Morphological Characterization of Wear Surface in Ceramics Composites Si_3N_4-$SiC_{(w)}$

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Abstract

Previous studies on tribological performance of Si3N4 against steel and cast iron at room temperature have showed that tribochemical reactions, plastic deformation and microfracture control the dominant wear mechanisms. The factors are related to intrinsic factors, such as porosity and intergranular phase volume, and extrinsic parameters, such as humidity, sliding speed and contact load. In the present work, unlubricated pin-on-disk experiments of Si3N4-SiC(w) / gray cast iron were performed at 5N of normal load, 2m/s of sliding speed at room temperature. The morphological characterization of the worn surfaces of the pins ceramics composites and the wear debris were performed using scanning electron microscope (SEM) with chemical analysis (EDS). Depending upon the density of the ceramics composites, the dominant wear mechanisms were either abrasive polishing or tribooxidation process.

Keywords: Ceramics composites, Silicon nitride, Scanning electron microscopy, Wear surface.

Introduction

Advanced ceramics are successfully used in a wide variety of engineering applications as triboelements involving contacts with metallic surfaces, such as drawing dies, roller bearings, automotive or aerospace engine parts and power generation systems components. Si_3N_4 based ceramics are high-performance materials for such applications (1;9-10;15-16).

The Si_3N_4 based ceramics materials have lower density and thermal expansion than metals, and their mechanical stability and corrosion resistance over a wide range of temperatures are superior to those of several other high-strength ceramics materials (5;14).

Detailed information about the friction and wear behavior of any systems in needed before its effective application as a successful tribosystem. Iron alloys, such as steel and cast iron, are the most common metallic materials for tribological applications.

Previous studies on tribological performance of Si_3N_4 against steel and cast iron at room temperature have show that tribochemical reactions, plastic deformation and microfracture control the dominant wear mechanisms (2). Intrinsic factor, such as porosity and intergranular phase volume, and extrinsic parameters, such as humidity, sliding speed and contact load, determine the dominating wear mechanisms (4;7).

Studies show that moisture adsorption and sliding speed have a major influence on the friction and wear behavior of nitrides ceramics. The wear rate is usually larger at high humidity but, when sliding speed is increased, the contact surface becomes dry owing to frictional heating. The increase of the wear coefficient of Si_3N_4 with moisture was explained by corrosion effects (10) or weakening of adhesion of the oxidized wear particles to the ceramics surface [6].

Papers on the influence of microstructural properties of silicon nitride materials on the tribological behavior are also rare (8). However, the following effects were reported: grains of rounded shapes are low stress concentrators compared with angular ceramics grains; pores can either work as stress concentrators or can blunt the crack fronts; the role of the intergranular phase is contradictory, because segregated impurities weak the grain boundaries and increase the mechanical wear and, on the reverse case, an amorphous grain boundary phase can enhance creep flow and improves the wear resistance.

Therefore, the wear mechanisms of Si_3N_4 based ceramics materials depend on microstructural characteristics, such as the intergranular phase and porosity, and also on the mechanical properties, such as hardness and fracture toughness (3;12).

The purpose of the present investigation was to evaluate of the worn surfaces of the ceramics composites pins using scanning electron microscope (SEM). The obtained results were correlated to density and to the dominant wear mechanisms for these compositions.

Materials and Methods

Silicon nitride based ceramics materials containing 5 wt% aluminum nitride and yttrium oxide, respectively, as sintering additives, reinforced with 20% vol. of silicon carbide whiskers (ICD Group Inc.) were pressureless and hot uniaxial pressed sintering, both at 1750 °C, in nitrogen atmosphere, during 30 min, under 20 MPa pressure.

Ceramics composites pins were tested against gray cast iron disk in a pin-on-disk tribometer. All tests were performed without lubrication at a sliding speed of 2m./s with a constant normal force of 5 N in room temperature. The surface of the gray cast iron disks were polished with 800 grit silicon carbide paper, followed by finishing with 1 µm diamond paste, ultrasonically cleaned and degreased with ethanol.

Two Si_3N_4-$SiC_{(w)}$ samples (pressureless and hot uniaxial pressed sintering) with distinct values of density were tested. The morphological characterization of the worn surfaces of the pins and the wear debris were examined by analytical scanning electron microscopy (SEM) with EDS X-ray analysis. The results obtained were related with dominant wear mechanisms.

