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Hard thick-film and wear resistance of Al–50Si–10M ternary alloys on A6063 aluminum alloy coated by low pressure plasma spraying

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Abstract

Aluminum-based hard thick-films were coated on A6063 aluminum alloy with a binary alloy powder of Al–50Si and three ternary alloy powders of Al–50Si–10Mg, Al–50Si–10Cu and Al–50Si–10Co by low pressure plasma spraying in Ar–H_2 atmosphere. Experimental results show that thick-films were compact without large porosity and cracking in them or at interface between coated films and base metal, and intermetallic compounds of Mg_2Si, $CuAl_2$ and Co_2Al_9 were dispersedly precipitated in their matrix by X-ray diffraction analysis. Compared with hardness of A6063 base metal (45 HV), hardness of coated films was 250 HV for Al–50Si, 350–400 HV for Al–50Si–10Mg and Al–50Si–10Cu, and 650 HV for Al–50Si–10Co. The hardness was obviously modified by dispersion strengthening mainly from precipitated intermetallic phases and partly from primary Si particles. Wear property was determined by ball-on-disc sliding wear test under Al_2O_3 ball revealed that friction coefficient of coated films was decreased from 0.61 to 0.34 and wear depth was remarkably reduced as one third as that of A6063 since dispersion hardening of those intermetallic phases is beneficial to improvement of wear resistance.

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Keywords: Plasma spraying; Aluminum alloy; Ternary alloy; Thick-film; Wear resistance

1. Introduction

Aluminum and its alloys are very important metallic structural materials, and widely used in various industrial areas and daily life due to their many good properties. However, they often suffer severe damage under the failure of wear [1], so that their extensive use is restricted. In order to reinforce Al alloy matrix and to improve its wear resistance, many kinds of surface modification processes have been developed, such as layer alloying [2–4], alumina coating [5], PVD hard coating [6], sputter-deposited thin film [7], rutile-TiO_2 coating [8], micro-arc discharge oxide coating [9], plasma-nitrided coating [10], plasma immersion ion implantation coating [11], plasma-sprayed thick coating [12–14] and some combination of those methods [7,15,16]. Among these coating processes, thermal plasma spraying is a superior one, capable of coating a thick-film in short operating time. Al-based alloy material is beneficial as a kind of coating materials [12]. The authors have studied the wear resistance of Al alloy layer coated on Al alloy substrate by using highly-alloyed Al powders with Si and / or Fe [12–14].

In present work, we selected Al–50Si binary alloy powder and Al–50Si–10M (Magnesium, Copper and Cobalt respectively) ternary alloy powders as coated materials to deposit aluminum-based hard thick-films on base metal surface of A6063 aluminum alloy by low pressure plasma spraying in Ar–H_2 atmosphere. The

Table 1
Chemical composition of base metal and plasma spray powders

Alloy		Chemical composition (mass %)			
		Si	Mg	Cu	Co
Base metal	A6063	0.45	0.55	–	–
	Al–50Si	45.5	–	–	–
	Al–50Si–10Mg	47.7	9.8	–	–
Powder	Al–50Si–10Cu	48.1	–	9.1	–
	Al–50Si–10Co	46.9	–	–	9.7

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Table 2
Conditions of low pressure plasma spraying

Item	Data
Main plasma gas flow (Ar)	4.7×10^{-2} (m^3/min)
Secondary plasma gas flow (H_2)	0.7×10^{-2} (m^3/min)
Chamber pressure	27 (kPa)
Plasma power	32.4 (kW)
Arc current	600 (A)
Arc voltage	54 (V)
Spray distance	250 (mm)
Rotating speed of specimen holder	70 (rpm)
Traverse speed of specimen holder	300 (mm/min)
Feed rate of powder	20 (cc/min)

Table 3
Parameters of ball-on-disc sliding wear test

Parameter	Data
Load	10 (N)
Sliding speed	150 (mm/s)
Total sliding distance	100 (m)
Ball (diameter)	Al_2O_3 (6.35 mm)

precipitated phase, microstructure and microhardness of coated films were analyzed, and their wear property was evaluated by ball-on-disc sliding wear test. The wear feature and effects on wear resistance were discussed.

