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ASPECTS CONCERNING THE TRIBOLOGYCAL BEHAVIOUR OF ENGINEERING CERAMICS TYPE ALUMINA (AL2O3) IN DRY SLIDING POINT, LINE AND PLANE CONTACTS.

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Abstract: *The study from this paper is based on unlubricated sliding tests with high performance alumina in three different contact geometries. In each contact geometry, both mild and severe wear were observed, at a normal force that was applied on each test, the transmition into severe wear occurred at a velocity specific to the geometry. The bearing capability of alumina, however, was quite low. Alumina can be recommended only for dry sliding applications in which the load and speed safely remain below the limit for the transmition from to severe wear.*

Key words: *alumina, coefficient of friction, mild- severe wear*

1. INTRODUCTION

Among the different types of advanced ceramics, alumina is the most widely used material (Gates et al 2002), owing to properties beneficial in wide range of applications and the relatively good cost effectiveness (Gee, 2004). Many studies on friction, wear and lubrication of ceramic materials have been published in recent years, (Davim et al, 2008) and a large proportion of these works are related to alumina. Most of them have been carried out in order to investigate the basic tribological mechanism of ceramics in sliding under small loads and/or low velocities (Said 1994). Under such conditions (Anton van Beek 2004), wear of alumina is almost negligible, even when lubrication is not applied. This paper concerns high grade alumina sliding against itself without lubrication. Three different contact geometry – more exactly point, line and plane contact – were studied. In each contact geometry the material was tested in both the mild and severe wear regime, by applying different combination of contact parameters. The bearing capability of alumina is discussed with respect to its tribological characteristics and with emphasis on the transition from mild to severe wear.

2. EXPERIMENTAL TRIBOMETERS

Each of the three contact geometries was studied using different equipment. The point contact, defined by a pin sliding on a flat, was studied using a three pins machine with a horizontal rotating disc (fig. 1).The line contact was formed by using an Amsler tribometer which had like a friction sliding couple two rings in contact like in fig. 2. The plane contact was realized using the first tribometer in which was changed the alumina pin with a round tablet from alumina.

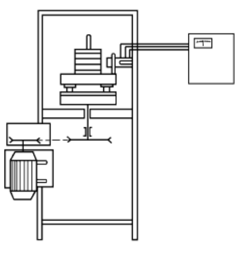

Fig. 1.Three pins on disc tribometer

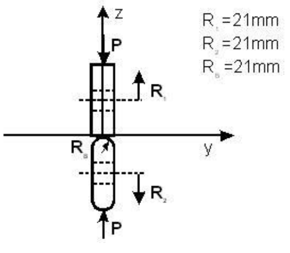

Fig. 2. Amsler Couple

3. SAMPLES CHARACTERISTICS

All specimens tested were made from alumina – 99,7% with SiO_2, Fe_2O_3 and MgO as the main sintering aids and impurities. The test specimens were supplied by three manufacturers (H.P. USA, Gerasiv DE and Sinterom RO). Some differences between the materials are evident (see table 1) but they all are well representative of alumina 99%. In comparison with the test geometry differences, the influence of the material differences on the tribotest results was regarded as minor. The three pin on disc tribometer samples were polished Ø6x10 mm pins and lapped Ø200x5 mm disc. The samples for Amsler tribometer were lapped cylindrical rings with 21mm radius and 6mm thickness respectively. The samples used for simulations the plan contact were lapped ceramic round tablet Ø12x3mm sizes and respectively Ø200x5mm disc.

sample	Cer 004 Pin/disc	Cer 005 Tabl./disc	Cer 006 Amsler
HV	1650	1500	1620
K_{IC} $MPam^{1/2}$	<3	4,5	<4
Grains size (μm)	1 – 10	1 – 20	1 – 10
density (g/cm^3)	3,8	3,8	3,8
Porosity (%)	< 1	< 3	< 0,5
Roughness, R_a (μm)	0,1	0,05	0,4

Tab. 1. Samples parameters at room temperature

4. TESTS AND ANALYSIS

Before testing the samples were cleaned and dried. The testing atmosphere was air at room temperature with 30 – 50% relative humidity. The frictional force and torque was recorded during the test. Each three pins on disc test were performed with a pair of new surfaces, a 25 till 150N normal forces and a constant sliding velocity. The velocities chosen ranged from 1,46 m/s until 2,38 m/s. The sliding distance was only 250 m at each velocity, but this was considered sufficient for the small sliding surfaces involved. Each rings test (Amsler test) was carried out with a new rings pair at a normal force 50 – 150N. The shafts of the Amsler tribometer rotated with n_1/n_2= 386/347 rpm and the number of test cycles $n_{cycle}=2x10^6$ cycles. The third test was carried out in the same conditions like the first. After testing, the pin and the round tablet wear scars were measured using an optical microscope. The discs and the rings were measured by stylus profilometry. The specific wear rates were calculated by dividing the wear volume by the normal force and the sliding distance elapsed after the frictional increase in the severe regime tests. The wear surfaces were studied by SEM in order to characterize dominant deteriorating mechanisms.

5. RESULTS

5.1 Three pins-on-disc tests. Friction and wear

The three pins-on-disc test were carried out with the 25-150N load at the low sliding velocities of 1,4- 2,38m/s typically showed steady state coeff. of friction of 0,52-0,59.