Results and Discussion

Pressureless sintering

The ceramic composite pin obtained by pressureless sintering achieved a low densification (<90% theoretical density) and revealed a extensive layer of iron-rich wear debris adherent to the surface, figure 1 and figure 2, as the result of intense metal removal from the gray cast iron surface disk.

Representative EDS analysis of the worn surface of the pin is showed in figure 3. The EDS spectrum reveals the high Fe-peak, related to the metallic-rich deposits reported above.

The wear debris spreads on the ceramic pin surface in the sliding direction, performing third-body protection, leading to protection and to decreasing of wear coefficient. In severe wear regime, the metallic disk also undergoes high wear, and a considerable amount of wear debris is formed, which accumulates on the pin counterface.

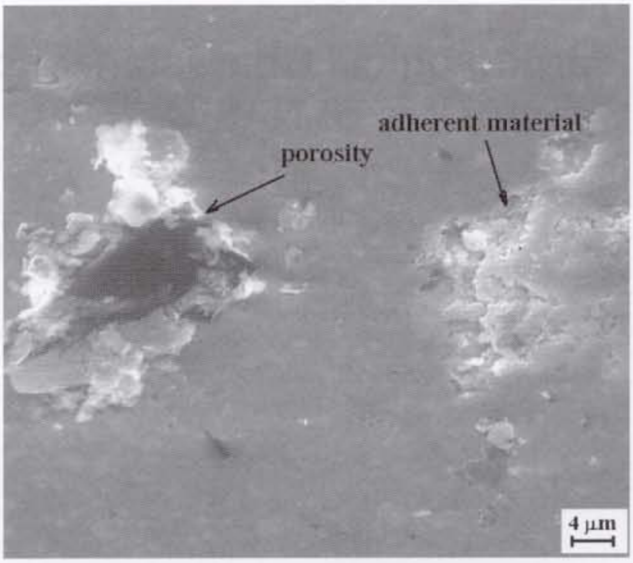

Figure 1 – SEM images of Si_3N_4-$SiC_{(w)}$ pin worn surfaces, pressureless sintered. Observed the presence of the porosity and extensive layers of material adherent.

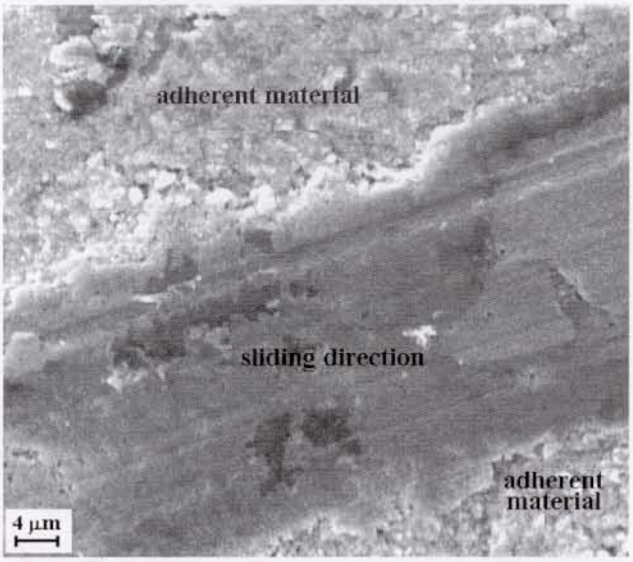

Figure 2 – SEM images of Si_3N_4-$SiC_{(w)}$ pin worn surfaces, pressureless sintered, showing extensive layers of iron-rich wear debris adherent.

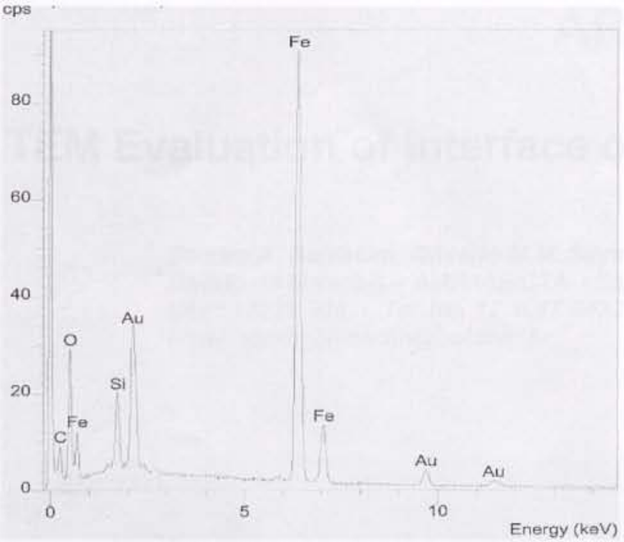

Figure 3 - SEM/EDS spectra of adherent material in Si_3N_4-$SiC_{(w)}$ pin worn surfaces, pressureless sintered.

