measured in an analytical balance with 0.000 1 g precision. The ratio of mass loss of samples to that of original copper was used as relative wear resistance.

The atmospheric corrosion test was carried out in a closed chamber. The corrosion medium was 5% HNO_3 aqueous solution, which was laid at the bottom of the chamber and was refreshed every two days. The chamber temperature was maintained at 35 ℃ using a 100 W lamp, and the relative humidity was 96%. The samples were suspended above the HNO_3 solution. The corrosion area of samples was 25 mm × 25 mm. The other region of the samples was protected by plastic. Fig. 2 shows a sketch of the corrosion test set-up.

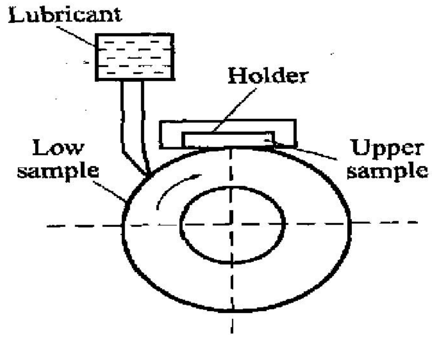

Fig. 1 Schematic illustration of block-on-ring apparatus

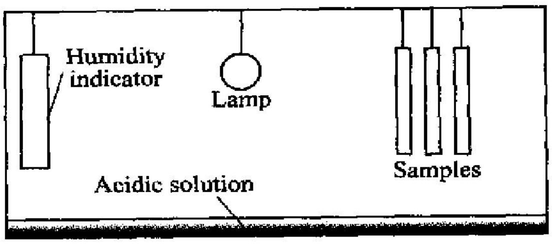

Fig. 2 Sketch of corrosion test set-up

3 RESULTS AND DISCUSSION

3.1 Microstructure of plasma sprayed and laser remelted coatings

Fig. 3 shows the SEM images of the cross-section of plasma sprayed and laser remelted Cr coatings. From these two images, it can be seen that the plasma sprayed coatings do not join the copper substrate very well, and there are some flake cracks in the coatings. After laser remelting, the coating joins the substrate pretty well and the defects in the coatings are insignificant. Fig. 4 shows the XRD patterns of the plasma sprayed and laser remelted Cr coatings. It can be seen that the structures of plasma sprayed coating and laser remelted coating are basically the same, that is, they are all single phase Cr. The SEM images and X-ray analysis of the plasma sprayed and laser remelted Ni coating are similar to that of Cr coating.

Fig. 5 shows the hardness distribution of different coating samples. From Fig. 5, it can be seen that the hardness of plasma sprayed Cr coating is the highest. The average hardness of the coatings is up to HV 195, while the average hardness of the laser remelted Cr coatings is HV 186. The hardness of the laser remelted and plasma sprayed Cr coatings increases slightly in the sub-surface layer. This phenomenon may be caused by the fast cooling of substrate. The plasma sprayed and laser remelted Ni coatings display lower hardness. The hardness of laser remelted coating is HV156 and that of plasma sprayed coating is HV140. However, this hardness is twice as high as that of the original sample.

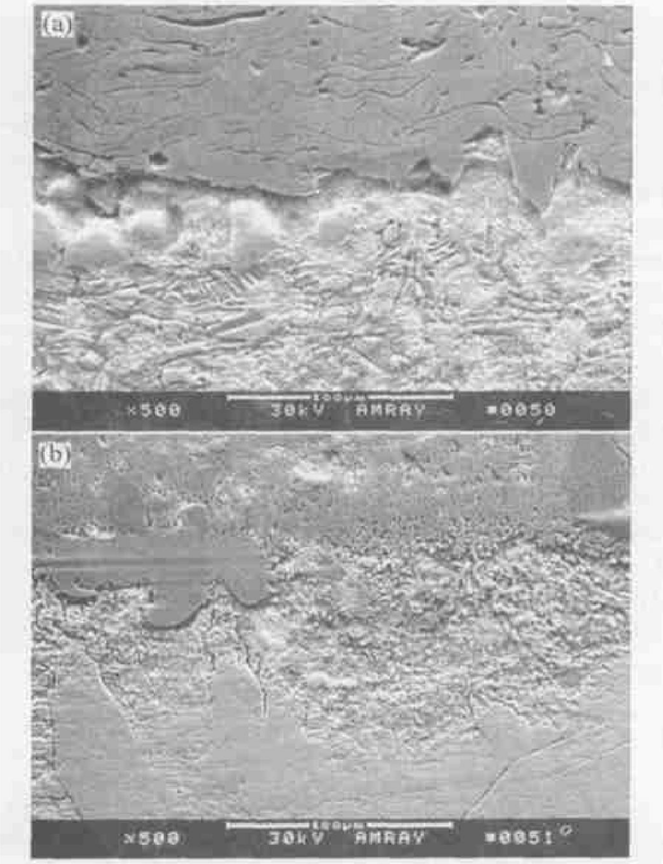

Fig. 3 SEM images of cross-section of plasma sprayed(a) and laser remelted(b) Cr coatings

