Tribology International 101 (2016) 1–9

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

# Effect of EDM dimple geometry on friction reduction under boundary and mixed lubrication

K.W. Liew [1], C.K. Kok, M.N. Ervina Efzan

*Centre for Advanced Materials and Green Technologies (CAMGT), Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia*

ARTICLE INFO

*Article history:*
Received 29 December 2015
Received in revised form
24 February 2016
Accepted 25 March 2016
Available online 8 April 2016

*Keywords:*
Friction
Wear
Surface texture
Mixed lubrication

ABSTRACT

The purpose of this work is to study the effect of electrical discharge machined (EDM) dimple geometry on friction reduction under boundary and mixed lubrication. Three different types of dimple geometry were designed with equal area density of 10.4% and EDM on test surfaces of aluminium alloy 7075 square pins. The specimens were tested against a rotating high speed steel counter-disc using a pin on disc apparatus under mixed lubrication condition. Tribo-tests were conducted at increasing sliding speed with varying nominal contact pressures. The friction coefficient of the EDM dimpled specimens are found 11–24% lower than that of the non-textured specimens. It is also found that the round dimple geometry gives the lowest friction and wear among others.



## 1. Introduction

Friction reduction and wear control on mechanical sliding components are essential to extend the lifetime of mechanical systems, improve their efficiency and reliability, and conserve energy [1–3]. In an internal combustion (IC) engine, about 15% frictional losses due to mechanical action were reported [2]. These losses in an IC engine can be attributed to four major sources, namely the piston assembly (45%), engine bearings (25%), pump (20%), and valve train (10%) [2]. Engine bearing is the second most important friction source in the IC engine [2]. The enhancement of tribological properties remains an area of intensive research for the selection of bearing materials or coatings. Journal bearings have a major disadvantage that required a certain speed to form a thick film lubrication to attain full separation of the sliding surfaces [4]. Below that minimum rotational speed, boundary or mixed lubrication prevails, which involves asperities to asperities contact in the rubbing surfaces. Therefore, when the journal rotates at low speed for the moment of starting and stopping, even if the bearing is well designed for high rated speed on a machine or engine, it can be encountered a high friction and wear [4]. For this reason, surface engineering such as texturing is expected to be an effective way to reduce the friction and wear behaviour of the engine bearing, thereby reduce fuel consumption. Surface texturing has been successfully applied to mechanical seals for its life improvement [5]. Partial laser surface texturing on hydrodynamic thrust bearings was also shown to increase load carrying capacity substantially [6]. Furthermore, surface texturing is effective in enhancing surface anti-seizure ability [5].

The various techniques employed for surface texturing include jet machining [7], etching techniques [8,9], pellet-pressing [10], embossing technique [11,12] and laser surface texturing [7,13–18]. The dimples or oil pockets created by these techniques on sliding surfaces act as a reservoir of lubricant, and have been shown to reduce friction by providing hydrodynamic lift. The dimples also serve as micro-traps for wear particles in oil sliding [13]. Although laser surface texturing is the most advanced technique for tribological application, it has a dimple diameter limitation in micron level only. Besides, the laser surface texturing often causes bulges or burr around the dimple edge. This may affect the mechanical properties and surface integrity around the dimple edge due to high heat during laser machining [13–18]. The coefficient of friction would be higher if the burr around the dimple edge was not subjected to grinding or burr removing [17]. According to Zhou et al. [19], electrical discharge texturing technique can also be used to mass-produce surface textures. In their work, the surface textures on the aluminium specimen were produced by transferring the surface textures from the electrically-discharge-textured forming rolls to the specimen surface. Their results showed that the transferred electrical discharge texturing on the specimens can reduce the friction coefficient of contacting pair at high contact pressure, but increase friction in low contact pressure [19]. However, no study has been done to investigate the effect of dimple geometry produced by electrical discharge machining (EDM) on the tribological behaviour.

*E-mail addresses:* kwliew@mmu.edu.my, mscalec@yahoo.com (K.W. Liew).
[1] Tel.: +60 6 2523241.

http://dx.doi.org/10.1016/j.triboint.2016.03.029
0301-679X/

Many researchers have shown that the presence of dimples reduces the coefficient of friction substantially from that of an untextured surface of comparable surface roughness [7–19]. These experiments indicated that the 7–12% of lower dimple area density was given more advantage for lubrication regime transitions than the 15% of higher dimple area density [17]. Most of the experiments use pin-on-disc tribometer [8,13,15,17,20–24], which is one of the test techniques used to investigate the friction and wear behaviour of an aluminium-based journal bearing alloys [25]. Furthermore, most of these studies focused on the hydrodynamics lubrication conditions, while limited studies had been reported on the boundary and mixed lubrication regimes [18,26–28].

