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Friction and Wear of Ti_3SiC_2-Ag/Inconel 718 Tribo-Pair Under a Hemisphere-on-Disk Contact

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Abstract. Room temperature friction and wear of Ti_3SiC_2-Ag sliding against Inconel 718 with a hemisphere-on-disc configuration were investigated in air. The effects of Ag content and TiAlN coating on Inconel 718 substrate were also included. Ti_3SiC_2/Inconel 718 tribo-pair showed high friction coefficient (0.6) and severe wear due to pullout of Ti_3SiC_2 grains was observed at a sliding speed of 1 m/s. Ti_3SiC_2-Ag composites had better tribological behavior than that of monolithic Ti_3SiC_2 in sliding against Inconel 718. At a sliding speed of 0.01 m/s, Ti_3SiC_2-Ag/Inconel 718 tribo-pairs exhibited moderate friction coefficient (0.32-0.4). At a sliding speed of 1 m/s, severe wear was not observed for Ti_3SiC_2-15vol.%Ag and Ti_3SiC_2-20vol.%Ag composites although the tribo-layer was not rich in Ag. When Ti_3SiC_2-Ag composites mated with TiAlN coating on Inconel 718 substrate, moderate friction coefficient (0.29-0.36) and low wear rate (10^{-6} $mm^3N^{-1}m^{-1}$) were obtained at 0.01 m/s. A transition from mild wear to severe wear of Ti_3SiC_2-Ag composites at 0.1 m/s can be attributed to the ploughing effect by hard asperities on TiAlN coating.

Introduction

The ternary compound Ti_3SiC_2 as a member of MAX phase (M: early transition metal, A: an A-group element, and X: C or N) possesses combined properties of metallic and ceramic [1] and it is a promising candidate material in tribological applications, e.g. heavy-duty electric contacts, turbine blades and bearings. To our knowledge, the friction coefficient of the basal plane of Ti_3SiC_2 determined by lateral force microscope was ultra-low (5×10^{-3}) [2]. The macro-tribological behavior of Ti_3SiC_2 under dry sliding condition depends on the sliding conditions (e.g. load, speed), environment (e.g. atmosphere, temperature) and counterpart material [3-6]. In wear regime dominated by grain fracture and extraction of Ti_3SiC_2, high friction coefficient and severe wear were observed. In other cases, the formation of lubricious tribo-oxide films can reduce the friction and wear. That is why at high temperature or high speed Ti_3SiC_2 exhibited good tribological properties. In addition, it is known that Ag can improve the tribological properties of MAX (e.g. Cr_2AlC) [7]. In this study, Ti_3SiC_2-Ag composites of various Ag contents were prepared. The tribological properties of Ti_3SiC_2-Ag composites in sliding against Inconel 718 with and without TiAlN coating in room air were investigated.

Experimental details

Materials. Ti_3SiC_2 (TSC) and Ti_3SiC_2-Ag composites with volume fractions of 5, 10, 15, 20% (noted as TSC-5Ag, TSC-10Ag, TSC-15Ag, TSC-20Ag) were prepared by spark plasma sintering in vacuum. The starting powders of Ti_3SiC_2 (average particle size 10 μm and 99% in purity) and Ag (200 mesh and 99% in purity) were commercially available. The sintering temperature was 1250 ºC for TSC and 1170 ºC for TSC-Ag composites. It is revealed by XRD spectrum that TSC-Ag composites were composed of Ti_3SiC_2 and Ag. Neither decomposition of Ti_3SiC_2 nor reaction between Ti_3SiC_2 and Ag was found. The relative densities of as-sintered samples were 93-98 %. The Vickers microhardness were 4-7 GPa for TSC-Ag composites and 8 GPa for TSC. Inconel 718 was commercially available and its chemical composition was 50 wt.% Ni, 25 wt.% Cr and 25 wt.% Fe. A TiAlN coating with a thickness of 3 μm on top of Incone 718 was fabricated by PVD.

