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The Effect of Micro Tools Fabricated Dent on Alumina/Alumina Oxide Interface

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Abstract**—**The tribological outcomes of micro dent are found to be outstanding in many engineering and natural surfaces. Ceramic (Al_2O_3) is considered one of the most potential material to bearing surfaces particularly, artificial hip or knee implant. A well-defined micro dent on alumina oxide interface could further decrease friction and wear rate, thus increase their stability and durability. In this study we fabricated circular micro dent surface profiles (Dia: 400µm, Depth 20µm, P: 1.5mm; Dia: 400µm, Depth 20µm, P: 2mm) on pure Al_2O_3 (99.6%) substrate by using a micro tool machines. A preliminary tribological experiment was carried out to compare friction coefficient of these fabricated dent surfaces with that of non-textured surfaces. The experiment was carried on well know pin-on-disk specimens while other experimental parameters such as hertz pressure, speed, lubrication, and temperature were maintained to standard of simulated hip joints condition. The experiment results revealed that micro dent surface texture reduced 15%, 8% and 4% friction coefficient under 0.132,0.162, 0.187 GPa contact pressure respectively. Since this is a preliminary tribological study, we will pursue further experiments considering higher ranges of dent profiles and longer run experiments. However, the preliminary results confirmed the suitability of fabricating dent profile to ceramic surfaces by using micro tooling, and also their improved tribological performance in simulated hip joints.

Abstract**—**Micro dent, tribology, ceramic on ceramic hipjoints.

I. Introduction

MICRO dents have been proven to be effective in improving tribological performances of parallel sliding surfaces — they could escalate load carrying capacity by increasing load carrying capacity; they could curb friction and wear rate by thickening film thickness; furthermore, they could decrease the third body abrasive wear rate by removing wear debris from the interface. Various forms micro dents are visible even in natural skins, and their functions work superbly based on their structure. For example, ribs and grooves found on the shark skin which decrease drag and friction forces effectively [1]-[4]; again Tree frogs is capable to climb smooth surfaces without slipping because of their special microstructure surface profile feet, in that case, drag and friction increase [5].

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The application of micro dent has attracted many researchers, and their commercial applications are not very rare now a day [6]-[10]. Ceramic based material is also increased in tribological applications because of their excellent mechanical property including hardness, wear resistance and superior surface finishes. The example of applying ceramic surface in biomedical implant is also incredible; partially we can find a great potentiality of high performance ceramic on ceramic hip joints. Only one drawback of ceramic surfaces is brittleness thus its fatigue toughness is questionable.

A micro dents could decrease the magnitude of frictional fatigued load thus increasing the durability of ceramic based rubbing surfaces [11]. However, to fabricate a well-defined micro a dent on conventional ceramic surface such as Al_2O_3 is a big challenge for manufacturer. Particularly, the possibility of generating a high heat is usual from a laser beam texturing (LBT)—a well-known dent fabricating procedure [12]-[15]. These heats can change the material properties of Al_2O_3. Electric Discharge machine (EDM) is not suitable for ceramic since EDM is unlikely to be ideal for non-conductive material (ceramic). Water jet or ultrasound based texturing are precise technique, however, initial set up and operation costs are high [11]. Micro tooling is another state of the art technology of fabricating dent; however their applications are still limited on either softer plastic and metallic application. Although very recently, a diamond base micro drill bit available in commercial market which could be a key accessories to fabricate micro dent on hard ceramic surfaces. This study focused on the ability of fabricate précised micro dent surface on Al_2O_3 surfaces with the aid of micro tools, and investigate whether these fabricated dent have any effective influence in improving tribological performances on simulated hip joints.

II. Material & Methodology

A. Sample Preparation

A Ceramic (99.6% Al_2O_3) block of 90×65×6mm and a rod of Ø6.35×152.4mm were by AdValue Technology (Tucson, USA).The material properties of the ceramic block and rod are shown in Table I. According to the specimen specification of our tribology simulator (Reciprocator friction and wear monitor TR-281-M8), the block was segmented into smaller dimensions: Block-15×15×6mm and rod- Ø6.35×6mm. A IsoMet® 5000 Linear Precision Saw was used in the cutting process considering the high hardness of alumina. Fig. 2 (a) shows the tribometer.

