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Dry sliding wear behavior of Fe_3Al and Fe_3Al/TiC coatings prepared by HVOF

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ABSTRACT

This investigation aims to reveal the effect of TiC particles on the wear resistance of Fe_3Al/TiC composite coatings against alumina counterbody. The coating feedstock, in powder form, was produced by high-energy ball milling of Fe_3Al, Ti and graphite powders. The coatings were provided by spraying the feedstock on a steel substrate using the High-Velocity Oxy-Fuel (HVOF) technique. The effect of TiC addition on dry sliding wear rates of the coatings at sliding speeds ranging from 0.04 to 0.8 $m.s^{-1}$ and under a constant load of 5 N was studied. Coatings made from pure Fe_3Al exhibited a relatively high wear rate. The Vickers hardness and wear resistance of the coatings increased with increasing TiC content in the Fe_3Al matrix. The wear mechanism strongly depends on the sliding speed and the content of TiC particles. It was observed that at low sliding speed, the predominant wear mechanism of the coatings with 0, 10 and 30 mol.% TiC was fatigue wear, whereas at high sliding speeds, the wear mechanism is oxidation. For Fe_3Al–50 mol.% TiC and Fe_3Al–70 mol.% TiC composites, abrasive and oxidation wear are most likely the dominant wear mechanisms.

1. Introduction

Iron aluminides have recently been identified as potential protective coatings for steel substrates in sulfidation and corrosion resistant applications such as mining, oil sand process and hydroelectric power generation [1,2]. The satisfactory corrosion resistance of the Fe–Al system was first reported in the 1930s [3] and detailed investigations were performed in the 1960s [4,5]. However, limited room temperature ductility (less than 5%) and poor wear resistance at room temperature [6] have been the principal obstacles to the acceptance of Fe–Al alloys in many applications. Incorporation of hard ceramic particles in the iron aluminide matrix is reported to alleviate those disadvantages. Some studies [6,7] have demonstrated that incorporation of hard ceramic particles may improve the tribological properties of iron aluminide coatings. Thus, in many applications under aggressive environments, the use of an iron aluminide coating reinforced with ceramics could be a promising solution.

There are two main categories of techniques by which iron aluminide coatings are being applied over different substrates: (1) a thermal spray process, which is utilized to deposit coatings with thicknesses ranging between few hundred microns to more than 3 mm; and (2) reaction coating process to apply thin coatings with thicknesses less than 20 μm [8]. For many applications involving harsh environments like high temperature corrosive, erosive or abrasive environments, deposition of a relatively thick coating is preferred in order to improve durability. The High-Velocity Oxy-Fuel (HVOF) technique appears to be a convenient process to deposit thick coatings with superior properties at low costs on a variety of metallic substrates [8,9]. It has been reported that iron aluminide coatings made by the HVOF have relatively high densities and good adhesions on many substrates [10–12].

There are few studies on dry sliding wear behavior of TiC-reinforced iron aluminide coatings, and these studies are focused on bulk composites with pre-formed ceramic particles for reinforcement. Chen et al. [13] noted that FeAl intermetallics, having TiC reinforcements, possessed excellent sliding wear resistance. More recently, Zhang et al. [14] found similar results in their studies on the effect of TiC content on the dry sliding wear behavior of the Fe_3Al/TiC composites. However, to the authors' best knowledge, there were no systematic studies undertaken to elucidate the role of in-situ formed ceramic reinforcement content on wear resistance of iron aluminide coatings. In this paper, we report the dry sliding wear behavior of Fe_3Al coatings reinforced with TiC

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particulates formed in-situ by a mechano-chemical reaction between Ti and graphite. The paper highlights the effect of sliding speed and TiC content on wear rates of the composite coatings.

2. Experimental procedure

2.1. Sample preparation

The composite powders were prepared by mechanically alloying commercial iron aluminide (Fe_3Al, 96% purity, Ametek), titanium (Ti, 99.4% purity, Alfa Aesar) and graphite (C, 96% purity, Asbury Graphite Mills) powders. Several compositions were considered and the nominal composition of each sample is given in Table 1. A 300 g batch of each composition was placed in a high-energy ball mill (Zoz, Gmbh, Simoloyer) and milled under argon atmosphere for 6 h. Hardened steel balls and vials were used and the weight ratio of ball-to-powder was 10:1. After milling, heat treatment of the powders was carried out at 1000 °C for 2 h under high vacuum ($\sim 10^{-6}$ mbar).