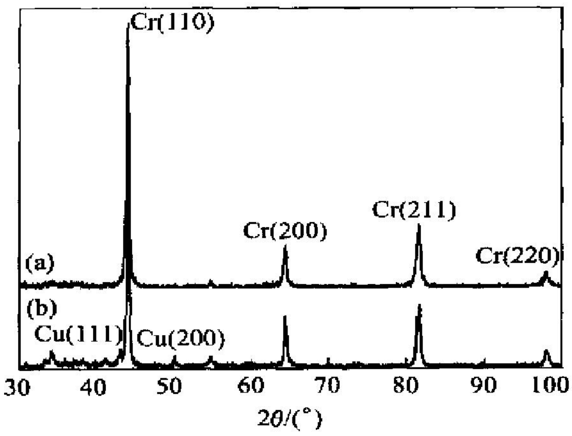

Fig. 4 XRD patterns of plasma sprayed Cr coating(a) and laser remelted coating(b)

3.2 Wear resistance of plasma sprayed and laser melted coatings

Fig. 6 shows the relative wear resistance of plasma sprayed and laser remelted coatings. Form this figure, it can be seen that the plasma sprayed and laser remelted Cr and Ni coatings all have very high wear resistance. The wear resistance is 8 ~ 10 times as high as that of copper.

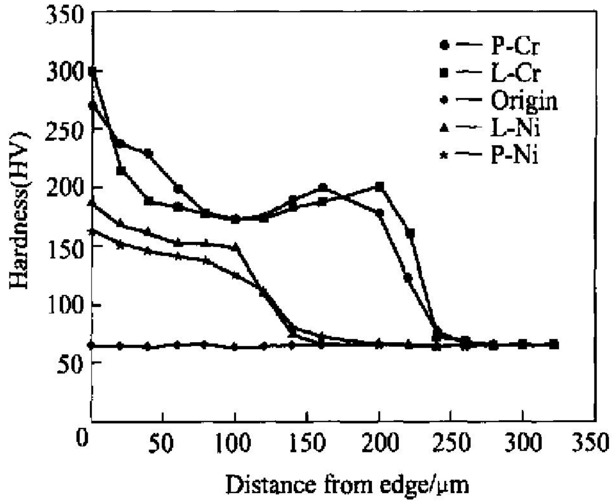

Fig. 5 Hardness distribution of different coating samples

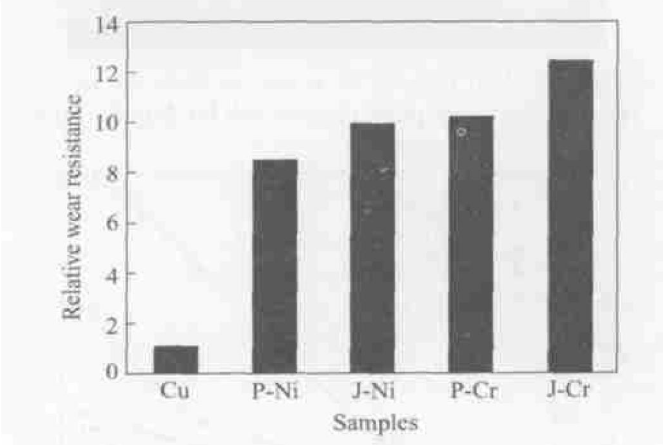

Fig. 6 Relative wear resistance of plasma sprayed and laser remelted coatings

The wear resistance of the Cr coatings is higher than that of Ni coatings, and the wear resistance of the laser remelted samples is higher than that of the plasma sprayed samples. Fig. 7 shows the images of worn surface of laser remelted and plasma sprayed Ni coatings. It is seen that the worn surface is quite compact, and the wear process of the laser remelted coating is dominated by cutting mechanism. However, although the worn surface of the plasma sprayed coating shows some cutting trace, a lot of holes of coating display on the worn surface. The worn surfaces of laser remelted and plasma sprayed Cr coatings are similar to those of laser melted and plasma sprayed Ni coatings.