Friction and wear tests. The wear tests were conducted on a THT pin-on-disc tribometer. The hemispherically tipped TSC and TSC-Ag pins with the diameter of 5 mm slided against Inconel 718 disc with or without TiAlN coating. The tests were conducted in room air (relative humidity of 40-50%) under a load of 5 N and different linear speeds (0.01, 0.1 and 1 m/s). The wear volume of discs was calculated by the cross-sectional area of the wear track using 3D surface profilometry. The wear volume of pins was approximated by the equation (1).

$$V = \frac{\pi d^4}{64r} \tag{1}$$

where V is the wear volume, d is the wear scar diameter, and r is the radius of the hemisphere. Wear rate was calculated from the wear volume divided by sliding distance and normal load.

SEM observation of worn surfaces. The worn surfaces of TSC, TSC-Ag composites and Inconel 718 were observed by scanning electron microscopy (SEM).

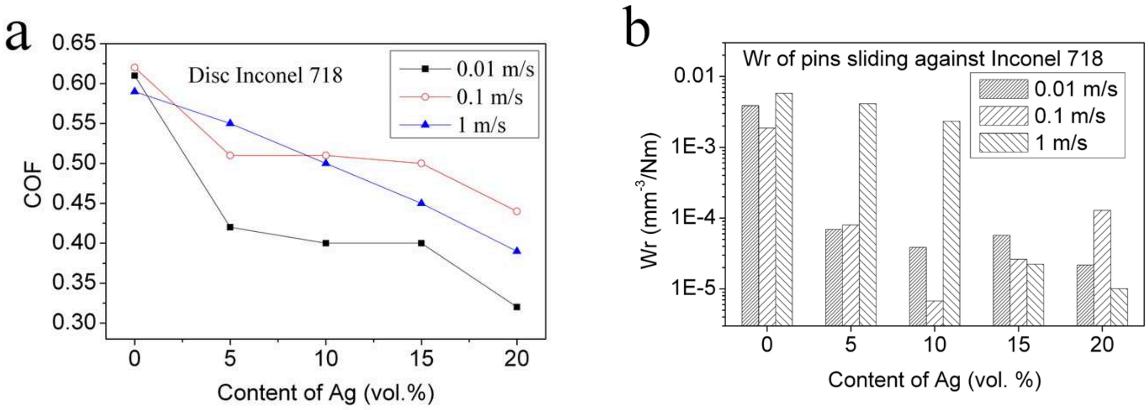


Fig. 1. Friction and wear of TSC and TSC-Ag composites in sliding against Inconel 718.

Results and discussion

Friction and wear of TSC and TSC-Ag against Inconel 718. The friction coefficient of TSC in sliding against Inconel 718 was as high as 0.6 and independent of sliding speeds, see Fig. 1a. In addition, the wear rate of TSC was as high as the order of 10^{-3} $mm^3N^{-1}m^{-1}$ (see Fig. 1b). TSC-Ag composites had better tribological behavior than that of monolithic Ti_3SiC_2 in sliding against Inconel 718, see Fig. 1. The most striking results were obtained at a sliding speed of 0.01 m/s, i.e. TSC-Ag/Inconel 718 tribo-pairs exhibited moderate friction coefficient (0.32-0.4). The wear rates of TSC-Ag at 0.01 m/s were much lower than that of TSC. At a sliding speed of 1 m/s, severe wear was found for TSC, TSC-5Ag and TSC-10Ag but was not observed for TSC-15Ag and TSC-20Ag. In short, TSC-15Ag and TSC-20Ag showed good tribological behavior.

Friction and wear of TSC and TSC-Ag against TiAlN coating on Inconel 718. The friction coefficient of TSC in sliding against TiAlN coating on Inconel 718 substrate was as high as 0.6 and independent of sliding speeds (Fig. 2a). When mated with TiAlN coating on Inconel 718 substrate, moderate friction coefficient (0.29-0.36) and low wear rate (10^{-6} $mm^3N^{-1}m^{-1}$) were obtained for TSC-Ag composites at 0.01 m/s. At 0.1 and 1 m/s, however, high friction coefficients were obtained for TSC-Ag composites. A transition from mild wear to severe wear of TSC-Ag composites at 0.1 m/s can be attributed to the ploughing effect by hard asperities on TiAlN coating (Fig. 2b).

