Effect of Electroless Nickel Plating On Fatigue Strength of 30CrMoA Steel

By Y. Wu, Y. Zhang and M. Yao

The effect of electroless nickel plating on the fatigue properties of 30CrMoA steel was investigated by means of up and down load fatigue tests, scanning electron microscopy (SEM) and optical metallograph. The results show that electroless Ni-P alloy on quenched and tempered 30CrMoA steel decreases its fatigue strength by 39 percent, but that shot-peening before plating can increase the strength by 30 percent, compared with plating directly, and that the fatigue source appears almost at the interface between the coating and the substrate. On the coating, some parallel cracks vertical to the stress axis form after testing.

As an extensively studied and applied surface protection technique, electroless nickel has desirable properties, such as good corrosion resistance, wear resistance and uniform coverage of nearly all substrates, and is especially suitable for complex shapes.[1,2] Applications for electroless nickel are found in the machinery, chemical, and oil industries. Materials plated with it can be subjected to successive forming steps that can induce fatigue fracture in the plating, a failure more important than fracture at the necking points as seen in stress/strain tests.

Currently, there is little information related to fatigue characteristics of materials plated with electroless nickel. Some reports suggest that such materials do not lose their strength;[3,4] however, others disagree.[5,6] This paper reports the study of plated 30CrMoA steel and suggests methods of improving fatigue strength.

Experimental Procedure

The substrate was 30CrMoA steel (composition—wt percent: 0.3 carbon, 1.09 Cr, 0.24 Mo, P < 0.005, S < 0.005), used as specimens and oil-quenched at 870 °C, then tempered at 620 °C for 3 hr. The specimens were divided into three groups:

a. Heat treatment only (quenched at 870 °C, then tempered);
b. Heat treatment, followed by electroless nickel plating, then aging to remove hydrogen (1.5 hr at 200 °C);
c. Heat treatment, followed by shot peening, then plating, then aging, as before.

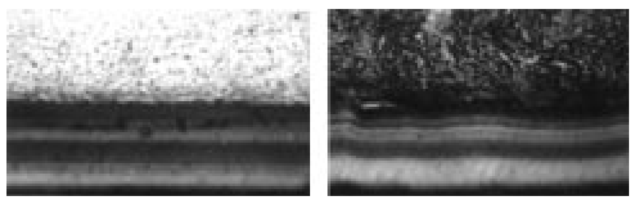

Fig. 1—Cross section of Ni-P(10 wt %) coating: (a) on steel; (b) on shot-peened steel.

The electroless nickel specimens were descaled in a solution containing 25 g/L NaOH, 30 g/L Na_2CO_3, and 25 g/L Na_3PO_4 for 30 min, then pickled with 10-percent HCl. The plating solution had the following composition (g/L):

$NiSO_4 \cdot 6H_2O$	30
$NaH_2PO_2 \cdot H_2O$	30
lactic acid	25
propionic acid	3
sodium acetate	10
prop. brightener	4
stabilizer (KIO_3)	5 ppm
temperature	88 ±2 °C
pH	4.5

After plating, the specimens were passivated in a one-percent solution of $K_2Cr_2O_7$.

Fatigue strength was tested by three-point fatigue testing equipment, according to an up and down loading method.[7] The load ratio was 0.05, the cycle index was determined as 1 x 10^6, the frequency was 125 Hz, and test data were analyzed using the normal distribution function.

The microstructure, hardness and fracture morphology were studied by X-ray diffraction spectra, microhardness testing, and scanning electron microscopy (SEM).

Results

The composition of the electroless coatings, with hypophosphite as reducing agent, is 90 wt percent Ni and 10 wt percent P. Figures 1a and 1b are metallographs of the cross section of the Ni-P coating, showing a banded structure. X-ray diffraction data (Figs. 2a and 2b) indicate that the Ni-P coatings on both the shot-peened and non-shot-peened steel, after aging for 1.5 hr at 200 °C, are amorphous. The hardness of both coatings is about HV 700. These results indicate that shot peening cannot change the hardness and microstructure of the Ni-P coating, but can increase surface roughness and cause fluctuation of the banded structure (Fig. 1b).

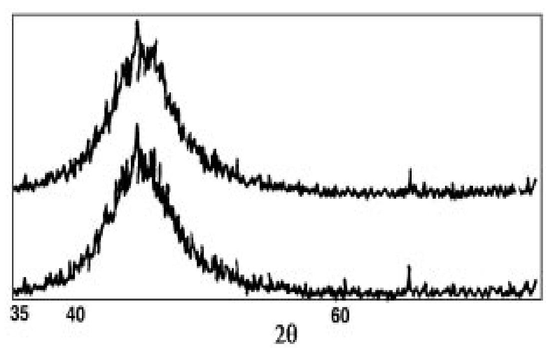

Fig. 2—X-ray diffraction data for Ni-P (10 wt %) coating: (a) on steel; (b) on shot-peened steel after aging for 1.5 hr at 200 °C.

