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Materials

Abrasive wear behaviors of high velocity arc sprayed iron aluminum composite coatings

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Abstract: The High Velocity Arc Spraying (HVAS) technology was used to prepare Fe-Al composite coatings by the adding of different elements into cored wires to obtain different Fe-Al coatings. The added compounds do great effect on the properties of the composite coatings. The microstructures and abrasive wear performances of the coatings were assessed by transmission electron microscopy (TEM), scanning electron microscopy (SEM), and THT07-135 high temperature wear equipment. It was found that the adding of Cr_3C_2 can greatly increase the room temperature wear behavior, and Fe-Al/WC coatings have adapting periods at the beginning of wear experiment. With the rise of temperature, the wear resistance of Fe-Al/Cr_3C_2 coatings becomes bad from room temperature to 250°C, and then stable from 250°C to 550°C; the wear resistance of Fe-Al/WC becomes well with the rise of temperature. The adding of Cr and Ni can also improve wear performances of Fe-Al composite coatings.

Key words: high velocity arc spraying; iron aluminum composite coatings; chromic carbide; tungsten carbide

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1 Introduction

The Fe-Al matrix composite possesses excellent high temperature oxidation and sulfuration resistance, good erosion resistance, high temperature strength, and low density, and has no expensive elements, so it is an ideally high temperature framework material. However, low room-temperature ductile and bad crack resistance limit its applications. Though its ductile properties had been researched for years, there still have difficulties in industrial production. The Arc Spraying (AS) is a technique that utilizes an electric arc as the heat source to melt wires into droplets, which are subsequently sprayed onto substrates by the flow of compressed air. The High Velocity Arc Spraying (HVAS) technology was developed on the basis of AS. A special tube designed according to the principle of aerodynamics has mounted at the exit of compressed air. Hence, a higher velocity and a better atomizing of melted droplets were obtained. HVAS has all the merits of AS, it can also achieve low porosity (2%), dense structure coatings and high bond strength between coatings and substrates [1-3]. Using HVAS technology to spray iron aluminum powers onto framework substrates can obtain iron aluminum intermetallic coatings that possess good high temperature abrasive and erosion properties. It can avoid defects of Fe-Al matrix composites, and can fully exert virtues of HVAS [4-7].

In this study, HVAS-sprayed Fe-Al, Fe-Al/WC, Fe-Al/Cr_3C_2, and FeAlCr/Ni wrapped Cr_3C_2 composite coatings were synthesized using HVAS technology combined cored wires; the wear behaviors especially high temperature wear behaviors of HVAS-sprayed iron aluminum coatings were investigated. The coatings and substrates were isothermally treated at 25, 200, 250, 300, 450, 550, and 600°C at different loads. The microstructures, elements of coatings, and wear characteristics were studied by SEM and TEM [8-9].

2 Experimental

2.1 Materials

Four types of iron aluminum cored wires of $\phi 3$ mm were used in this work. They were fabricated on welding wire equipment by stretching steel band and wrapping powers into the band. The steel band is an excellent low carbon steel, it had good ductile properties and can be stretched continually. The added powers into cored wires include Fe, Al, WC, Cr, Cr_3C_2,

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and Ni wrapped Cr_3C_2. The substrates used in spraying were the high press boiler steel of which the carbon content is 0.2wt% (20 grade steel).

2.2 HVAS spraying

The spraying facility was CMD-AS300 type HVAS equipment and HAS-01 type torch. The substrates were machined into specimens of ϕ25 mm×7.7 mm, they were grit-blasted on one side to clean and roughen the surface. The specimens were then placed under the nozzle and blown by compressed air to clean again. The parameters used in spraying are listed in following: spraying voltage, 32 V; spraying current, 180 A; air pressure, 0.55MPa; spraying distance, 300 mm.

2.3 Microstructure characterization

The morphologies of the coatings were investigated using a Philips Quanta 200 scanning electron microscope (SEM) utilizing secondary and back scattered electron imaging. The composition of the coatings was studied with a H800 transmission electron microscope. The coatings were heated at 650°C for 0.5h in a resistance stove, and then cooled, their heat tremble bond strength was tested.

