JOURNAL OF MATERIALS SCIENCE 28 (1993) 3513–3518

Strength evaluation and effect of graphite on strength of electroless nickel plating on cast iron

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The effect of graphite on the strength of electroless nickel plating on cast iron was studied. Specimens of cast irons with four types of graphite and of 0.4% carbon steel were prepared and machined into plates with dimensions of 10 mm × 3 mm × 80 mm. Electroless nickel plating, about 40 μm thick, was deposited on the test pieces. The plated test pieces were tested by three-point bending tests using both acoustic emission (AE) and microscopic observation to evaluate the strength of the plating film. It was found that the first AE signal was generated when the cracks initiated and the final AE signal was generated when the film was fractured by crack penetration into the film. In addition it was found that film cracks on cast iron were initiated by the graphite existing at the interface between the plating film and the substrate, and propagated to the surface of the film, unlike carbon steel. The strength of the plating film on cast iron measured by this method, decreased more sharply with increasing amount of graphite than with graphite shape. Observations of cast iron surfaces at early stages of plating showed that the nickel was deposited only on the matrix and not on the graphite. It is believed that the non-deposited areas of the cast iron acted as types of defects. It is concluded that the strength of electroless nickel plating film on cast iron is strongly influenced by graphite on the surface.

1. Introduction

The importance of surface coating in ensuring both reliability and efficiency of machines has recently been highlighted. Many studies of surface coating and its properties have therefore been carried out [1]. Among conventional surface-coating techniques, electroless nickel plating is widely used for forming precise films because of its excellent corrosion and wear resistance in addition to low coating cost. It is well known that the properties of electroless nickel films are influenced by the structure of the substrate materials due to certain intrinsic differences, e.g. surface defects, grain size, etc. [2]. In particular, the interfacial adhesion between film and substrate is important in tribological applications in corrosive atmospheres [3].

The casting process is capable of producing complex shapes and cast iron is widely used for castings because of both producibility and cost. It is nevertheless necessary, in certain manufacturing operations, to modify the surface of cast iron by coating in order to ensure reliability. In this case, electroless nickel plating is usually considered to be one of the most suitable methods for these coatings. However, it is reasonable to assume that the interfacial adhesion of electroless nickel plating film on cast iron is influenced by the presence of graphite.

Although many studies of electroless plating have been carried out using steel, few studies using cast iron have been reported [4, 5]. Therefore, more detailed studies of the effect of graphite on the plating film are needed in order to improve the reliability and cost-effectiveness of electroless nickel plating. In this paper, the results of a study of the effect of graphite shape and amount on the strength of electroless plating film using several cast iron samples are reported.

2. Experimental procedure

2.1 Specimens

Samples of cast iron with four types of graphite shape and a sample of 0.4% carbon steel were prepared. The chemical composition of these specimens are shown in Table I.

Fig. 1 shows the microstructure of the cast iron. The graphite shapes of Specimens A, B, C and D are eutectic (ASTM E type), flaky (ASTM A type), semi-spheroidal and spheroidal, respectively. The amount of graphite on the surface of the specimens was measured with a planimeter. The amount and type of graphite on the specimen surface are also shown in Table I. The amount of graphite on the surface is maximum for Specimen A (about 23%) and minimum for Specimen D (about 13%). It also shows that the number of the graphite is changed with the graphite shape.

