Study on the laser treatment of electroless Ni-P-SiC composite coatings

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Received August 17, 2006

Effect of the laser treatment on electroless Ni-P-SiC composite coatings was investigated. The microscopic structure, surface morphology, ingredient, and performance of the Ni-P-SiC composite coatings were synthetically analyzed by the use of X-ray diffraction apparatus, scanning electron microscope, energy distribution spectrometer, micro-hardness tester, wear tester and so on. It was found that the composite coatings did make crystalloblastic transformation after laser heating. Structural analysis confirmed that some new types of phase Ni_2Si or Ni_3Si compound would emerge in the Ni-P-SiC coatings after laser treatment. The micro-hardness measurement results showed that when the laser power was 450 W with scanning speed of 0.5 m/min, the hardness of the coating was superior to the coating obtained by the conventional furnace heating, and wear resistance of the composite coating after laser treating could also improve.

OCIS codes: 310.6120, 140.0140, 050.5080, 120.6650.

Electroless Ni-P alloy is an engineering coating largely used in industry because of its good properties. The composite coatings can increase significantly the hardness and wear resistance of the Ni-P coating by adding inert particles of high hardness, such as SiC, Al_2O_3, WC, diamond and so on in it. It has been known that the matrix of common electroless Ni-P-SiC composite coating is of amorphous as coated. As a noncrystalline phase, it shows excellent corrosion resistance, but its hardness and wear-resistance are mediocre. Noncrystalline phase is to be transformed into crystalline when subjected appropriate heat treatment. Thus the hardness and wear resistance of the crystallized coatings will be further improved. So in practical use, most of the electroless Ni-P-SiC composite coatings are properly heat-treated. Conventionally, the crystallization treatment of the electroless coatings is implemented in furnace. In order to obtain higher hardness and wear resistance, the furnace heating temperature is always set at about 350 °C. But the temperature is somewhat too high for those tools and moulds and thereafter tempering at about 200 °C to maintain the matrix hardness[1]. Therefore its application suffered from certain limitation. It is well known that laser is typified by a high density energy. Compared with the furnace heating, the laser treatment has more superiority. The coatings are transiently heated part by part, and then cooled at very high speed for they have good thermal conductivity, thus avoiding undesired heat effect on the matrix[2]. Because few works have been reported on laser treatment of eletroless-plated composite coatings, this paper focuses attention on the effect of laser treatment on morphology, structure, ingredient, hardness, and wear resistance of eletroless-plated composite coatings, aiming at the application of the eletroless-plated composite coating process.

The laser treatment was conducted on continuous and rapid axial CO_2 laser apparatus with laser radiation spot of 3 mm in diameter. The incident energies of laser treatment were adjusted either with constant laser power, changing the scanning speed of laser beam, or with constant scanning speed, changing laser power. In order to prevent oxidization, argon shield was adopted to the treated area, and the surface of the coating was blacked to increase the laser energy absorbing.

The composite coatings, before and after crystallization treatment, were examined with X-ray diffraction, scanning electron microscope, energy spectrum analysis, micro-hardness tester, and wear test machine to reveal the effect of laser treatment on the Ni-P-SiC composite coatings.

The surface and cross-section morphologies of the Ni-P-SiC composite coatings (the substrate was carbon steel 45 (equivalent to AISI 1045)) are shown respectively in Figs. 1(a) and (b). It can be seen that SiC particles

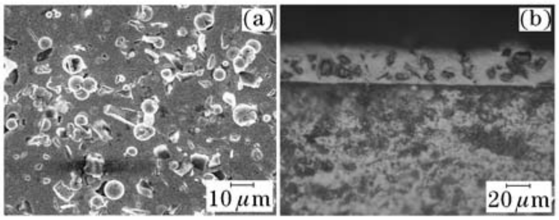

Fig. 1. Surface (a) and cross-section (b) morphologies of the composite coating.