2.4 Wear testing

The samples were tested using the high temperature THT07-135 equipment made in Switzerland. The counter parts were fused into fused Si_3N_4 balls of ϕ3 mm; the wear rate was 0.8 m/s, and the wear diameter was 5 mm, the wear distance was 500 m. Tests were taken at room temperature, 200, 250, 300, 450, 550, and 600°C. The worn coatings were tested by SEM.

3 Results

3.1 Friction coefficient and wear rate

The friction coefficient and the wear rate are shown in **figures 1 and 2.** The following conclusions may be drawn from these figures.

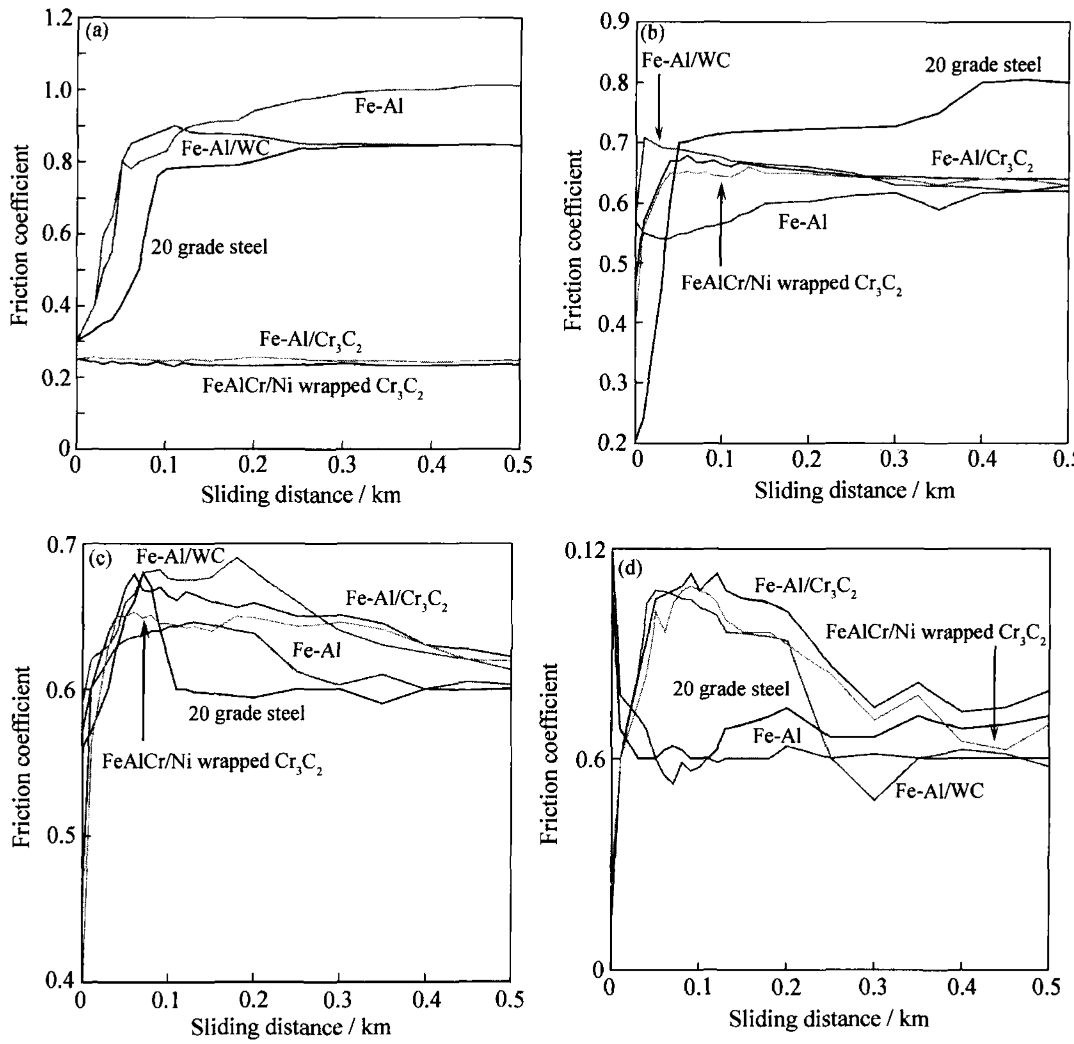

Figure 1 Friction coefficients at different sliding distances: (a) r=25°C, *P=S* N, v=0.8 m/s; (b) *T*=300°C, *P=5* N, v=0.8 m/s; (c) *T*=450°C, P=5 N, v=0.8 m/s; (d) r=550°C, *P=5* N, v=0.8 m/s.