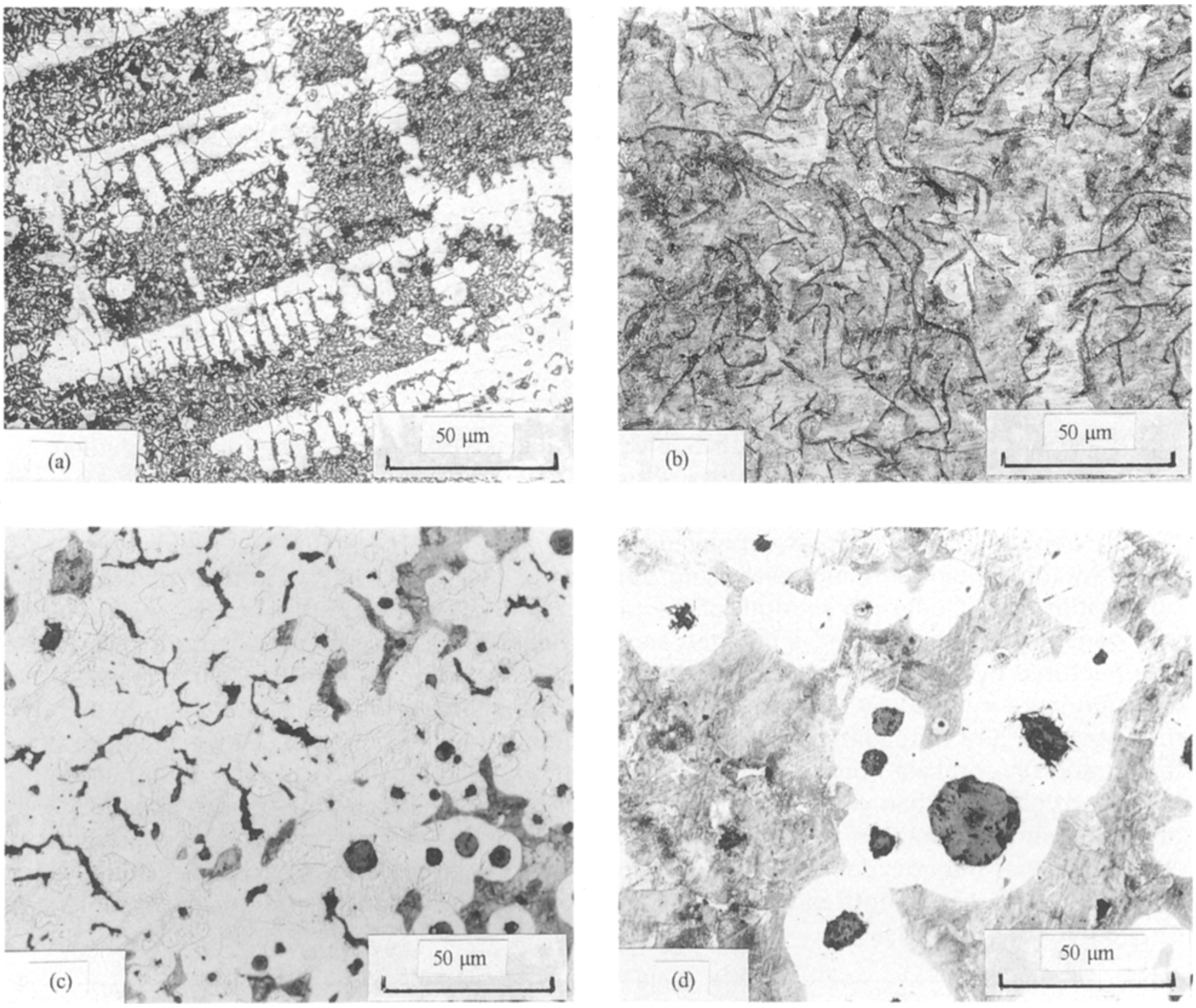

Figure 1 Microstructure of specimens (a) A, (b) B, (c) C and (d) D.

TABLE I Chemical composition, graphite shape and graphite amount

	Chemical composition (wt %)					Graphite shape	Amount of graphite (%)	Number of graphite (mm^{-2})
	C	Si	Mn	P	S			
A	3.74	2.56	0.61	0.19	0.13	Eutectic	23.2	1120
B	3.39	2.07	0.83	0.08	0.08	Flaky	20.3	429
C	3.55	2.29	0.30	0.02	0.01	Semi-spheroidal	17.2	432
D	3.64	2.50	0.22	0.01	0.04	Spheroidal	13.6	238
E	0.45	0.21	0.80	0.21	0.17	–	–	–

The plate test pieces shown in the Fig. 2 were machined from the specimens. The surface roughness of the test pieces was fixed at R_{max} of about 15 μm by grinding.

Only one side of each test piece was plated, as shown by the cross-hatching in Fig. 2. The plating temperature was 363 K, plating time 7.2 ks and the pH of the plating bath was 6.0. The thickness of the plating film was fixed at about 40 μm. In some cases, the first stage of deposition on the graphite was observed and the plating time was then controlled between 45 s and 3.6 ks.