Hot uniaxial pressed sintering

The ceramic composite pin obtained by hot uniaxial pressed sintering, due a high densification (>97% theoretical density), presented, figure 4 and figure 5 respectively, only few adherent wear debris, with smooth appearance.

For this compositions where the surface of the ceramic pin is not protected by an adherent third-body layer, as found in the ceramic pin obtained by pressureless sintering, the mechanical wear (abrasive polishing) mode must become the main mechanism of wear (11;13).

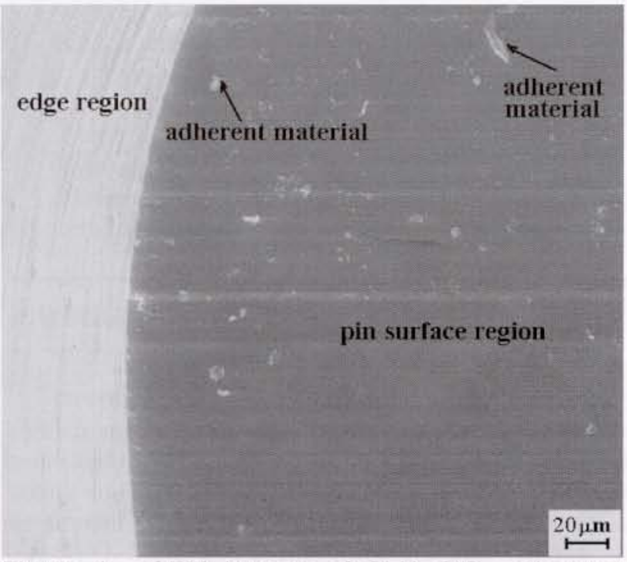

Figure 4 - SEM images of Si_3N_4-$SiC_{(w)}$ pin worn surfaces, hot uniaxial pressed sintered, showing an general morphological aspects of worn surfaces.

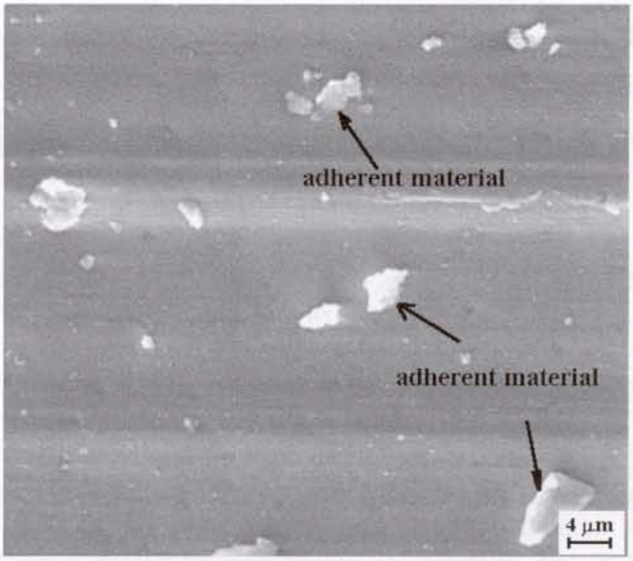

Figure 5 - SEM images of Si_3N_4-$SiC_{(w)}$ pin worn surfaces, hot uniaxial pressed sintered. Observed few adherent wear debris has large plate, with smooth appearance.

Conclusions

As expected, the density has a remarkable effect on the tribological behavior of Si_3N_4-$SiC_{(w)}$ ceramics composites. Because the low densification in this case, the pores of the pin pressureless sintered retain most of the metallic debris, evidencing the triboxidation process. On the other hand, the worn surface of the dense hot uniaxial pressed pin sintered, tested under the same conditions, is smoother and adhesion of the wear debris is weaker, showing the abrasive polishing wear mechanisms.

Therefore, in this work, the dominant wear mechanisms observed for the Si_3N_4-$SiC_{(w)}$ on the metallic surface were abrasive polishing and triboxidation process.

Acknowledgments

FAPESP – Fundação de Amparo à Pesquisa do Estado de São Paulo

CTA/IAE/AMR – Divisão de Materiais

IPEN – Divisão de Materiais Cerâmicos

UNIVERSIDADE DO MINHO – Departamento de Engenharia Mecânica

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