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Original Research

The effect of laser surface texturing on the tribological performance of different Sialon ceramic phases

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ABSTRACT

A tribological performance was carried out on different types of hot press Sialon ceramics regarding the phases, i.e., the α-Sialon phase, the β-Sialon phase, and the α/β-Sialon composite phase. The different phases of Sialon ceramics were analyzed by XRD patterns. For the tribological performance, the Sialon ceramics were laser textured and the starved lubrication method was applied with different dimple pitches under a load of 10 N at room temperature. The material having a dimple pitch of 200 μm shows the lowest coefficient of friction. The α/β-Sialon composite phase shows the least coefficient of friction i.e. 0.04 and 0.1 for the textured and polished (without being textured) samples, respectively. The Sialon ceramics show mild wear and therefore, the wear rate of the steel ball (mating partner) was taken into account for the wear analysis. The α-Sialon phase having a higher hardness shows the least wear in comparison to the α/β-Sialon composite phase and the β-Sialon phase.

1. Introduction

The two common polymorphs of Sialon i.e. α-Sialon and β-Sialon are isostructural with α-Si_3N_4 and β-Si_3N_4, respectively, and are formed with the partial substitution of Si–N bond of Si_3N_4 by Al–N and Al–O bonds [1,2]. The Sialon ceramics are known for their excellent mechanical and thermal properties and used as cutting tools, mechanical sealants, etc. [3]. These materials are potential candidates for frictional materials because of their excellent mechanical and thermal properties as well as their oxidation resistance compared to other ceramics [4–6]. Previously there have been some works on the tribological properties of Sialon ceramics. Previous study shows that the Sialon ceramics have a higher wear resistance and hence, can be applied in varied conditions or environments [3,5].

Herein, three types of Sialon ceramics have been fabricated i.e. α-Sialon, β-Sialon and duplex α/β-Sialon ceramics. The hardness of the material depends on the α-phase while the toughness on the β-phase [7]. Depending upon the different nature of the phases in Sialon ceramics, the different properties can be observed. On the basis of that here we study the tribological performance on the different Sialon phases.

A study on laser textured Sialon ceramics is rare, and here we show the effect of laser texturing on the tribological performance regarding the different phases that exist in Sialon ceramics. Other methods can be used for texturing the surfaces, such as the mechanical (polishing, lapping, grinding, ultrasonic machining, etc.), lithographical or the energy beam process [8,9]. However, Laser Surface Texturing (LST) has created huge influence in texturing, because of its applicability on almost all materials such as metals, ceramics, and glass, to produce topographical features [10]. The frictional forces and wear rate can be minimized by the introduction of selective micro-structures on the sliding surfaces using LST [11–14]. According to most of the studies, these micro-structures can serve as micro-traps for wear debris in either a lubricated or dry sliding condition. Also, these microstructures act as micro-reservoirs for lubricant in starved lubrication conditions and are expected to assist in the formation of a lubricating film that reduces friction [15–17]. The kind of structures, the geometry and the density of the cavities on the flat surface play an important role in the tribological properties.

2. Experimental

2.1. Materials and methods

The values of m = 0.9 and n = 0.45 were taken to fabricate a Sialon composite (S0), where m and n correspond to the level of substitution of the Si–N bond by (Al–N) and (Al–O) in Si_3N_4 crystal structure, respectively. The starting powder used for the preparation of the composition was α–Si_3N_4 (SN-E10, UBE Co., Japan), AlN (Grade F, Tokuyama Corp., Japan), and MgO (High Purity Chemicals

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Co., Ltd., Japan). The α-Sialon (S1) and β-Sialon (S2) ceramics were fabricated by the addition of 1 wt% and 2 wt% of Y_2O_3 (High Purity Chemicals Co., Ltd., Japan), respectively. The powders were mixed in ethanol with high purity silicon nitride balls and were ball milled for 24 h. After wet ball milling, the powders were dried and again dry milled for 12 h. Then the mixed powders were sieved through a 150 μm aperture. The powder mixtures were hot press sintered under a uniaxial compression of 30 MPa pressure in 0.1 MPa of an N_2 environment at 1850 °C for 1 h.

After sintering, the crystalline phase was examined by X-ray diffractometer (XRD, Cu K, RIGAKU D/MAX2200HR Diffractometer, Japan).

2.2. Laser surface texturing

The substrate used for LST was Sialon ceramics (α-Sialon, β-Sialon, and α/β-Sialon composites). LST was accomplished using an Indium YAG laser beam of a wavelength of 1064 nm. The laser was operated in the pulse mode with a pulse width of 200 ns and a frequency of 20 kHz. The laser beam was focused onto the sample surface by an objective lens and scanned over the sample surface via deflection mirrors.

The laser was used to generate the dimples with an average depth of about 30 μm on the surfaces of the polished samples. Dimples having an average diameter of 60 μm were created with the variation of a dimple pitch of 80–200 μm. All the sample surfaces i.e. before and after patterning the surfaces were studied and observed carefully using optical microscopy.