2.2. Strength evaluation

The strength of the plating film was evaluated by a three-point bending test. The span was 50 mm. The

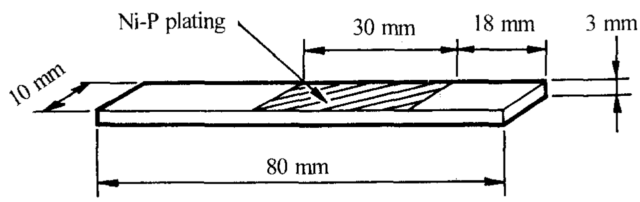

Figure 2 Shape of the test piece.

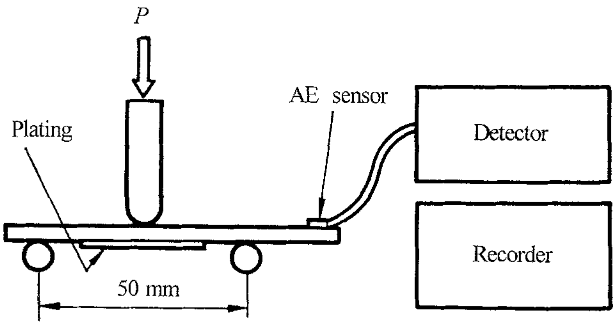

Figure 3 The bending test.

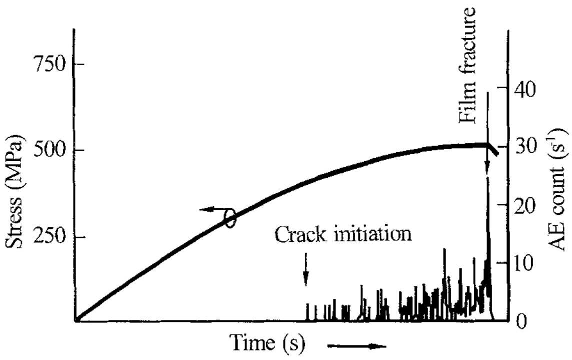

Figure 4 Change of AE count during the bending test.

test piece was positioned as shown in Fig. 3 before applying tensile stress to the plating film. An acoustic emission sensor was attached to the side opposite the plating film and crack initiation and propagation were monitored. The film surface and the interface between the film and the substrate were observed by microscopy. This was carried out simultaneously with the acoustic emission observations during the bending test.

3. Results and discussion

3.1. Strength of plating film

Fig. 4 shows an example of acoustic emission (AE) change when test piece B was used. As the applied load was increased, no change in AE count was observed up to about 400 MPa. An AE signal was observed when the bending stress exceeded about 400 MPa. The AE count was increased with increasing bending stress. Bending tests applied to unplated cast iron under the same conditions showed no detectable AE count. As described above, both the surface and interface of the plating film were simultaneously observed by microscopy during the bending test. Fig. 5 shows some examples of the observations when the first AE signal was detected during the experiment. These

