THE ROLE OF TRIBOFILM EVOLUTION ON TRIBOLOGICAL BEHAVIOUR OF Ti₃SiC₂ CERAMIC

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ABSTRACT
The Ti₃SiC₂ compound is a thermodynamically stable nano-layered ternary carbide, that belongs to a family of over 50 ternary carbides and nitrides, so-called MAX phases. These phases are a new class of solids that possess a unique combination of properties: they are readily machinable, relatively soft for ceramics, but elastically stiff, and electrically and thermally conductive. However, only very few studies are dedicated to their tribological behavior. This paper presents some results on the tribological behavior of Ti₃SiC₂. During dry sliding on a Ti₃SiC₂ plane, a first regime of low friction and mild wear can be observed, with the build-up of a tribofilm on the counterface. Then, while in an apparently steady state, the tribological behavior suddenly turns to higher friction and severe wear of both counterfaces. Combining friction experiments and topographical observations of contacting surfaces during the first regime, we propose some explanations for such drastic transition in tribological behavior. While tribofilm thickness and roughness stabilize in the mild wear regime, the covering of the ball surface still increases. Thus, matter accumulation on the ball finally leads to seizure of the contact.

Keywords: MAX phases, tribofilm, surface topography

INTRODUCTION
Ti₃SiC₂ is one of the nanolamellar ceramics called MAX phases. This class of materials combines good properties of both metals and ceramics [1]. In a previous paper [1], we reported some particularities of its friction behavior as a plane sliding against bearing steel or Si₃N₄ balls. Two regimes of friction separated by a transition were evidenced, respectively called type I and type II regimes. While type I is characterized by low friction and very low wear with formation of a tribofilm on the ball, type II regime exhibits higher friction and wear of both counterfaces.

The aim of this study is to improve our understanding of the transition occurrence. We show evidence of the tribofilm evolution during the type I regime, and partly characterise this evolution.

METHODOLOGY
Coarse-grained planes of Ti₃SiC₂, with grains sizes between 25 and 50 μm, were made by a hot isostatic pressing technique (HIP) and cut with a diamond wheel. The final structure contains about 4% vol. of remaining TiC, with an average grain size of 5 μm. Surfaces were polished down to a 1-μm diamond suspension, cleaned in successive ultrasonic baths of acetone and alcohol, and dried.

Tribological experiments were conducted on a linear reciprocating ball-on-plane tribometer, in ambient air at room temperature. A 9 mm-diameter 52100 bearing steel ball has been rubbed against the plane at a sliding velocity of 1.35 mm/s, with a track length of 3.4 mm. The load applied was 1 N, which implies an average contact pressure of 375 MPa. Identical experiments were conducted several times, and stopped at different numbers of cycles in order to study the evolution of the sliding interface. After each experiment, the flat wear track and the ball wear scar were optically examined. White light interferometric analyses were also performed to determine surfaces topography.
TRIBOLOGICAL BEHAVIOR

Figure 1 displays the typical evolutions of friction coefficient and electrical contact resistance as a function of number of cycles. Type I regime is characterized by very low wear, a relatively low friction coefficient (~0.11 to 0.15 depending on the nature of the counterpart), and the presence of a tribofilm on the ball. This tribofilm contains titanium, oxygen and carbon, mainly as titanium carbide/oxides, but no silicon. The presence of such layer is consistent with a high electrical contact resistance. When the type II regime appears, the friction coefficient reaches higher values (~0.25 to 0.5) and important wear of the surfaces can be observed, with removal of tribofilm and decrease in electrical contact resistance.

Figure 1. Friction coefficient and electrical contact resistance of Ti₃SiC₂ sliding against steel.

As mentioned above, tribological experiments were conducted for different number of cycles against steel balls, to study the evolutions of the tribofilm [3]. The friction coefficient observed for the last cycle of these experiments increases slightly from ~0.1 and then stabilizes at ~0.15 after about 300 cycles. The friction remains then at this stabilized value at least until 800 cycles, before transition to type II.

TRIBOFILM OBSERVATIONS

The apparent contact area on the ball is partly covered by a tribofilm, formed with iridescent “dots” of material, adherent to the ball (not removable by a few minutes of ultrasonic cleaning), and distributed within the contact area. Single dots are more difficult to distinguish past 250 cycles, and an orientation along the sliding direction becomes clearly visible. The flat wear track is not really visible until 250 cycles, and gets fully visible after 500 cycles. Its optical aspect is then similar to the tribofilm aspect, with iridescent dots on the surface, but with more scratches.

Topographic characterizations [3] of the surfaces confirm these observations. Furthermore, these characterizations show that the thickness of the tribofilm evolves concomitantly with friction, first increasing until 300 cycles, and then stabilizing at about 500 nm. Surface coverage by the tribofilm was also evaluated as the ratio between covered area and apparent contact area. Contrary to thickness, the coverage linearly increases without stabilization (Fig. 2). Attack angles of asperities were finally computed for both counterparts. On the tribofilm, the mean attack angle increases from 8 to 17° while friction increases, stabilizing at 12° after 300 cycles. On the plane, attack angles are small and stable at ~3° until 200 cycles, and then increases to 9°, probably because of scratching.

Figure 2. Evolution of tribofilm thickness (a) and surface coverage (b) on the pin, vs. number of cycles.

DISCUSSION

As stated above, matter accumulates on the pin throughout the experiments. Type I regime is thus not a steady state of the system. In a first stage, dots grow in the contact area, increasing attack angles on the pin. Increasing abrasiveness of the pin indeed leads to scratches on the plane. Then a second stage starts, involving some regulation process of the tribofilm, with stabilization of its thickness, as well as friction coefficient. However, matter still accumulates between the dots, since surface coverage continue to increase. Attack angles also stabilize, at a slightly lower value.

Transition to type II regime could be attributed to abrasion by the tribofilm, leading to the production of more debris and important wear. But the change in surface morphology, from independent dots to a continuous film, could also play a role. If shearing the tribofilm was what enabled the sliding movement, this shear is going to be more difficult, due to the film geometry: instead of shearing little dots of matter, the system has here a whole bulk to deform.

REFERENCES