TABLE I
MATERIAL PROPERTIES OF TESTED ALUMINA CERAMIC

Chemical Composition (%)		Mechanical properties	
Al_2O_3	>99.6	Density (g/cm^3)	>3.80
SiO_2	<0.1	Vickers hardness (kg/mm^2)	14440
Fe_2O_3	<0.05	Flexural strength (MPa)	379
R_2O	<0.1	Fracture toughness K_{IC} (MPa m$^{1/2}$)	6.1

Prior to surface texturing, the specimen was polished through a series of polishing process for achieving a mirror type surface smoothness. The specimen was polished by a diamond grinding disc (30µm) at the beginning of the surface polishing, followed by the steps of 9µm, 6µm, and 1µm diamond polycrystalline suspension. Finally, a polishing suspension of 0.05µm diamond polycrystalline was utilized to achieve mirror finish (Ra 0.1±0.05µm). The surface roughness was measured by at random locations (5 times parallel, 5 times across to the each of the sample; 4.5mm spans) by using a Mitutoyo Surface Roughness Tester (sj210). Average surface roughness of the samples was R_a 0.15µm. However, we did not polish the cylindrical specimen which roughness was around 0.3µm.

TABLE II
DIMPLE PROPERTIES

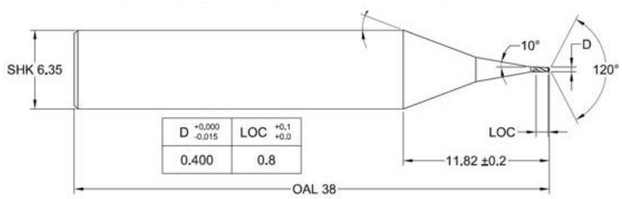
	R_a (µm)	Dent dia (µm)	Dent depth (µm)	Pitch (mm)	Area ratio (%)
No-dimple	0.145±.05	-	-	-	-
Dimple1	0.151±.05	400	20	1.5	13.92
Dimple2	0.153±.05	400	20	2	8.73

There selected three set of dent profiles based on literature — diameter 400µm, depth 20µm and distance between two dents were 2 and 1.5mm. The desired micro-dent surface were prepared by using a Mikrotools DT110 multipurpose micro machine with a set of solid carbide drill bit (0.4mm diameter, n=6. The drill bits were supplied by PrecisetechSdn. Bhd. (Selangor, Malaysia), where the recommended spindle speed was 55,000 rpm and feed rate was 334mm/min for effective drilling on hard ceramic substrate. The CNC Mikrotools DT110 and drill bits are shown in Fig. 1. Based on the recommendation and designed surface geometry, a numerical program (CNC) was prepared and installed in the Mikrotools DT110. To avoid the machining error due to wear of drill bit, every single surface was drilled by a brand new drill bit. Moreover, a further surface polishing was conducted in order to remove the dent burs. Finally an ultrasound cleaner was used to clean so; it was made sure that no foreign particles were stuck inside the dent generated from polishing material or drill bit. AnEDS examination was carried to confirm the purity of dent from these foreign particles.

B. Tribological Experiment

Friction tests were carried out by using a pin-on-disk tester, which is shown schematically in Fig. 2. This simulator machine was specially designed for modeling the sliding line contact between a cylindrical and planar interface. Three tribological systems, comprising the three different disc surface profiles (non-dimple, dimple-1 and dimple-2) were investigated. The pin was installed into a metallic holder, and fixed such that they could not rotate themselves. The center of the pin holder was loaded in the direction normal to the alumina plate located beneath the pins. The pin was moving along to the reciprocating direction the plate was fixed.

(a)



(b)

Fig. 1 (a) Mikrotools DT110 and (b) Micro drill tools

The experimental parameters of the tribology testing conditions are described in the Table III. Three different loading conditions were applied with fixed speed. During test the applied loads were 10, 15, 20 N, which produced the Hertzian contact pressure of 0.132, 0.162, 0.187 GPa respectively. The sliding contact zone was fully soaked in lubricant, bovine synovial fluid. The temperature was kept at 37^{0}C throughout the tests.