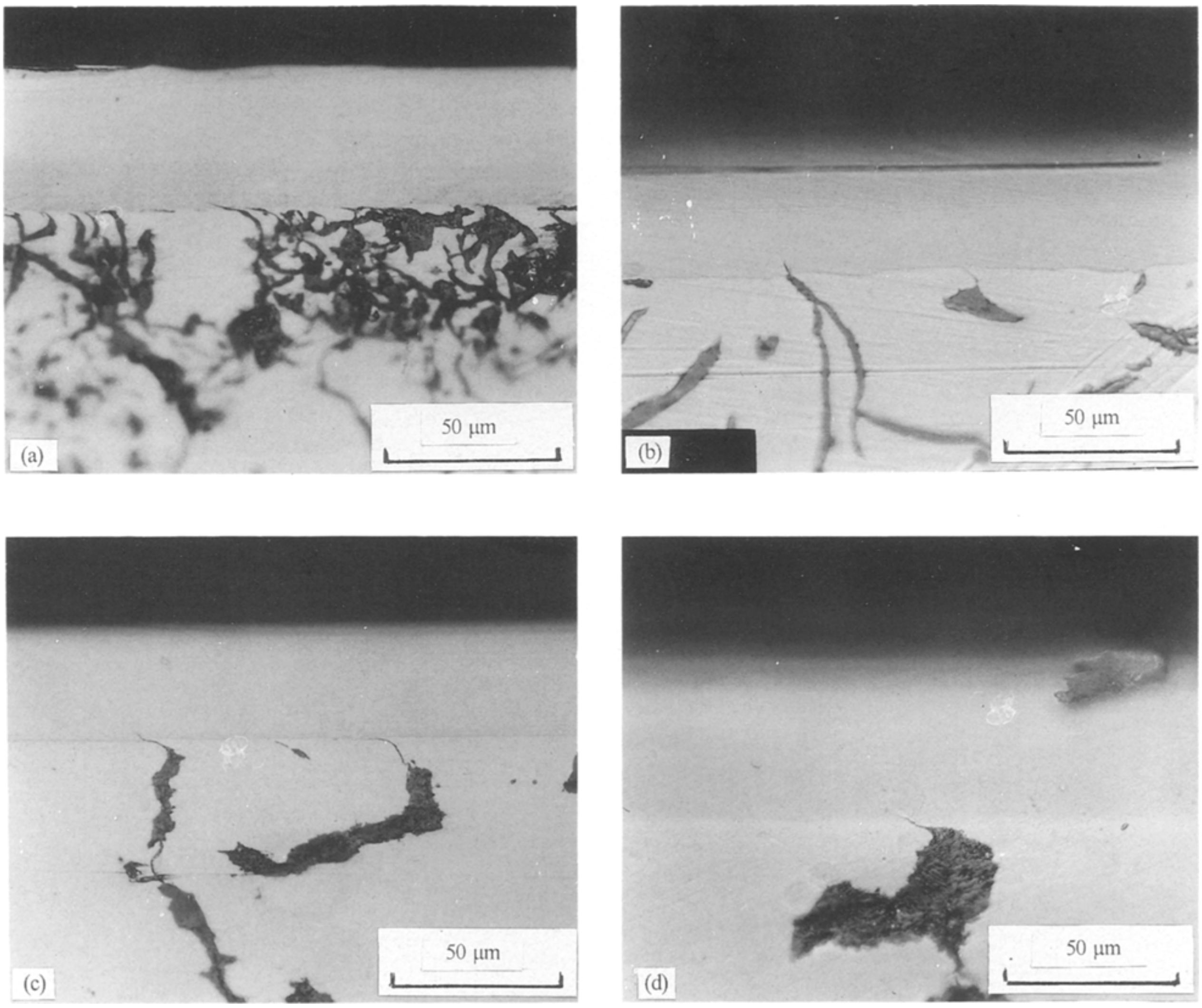

Figure 5 Interface between plating film and substrate for specimens (a) A, (b) B, (c) C, (d) D.

clearly show that cracks in the plating films on the cast iron test pieces initiate from graphite on the surfaces of the test pieces and propagate into the plating film. Unlike cast iron, the crack was initiated from the surface in the case of 0.4% C steel. These results show that the first AE signal in Fig. 4 is derived from crack initiation at the interface between the plating film and the cast iron. The number of cracks in the plating film increased when the bending stress was increased and they propagated into the film surface. Cracks which were initiated by the graphite existing near the interface between the plating film and the substrate, penetrated the plating film when the bending stress reached about 500 MPa and a high AE count was observed, as is clear in Fig. 4. From this result it is clear that the first AE signals indicate crack initiation in the plating film and the final signals indicate fracture of the plating film due to crack penetration.

Although there are several techniques for evaluating mechanical properties of plating films, scratch testing [6], indentation testing [7], and stress-wave emission testing [8], none of these methods measures exact mechanical properties [6]. Therefore, the bending test used in this experiment is believed to be one of the most useful techniques for evaluating mechanical properties of plating film.

Stress, when cracks were initiated and the film was fractured due to crack penetration into the plating film, was estimated using AE measurement. The results are shown in Fig. 6: the strength of the electroless nickel plating film on cast iron can be represented quantitatively in the figure. The maximum bending strength, about 750 MPa, was obtained with the spheroidal graphite cast iron specimens. The bending strength of plating film on flaky cast iron gave the minimum value, about 400 MPa. The stress level which induces crack initiation or fracture of the film is different for each test piece, as shown in Fig. 6. Therefore, the difference in graphite shape affects such properties.