3.3 Corrosion resistance of plasma sprayed and laser remelted coatings

Fig. 8 shows the variation of the contact resistance of different samples with various surface treatments shown in Table 1, with corrosion time, for a constant interfacial force of 4 kN. From these curves, it can be seen that the contact resistances of all the

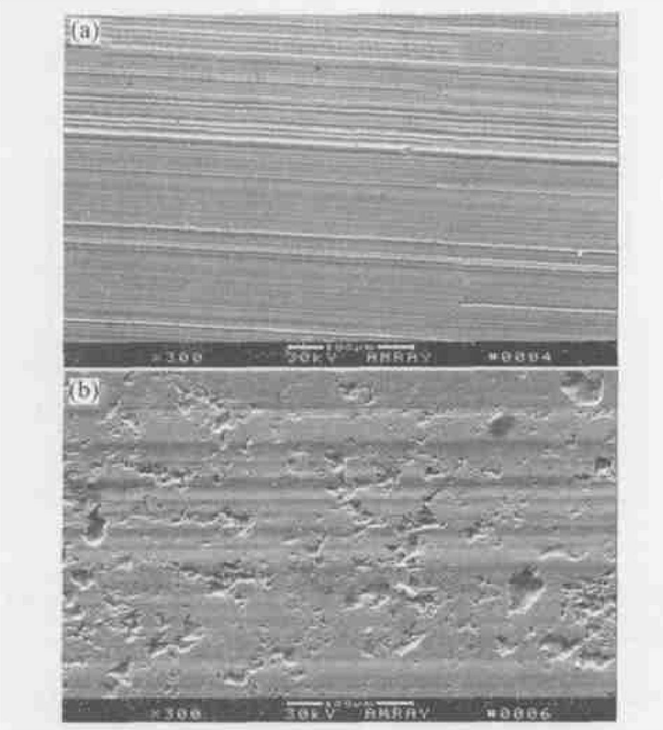

Fig. 7 SEM images of worn surfaces of laser remelted(a) and plasma sprayed(b) Ni coatings

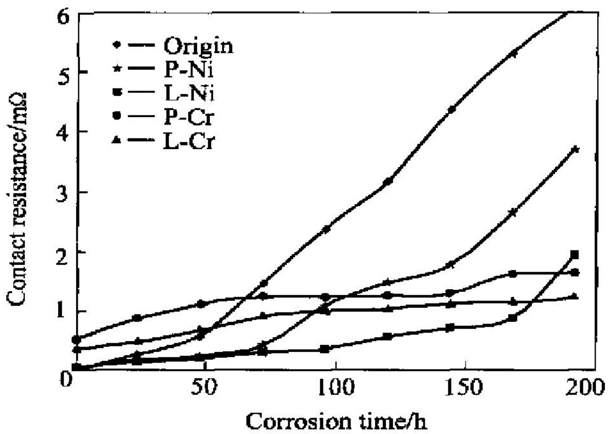

Fig. 8 Variation of contact resistance of different samples

sample joints increase with corrosion time increasing, due to the deposition of corrosion product. There appear to be three stages in the corrosion process, namely, a primary deposit stage, a steady deposit stage and an accelerated deposit stage. The contact resistance rises during the primary stage, changes relatively little in the steady deposit stage, and increases rapidly in the accelerated-deposit stage. Obviously, the later the accelerated deposit stage appears, the better the corrosion resistance of the sample will be.

It is seen that original sample, copper, shows no steady deposit stage and reaches the accelerated deposit stage in the shortest corrosion time. The increase in contact resistance of plasma sprayed nickel is less than that of copper, and the steady deposit stage appears. Laser remelted nickel sample displays very small contact resistance and longer steady deposit stage. Although chromium coatings show higher contact resistance before the corrosion test, both plasma sprayed coating and laser remelted coating show very low resistance after corrosion. Indeed, the accelerated deposit stage does not appear even corroded near 200 h. The corrosion resistances of the laser remelted nickel and chromium samples are better than that of the plasma sprayed samples respectively. If the corrosion rate is defined as the increased rate of contact resistance with corrosion time, it is seen that the original copper displays the highest corrosion rate, the corrosion rate of Ni coatings is higher than that of Cr coatings, and the corrosion rate of the laser remelted samples are less than that of plasma sprayed ones.

4 CONCLUSIONS

1) Nickel and chromium coatings display better wear resistance and corrosion resistance properties relative to the original pure copper sample. The wear resistance of the coatings is 8 - 12 times as large as original sample, and the wear resistance of laser remelted samples is better than that of plasma sprayed ones.

2) Both nickel and chromium coatings show better corrosion resistance in comparison with copper. The corrosion resistance of laser remelted coatings is better than that of plasma sprayed coatings. The corrosion rate of Cr coatings is less than that of Ni coatings, and the laser remelted Cr coating exhibits the least corrosion rate.

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