Results of Fatigue Experiments

Treatment	Fatigue Strength MPa	Percent Decrease
Quench & temper	880	—
Heat treatment + Ni-P coating	540	39
Heat treatment + shot peening + Ni-P coating	700	20

The table lists the measured fatigue strength for different conditions of treatment. The plating results in decrease of fatigue strength by 39 percent, but shot peening before plating can improve this property remarkably—in this case, by 30 percent, compared to direct plating.

Figure 3 shows the micrograph of fatigue morphology for 30CrMoA steel.Without plating, the fatigue characteristics are obvious on the surface for the largest stress (Fig. 3a). After plating on the substrate, with or without shot peening, fatigue fringes cannot be observed in the Ni-P coating; their origin is not obvious and they move from the surface to the interface between the coating and the substrate (Figs. 3b and 3c). Sometimes, shot peening produces microcracks in the subsurface of the substrate; these become fatigue sources (Fig. 3d).

On the surface of the electroless specimens after fatigue testing, some parallel cracks normal to the stress axis can be seen by metallography (Fig. 4), but the number of cracks is smaller on shot-peened specimens (Fig. 4b). Frequently, the coating delaminates near the fatigue fracture location (Fig. 5).

Discussion

The results indicate that fatigue damage may ensue from two factors—low plasticity or low fatigue property of the Ni-P coating. To determine the dominating factor, two additional experiments were made. The first was a static bending test, the bending load being the fatigue limit of the plated steel without shot peening. Optical metallography reveals no cracks on the surface of the coating. In the second experiment, the cycle load was decreased by 15 percent, compared with the fatigue limit of the steel plated with electroless nickel. The cycle index is about 1 x 10^6, followed by increasing the load until fracture. In this case, the fatigue morphology appears, plus fatigue fringes in the coating (Fig. 6). These results show that the decrease of fatigue strength is dominated by low fatigue strength of the Ni-P coating. This fast fatigue fracture of the coating causes the cracks to penetrate quickly to the interface. The fatigue fringe is therefore difficult to see in the coating under the fatigue limit load. The measured fatigue strength is apparent, inasmuch as the penetrating cracks of the coating lead to stress concentration in the substrate. If the fatigue strength is lower, however, as with an aluminum alloy, the structure of coating plus substrate may have greater strength than the substrate, which some experiments have proved.[4]

The increase of fatigue strength for the shot-peened specimens results from two factors. One is a change in the stress state of the coating. Residual compressive stress is relaxed after aging for 1.5 hr at 200 °C, resulting in increase of fatigue strength of the coating and reduction of the number of surface cracks (Fig. 4b). Another factor is that residual compressive stress in the substrate itself strengthens the interface, limiting propagation of the cracks.

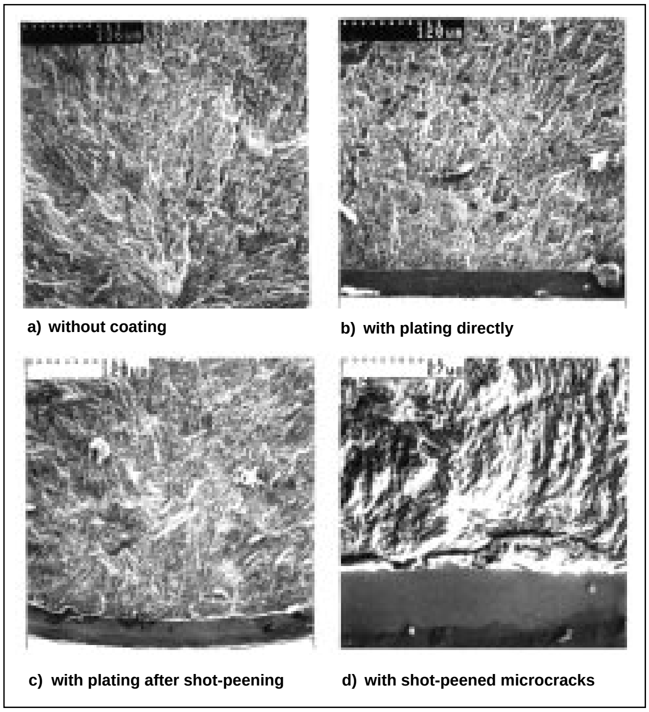

Fig. 3—SEM photographs of fatigue fracture morphology: (a) unplated; (b) plated directly; (c) plated after shot peening; (d) with shot-peened microcracks.

