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Effect of Fe content on wear resistance of thermal-sprayed Al–17Si–*X*Fe alloy coating on A6063 Al alloy substrate

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Abstract

To improve the wear resistance of Al alloy, Al–17 mass% Si–*X* mass% Fe Al alloy powders with different Fe content from 5 to 30 mass% and Al–50 mass% Fe alloy powders were thermal-sprayed on Al alloy A6063 substrate by a low pressure plasma spraying. Microstructure and wear property of the coatings were evaluated. The most beneficial coating can be obtained with Al–17 mass% Si–10 to 15 mass% Fe alloy powders, showing good wear resistance, four times of the substrate and low friction coefficient, approximately 0.4 without cracking and peeling in the coating and the interface between the substrate.

Keywords: Plasma spraying; Aluminum alloy substrate; Aluminum–silicon–iron alloy coating; Hardness; Wear; Friction coefficient

1. Introduction

Many kinds of surface modification processes are applied to improve the wear resistance of Al alloy [1]. Among coating processes, thermal spraying is superior one, capable of coating a thick layer in short operating time. Taking the weight saving effect into consideration, Al-base material is beneficial as a coating material. However, there is little research on the combination of the Al alloy substrate and the coating materials of Al alloy [2–6], including Al-base metal matrix composite with SiC, TiC, Al_2O_3 or $FeO+TiO_2$ as reinforcement as the coating material [2–4]. The authors have pointed out the possibility of coating a wear resistant Al alloy layer on the Al alloy substrate by using highly-alloyed Al powders with Si and/or Fe [5]. In our last report [6] we have made clear that Al–Si hypereutectic binary alloy coatings with Si content from 30 to 50 mass% showed good anti-wear property. In this work, as a coating material we focused Al–hypereutectic Si–Fe ternary alloys with different Fe contents up to 30 mass%, and evaluated the effect of Fe content on the anti-wear property of the coatings by using a low pressure plasma spraying process.

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2. Experimental details

2.1. Materials used

An A6063 (Al–0.55 mass% Mg–0.45 mass% Si) alloy plate of dimensions 50×60 mm and thickness 6 mm was used as a substrate. Al–17 mass% Si hypereutectic alloy powders containing a small amount of Cu, Mg, Ni and Mo with different Fe contents from 5 to 30 mass%, and Al–50 mass% Fe binary alloy powder were used as a spray material, which were tentatively made with a rapid solidification method by atomizing a molten alloy into running water. Powder size was approximately 80 μm in mean diameter with a size distribution from 53 to 105 μm. Compositions of these materials are shown in Table 1. These ternary alloy powders are based on AC9B cast alloy in Japan Industrial Standard, but Fe content was selectively increased.

2.2. Methods

Low pressure plasma spraying in a vacuum chamber was employed to prevent oxidation of the powder during spraying. An Ar–H_2 gas mixture was used as a plasma gas, with flow rates of 47 l/min of Ar and 7 l/min of H_2 at a plasma power of 32.4 kW (600 A and 54 V) under a chamber pressure of 27 kPa. Powder feed rate was 20 ml/min with Ar as the carrier gas, and spraying

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Table 1
Chemical composition of the substrate and Al alloy powders

Alloy	Chemical composition (mass%)					
	Si	Fe	Cu	Mg	Ni	Mo
Substrate						
A6063	0.45	0.19	0.02	0.55	–	–
Powder						
Al–17Si–5Fe	15.9	5.0	1.1	1.9	1.0	0.6
Al–17Si–10Fe	16.7	10.0	1.0	2.0	0.9	0.7
Al–17Si–15Fe	17.3	15.1	1.0	1.8	1.0	0.7
Al–17Si–20Fe	16.7	19.4	1.0	2.0	0.9	0.7
Al–17Si–30Fe	16.1	29.9	1.1	0.9	1.0	0.8
Al–50Fe	–	49.8	–	–	–	–

distance was 250 mm. These conditions were selected from the result of our previous work [5,6]. Before spraying, the substrate surface was blasted with Al_2O_3 powders of 710–850 μm by compressed air abrasive blasting equipment with 0.4 MPa blasting pressure to ensure surface cleaning. With this spray condition a coating of 100–200 μm thickness was applied. The structure of the coatings was studied by scanning electron microscope and X-ray diffraction analysis. Hardness measurement with a 0.5 N load was performed on the spray coating cross-section. The wear resistance of the coatings was evaluated with a ball-on-disc type sliding wear test at the condition in air without lubricant by using Al_2O_3 ceramic counter ball of 6.35 mm in diameter