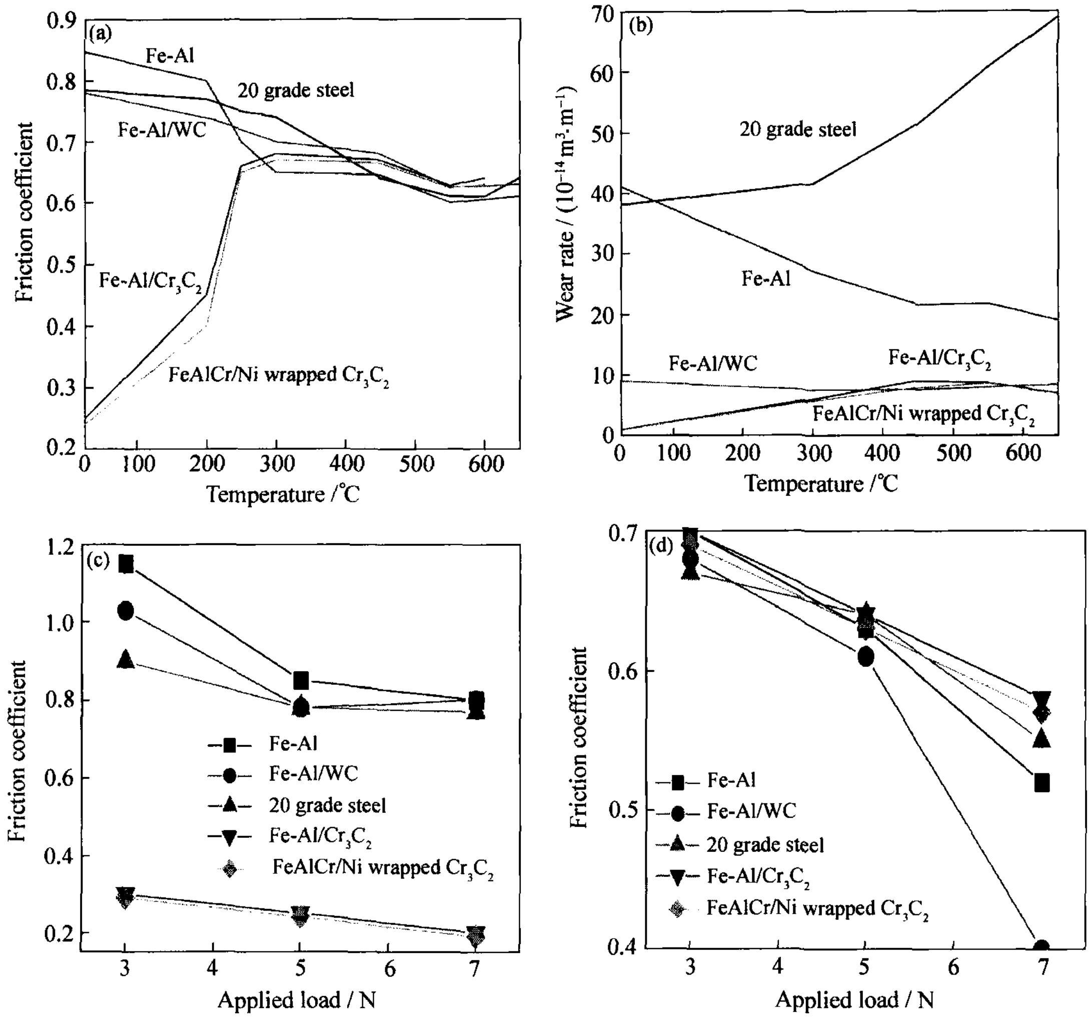

Figure 2 Friction coefficients and wear rates at different temperatures and loads: (a) 5=0.5 km, *P*=5 N, v=0.8 m/s; (b) S=0.5 km, *P*=5 N, v=0.8 m/s; (c) *T*=25°C, S=0.5 km, v=0.8 m/s; (d) T=650°C, S=0.5 km, v=0.8 m/s.