The composite powders were deposited using a Praxair JP-8000 HVOF spray system with spray parameters listed in Table 2. The spraying parameters were selected based on a previous study conducted in partnership with Praxair Surface Technologies, Inc. on iron aluminide coatings which investigated the influence of various parameters such as oxygen/kerosene ratio, gas pressure and spraying distance on deposition efficiencies and coating characteristics such as residual stress. Mild steel plates (grade AISI1020 with dimensions of 190 mm × 120 mm × 5 mm) were used as substrate material. The substrates were sand-blasted and then washed with acetone and ethanol in order to roughen and clean the surface prior to deposition. Argon was used as the powder carrying gas and kerosene was the fuel during the HVOF thermal spray process.

2.2. Friction and wear testing

Dry sliding wear tests were carried out according to ASTM G99-03 using a pin-on-disk method at room temperature. The wear experiments were performed using an Al_2O_3 ball (6.33 mm diameter with a Vickers hardness of 1600–1700) as a counterpart sliding against the polished coating surface (R_a=0.8 μm). In order to retain the test conditions a new alumina ball was used for each sample. The wear tests were conducted using a total sliding distance of 1000 m and a constant load of 5 N at four different speeds (i.e. 0.04, 0.1, 0.3 and 0.8 $m.s^{-1}$). The worn area of each wear track was scanned using a DEKTAK surface profiler. The volume loss was evaluated using the worn cross sectional area multiplied by the wear track circumference. Finally, the wear rate, K ($mm^3.N^{-1}.m^{-1}$) was calculated based on Eq. (1),

$$K = V/w.s \tag{1}$$

where V (mm^3) is the worn volume, w (N) is the normal load, and s (m) is the total sliding distance. The sliding wear tests for each composition were conducted on three different samples under the same conditions to ensure repeatability of the results. All coatings were however produced using the same feedstock for each composition.

Table 1
Nominal composition of the samples.

Sample	TiC content (mol.%)	Fe_3Al content (mol.%)	Equivalent TiC volume fraction (%)	Equivalent Fe_3Al volume fraction (%)
Fe_3Al	0	100	0	100
Fe_3Al–10TiC	10	90	4	96
Fe_3Al–30TiC	30	70	15	85
Fe_3Al–50TiC	50	50	29	71
Fe_3Al–70TiC	70	30	49	51

2.3. Characterization

The phase content of the feedstock powders was investigated using an X-ray diffractometer (SIEMENS, D5000) equipped with CuK_α radiation. The readings were collected in a 2θ range covering the Fe_3Al and TiC main peaks. A scanning electron microscope (JEOL, 840A) was used to study the microstructure of composite powders, coating cross sections and topographical features of wear tracks and the alumina counterbody. Microhardness measurements were performed on the polished cross-section of each coating by Vickers microindentaion (LECO, M-400FT) at a load of 200 g and a dwell time of 15 s. For each sample, the average of twelve indentations at different points was calculated and reported as the hardness value.

3. Results and discussion

3.1. Feedstock powder and coating characterization

Fig. 1 illustrates the XRD peaks of the Fe_3Al and Fe_3Al–Ti–C powders milled for 6 h as a function of Ti+C content. In these profiles the (220) peaks of Fe_3Al became much broader and asymmetric as the contents of titanium and graphite elements increased. It should be mentioned that a highly exothermic reaction occurs during high energy ball milling of a mixture of pure elemental Ti and C powders. However, in the presence of large quantities of Fe_3Al phase this exothermic reaction is less pronounced. Dilution of Ti and C with Fe_3Al hinders significantly the direct contact between titanium and graphite particles. The XRD patterns of all powders, except for the pure Fe_3Al, are asymmetric, broader on the low angle side where the most intense peak of TiC (200) is located. Although the XRD spectra of the milled powders do not show any peaks of TiC, it is expected that some TiC nanocrystals could be formed during high energy ball milling.

Table 2
HVOF spraying parameters.

Oxygen flow rate (SCFH)	Kerosene flow rate (GPH)	Carrying gas	Spraying distance (m)	Number of deposition passes
1900	5.3	Argon	0.38	5

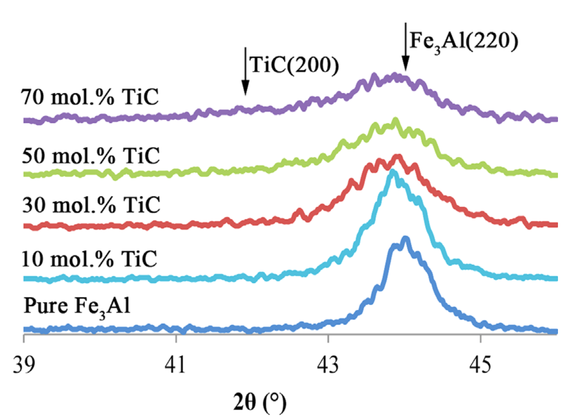

Fig. 1. XRD profiles of powders mechanically alloyed for 6 h.