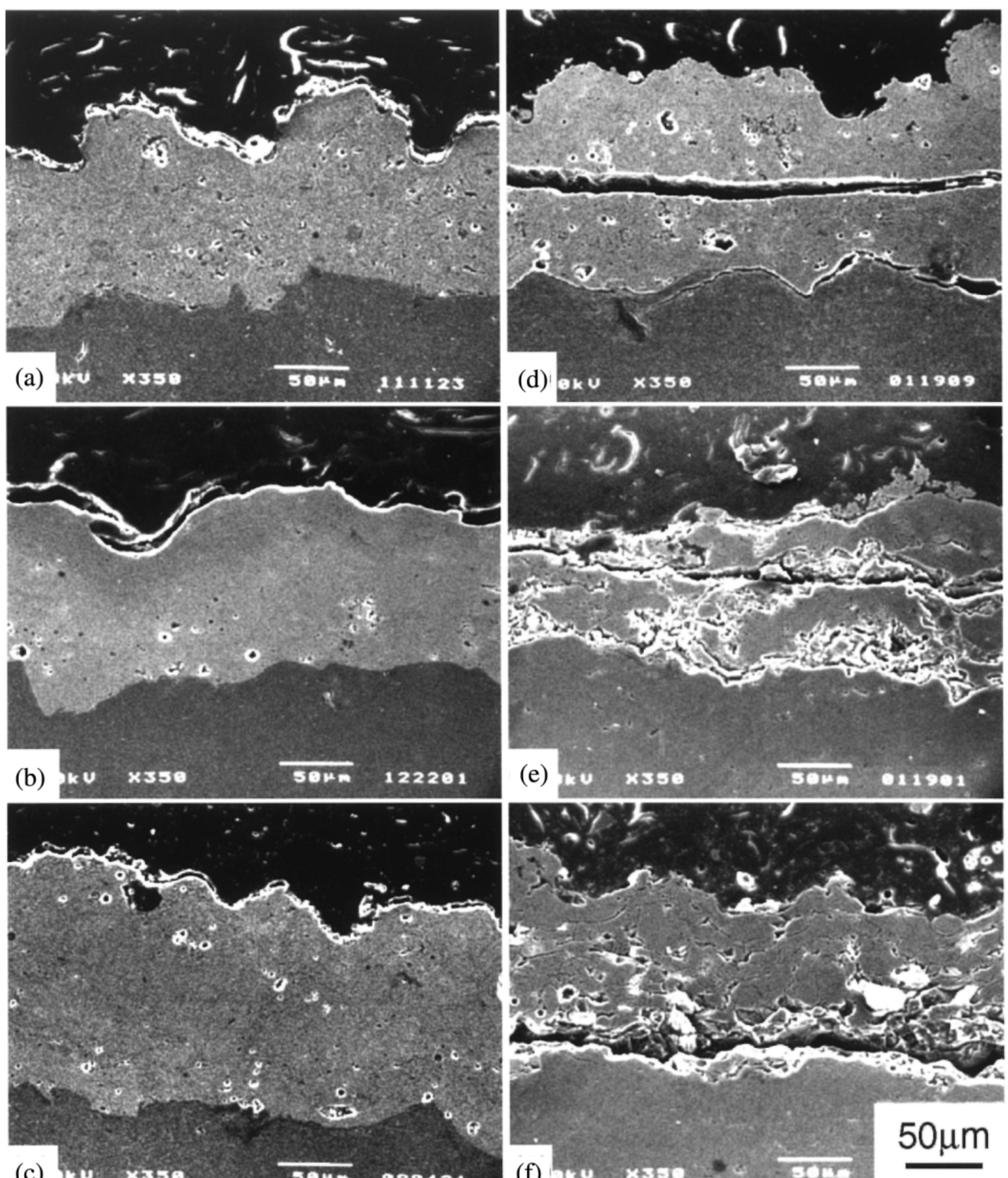

Fig. 1. Structure of spray coatings on cross-section: (a) Al–17Si–5Fe; (b) Al–17Si–10Fe; (c) Al–17Si–15Fe; (d) Al–17Si–20Fe; (e) Al–17Si–30Fe; (f) Al–50Fe.