The wear resistances of the materials are different. At room temperature, the friction coefficients of the substrates, Fe-Al, and Fe-Al/WC coatings increase with the increase of sliding distance at the beginning of sliding, then become stable; the friction coefficients of Fe-Al/Cr_3C_2 and FeAlCr/Ni wrapped Cr_3C_2 are low and stable. At 300°C, the friction coefficient transformations of all the materials are almost the same; the friction coefficient of the substrates is higher than that of the coatings. The friction coefficients of the materials at high temperature are nearly the same, but the friction coefficient of Fe-Al coatings is lower than those of other materials. The friction coefficients of the materials are also affected by temperature. With the rise of temperature, the friction coefficients of the substrates, Fe-Al and Fe-Al/WC coatings become low and stable over 550°C; the friction coefficients of Fe-Al/Cr_3C_2 and FeAlCr/Ni wrapped Cr_3C_2 are low at room temperature, then high at 200°C, increase with the rise of temperature from room temperature to 250°C, finally become stable. The friction coefficients of the materials are also affected by applied load, with the rise of load, the friction coefficients become low at room temperature and high temperatures.

It is also found that the wear rates of the materials are affected by temperature. The wear rate of the substrates is always increased with the rise of temperature, it concludes that the wear resistance of the substrates becomes worse with the rise of temperature. The wear rate of Fe-Al coatings becomes low with the rise of temperature, it concludes that Fe-Al coatings have good high temperature wear resistance. Fe-Al/WC coatings possess stable wear resistance with the change of temperature. The wear rates of Fe-Al/Cr_3C_2 and FeAlCr/Ni wrapped Cr_3C_2 coatings are low at room temperature, and then become stable at high temperature. As a result, they have excellent room-temperature wear resistance.

3.2 SEM of worn surfaces

Figure 3 shows the SEM morphologies of the worn surfaces. It can be found that the worn characteristics of the coatings are different at different temperatures. The Fe-Al coatings show the lowest wear resistance at

550°C, but have the same trend as Fe-Al/WC and Fe-Al/Cr_3C_2, they all present wide scars and black oxidations on the worn surfaces. The Fe-Al/Cr_3C_2 coatings at room temperature have the best wear resistance. They present low and slim scars and no black oxidations.

