EVALUATION OF Al-Si/ POLYESTER ABRADABLE SEAL COATING①

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ABSTRACT Abradability and erosion resistance of the seal coatings were evaluated by sliding wear and erosion respectively. The results show that the mechanism of sliding wear is ploughing wear accompanying with adhesive wear and oxidation wear. The friction coefficient decreases because polyester film forms on the surface of the counterpart during wear. The erosion resistance of the coating is mainly dependent on the hardness, but polyester does increase erosion resistance at high impact angle due to its cushion effect.

Key words seal coating aluminum-silicon/ polyester abradability erosion resistance

1 INTRODUCTION

The clearance between the rotor blades and the casing should be as small as possible in order to increase the efficiency of an aircraft turbine engine. Thermally sprayed abradable seal coatings are usually used for this purpose. The rotating blades scrape the coating and form the minimum clearance without damaging the blades[1]. Abradable seal coatings are mostly composed of metal phase and self-lubricating non-metal phase. The coating requires not only softness to be scraped easily but also high resistance against erosion by the solid particles in the gas. So, the coating should provide a good balance between abradability and erosion resistance.

Aluminum-silicon/ polyester powder was developed by Metco for the seal coating in the 1970s. The optimization of composition and spraying parameters were based on the trial and error method by field testing[2]. However the expensive platform test cannot evaluate abradability and erosion resistance separately. Since the criteria for quality control have not been developed, this paper studies the abradability and erosion wear behaviour of the plasma sprayed Metco601 and KF601 coatings.

2 EXPERIMENTAL

Two kinds of 601 powders named Metco601 and KF601 with 140 mesh were used. The composition of 601 is 60% Al-12%Si alloy and 40% polyester. Coatings were sprayed on the blasted low carbon steel plates by a Metco7-MB plasma spray system. The thickness of the coatings was about 1.5 mm. Some properties of the coatings are shown in Table 1. Fig. 1 shows the microstructure in the cross section of the M601-2 coating, and the black phase is polyester.

Abradability evaluated by sliding wear was carried out on an M-200 wear testing machine using the form of block-ring. The block specimen was coated and the counterpart ring with 36 mm in diameter was made of hardened AISI52100 steel. The sliding speed was 0.377 m/s and the test loads were 40, 70 and 100 N for 1 h without lubricant. The worn volume was calculated by the width and length of the scar and it was used to evaluate the abradability.

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Table 1 Hardness and microstructure of coating specimens

Specimen	Hardness HR15y	Volume percent/%		
		Metal phase	Non-metal phase	Porosity
M601-1	51	29.4	68.6	2.0
M601-2	53	36.1	62.2	1.7
F601	65	53.9	44.6	1.5

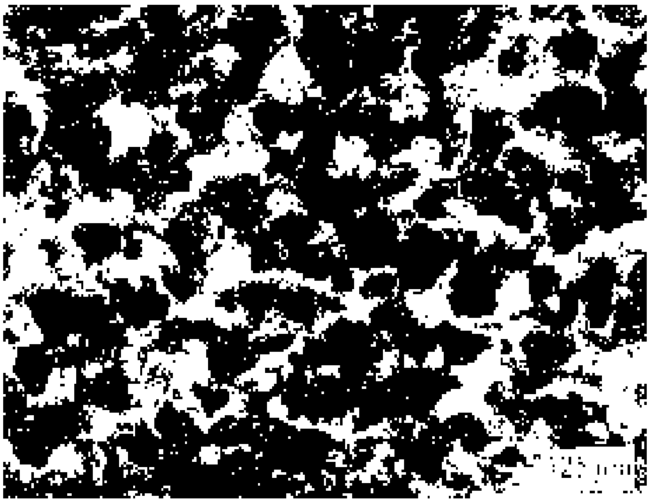

Fig. 1 Microstructure of M601-2

Erosion test was made on a CMS-100 self-made erosion machine in a 1.3~ 6.5 Pa chamber[3]. The abrasive particle was 100 mesh corundum whose feeding rate was 16g/min. The impact angles were 30, 60 and 90°. Erosion time and impact speed were changed for some specimens. The ratio of the weight loss of the specimen to the mass of the grit is called erosion rate, $E/mg \cdot g^{-1}$.

3 RESULTS AND DISCUSSION

3.1 Abradability of the coating

Fig. 2 shows that the worn volume increases with the increase of the load. Even the hardness of F601 is higher yet, the worn volume of F601 is larger than that of M601. The friction coefficients change little with the increase of load and wear time.

EDAX analysis shows that oxygen is involved on the worn surface and scrapes. The result shows there is oxidation wear. The existence of Fe from the counterpart on the worn surface of the coating indicates that adhesion occurs. Fig. 3 shows ploughing ditches are clearly exhibited on the metal phases and non-metal phases. The abrasive particles could be hard oxides and scrapes produced in the adhesion layer and fallen from the surface.