2. Experimental

2.1. Materials

The base metal of an aluminum alloy (A6063) was used, which plate dimension was 50 mm wide, 60 mm long and 6 mm thick. Four types of plasma spray materials, that is, binary alloy powder of Al–50 mass % Si and three ternary alloy powders of Al–50 mass% Si–10 mass% M (Mg, Cu and Co respectively), were utilized. The spray powders were made with a rapid solidification method by atomizing molten alloys into running water. Powders granularity was the range between 53 and 105 μm, and mean diameter was approximately 80 μm. Table 1 shows chemical composition of the base metal and plasma spray powders.

2.2. Plasma spraying process

Low pressure plasma spraying (LPPS) in a vacuum chamber was employed to prevent oxidation of the powder during spraying. Table 2 gives the appropriate spray conditions. An Ar–H_2 gas mixture was used as a plasma gas, and Ar was the carrier gas for powder feed. Before spraying, the surface of base metal was blasted with Al_2O_3 powders of 710–850 μm to clean surface by compressed air blasting equipment. 200 μm thick-films were coated on the surface of A6063 alloy plates with this spray condition. The structures of coated thick-films were analyzed by X-ray diffraction. The microstructures of coated films on cross-section were observed by optical microscopy (OM). Vickers hardness along spray-coated cross-section was measured with a 0.5 N load.

2.3. Wear testing

The wear testing of coated thick-films was performed by a ball-on-disc type sliding wear test in air without lubricant with using Al_2O_3 ceramic counter ball. Wear test parameters are shown in Table 3. The wear resistance was evaluated with the depth of a wear trace, and friction coefficient during test was determined. The wear trace character and surface appearance of Al_2O_3 ball were observed.

3. Results and discussion

3.1. Precipitated phases

Fig. 1 shows typical X-ray diffraction patterns gained from the surfaces of coated films on A6063 plates. In Fig. 1a for Al–50Si binary alloy, it mainly consists of strong peaks of α—Al together

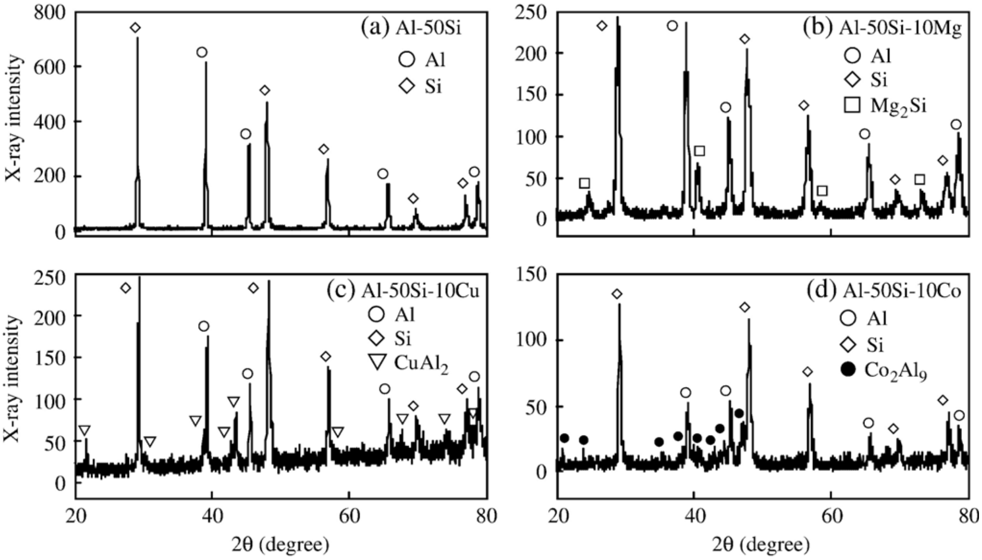

Fig. 1. X-ray diffraction patterns of coated thick-films by LPPS.