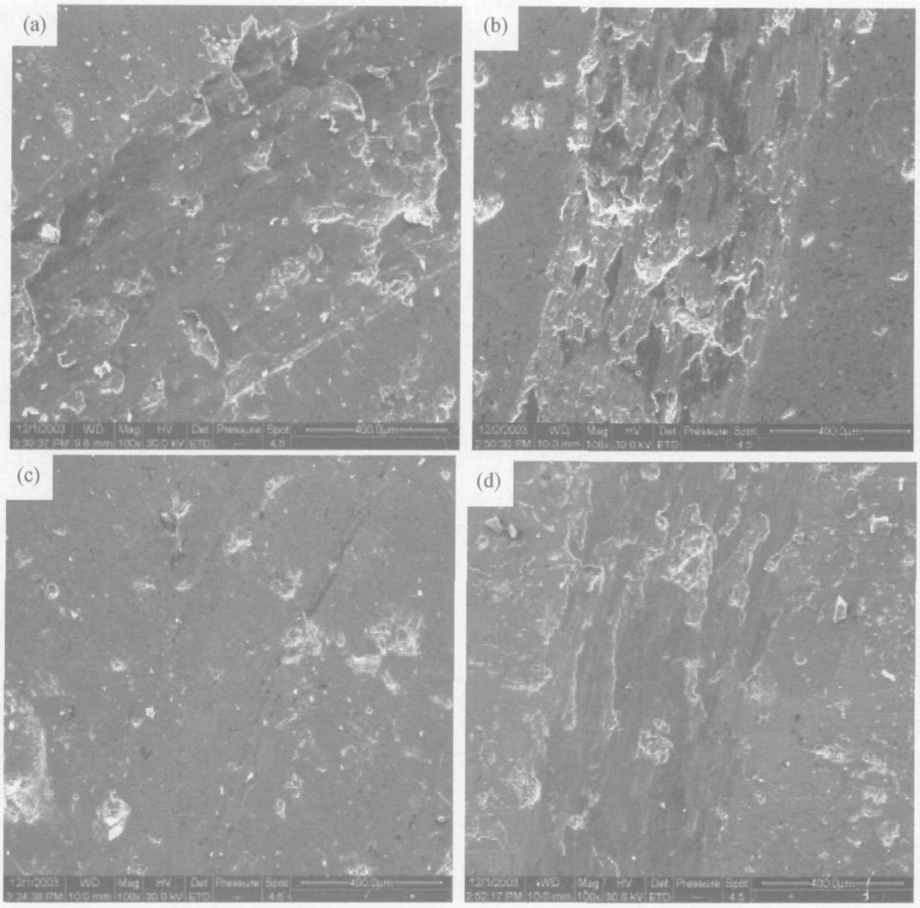

Figure 3 SEM morphologies of worn coatings: (a) Fe-Al coating at 550°C; (b) Fe-Al/WC coating at 550°C; (c) Fe-Al/Cr_3C_2 coating at 25°C; (d) Fe-Al/Cr_3C_2 coating at 550°C.

4 Discussion

At room temperature, the substrates, Fe-Al and Fe-Al/WC coatings have adapting periods at the beginning. The reason is that they have low room-temperature wear resistance and low room-temperature ductile properties. With time going on, the temperature at worn places becomes high, there will be some oxidations and these can protect the surface of coatings, and then wear resistance becomes stable. Cr can increase the ductile properties of Fe-Al intermetallic matrix compounds and thus increase the wear resistance of coatings at room temperature. It is also found that there are more carbon elements at worn places than other places. The component contrast is shown in **table 1.** Carbon elements can increase the lubrication of coatings' surfaces and then increase the wear resistances.

Table 1 EDS analysis of the wear and non-wear surfaces of Fe-Al/Cr_3C_2 coatings

Place	Composition /wt%				
	C	O	Al	Cr	Fe
Wear place	7.07	6.35	13.56	11.56	61.86
Non-wear place	2.93	4.42	15.15	11.26	66.24

The special compound relationship of Fe-Al/Cr_3C_2 coatings also enhances the wear resistance. The TEM test of Fe-Al/Cr_3C_2 coatings shows that there are (002) FeAl//(202) $AlFe_3C_{0.5}$, (110) α-Al(Fe)//(012) Fe_3C, (110) FeAl//(001) FeO·Al_2O_3, (022) FeO·Al_2O_3//(102) Fe_3C crystal relationships, which can increase the bonding of coatings. The bonding strength of Fe-Al/Cr_3C_2 is 40 MPa in contrast to 20 MPa of Fe-Al/WC. At the surface of Fe-Al/Cr_3C_2 coatings, there have some Cr_3O_2 compounds, which can lower the breaking of Al_3O_2, and thus protect Fe-Al/Cr_3C_2 coatings from being broken during the wear experiment.

At high temperature, the adding of ceramic reinforcements influences the wear resistance. The adding of them can apparently increase the wear resistance of iron aluminum composite coatings. Cr_3C_2 has a good working period at 550-980°C, so the wear resistance of Fe-Al/Cr_3C_2 coatings increases after 550°C. WC can change into W_2C and thus lowers the wear resistance of coatings after 450°C.

5 Conclusions

(1) Fe-Al coatings have a better wear resistance than the substrates with the rise of temperature. The friction coefficients of the substrates, Fe-Al and Fe-Al/WC coatings increase with the increase of sliding distance at the beginning of wear at room temperature; Fe-Al/Cr_3C_2 and FeAlCr/Ni wrapped Cr_3C_2 coatings possess excellent room-temperature wear resistance.

(2) All the coatings have good high-temperature wear resistance. The wear resistance of Fe-Al, Fe-Al/Cr_3C_2 and FeAlCr/Ni wrapped Cr_3C_2 coatings increase with the rise of temperature, but that of Fe-Al/WC is stable.

(3) The wear resistances of all materials become low with the rise of load.

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