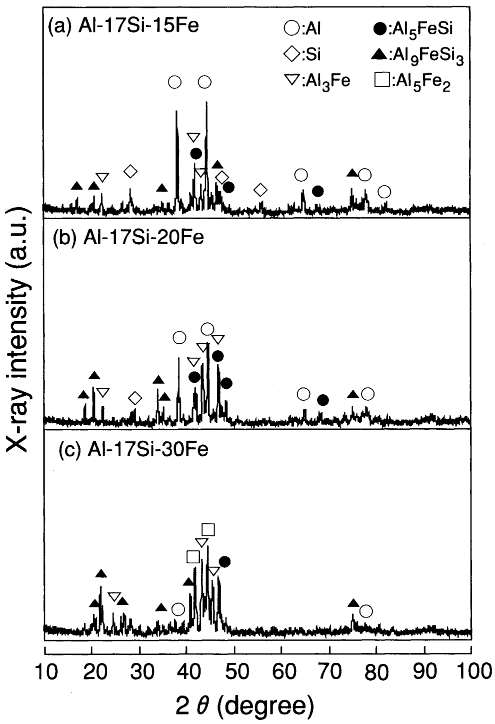

Fig. 2. X-ray diffraction patterns of spray coatings.

with a total sliding distance of 100 mm at a sliding speed 150 mm/s and a load 10 N. The wear resistance was evaluated with the depth of a wear track, and friction coefficient during test was measured.

3. Results and discussion

3.1. Structure

Fig. 1 shows the structures of coatings on the cross-section. A dense layer without cracking was made up

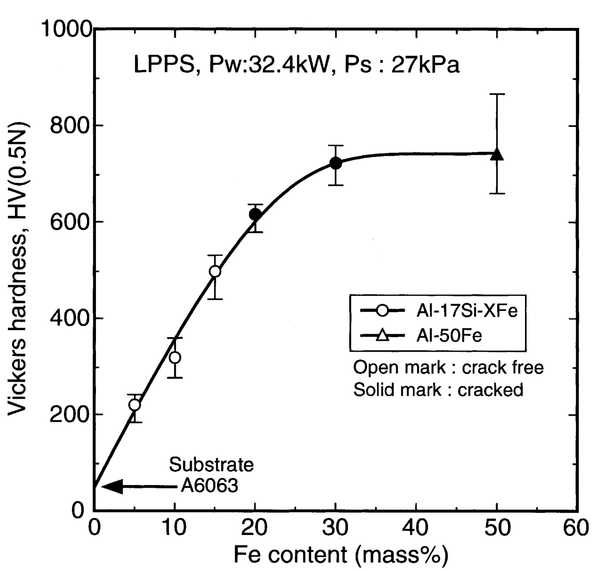

Fig. 3. Effect of Fe content on hardness of spray coatings.

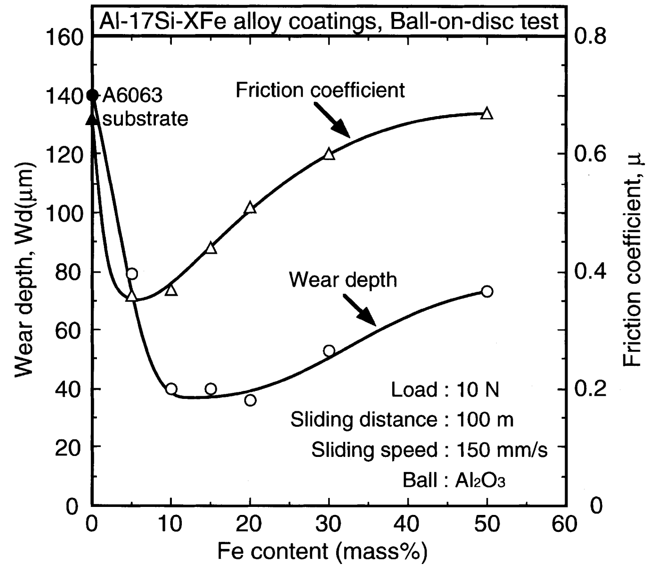

Fig. 4. Effect of Fe content on wear depth and friction coefficient of spray coatings evaluated by ball-on-disc test.

to 15 mass% Fe. At more Fe content, the cracking occurred both in the coatings and the interface between coatings and the substrate, and became severe with increasing Fe content.

Typical X-ray diffraction patterns obtained from the surface of the coating are collectively shown in Fig. 2. Up to 15 mass% Fe, X-ray pattern consists dominantly of strong peaks of α-Al together with weak peaks corresponding to Si and intermetallic compounds, Al_3Fe, Al_9FeSi_3 and Al_5FeSi. This means that coating structure is a compound-dispersed type in Al alloy matrix. In addition, similar pattern is observed at 20 mass% Fe, but peaks from the intermetallic compound became strong relatively against α-Al peaks. Thus, apparently the increase in Fe content increased the amount of intermetallic compounds. On the contrary, at more than 30 mass% Fe, α-Al peak was very weak; almost difficult to detect, and intermetallic compounds, Al_5Fe_2 became dominant in the coatings. As these intermetallic compounds are inherently brittle, they caused the cracking in the coatings and/or in the interface between the substrate and the coating. The maximum content of Fe to allow a crack-free coating is made clear to be 15 mass% in this alloy system discussed.