TABLE III
CONDITIONS OF PIN-ON-DISK TESTING

Pin and disc	Alumina ceramic
Load (N)	10,15,20
Sliding velocity (mm/s)	10
Stroke length(mm)	2
Lubricant	Synovial fluid from cow
Temperature (^{0}C)	37

Friction coefficients were calculated using the friction force measured at different loading condition. Total running time of every sample was 90min. For every sample, first 30min at

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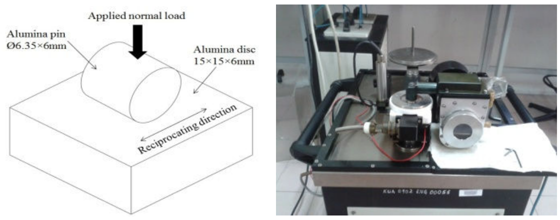
10N then next 30min at 15N and last 30min at 20N.

III. Results

A. Dimple Profile

The micro dents produced by micro tools were then analyzed using optical microscopy and field emission scanning electron microscopy (FeSEM). A stylus profilometer (Mitutoyo Surface Roughness Tester sj210) was also used to characterize their surface topography.



(a) (b)

Fig. 2 (a) Schematic diagram of pin-on-disk friction testing method; (b) Tribology simulator

The dent size was set at 400µm in diameter with pitch 2 and 1.5mm for area densities of 8.73 and 13.92%. An ex-ample of the textured surface morphology is shown in Fig. 4. The dent depth was 20µm for all the dimples. Because of using the drill bit of 0.4mm diameter the dent was an average 405µm.

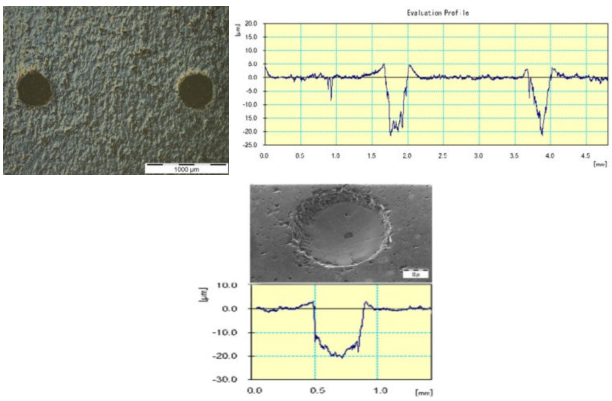


Fig. 3 Dimple surface topography

B. Tribological Performance

Tribology test was done in three stages. In every stage contained 9,000 cycles and the presented friction coefficient profiles were the average friction coefficient profiles of each type of surface patterns. The comparisons of friction coefficient profiles were presented after each of the stages. Friction tests were first carried out at a normal load of 10N for no-textured surface morphologies. Then the machine stopped a moment for changing the normal load for 15N and 20N. The friction coefficient was measured at different surface at a speed 10mm/s for every normal load, following the running-in period. The surface roughness of both the pins and the plates showed no obvious change following the friction test.

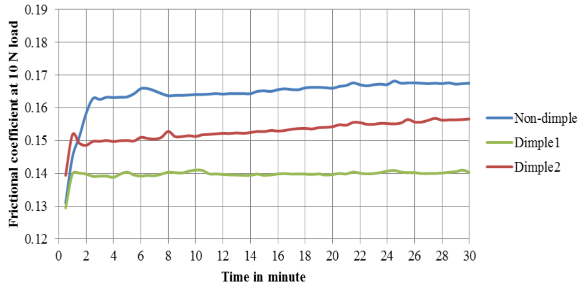


Fig. 4 Friction coefficient for different sample at 10N load

The frictional properties of the samples with the 10N load for different surfaces are shown in Fig. 4. The frictional coefficient with dimple1surface shows the lower. From Fig. 3, at initial stage friction was lower for all surfaces and sharply rises up to 2 minutes and then went to steady with slightly increase but the dimple1 surface was steady after 2 minutes. The micro-dents with higher area density performed well to reduce friction as fluid reservoirs and/or promoting the retention of a lubricating film. In addition, an increase of the dimple density alone, resulting in a decrease of the direct contact area.

The test results for the samples with 15N load illustrated in Fig. 5. For the cases where the dimple density was same, reduced friction coefficients were also successfully realized over the entire range of testing period but due to increase of load frictional coefficient slightly increased but after time to time it was decreased slowly. At 15N load dimple1 with higher dent area density also performed well and frictional coefficient was also constant. Fig. 4 shows at 60 minute Dimple1 surface shows 0.166 which reduces frictional coefficient by 6% with compare to non-dimple surfaces.

