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Effect of SiC particles on the friction and wear behavior of $Ti_3Si(Al)C_2$-based composites

D.T. Wan [a,b], C.F. Hu [a,b], Y.W. Bao [a], Y.C. Zhou [a,*]

[a] Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, PR China
[b] Graduate School of Chinese Academy of Sciences, Beijing 100039, PR China

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Abstract

The non-lubricated, sliding friction and wear behavior of $Ti_3Si(Al)C_2$ and SiC-reinforced $Ti_3Si(Al)C_2$ composites against AISI 52100 bearing steel ball were investigated using a ball-on-flat, reciprocating tribometer at room temperature. The contact load was varied from 5 to 20 N. For monolithic $Ti_3Si(Al)C_2$, high friction coefficients between 0.61 and 0.90 and wear rates between 1.79×10^{-3} and 2.68×10^{-3} $mm^3 (N\,m)^{-1}$ were measured. With increasing SiC content in the composites, both the friction coefficients and the wear rates were significantly decreased. The friction coefficients reduced to a value between 0.38 and 0.50, and the wear rates to between 2.64×10^{-4} and 1.93×10^{-5} $mm^3 (N\,m)^{-1}$ when the SiC content ranged from 10 to 30 vol.%. The enhanced wear resistance of $Ti_3Si(Al)C_2$ is mainly attributed to the facts that the hard SiC particles inhibit the plastic deformation and fracture of the soft matrix, the oxide debris lubricate the counterpair, and the wear mode converts from adhesive wear to abrasive wear during dry sliding.

Keywords: $Ti_3Si(Al)C_2$-based composites; SiC; Friction; Wear resistance; Mechanism

1. Introduction

Ti_3SiC_2 possesses many excellent properties, such as low density, high elastic modulus and strength, easy machinability, good oxidation resistance below 1100 °C, good thermal shock resistance, and good damage tolerance [1–5]. It is expected, therefore, to apply Ti_3SiC_2 to various components such as commutating brushes, bearings, extrusion modes, and turbine blades [6]. Friction characteristics and wear resistance are two important properties that need to be characterized for Ti_3SiC_2-based materials as candidates for structural components. Many works have been carried out to investigate the friction and wear behaviors of the Ti_3SiC_2 ceramic during the past decade. Myhra et al. [7] estimated the kinetic friction coefficient of the basal planes of Ti_3SiC_2 to be as low as $(2–5) \times 10^{-3}$ using lateral force microscopy. They also reported that the coefficient was 0.12 for a polycrystalline sample against a lightly peened stainless steel sheet under a load of 0.15–0.9 N. Zhang et al. [8] investigated the tribological behaviors of Ti_3SiC_2/Ti_3SiC_2 and Ti_3SiC_2/diamond friction pairs and found that Ti_3SiC_2 ceramic was not intrinsically self-lubricating. El-Raghy et al. [9] reported that coarse-grained Ti_3SiC_2 (100–150 μm, with a wear rate of 1.34×10^{-3} $mm^3 (N\,m)^{-1}$) had better wear resistance than fine-grained Ti_3SiC_2 (3–5 μm, with a wear rate of 4.25×10^{-3} $mm^3 (N\,m)^{-1}$) against a 440 C steel pin, and the friction coefficient was in the range of 0.15–0.45 at beginning and then jumped to a steady value of ≈0.82. Sun et al. [10] found that the friction coefficient of Ti_3SiC_2-based material was not very sensitive to the applied loads, and the wear rate is about 9.9×10^{-5} $mm^3 (N\,m)^{-1}$ when a AISI 52100 bearing steel ball was used as the counterpair. Gao et al. [11] reported that the friction coefficient of Ti_3SiC_2 was in the range of 0.4–0.9 and temperature dependent. Zhai et al. [12], using a low carbon steel as the counterpair, demonstrated that the presence of an oxide layer on the friction surface of Ti_3SiC_2. Sarkar et al. [13], using a Ti_3SiC_2/steel as the tribocouple, confirmed that the triboxidation occurred with the formation of TiO_2, SiO_2, and Fe_2O_3

* Corresponding author. Tel.: +86 24 23971765; fax: +86 24 23891320.
E-mail address: yczhou@imr.ac.cn (Y.C. Zhou).

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on the contact surface, and the wear rate was in the order of 10^{-5} mm^3 (N m)$^{-1}$.

Ti_3SiC_2 is not very wear resistant because of its relatively low hardness (4 GPa), low shear strength [14,15], and low ratio of hardness to elastic modulus [2–4]. However, few attempts to improve its poor wear resistance can be found in the literature. Recently, to improve the hardness, wear and oxidation resistance of Ti_3SiC_2, the $Ti_3Si(Al)C_2$/SiC composites were prepared by an in situ hot-pressing/solid–liquid reaction synthesis method [16]. The results revealed that both the friction coefficient and wear rate under a load of 10 N were dramatically decreased by incorporating the hard SiC particles into the $Ti_3Si(Al)C_2$ matrix, viz. the wear resistance of $Ti_3Si(Al)C_2$ was greatly enhanced by forming $Ti_3Si(Al)C_2$/SiC composites. Because the mechanism for the improvement is not well understood, further investigations on the tribological behaviors of these materials are strongly needed.

