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High temperature wear resistance of Fe–28Al–5Cr alloy and its composites reinforced by TiC

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ABSTRACT

The high-temperature tribological behaviour of Fe–28Al–5Cr alloy and its composites containing TiC was investigated against a Si_3N_4 ceramic from 25 to 800 °C. The high-temperature wear resistance of the materials was significantly improved by the addition of TiC, which was attributed to the high hardness of the composites, as well as the support role of hard TiC. The oxidation played an important role to friction and wear.

1. Introduction

With the development of technology, there is an increasing need for tribosystem capable of running under high temperatures [1]. Due to the anticipated applications such as hot working required for moving parts, bearing in aerospace propulsion systems, cutting tools, metalworking processes and vehicle brakes, the high temperature wear resistance becomes an important issue [2,3]. High temperature wear is one of the life-limiting factors when metallic surfaces are in repeated contact [1,4]. Thus, control of high temperature wear is conducive to not only save materials consumption but also reduce pollution. High temperature impacts the wear behaviour of materials through loss of mechanical strength and enhanced oxidation, and the latter plays an important role in high temperature sliding wear [5,6]. It is well known that oxidation leads to material degradation, and consequently reduces material resistance to wear. However, surface oxide layers also may reduce further oxidation and help to decrease the wear loss if it is dense and strong [7,8]. Intermetallic-based materials possess good oxidation resistance and high-temperature mechanical properties, so they were very promising for high-temperature wear resistance applications [9–12].

Fe_3Al matrix alloys reinforced with ceramic particles exhibit excellent mechanical properties, lower density, high strength–to–weight ratio [13,14], high oxidation resistance, high hardness and excellent sulphidation corrosion resistance [15–18]. Above all, these composites have shown a significant improvement in tribological properties, including sliding and abrasive wear resistance, and they have been used as tribological parts in some vehicles for years [19–21]. Therefore, extensive attention has been directed towards particulate metal matrix composites for tribological applications due to the advantages of high load carrying capacity and good sliding wear resistance. Recently, it has been validated that the improvements in tribological properties of Fe_3Al alloys can be achieved by incorporating ceramic particles or fibres, such as TiC, SiC, Al_2O_3 and TiB_2 [22–25]. Among them, TiC with high melting point (3200 °C), high hardness (20–30 GPa), low density (4.93 g/cm^3) and low chemical reactivity was found to be suitable for high temperature applications [26,27]. Some early reports showed that the hardness of the Fe_3Al alloys was significantly improved by the addition of TiC hard particle, as was the wear-resistance [27–32]. High wear resistance of ceramic-reinforced Fe_3Al matrix composites is attributed to the hard ceramic phase protecting the metal matrix from wear [33,34].

In the last several years, some studies on the tribological properties of the Fe_3Al based materials were mainly focused on dry-sliding, wet abrasive wear and corrosive environment tribology at room temperature [31,35–39]. However, wear resistance materials at elevated temperatures are needed in a large number of industrial applications such as high temperature bear, transport, materials processing, etc. [40,41]. Thus, it is quite important to investigate the high-temperature tribological performance of Fe_3Al-based

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composites. In this paper, we attempt to study the effect of TiC contents on high-temperature tribological properties of the Fe–28Al–5Cr intermetallics and to delineate the wear mechanisms.

2. Experimental procedures

The Fe–28Al–5Cr (atom percent ratio) powder produced by high-energy ball-milling in our laboratory and a commercial TiC powder with a purity of 99.9%, the average grain size of 50 nm, the melting point of 3200 °C and the hardness of above HRA90 were used as starting materials in this study. The Fe–28Al–5Cr (FT0) and its composites with 15, 25, 35 and 50 wt% TiC (corresponded to 19.3, 31.2, 42.3 and 57.6 vol%, and referred to as FT15, FT25, FT35 and FT50, in turn) were produced by hot-pressing technique. Details about processing, mechanical properties and microstructural characteristics can be found in the literature [42]. Briefly, the TiC phase uniformly distributed with reticular structure. The relative density of all the samples was up to 99%. The Vickers hardness and compressive strength of all the materials at room temperature are listed in Table 1 [42]. The hardness and compressive strength of the composites increased with TiC content.

The tribological tests were conducted by a home-built ball-on-disc type high temperature tribometer. The disc was made of the sintered sample with a size of $18.5\times18.5\times5\ mm^3$, and the counterface was the commercial Si_3N_4 ceramic ball with a diameter of 6 mm, hardness of 15 GPa and roughness of Ra 0.2 μm. Prior to the friction and wear experiments, both the disc-shaped samples and the ceramic ball were ultrasonically cleaned in acetone for 10 min and dried in hot air to obtain clean surfaces. The selected testing temperatures were 25, 200, 400, 600, and 800 °C. The sliding speed of disc sample against the ball was 0.202 m/s with a wear track diameter of 10 mm. The applied load was 10 N, and the testing time was 20 min. The furnace temperature, monitored by a thermocouple, was raised at a heating rate of 10–12 °C/min to the set point, and the temperature deviation was maintained within ±5 °C.