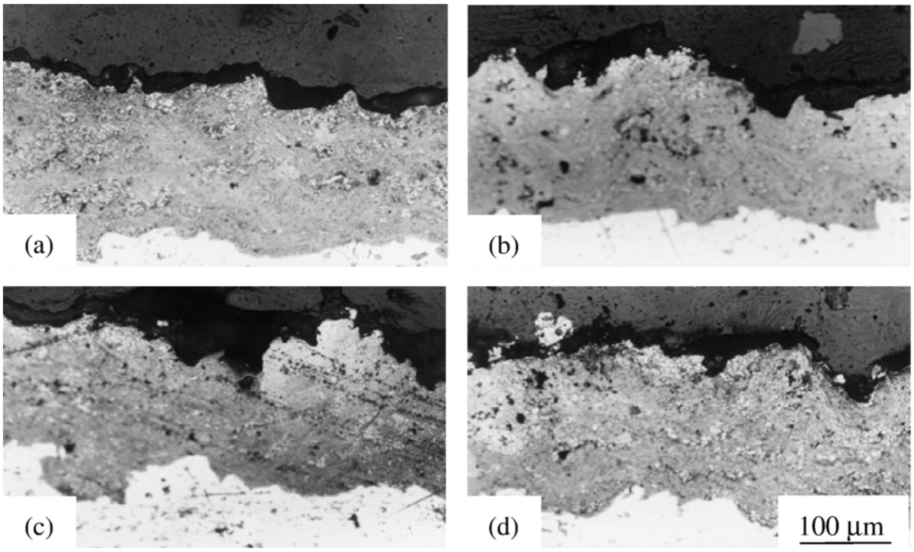

Fig. 2. Optical microstructures of coated films on cross-section, (a) Al–50Si, (b) Al–50Si–10Mg, (c) Al–50Si–10Cu, (d) Al–50Si–10Co.

with primary Si. When added 10 mass % Mg to Al–50Si, that is Al–50Si–10Mg ternary alloy in Fig. 1b, intermetallic compound of Mg_2Si was precipitated in its matrix. $CuAl_2$ and Co_2Al_9 intermetallic compounds were precipitated in Fig. 1c,d for Al–50Si–10Cu and Al–50Si–10Co respectively, thus α—Al peaks became weak. Their microstructures on the cross-section, as shown in Fig. 2, reveal that the coated thick-films were compact without large porosity and cracking in them or at interface between coated film and base metal. In Fig. 2a, many primary Si particles in Al alloy matrix were formed and the volume fraction of primary Si particles was high. In Fig. 2b primary Si particles decreased as precipitated Mg_2Si, but porosities appeared because magnesium is very active. It has been found that intermetallic phases of Mg_2Si, $CuAl_2$ and Co_2Al_9 were dispersedly distributed in the matrix. It means that coated film structure is a compound-dispersed type in Al alloy matrix.

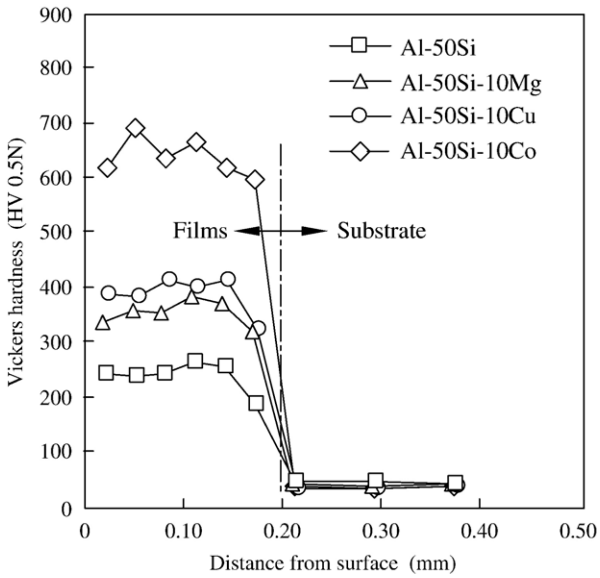

Fig. 3. Hardness distribution in cross-section of coated thick-films on A6063 plate.

3.2. Microhardness

The micro Vickers hardness distribution is shown in Fig. 3 along cross-sections of coated thick-films on A6063 plate. As contrasted with hardness of base metal (45 HV), the hardness of coated films was much high. That is, it was examined as 250 HV for Al–50Si, 350–400 HV for Al–50Si–10Mg and Al–50Si–10Cu, and 650 HV for Al–50Si–10Co. The distinct increase in hardness results from that intermetallic compounds of Mg_2Si, $CuAl_2$ and Co_2Al_9 are dispersedly precipitated on their matrix containing primary Si particles, therefore the matrix was improved by dispersion strengthening mainly from intermetallic compounds and partly from primary Si particles. Harder, larger and more Co_2Al_9 precipitated in the matrix contributed to higher hardness of the coated film.