Wear transition. It is well known that wear transition from mild wear to severe wear can be found by increasing speed or increasing load. For TSC-Ag composites, wear transition depended on the counterpart material. TiAlN coating had much higher hardness than TSC. Two-body abrasive wear by asperities on TiAlN coating can generate large amount of material removal. Higher speed meant more material removal. A transition from mild wear to severe wear of TSC-Ag composites at 0.1 m/s can be attributed to the ploughing effect by hard asperities on TiAlN coating.

Tribo-layer. Pullout of Ti_3SiC_2 grains and subsequent transfer to Inconel 718 were found for TSC/Inconel 718 tribo-pair at 0.01 m/s, see Fig. 3a. The presence of Ag can inhibit the pullout of Ti_3SiC_2 grains, which is beneficial for the reduction of wear. As a result, the thickness of the transfer layer on Inconel 718 against TSC-Ag composite was lower than that of Inconel 718 against TSC, see Fig. 3b. At 1 m/s, Ag also effectively inhibited the pullout of Ti_3SiC_2 grains and subsequent transfer to Inconel 718. The tribo-layers on TSC-Ag composites and Inconel 718 were not rich in Ag (SEM backscattered image and EDS spectra are not presented). This might be responsible for moderate and high friction coefficient of TSC-Ag/Inconel 718 tribo-pair.

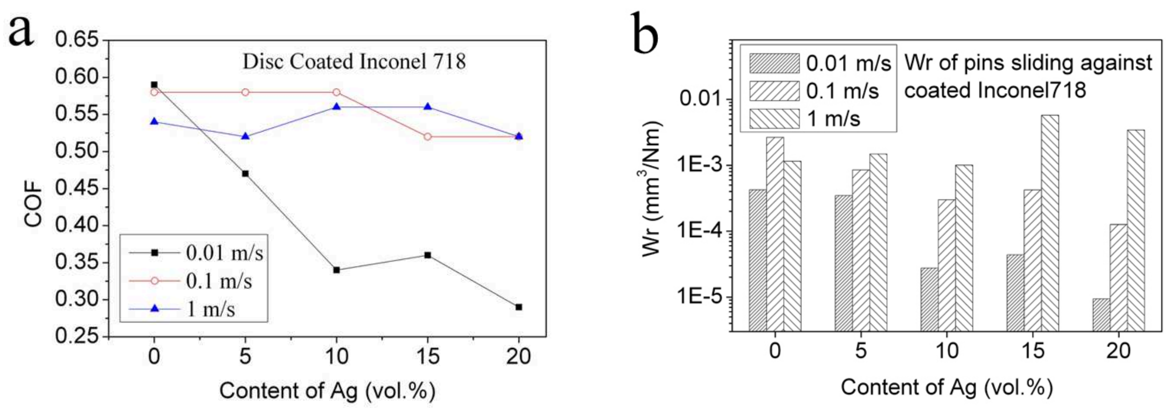
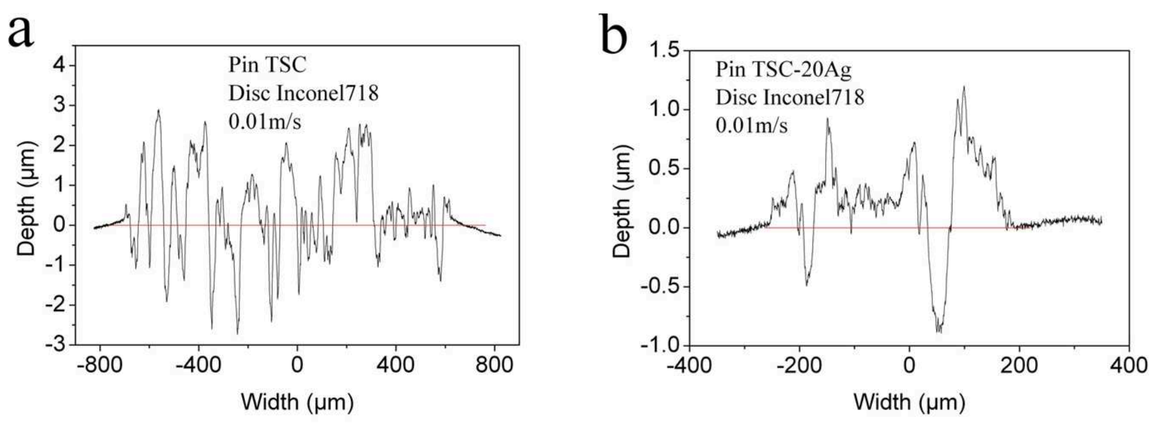