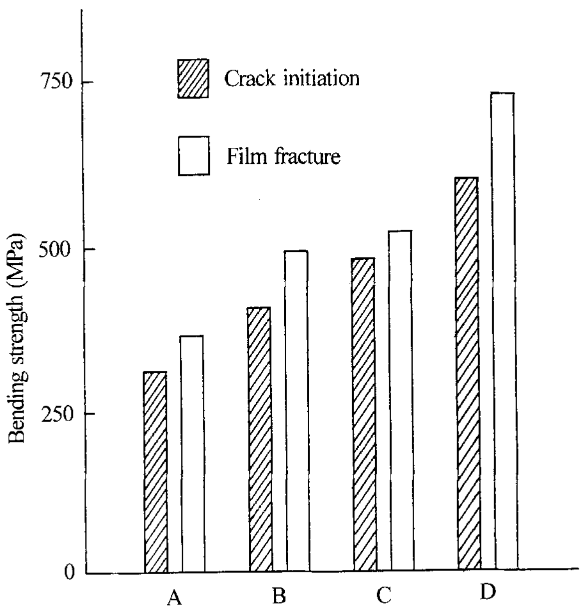

Figure 6 Results of the bending test.

By observing the interface between the film and the substrate, it was confirmed that not only graphite shape, but also the amount of graphite at the film-/substrate interface is an important factor in determining the strength of the films. Therefore, the relationship between the strength of the film and the amount of graphite (volume ratio of the graphite on the surface) was studied. The results are shown in Fig. 7. Strength related to the crack initiation and film fracture both decreased with increasing amount of graphite on the surface of the test piece. This result shows that, in this experiment, the strength of the plating film on cast iron depends more strongly on the amount of graphite than on the graphite shape within this experiment.

3.2. Effect of graphite on strength

The effect of graphite on the plating film was studied. Fig. 8 shows the relationship between the load and flexure of the test pieces. It was found that crack initiation and film fracture occurred when the load exceeded the elastic limit of the test pieces. These results suggest that the graphite near the surface of the test piece acts as the origin of the fracture due to stress concentration. Therefore, the relation between the graphite length and film strength was checked assuming that the graphite acts as a kind of defect. If the

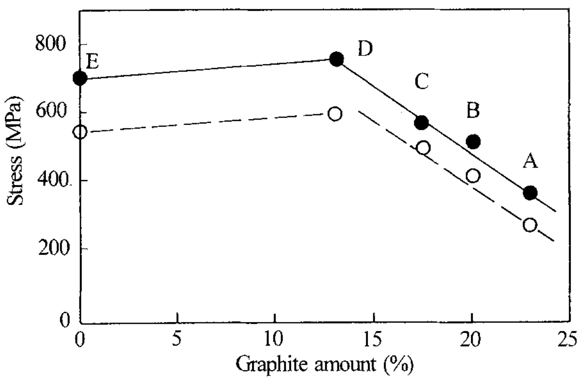

Figure 7 Relationship between film strength and amount of graphite. (○) Crack initiation, (●) film fracture.

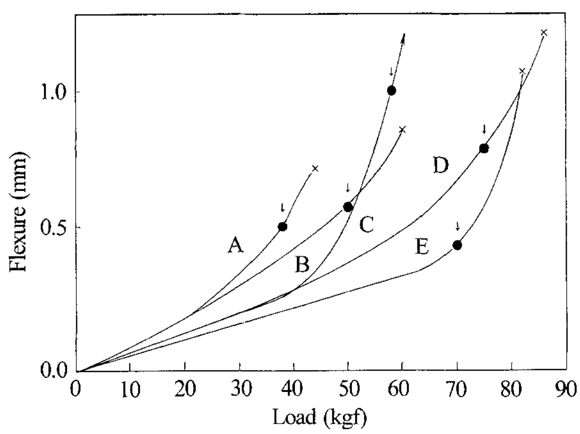

Figure 8 Results of the bending test. (●) Crack initiation, (x) film fracture.