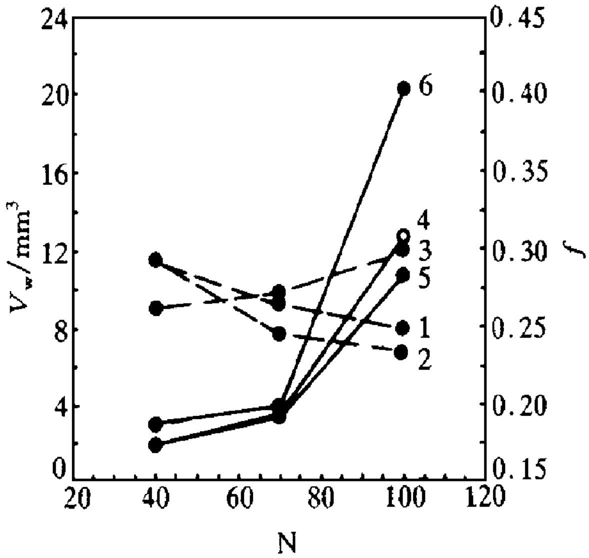

Fig. 2 Effect of test load on worn volume(V_w) and friction coefficient(f)

1—M601-1, f; 2—M601-2, f;
3—F601, f; 4—M601-1, V_w;
5—M601-2, V_w; 6—F601, V_w

Fig. 3 Worn morphology of M601-2

In comparison with the other seal coating materials which use graphite as non-metal phase, polyester holds better self-lubricating behavior with lower friction coefficient in wear. It was found that a layer of polyester film formed on the surface of the counterpart after testing. Friction occured between the film and the coating, thus the adhesive wear of 601 kind of coating was lighter than that of coatings with graphite[4].

3.2 Erosion wear behavior of coating

Fig. 4 shows the relation between impact speed V, and erosion rate E. The regression analysis shows

$$E = CV^n \quad (1)$$

where C is constant, n is speed exponent. Table 2 shows C and n values of regression analysis at different impact angles.

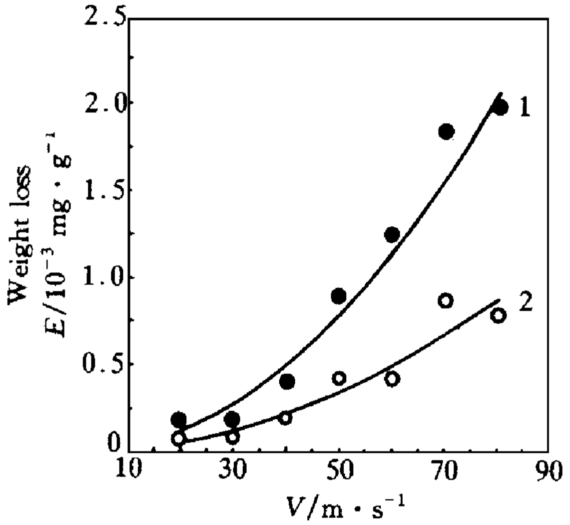

Fig. 4 Effect of impact speed on erosion rate
1—M601-1; 2—F601

Table 2 indicates that the speed exponent depends on impact angle. The different exponents result from different mechanisms of erosion wear at different impact angles. n increases with the increase of impact angle. This shows that the increase of impact speed leads to remarkable increase of erosion rate, the maximum weight loss moves to a higher angle with the increase of impact speed. Therefore the coating basically displays its erosion behavior as a brittle material. At low impact angle, the speed exponent of the coating is close to that of plastic material, yet, at 60 and 90° the exponent n is larger than that of brittle materials. This is related to the embrittleness of the coating at the high impact angle and high impact speed, pores and crack effect of weak bond between metal phase and non-metal phase.

Fig. 5 shows erosion rate vs impact angle and the erosion rate is largest at 60°. Micro-cutting traces at a low impact angle are observed in Fig. 6(a). According to the micro-cutting model[5] of plastic material, when the impact angle is larger than a critical value, the erosion rate is

$$E = KMV^2\cos^2\alpha/12p \quad (2)$$

where K is cutting wear coefficient, M is total mass of abrasive, p is plastic flow stress of material eroded, V is impact speed, α is impact angle. Eq. (2) shows that erosion rate decreases with the increase of impact angle.

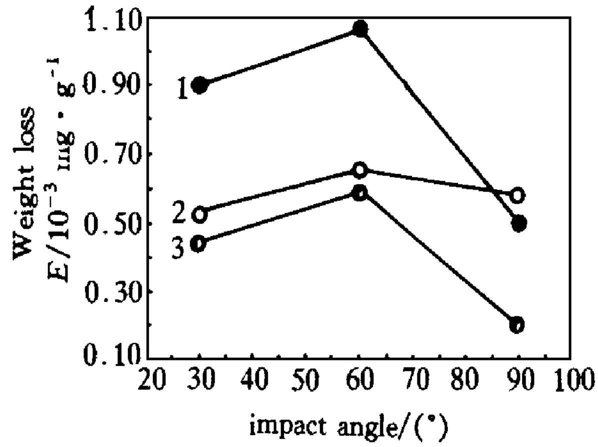

Fig. 5 Effect of impact angle on weight loss(E)
(impact speed is 50 m/s)
1—M601-1, HR15y= 51; 2—M601-2, HR15y= 53; 3—F601, HR15y= 65

For impact indenting model, as the impact angle increases, the fraction of normal impact increases and indentations on the surface are observed in Fig. 6(b). Using energy balance equation, the erosion rate can be obtained as:

$$E = 0.5M(V\sin\alpha - V_c^2)/\varepsilon \quad (3)$$

where V_c is the critical impact speed for an abrasive particle to produce an indentation, ε is indenting wear coefficient. Eq. (3) indicates that erosion rate increases with the increase of impact angle. Thus, the maximum erosion rate at 60° results from the balance of micro-cutting at low impact angle and indentation at high impact angle.