In this paper, the tribological characteristics of $Ti_3Si(Al)C_2$ and $Ti_3Si(Al)C_2$/SiC composites are studied and the effects of different loads under non-lubricated conditions are examined using a ball on flat sliding block, point contact wear mode. The results will be beneficial for the promotion of $Ti_3Si(Al)C_2$ and $Ti_3Si(Al)C_2$/SiC composites as candidates for structural materials and for the understanding of the effects of SiC on the tribological behaviors of $Ti_3Si(Al)C_2$-based materials.

2. Experimental procedure

2.1. Materials preparation

Bulk $Ti_3Si(Al)C_2$ and $Ti_3Si(Al)C_2$/SiC composites (10 and 30 vol.% SiC) were fabricated by in situ hot pressing/ solid–liquid reaction synthesis, which was also described elsewhere [16]. The true phase composition of $Ti_3Si(Al)C_2$ is $Ti_3Si_{0.95}Al_{0.05}C_2$. The elemental powders, Ti, Si, Al, and graphite, were precisely weighed according to the target compositions and mixed for 15 h in a wet medium. After milling and drying, the mixtures were screened through a 60-mesh sieve and cold compacted into a 50 mm in diameter cylindrical graphite mold coated with boron nitride (BN). The green samples were then hot pressed at 30 MPa in a flowing Ar atmosphere at 1560 °C for 60 min, and subsequently annealed at 1400 °C for 30 min. The detailed microstructure and mechanical properties of monolithic $Ti_3Si(Al)C_2$ and $Ti_3Si(Al)C_2$/SiC composites were studied in our previous work [16]. Table 1 lists some physical and mechanical properties of $Ti_3Si(Al)C_2$-based materials.

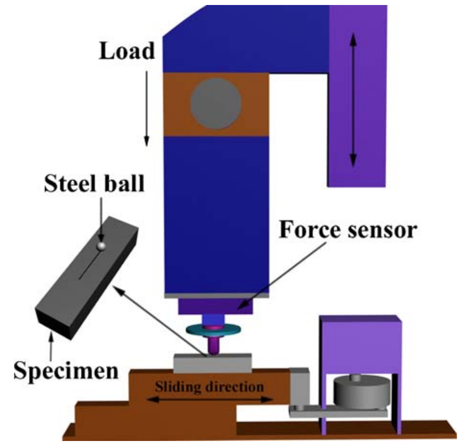

Fig. 1. A schematic illustration of the reciprocating ball-on-flat sliding block wear testing apparatus (UMT-2 multi-function test system, CETR, USA).

2.2. Wear test and characteristic

Friction and wear tests were performed with a reciprocating ball-on-flat sliding-block, point contact wear mode under non-lubricated conditions. All wear tests were conducted with a UMT-2 multi-function test system (CETR, USA) consisting of a reciprocating specimen sliding under a fixed ball, as shown schematically in Fig. 1. The sliding sample is fixed in the lower holder, which is driven by an automatic device. The ball is mounted in the upper holder, which is immobile during the wear tests and only allows a vertical movement to adjust the relative position. The friction force, induced between the steel ball and the sample, was measured by a force sensor and recorded in a computer automatically.

The flat sliding specimens, with dimensions of 3 mm × 4 mm × 15 mm, were cut by electrical discharge method and mechanically polished down to 1200# SiC paper. Before and after testing, all samples were ultrasonically cleaned, dried, and weighed. The counterpart ball was 4 mm in diameter and made of AISI 52100 bearing steel, which has a density of 7.85 g/cm^3 and a bulk hardness of HRC 59–62. The ball rubbed the surfaces (4 mm × 15 mm) of $Ti_3Si(Al)C_2$-based materials. The wear tests were performed under the loads of 5, 10, and 20 N with a constant stroke length of 4.50 mm at a frequency of 6.7 Hz. The total sliding distance was 30 m at a sliding velocity of 30 mm s^{-1} for 1000 s. All of the wear tests were conducted at room temperature in air with a relative humidity of 40–55%. After tests, the worn surfaces and the collected wear debris were investigated by means of X-ray diffraction (Rigaku D/max-2400, Japan) and

Table 1
Mechanical and physical properties of the monolithic $Ti_3Si(Al)C_2$ and $Ti_3Si(Al)C_2$–SiC composites

Samples	$Ti_3Si(Al)C_2$	$Ti_3Si(Al)C_2$–10 vol.% SiC	$Ti_3Si(Al)C_2$–30 vol.% SiC
Density (g/cm^3)	4.47 (98.7%)	4.33 (98.2%)	4.04 (97.3%)
Flexural strength (MPa)	475.0 ± 35.8	367.6 ± 21.7	355.3 ± 10.3
Fracture toughness (MPa m$^{1/2}$)	6.24 ± 0.18	6.49 ± 0.28	6.97 ± 0.33
Vickers hardness (GPa)	4.02 ± 0.12	6.99 ± 0.10	12.70 ± 0.77
Elastic modulus (GPa)	312	328	363
H_v/E	0.013	0.021	0.035

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