3.3. Wear resistance

Table 4 shows the wear property of plasma-coated thick-films by ball-on-disc sliding wear test. The wear depths of coated films (49.1–36.7 μm) declined markedly as compared with base metal (140.3 μm) measured by a non-contact profile meter, and wear depths of Al–50Si–10M (Mg, Cu and Co) ternary alloy powders were smaller than that of Al–50Si binary

Table 4
Sliding wear property of plasma-coated thick-films

Alloy		Wear property	
		Wear depth (μm)	Friction coefficient
Base metal	A6063	140.3	0.61
	Al–50Si	49.1	0.39
Coated film	Al–50Si–10Mg	39.6	0.35
	Al–50Si–10Cu	36.7	0.40
	Al–50Si–10Co	40.6	0.34

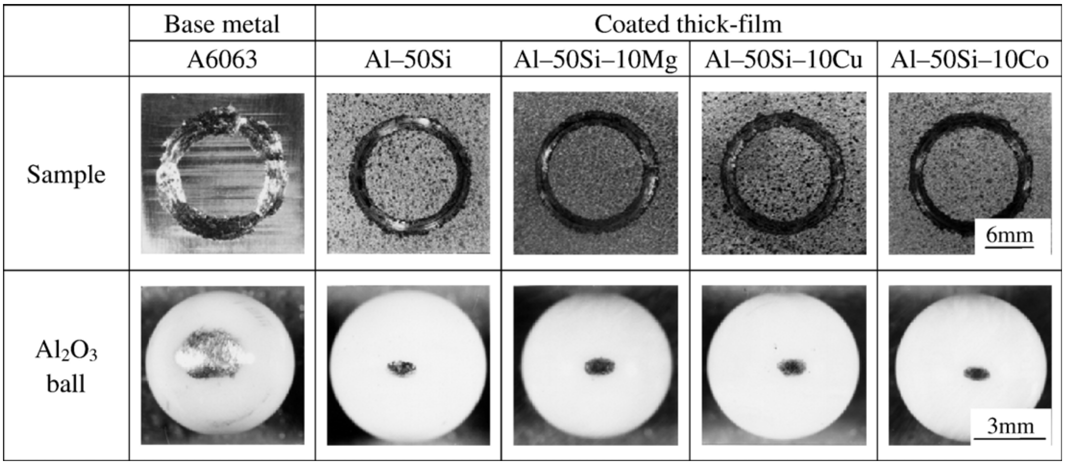

Fig. 4. Wear trace and surface appearance of Al_2O_3 ball after sliding wear test.

alloy powder. Similarly, the mean friction coefficient decreased from 0.61 (A6063) to 0.40–0.34 (coated films).

Fig. 4 shows wear trace on the wear tested surfaces and surface appearance of Al_2O_3 balls after ball-on-disc test. Observing Al_2O_3 ball appearances, it can be found some adhesion to alloys on their surfaces. The base metal shows severe surface damage and much adhesion to the surface of Al_2O_3 ball, whereas coated films show better wear resistance on their surfaces and less adhesion to Al_2O_3 ball. These photos display clearly the effect of coated thick-films on improvement of wear resistance.

Thick-film coated with Al–50Si–10Co ternary alloy powder was much big in hardness, thus its friction coefficient was the lowest. But its microstructure got brittle, so that the wear depth was not least. Film coated with Al–50Si binary alloy powder was not so harder than Al–50Si–10M ternary alloy powders, so its wear depth was a little deeper. To sum up, ternary alloy system of Al–50Si–10M is considered to be more effective for anti-wear property plasma-coated on aluminum alloy.

4. Conclusions

The aluminum-based alloy hard films of 200 μm in thickness were coated on the surface of A6063 aluminum alloy plate with four alloy powders, that is an Al–50Si binary alloy powder and three Al–50Si–10M (Mg, Cu and Co respectively) ternary alloy powders, by using a low pressure plasma spraying in Ar–H_2 atmosphere in order to reinforce Al alloy matrix and to improve wear resistance. The microhardness of coated films was 250 HV for Al–50Si, 350–400 HV for Al–50Si–10Mg and Al–50Si–10Cu, and 650 HV for Al–50Si–10Co. Compared with the hardness of A6063 base metal (45 HV), the distinct increase in hardness results from that intermetallic compounds of Mg_2Si, $CuAl_2$ and Co_2Al_9 were dispersedly precipitated in their matrix containing primary Si particles as characterized by X-ray diffraction and OM. The wear property determined by ball-on-disc sliding wear test under Al_2O_3 ball shows that wear depth was markedly reduced as one third as that of base metal, and friction coefficient of coated films was decreased from 0.61 to 0.34. In contrast to coated film with Al–50Si binary alloy powder, the wear resistance of coated films with Al–50Si–10M ternary alloy powders was modified since the dispersion hardening of intermetallic phases is beneficial to wear property by added alloys of Mg, Cu and Co.

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