The friction coefficient (COF) was recorded automatically. The profile of the worn surface cross-section was measured using a Micro-XAM-3D noncontact surface profiler and the wear volume was calculated automatically by the equipment using the integral method. Then, wear rate was calculated as wear volume divided by sliding distance and load. All COFs and wear rates herein were evaluated as averages of three replicate tests for each experimental material under the same sliding conditions. The relative error for the friction and wear tests was below 10%.

In order to understand the wear mechanism, detailed morphologies of the worn surfaces of all the samples were examined by a JSM-5600LV scanning electron microscope (SEM). The chemical states of elements on the worn surface were examined on a PHI-5702 multifunctional X-ray photoelectron spectroscope (XPS). The XPS analysis was conducted at 400 W and a pass energy of 29.4 eV, using Al-Kα radiation as the exciting source and the binding energy of carbon contaminant (C1s: 284.8 eV) as the reference.

Table 1
Mechanical properties of the materials studied [44].

	FT0	FT15	FT25	FT35	FT50
Vickers microhardness (GPa)	3.49	4.74	5.13	6.44	11.51
Compressive strength (MPa)	950	1605	1710	1753	1968

Note: compressive strength for the FT0 is yield stress owing to no appearing fracture, but for the other materials it is fracture stress.

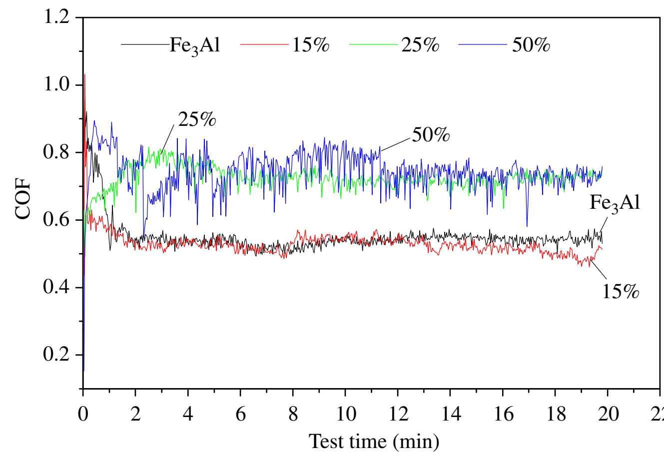

Fig. 1. Typical COF curves of the materials with testing time at 800 °C at applied load 10 N and sliding speed 0.202 m/s.

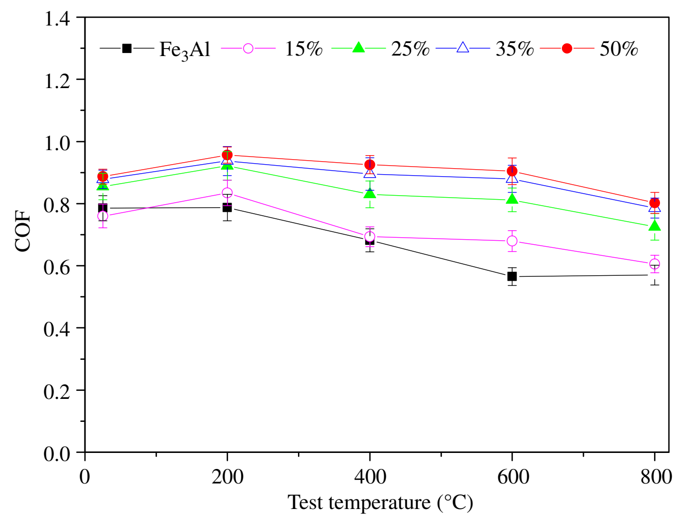

Fig. 2. Variation of the COFs of all the materials with testing temperature at a load of 10 N and a sliding speed of 0.202 mm/s.

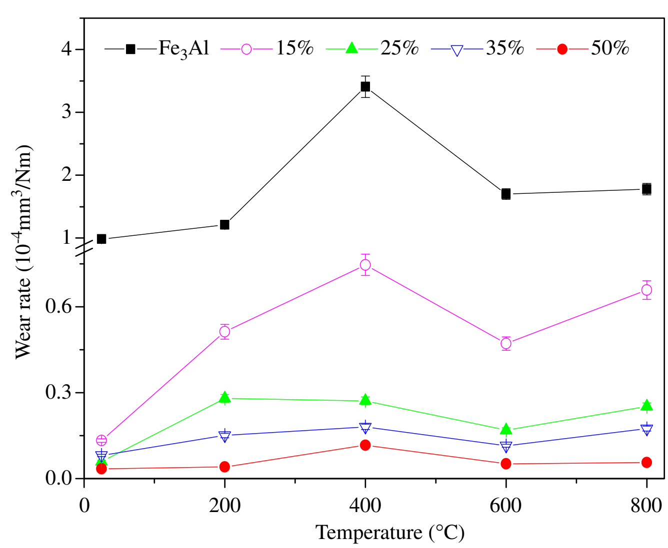

Fig. 3. Variation of the wear rates of all the materials with testing temperature at a load of 10 N and a sliding speed of 0.202 mm/s.