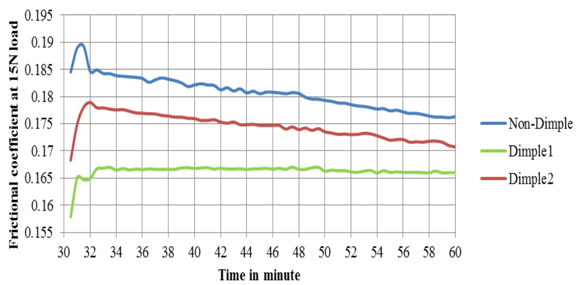


Fig. 5 Friction coefficient for different sample at 15N load

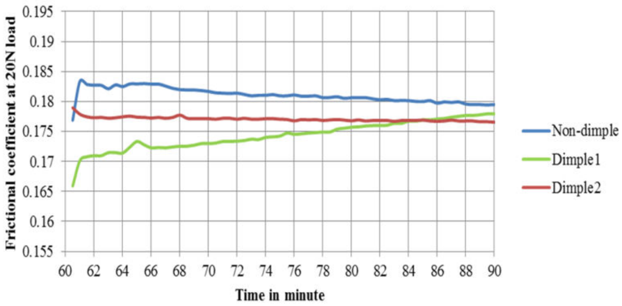


Fig. 6 Friction coefficient for different sample at 20N load

The results for the samples with 20N dimples are shown in Fig. 6. From figure it is clearly shown that due to increase of load the friction also increased. At the 20N load, initial the frictional coefficient was less on dimple1 but it was gradually increased and 90 minute it was higher than the dimple2 surface.

IV. Discussion

The present study was a preliminary study to justify the potentiality of applying micro dent surface profiles (n=3; one non dimple and 2 dimples) on Al_2O_3 surfaces. The dent parameter was selected based on a published theoretical article which studied on metal on metal hip joints [3]. The fabrication procedure was successfully completed by the Micro tools machine which deviation was less than 1.5%.However the main limitations of the study were: 1) lower number of cycles (approximate one million cycles performs per year [16]); 2) Fewer amount of samples; and 3) only one tribological parameter (friction coefficient) was identified. Despite of these limitations, a realistic simulated hip joints experiment conditions were maintained. These parameters are: 1) Bovine synovial fluid, which was collected from four joints of a cow [17]; 2) load 10, 15, 20 N (Hertz pressure 132, 162, 187 MPa) which are similar to other published articles for ceramic-on-ceramic hip joints [18]; 3) Speed 10mm/s which is simulated medium walking speed [16]; 4) 37^0C temperature which is body temperature [17]; and 5) a very smooth surface (Ra 0.15µm) [1].

Much lower friction coefficient was observed to the dimple surface 1 at load 10 and 15N, however, dimple surface 2 performed better at load 20. This may be because the dent produced hydrodynamic pressure of dimple surface 1 (which was fewer in number compare to dimple surface 2) did not control the high pressure of 187 MPa (20 N load). However, a film thickness measure could justify this prediction better. Unfortunately, the tribology simulator was not capable to measure that tribological parameter. Moreover, we did not consider wear rate measured by the tribology simulator since these were affected by the wear debris. However the reduction of friction coefficient is justified by other published similar study, although they were conducted in other material combination [1], [19], [20].

V. Conclusion and Future Works

This study has revealed two major achievements—a) the ability of fabricating micro dent profiles on hard Al_2O_3 surfaces; and b) the better performance of micro dent surface profile in reducing friction coefficient to a simulated hip joints condition. From this study we can conclude the key points following as:

i. A precision fabrication of micro dents (Dimple-1: Dia 400µm, Depth 20µm, P: 1.5mm; Dimple-2: Dia 400µm, Depth 20µm, P: 2mm) were achieved by using micro tools on ceramic surface, whereas deviation was below 1.5%.
ii. Dimple surface reduced 15%, 8% friction coefficient under 132 and162 MPa compared to the non-textured surface after 90,000cycles.
iii. Dimple surface-2 reduced 4% friction coefficient under 187 MPa contact pressure compared to the non-textured surface after 90,000 cycles.

Further work is warranted to identify the optimized dent parameters to minimize wear and friction coefficient. The optimized parameters need to be tested with longer cycles and to a spherical shaped specimen for better reliability of artificial hip joints.

Acknowledgments

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