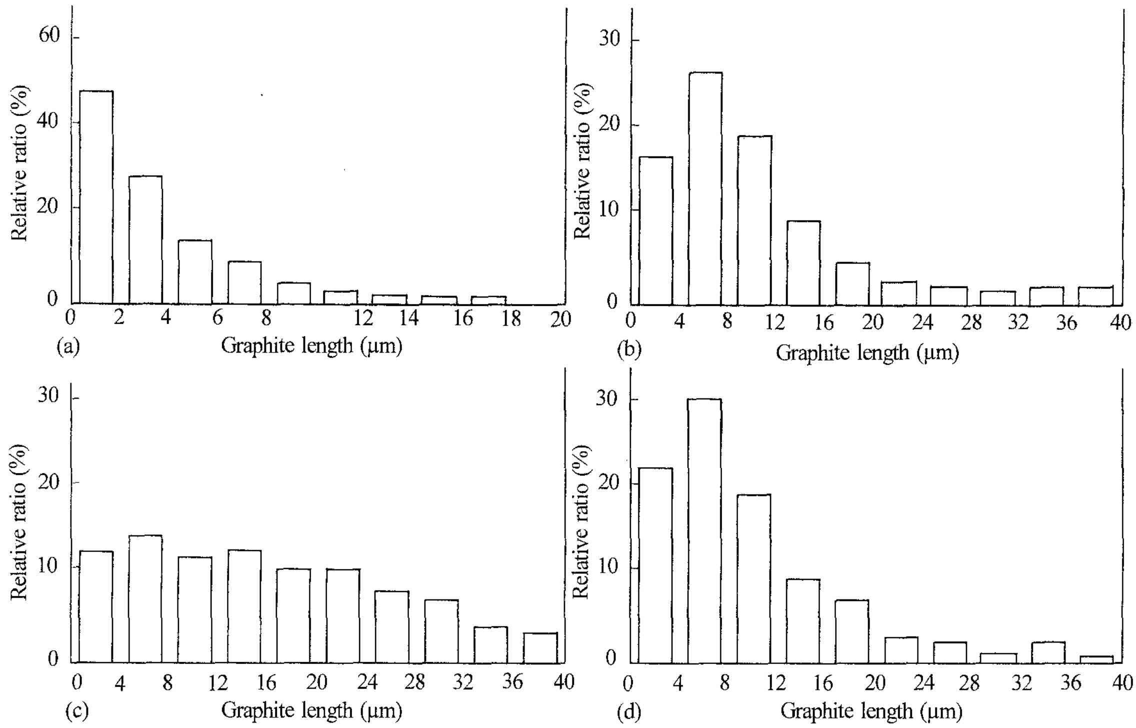

Figure 9 Graphite length of specimens (a) A, (b) B, (c) C, (d) D.

graphite of the cast iron acts as a defect and the stress intensity factor of the electroless nickel plating film is not changed by the type of substrate, the strength of the film decreases with graphite length according to the fracture theory. In order to confirm this point, the effect of the graphite length on the strength of the plating film was studied. Fig. 9 shows the graphite length of the specimens. It shows that there is no clear relation between the graphite length and the strength of the plating film.

As the next step, the relationship between the graphite length at the interface and the strength of the plating film was studied, when the crack initiation was recognized by both AE signal and microscopic observations. Graphite length when the film crack was initiated from the graphite as shown in Fig. 5, was measured. Results are shown in Fig. 10. It is difficult to recognize a clear relation between the graphite length and the film strength, although the measured graphite was limited.

From these results it is tentatively concluded that the graphite length itself does not directly influence the film strength, and other factors should therefore be considered.

In order to check the early stages of nickel deposition, detailed observations of the plating process were made using flaky graphite cast iron (test piece A) by controlling the plating time from 45 s–3.60 ks. The film thickness increased linearly with plating time. Fig. 11 shows some SEM images of the interface microstructure. About 0.3 μm thickness of film was deposited on the surface after 120 s plating time. The images show that nickel deposited only on the matrix and not on the graphite. A groove appeared to be generated between the graphite and the plating film. The groove was filled with nickel plating after the film thickness became more than 3 μm, as shown in