The pin on disc specific wear rates at sliding were below $0{,}1\times10^{-6}mm^3/Nm$ for each sample. At the higher coefficient of friction the sliding was characterized by a dull sound and the formation of loose wear debris. The pin on disc specific wear rates in this severe wear regime were about $20\times10^{-6}mm^3/Nm$ for each sample. The SEM image shows the seemingly unaffected wear surface of an Al_2O_3 disc tested in the mild regime. Surface subjected to mild wear appears slightly polished. A closer inspection revealed small grooves in the sliding direction, micro fracture at the edge of pores and preparation defects, and also some transverse microcraks. The pin wear scar was polished smooth, and a sliding shoe of wear particles was situated in front of the worn surface in the sliding direction. The wear surface of the alumina disc after sliding in the severe wear regime exhibits a rough surface topography with bands of tribofilm, 1-2 µm in thickness, expanding in the sliding direction. The tribofilm, which consists of wear particles well sintered together, shows a smooth surface comprising tiny longitudinal grooves. The debris occurred as fragments, 50-500nm in diameter. SEM of the surface showed a pattern, suggesting fine crystalline α alumina without any apparent texture. Similar wear surface features to those typical of the disc characterized the pin –however, with more severe surface fracturing and a more extensive tribofilm with a thickness of 2 - 4 µm.

5.2 Amsler test. Friction and wear

Mild wear occurred when the tests were performed with 150N normal loads and a sliding velocity of 0,4m/s over sliding distances of up to 650m. The µ was about 0,52 during the tests. The specific wear rate of the rings was less than $0{,}01\times10^{-6}$ mm^3/Nm. The experiments for studding the wear transition were performed with normal loads of 50-150N. With the 50N load the transition from mild to severe wear occurred soon after the velocity had been increased from 1,4 to 1,6 m/s. The µ which stabilized at about 0,52 for velocities up to 1.4 m/s rapidly increased to about 1 after which it decreased slightly. When the friction began to increase, the temperature on the rings in the contact area also increased. The specific wear rate of the worn rings was in the order of $10^{-6}mm^3/Nm$. When dismantling the rings assemblies in the severe regime, an abundance of loose wear debris was found. The surfaces of the rings showed smooth and polished similar to those on the mildly worn disc. A severely worn ring surface is occurred. It is covered by patches of tribofilm, about 10µm in size and 3-4µm in thickness. On some of the severely worn surfaces, wear appeared as narrow band extending in the sliding direction.

5.3 Three round tablets on disc tests. Friction and wear

The mild wear regime of the tablets on disc test conducted at a 25-150N normal load was identified for sliding velocities of 1.46 to 2.38m/s. The stable µ was in the range 0.51-0.6. A transition into severe wear regime occurred at 60N and a sliding velocity around 2m/s. The specific wear rate of the stationary tablets was $15\times10^{-6}mm^3/Nm$. Within the first 350m of sliding the µ rose from 0,6 to 1,2. After reaching its peak the value it slowly decreased to about 1,05 towards the end of the sliding distance 1000m. During the test, the sliding couple ejected wear particles in abundance. Simultaneously, a weak squeezing sound could be heard. The triboluminescence phenomenon initially occurred at 50N and 2m/s. The specific wear rate of the stationary ring in severe wear was $40\times10^{-6}mm^3/Nm$. The surface topography was even smoother than before testing, with only a few remaining lapping grooves. The fundamental wear mechanism prevailing was microfracture at poreges, resulting in fine fragmented wear debris. The severally worn tablet surface reveals a rough surface topography with tribofilm formation fracturing and attached wear debris. The tribofilm consists of wear fragments sintered well together into patches, 10-100µm in size and 3-4µm in thickness. The tribofilm comprises fine, 20-200nm wide fragments clustered together to form lumps of 1.1-1µm size. The interface between the film and the underlying grains shows cracks and voids and the bulk material below the tribofilm contains an extensive system of inter and transgranular cracks into and parallel with the surface

6. CONCLUSION

Experimental results of friction and topography measurements are presented which demonstrate the mutual modification of friction and contact topography. The effect of topographical ‘landmarks’ on friction was tested by Al_2O_3-ring/disc sliding over The results of the present tests with three different geometries support each other and an overview of the wear rates and µ typical of the mild and severe regimes is shown in table 2. For self-mated alumina sliding in air or intermediate humidity, three modes of tribological behaviour common to the three test geometries can be differentiated: namely, initially low friction (µ=0.2) and mild wear under light conditions, stable intermediate friction (µ=0.5) and mild wear under light conditions, and high friction (µ=0.7) and severe wear under heavier operational conditions. The results of the three test geometries support each other well, indicating that pin-on-disc tests can well be used for the simulation of more complicated tribosystems with alumina. The mild wear could be described as a polishing, proceeding as micro-abrasion of the sliding interface. The µ remains fairly low as long as adsorbants are lubricating the surfaces. The low wear rates occurring in the mild regime should encourage an extended use of self-mated alumina in applications operating within this regime. The wear mode transition involves surface fracture due to the strength of the sub-surface region being exceeded by the interaction of frictional heating, thermal cycling and mechanical loading. Up to a certain limit, a larger contact area allows slightly higher sliding velocities, probably mainly by improving the dissipation of the heat from the sliding interface, although the velocity allowance of alumina at a set normal load is still quite low even when using fairly large sliding surfaces.

Wear particles and their exact behavior in the contact area can affect friction in a stochastical and hence unpredictable way. Most modern friction theories have difficulties in coping with this problem.

Any opinions, findings and conclusions expressed in this material are those of the author. However, for the present, this work has taken a positive step towards clarifying the dry sliding applications in which the load and speed safely remain below the limit for the transmition from to severe wear.

Test geometry	Mild wear		Severe wear	
	Coeff. friction	wear rate $10^{-6}mm^3/Nm$	Coeff. friction	wear rate $10^{-6}mm^3/Nm$
pins/disc	0.54	<0.1	0.7	20
Amsler	0.52	<0.005	1.0	~1
Tablet/disc	0.5-0.6	“zero”	>1	15

Tab. 2. Results

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