3.2. Hardness

The hardness of the coatings was much higher than that of the substrate (50 HV). The mean hardness of each coating increased linearly with increasing Fe content up to 20 mass% Fe as shown in Fig. 3, in which filled marks indicate the cracking in the coating. It seems that hardness increase results from dispersion strengthening mainly by intermetallic compounds and partly by primary Si particles. At more than 30 mass% Fe the hardness value saturated approximately 700–800 HV, which corresponds roughly to that of iron aluminide [7].

3.3. Wear property

Fig. 4 shows the effect of Fe content on the wear depth and mean value of friction coefficient during ball-on-disc sliding wear test. Wear depth decreased sharply with increasing Fe content and showed the minimum at 10–20 mass%, and then increased gradually at more than 30 mass% due to the brittleness of the coating. As to friction coefficient, the minimum value was obtained at 5 and 10 mass%, and almost linearly increased with increasing Fe content to the same level of the substrate at more than 30 mass%. Fig. 5 shows actual variation of friction coefficient during wear test. Large variation in friction coefficient of the substrate was due to severe adhesion to a counter ball. In 5 mass% Fe coating, at the beginning of the test, friction coefficient was small and stable, but at the last stage a large variation occurred due to adhesion to the counter ball. The coatings with 10–20 mass% Fe showed almost a constant value during wear test as representatively shown with 15 mass% Fe. Actually, the adhesion to the counter ball was a little in these coatings. However, progressive increase in friction coefficient during test was observed at 30 and 50 mass% Fe, which is due to the break of the coatings. Thus, these results indicate the most beneficial coating with high wear resistance and low friction coefficient can be obtained at 10–15 mass% Fe.

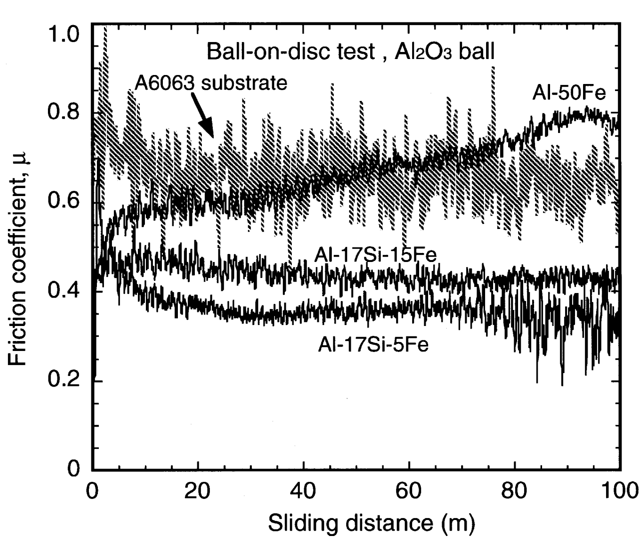

Fig. 5. Variation of friction coefficient during wear test, 10 N, 150 mm/s.

4. Conclusions

Al–17 mass% Si–*X* mass% Fe Al alloys with different Fe content from 5 to 30 mass% and Al–50 mass% Fe alloy powders were thermal-sprayed on Al alloy substrate by low pressure plasma spraying, and wear property of the coatings was evaluated. Conclusive remarks are as follow,

(1) Dense coatings without cracking and peeling were formed with powders containing up to approximately 15 mass% Fe. Spray coatings consisted of Al–Si hypereutectic structure with Al–Fe–Si and Al–Fe intermetallic compounds up to 20 mass% Fe, and consisted almost fully of these compounds at 30 mass% Fe and more. Hardness of the spray coatings increased monotonically with increasing Fe content and reached approximately 700 HV at more than 30 mass% Fe due to increasing volume fraction of hard intermetallic compounds.

(2) The highest wear resistance of the coatings was obtained with Fe content of 10–20 mass%, which was four times of the substrate. Higher Fe content decreased the wear resistance due to the brittleness of intermetallic compounds.

(3) The lowest friction coefficient was obtained with Fe content of 5–10 mass%, which was 0.36–0.37, and increased monotonically with increasing Fe content.

(4) The most beneficial coating can be obtained with Al–17 mass% Si–10 to 15 mass% Fe alloy powders with good wear resistance and low friction coefficient without cracking and peeling in the coating and the interface between the substrate.

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