During the laser process, an air flow was used to remove the sediments. However, all the textured surfaces required gentle re-polishing to remove the debris around the dimples owing to the heat influence of the laser.

2.3. Tribology test

Tribological investigations were performed in the air at room temperature with a relative humidity of 30% at unidirectional; a starved lubricated sliding motion using ball-on-disk tribometer (CSM Instruments, Switzerland). The SAE52100 steel balls were slid against substrate (15 mm × 15 mm × 4 mm). The normal load of 10 N (Hertzian contact pressure of 0.95, 0.96 and 0.92 GPa for S0, S1, and S2, respectively) was used with a rotational diameter of 6 mm. The test was carried out for an hour with a sliding distance of 180 m using the commercial engine oil 5W30. An average sliding velocity of 5 cm/s was noted. The wear scar developed on the steel balls during a friction test was also observed and measured by an Olympus MM6-RS3 optical microscope.

3. Results and discussion

3.1. Phase and morphology analysis

The completely dense Sialon ceramics exhibit very good mechanical properties and are listed in Table 1. The sintered Sialon consists of the α, β, and α/β phases as shown by the XRD patterns in Fig. 1. The volume % of the α and β phases was calculated by their XRD peak intensities [18]. A higher α-phase was observed for sample S1, while the β-phase for sample S2. For sample S0, both α and β phases were observed.

Fig. 2 shows a comparative study of the grains size and the shape of different types of Sialon ceramics. Smaller grains were observed for S0 as a comparison to S1 and S2. S0 corresponds to α/β composite Sialon ceramics whereas S1 and S2 correspond to α- and β-Sialon ceramics, respectively. It is well known that the smaller the grain size, the better will be the mechanical properties

Table 1
Phase composition and mechanical properties of different Sialon ceramics.

Samples	Phase composition (vol%)		Relative density (%)	Vickers hardness (GPa)	Fracture toughness K_{IC} ($MPa\ m^{1/2}$)	Young's modulus (GPa)
	α	β				
S0	64.50	35.5	99.05	18.96 ± 0.36	5.27 ± 0.09	311
S1	97.68	2.32	99.65	21.48 ± 0.37	6.00 ± 0.15	329
S2	2.73	97.27	98.87	16.27 ± 0.17	5.82 ± 0.31	273

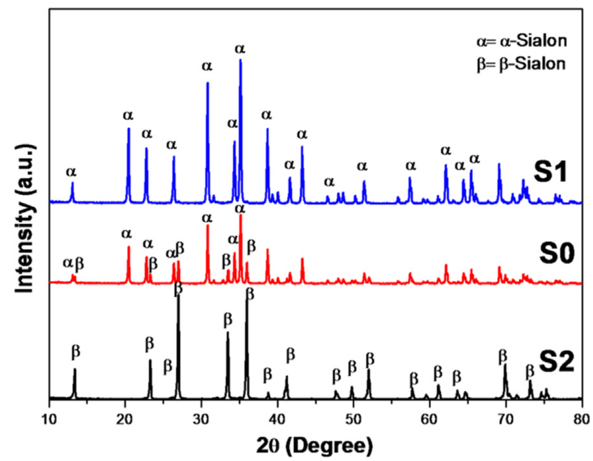

Fig. 1. XRD patterns of different Sialon ceramics showing different phases.

which consequently decrease friction and wear.

The mechanical properties were found to be slightly different in the various Sialon ceramics depending on the composition of the α- and β-phase as shown in Table 1. The α-phase gives higher hardness and wearing resistance, while the β-phase exhibits high fracture toughness and strength [19]. The higher fracture toughness and strength of the β-sialon ceramics can be explained by the presence of elongated grains [7,19]. Thus, S1 has a higher hardness, and S2 has a better fracture toughness. High hardness and toughness is good for being abrasion resistant and shows better tribological properties [19].

The surface topographies of the different Sialon ceramics before and after texturing are shown in Figs. 3–5 for samples S0, S1 and S2, respectively. They show that the dimples were distributed uniformly on the textured surfaces. The dimple spacing created on the samples is 80, 100, 150 and 200 μm for each sample.

3.2. Coefficient of friction of the Sialon ceramics with and without dimples

The coefficient of friction of the Sialon ceramics (S0, S1 and S2) was recorded as a function of time with the variation of the dimple pitch (Fig. 6). It shows the significant reduction of the coefficient of friction on the textured samples as compared to the polished samples. About ~60% reduction was noticed in the coefficient of friction in sample S0, as shown in Fig. 6(a). The coefficient of friction decreases when increasing the dimple pitch from 80 to 200 μm among the textured samples. It can be seen that the lowest coefficient of friction was achieved for the less-dense dimpled sample. The interference of the close dimple edges causes the increase in the roughness of the surfaces for the highly dense dimpled sample as compared to the sample with low dimple density. So, dense dimples on the surface result in unfavorable roughness parameters, much higher contact pressure and a more reduced contact area. These above mentioned unfavorable

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