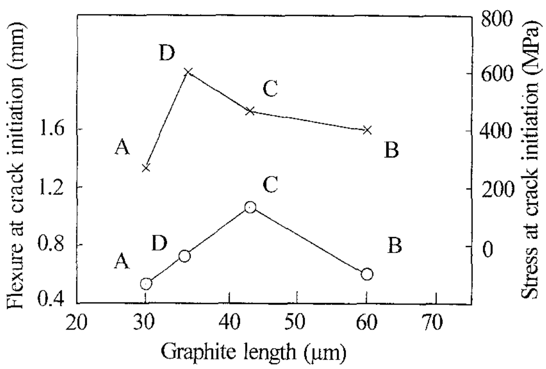

Figure 10 Relationship between graphite length and (○) flexure and (x) stress at crack initiation.

Fig. 11c. It can easily be envisaged that the nondeposition part on the graphite, i.e. the groove, acts as a sort of defect when applying stress and that the crack initiates from the graphite on the surface when using cast iron. It is also likely that an increase of graphite induces an increase in the nondeposited areas and a decrease of film strength simultaneously. Therefore, it is assumed that strength of the nickel plating film on cast iron is influenced more strongly by a thinner film than those used in this experiment.

From these results it can be concluded that the strength of the nickel plating film is influenced by the amount of graphite on the surface which induces a nondeposited area.

4. Conclusions

The effect of four types of graphite shape on the strength of electroless nickel plating on cast iron was studied by simultaneous AE and microscopic observation during bending tests. The results obtained here are summarized as follows.

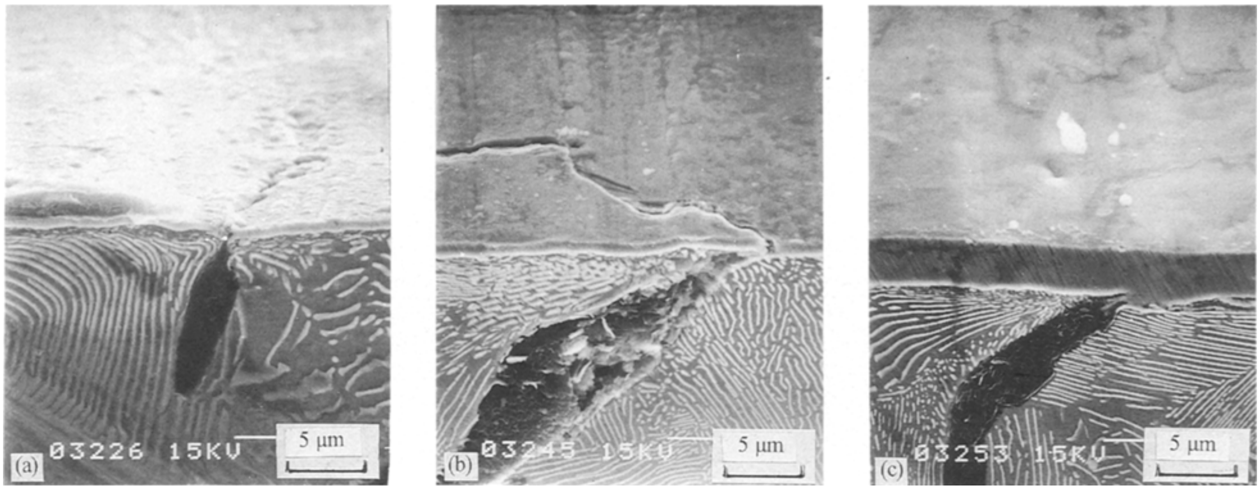

Figure 11 Surface changes after different treatment times: (a) 2 min (0.3 µm), (b) 5 min (0.9 µm), (c) 15 min (2.9 µm)

1. Cracks were initiated by graphite existing at the interface between the plating film and the substrate and were propagated into the plating film by bending tests.

2. Crack initiation and film fracture can be monitored by AE observation.

3. The strength of the plating film was affected by the amount of graphite near the interface between the plating film and substrate and the strength decreased with increasing amount of graphite.

4. Nickel did not deposit on the graphite during the first stage of plating. This non-deposited area is believed to form a kind of defect.

5. From these results it is concluded that the strength of the electroless nickel plating film is strongly influenced by graphite on the surface of the cast iron.

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Received 5 February,
and accepted 8 December 1992