Fig. 2. Friction and wear of TSC and TSC-Ag composites in sliding against TiAlN coating on Inconel 718.



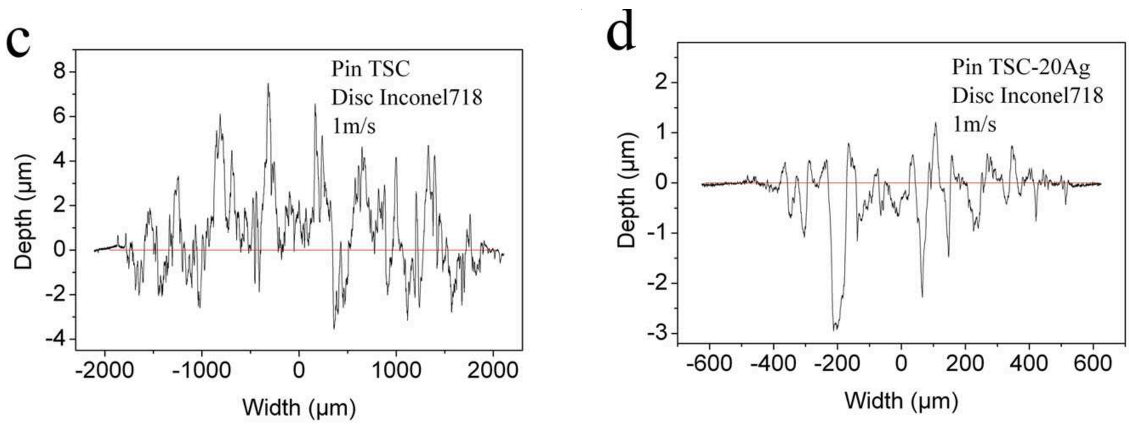


Fig. 3. Wear track profile of Inconel 718 in sliding against (a) TSC and (b) TSC-20Ag at 0.01 m/s, (c) TSC and (d) TSC-20Ag at 1 m/s.

Summary

Ti_3SiC_2/Inconel 718 tribo-pair showed high friction coefficient (0.6) and severe wear due to pullout of Ti_3SiC_2 grains was observed at a sliding speed of 1 m/s. Ti_3SiC_2-Ag composites had better tribological behavior than that of monolithic Ti_3SiC_2 in sliding against Inconel 718. At a sliding speed of 0.01 m/s, Ti_3SiC_2-Ag/Inconel 718 tribo-pairs exhibited moderate friction coefficient (0.32-0.4). At a sliding speed of 1 m/s, severe wear was not observed for Ti_3SiC_2-15vol.%Ag and Ti_3SiC_2-20vol.%Ag composites although the tribo-layer was not rich in Ag. When Ti_3SiC_2-Ag composites mated with TiAlN coating on Inconel 718 substrate, moderate friction coefficient (0.29-0.36) and low wear rate (10^{-6} $mm^3N^{-1}m^{-1}$) were obtained at 0.01 m/s. A transition from mild wear to severe wear of Ti_3SiC_2-Ag composites at 0.1 m/s can be attributed to the ploughing effect by hard asperities on TiAlN coating.

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