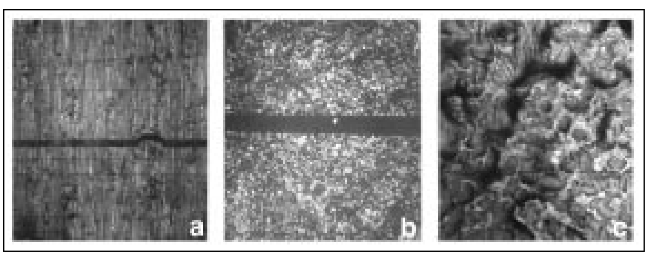

Fig. 4—Parallel cracks on coating surface: (a) plated directly; (b) plated after shot peening, 200X; (c) magnified photo of (b), 500X.

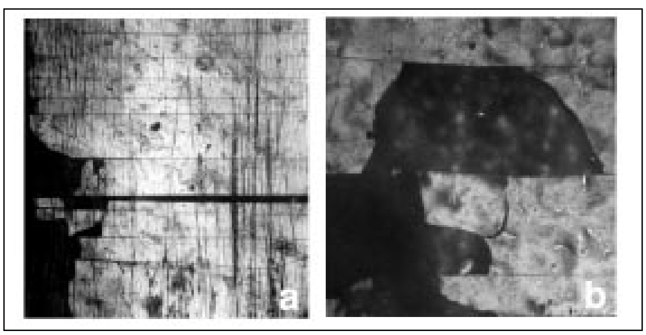

Fig. 5—Delamination of coating near fatigue fracture: (a) on steel, 200X; (b) on shot-peened steel, 500X.

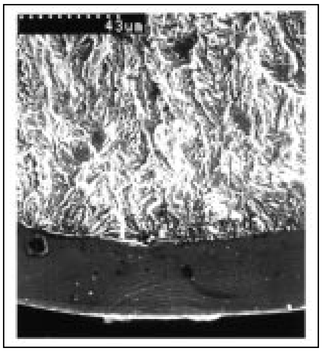

Fig. 6—Fatigue fringe on coating (SEM).

The implication of these results is that there are three significant objectives in increase of the composite fatigue strength. First is change of the stress state of the coating to compressive stress. To a large degree, the fatigue property of the materials is dominated by the surface property and its stress state. Shot peening or other mechanical treatment, pre- or post-plating, produces a certain compressive stress that can prevent fatigue cracks from nucleating and propagating in both the coating and the substrate. Appropriate control of the plating process can also improve the compressive stress of the coating.[8]

Second is improvement of the mechanical properties and decrease of the number of defects in the electroless nickel coating to as few as possible. Low fatigue strength of the Ni-P coating may be a result of defects and low mechanical properties. Improvement of the plating procedure and controlling the composition of the coating with proper heat treatment is effective. Alloying the electroless nickel coating by codeposition of another metal, such as copper, cobalt, tungsten, etc., is also effective.

The third objective concerns the interface between the steel and the Ni-P coating. For the composite of coating and steel, the interface is always the nucleating location of cracks and sometimes delamination occurs from loading; therefore, the weaker side of the interface must be strengthened through pretreatment of the substrate. This in turn can increase the bond strength of the as-plated condition, and by post-treatment, such as suitable heat treatment, form a diffusion zone for avoidance of cracks.

Conclusions

1. The fatigue limit of 30CrMoA steel plated with electroless nickel is 540 MPa, a decrease of 39 percent compared with unplated steel (880 MPa).
2. Shot peening of the steel before plating can increase the fatigue limit (700 MPa) by 30 percent, compared with plating directly on the steel.
3. Low fatigue strength of the Ni-P coating causes the decrease of the fatigue limit of the plated steel.

Editor's Note: *This paper was received for publication in January 1994.*

Acknowledgment

The authors wish to thank the Corrosion Science Laboratory of Academia Sinica for financial support.

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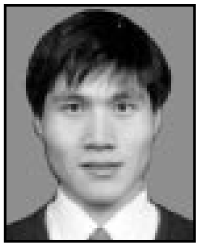
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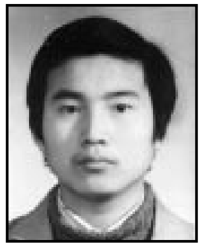
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