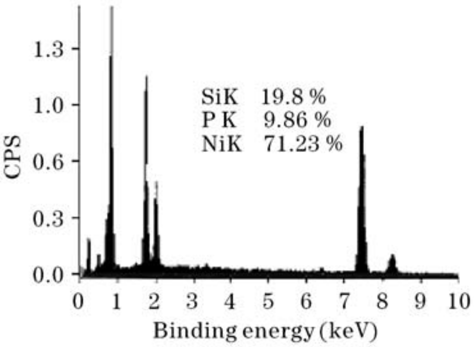

Fig. 2. Energy spectrum of the composite coating under as-coated condition.

are evenly distributed throughout the matrix of electroless Ni-P alloy. Figure 2 shows the energy spectrum of the composite coating. The coating contains 9.86 wt.-% phosphorus. The coating would produce non-crystal structure as-coated when phosphorus contents exceeded 8 wt.-%[3]. Therefore, the composite coatings developed in this experiment were of non-crystal structure under as-coated condition.

Figure 3 presents surface morphologies of the composite coatings by furnace heating and laser treating. It can be seen that the protuberances on the surface of the composite coating cracked basically when the temperature of the furnace heating was set at 350 °C for one hour. Figures 3(b)—(f) show that when the laser scanning speed was set at 0.5 m/min, the surface morphology of the coating changed gradually with the increase of the laser power, the protuberances on the surface of the coatings gradually disappeared and lost their original morphology. When the laser power reached 450 W, protuberances basically cracked. When the laser power finally reached 600 W, the coating exfoliated with the substrate. In Fig. 3(f), there was no coating in substrate. So under this condition, the laser treatment was just like hardening. The surface microstructure of the substrate was lath martensite and its micro-hardness reached 818 HV.

The structural analyses for the composite coatings after laser treatment were conducted on X-ray diffraction apparatus, as shown in Fig. 4. The diffraction pattern peaks correspond to those of Ni, Ni_3P, and SiC, and of full shapes. It can be seen that the composite coatings did make crystalloblastic transformation after laser treatment. It was also found that new types of phase Ni_2Si or Ni_3Si compound emerged in the coatings. It was inferred that part of SiC in the composite coatings would be decomposed when subjected to the high power laser treatment[1].

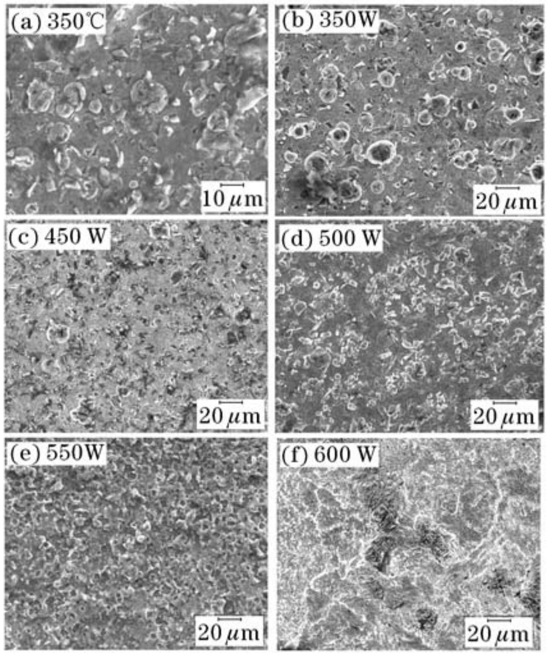

Fig. 3. Surface morphologies of the composite coatings by furnace heating and laser treating.

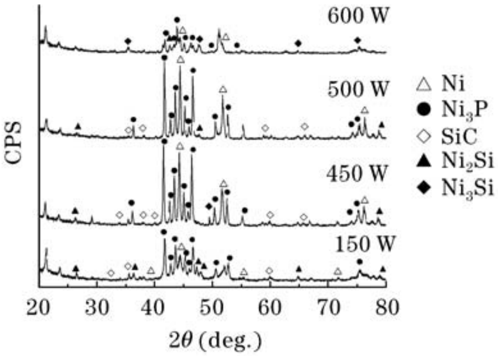

Fig. 4. X-ray diffraction spectra of composite coatings with different laser powers.

Hardness of the coatings was tested by means of an HVS-1000 micro-hardness tester with load of 0.98 N. For the sake of contrast, they were heated in furnace at different heating temperatures for an hour. The test results are listed in Tables 1 and 2 (the average hardness of the Ni-P-SiC composite coatings under as-coated condition was 685 $HV_{0.1}$).