The indentations and extruded lips are seen in Fig. 6(b). This shows that at 90° impact angle, the abrasive particles impinged on the surface of metal phase in the coating producing indentations and extruded lips. Then the lips impinged repeatly by impact particles became work-hardened and fell off. It's also noticed that the metal phase around polyester was eroded firstly, then polyester lost its support and fell away. Polyester stays longer than graphite in other type of seal coating because it can hold high elastic strain and absorb impact energy of abrasive particles. The cushion effect leads to high erosion resistance of the coating. Usually, the soft nonmetal phase in the seal coating would be eroded away first and reduces the erosion resistance. But polyester, under high angle impact, can exist longer than the metal phase, thus the erosion resistance is increased.

Fig. 5 also shows the relation between erosion rate and coating hardness, the erosion resistance increases with the increase of hardness of coating. But the erosion rate of M601-1 coating which is softer than M601-2, is lower than that of M601-2 at 90°, it is simply because that M601-1 has more polyester than M601-2.

Table 2 Results of regression analysis of E - V

Specimen	30°		60°		90°	
	$c/10^{-4}$	n	$c/10^{-6}$	n	$c/10^{-6}$	n
M601-1	2.98	2.02	6.69	3.00	2.25	3.22
F601	1.63	1.96	6.35	2.83	8.05	3.26

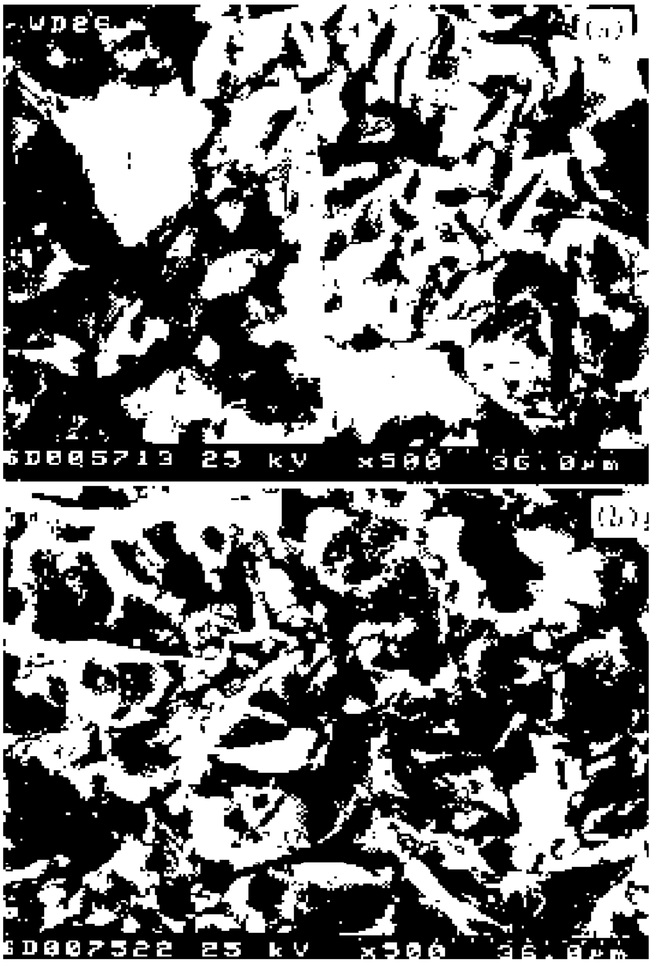

Fig. 6 Erosion worn morphology
(a) —30°, 50 m/s; (b) —90°, 50 m/s

Naturally, the erosion resistance of seal coatings mainly depends on the hardness. But, polyester may also play a role on the improvement of erosion resistance.

4 CONCLUSIONS

(1) The sliding wear mechanism of the coating is ploughing accompanying with adhesive wear and oxidation wear.

(2) During wear, polyester film formed on the surface of the counterpart, and resulted in a decrease of friction coefficient of the coating.

(3) At 60° impact erosion, the coating holds a maximum erosion rate. The relation between erosion rate and impact speed is exponential function. The speed exponent increases with the increase of the impact angle.

(4) At high angle impact, abrasive particles impinge on the surface of coating, and produce indentations and extruded lips. Then, the lips fall off. At low angle, erosion mechanism ismicro-cutting.

(5) Erosion resistance of the coating depends mainly on the hardness of the coating. But polyester in the coating plays a role of a cushion to the impact and increases the erosion resistance.

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