Table 1 shows that the hardness of the composite coatings consistently improves with the increase of heating temperature, reaching the maximum value of 1355 $HV_{0.1}$ at 350 °C. Thereafter the coating hardness gradually decreases as increasing the temperature. The reason is that when crystallization proceeded upon heating, the precipitation of Ni_3P resulted in the increase of the hardness. After the coatings hardness reached the maximum value, Ni_3P agglomerated to grow up as the increase of the temperature, and the lattice distortion disappeared due to crystallization, thus leading to the decrease of the coatings hardness[3].

Table 2 shows that variations of the coating hardness with laser energy are similar to those of heating in furnace. The hardness of the coating gradually improved with the increase of the laser power. When the power set at 450 W, the hardness reached 1436 $HV_{0.1}$, higher than that obtained by conventional furnace heating. The reason could be attributed to the formation of Ni_3P, which is

Table 1. Micro-Hardness of Composite Coatings by Furnace Heating

Temperature (°C)	200	250	300	350	400	450	500	550
Hardness ($HV_{0.1}$)	714	798	1032	1355	1247	1148	984	753

Table 2. Micro-Hardness of Composite Coatings by Laser Treating (Scanning Speed is 0.5 m/min, Beam Diameter is 3 mm)

Power (W)	150	200	250	300	350	400	450	500	550	600
Jardness ($HV_{0.1}$)	676	743	827	1012	1128	1343	1436	1185	967	818

verified from the X-ray diffraction in Fig. 4. The reason for why the highest hardness of the composite coatings by the laser treatment is higher than that by furnace heating is that when laser was used as the thermal sources for crystallization treatment, the amount of precipitated Ni_3P was much more than that of heating in furnace, thus resulting in greater lattice distortion[1]. Table 2 shows that the decrease of the hardness of the composite coatings after reaching maximum was rapider than that of heating in furnace. The reason was that under high energy density, the Ni_3P agglomerated to grow up rapidly.

Wear tests were carried out on the wear test machine M-2000 under the conditions of lubrication. Figure 5 schematially shows the arrangement of the specimens. The counter wear specimen was a ring of 50 mm in diameter, was made of GCr15, and was quenched and tempered to the hardness of 62HRC. The test load was 196 N. The rotation speed was 400 rpm. The wear test time in total was 7 h. Table 3 shows the weight loss of composite coatings during stable wear-off stage. The wear test results indicate that the higher the hardness of the coatings was, the better the wear resistance of the coatings had. When the hardness of the coating reached the maximum value at 450 W, the specific wearability was the lowest. The reason for the better wear resistance of the composite coatings by laser treatment could be attributed to the formation of new types of phase Ni_2Si or Ni_3Si except higher hardness of the coating. It is said that the formation of Ni_2Si or Ni_3Si promotes the ductility and tensile strength of the coating. So these good performances maybe hold good for wear resistance.

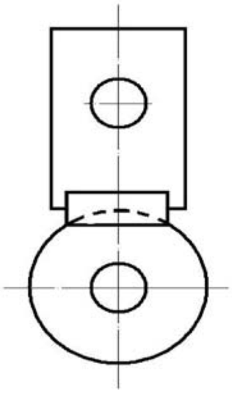

Fig. 5. Wear couples.

Table 3. Weight Loss during Stable Wear off Stage

Condition	Specific Wearability (mg/h)
350 ° in Furnace	0.1200
400 ° in Furnace	0.1471
400 W Laser Treating	0.1443
450 W Laser Treating	0.1043

In summary, we get the following conclusions: 1) Electroless Ni-P-SiC composite coating did make crystalloblastic transformation after laser heating. The highest hardness of the composite coating after laser treatment was 1436 HV, higher than the highest value obtained by furnace heating. 2) New types of phase Ni_2Si or Ni_3Si compound emerged in the composite coatings after laser treatment. 3) Wear resistance of the coatings after laser treatment was higher than that of heating in furnace. 4) The best parameters of the laser crystallization were beam diameter of 3 mm, scanning speed of 0.5 m/min, and laser power of 450 W. The highest hardness and wear resistance of the composite coating could be obtained under this condition.

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