The effect of dimple shapes on friction and wear in hydrodynamic regime has been widely reported. An excellent review of such work was given by Ibatan et al. [29]. The circle, triangle and ellipse dimple shapes were the most common among the shapes being investigated. Segu et al. [30] explored the feasibility of hybrid texturing in hydrodynamic regime but did not make conclusion on shape effect. Qiu et al. [31] established the superiority of ellipsoidal and elliptical shapes over the spherical and circular shapes in the hydrodynamic regime via analytical models. By numerical optimization, Shen and Khonsari [32] found that chevron and trapezoidal-like shaped dimples maximizes the load carrying capacity in hydrodynamic regime. It is noted that the current experiment focuses on the boundary to mixed lubrication regimes, which may not be directly comparable to the behaviour in hydrodynamic regime.

Thus, the current work aims to address the lack of studies on the tribological behaviour of metallic contacting pairs EDM textures in the boundary/mixed lubrication regime. The effect of EDM dimple geometry on friction and wear in boundary/mixed lubrication (without re-lubrication) contact condition is investigated. The sliding friction and wear test are performed using pin-on-disc (POD) technique tribo-tester under varying sliding speed and loads.

## 2. Experimental work

### 2.1. Specimens preparation and electrical discharge surface texturing

In this work, the aluminium alloy 7075 is selected as a pin specimen. The chemical composition and mechanical properties of the specimen are shown in Table 1 which was published in authors' previous work [33]. The square pin specimens were fabricated into a dimension of $11 \times 11 \times 20$ mm$^3$ using a CNC milling machine (MAZAK). The specimens were first ground to attain surface roughness $R_a$ of about 0.1 µm, Fig. 1. The dimple geometry on the Al-based alloy (Al-7075) specimen was produced by electric discharge surface texturing using EDM machine (Makino, EDNC65, Japan), with dimple geometry copper electrode reduction amount of 0.055 mm, jump amount of 6 times, cycle number of 3 times, feed rate of 0.0034 mm/s and electric current of 0.1 A. Fig. 2 shows the optical microscope images and photographs of the three different types of dimple geometry, namely rounds, diamonds and ellipses fabricated in this work. The design drawings of the dimple geometry with detailed dimensions are shown in Fig. 3. The dimples are arranged in a square array of four rows and four columns on the surface of each pin and the depth of each dimple is about 10 µm. With the purpose of studying the effect of dimple geometry on friction, these dimple arrays have the same area density of 10.4%, and the total dimple area of 12.6 mm$^2$ each pin. Fig. 4 shows the longitudinal cross-sectional profile and the two-dimensional (2D) scanning electron microscopic images before test of each dimple type.

**Table 1**
Chemical composition (wt%) and mechanical properties of aluminium alloy 7075 [33].

| Chemical composition – aluminium alloy 7075 | |
|---|---|
| Element | wt% |
| Si | 0.05 |
| Fe | 0.15 |
| Cu | 1.40 |
| Mn | 0.02 |
| Mg | 2.40 |
| Zn | 5.80 |
| Ti | 0.07 |
| Cr | 0.20 |
| Al | Balance |
| Mechanical properties | |
| Ultimate tensile strength, MPa | 571.58 |
| Yield strength, MPa | 524.69 |
| Elongation, % | 12.00 |
| Hardness, HV | 117.70 |

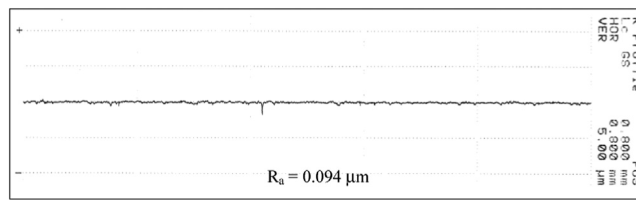


**Fig. 1.** Ground surface profiles of specimen before test.

### 2.2. Tribological test

The sliding tests of three different types of dimple geometry were carried out using a POD tribo-tester as presented in Fig. 5. The stationary square pin specimen ($11 \times 11 \times 20$ mm$^3$) slid against a rotating disc with a diameter and thickness of 170 mm and 6.5 mm respectively. The counter-disc material was made by high speed steel (HSS) of grade M50, with recorded average hardness of $64 \pm 1.0$ HRC. Its chemical composition is given in Table 2. The HSS disc surface was ground using silicon carbide abrasive wheel (grain size 1200) and polished to initial average arithmetic roughness, $R_a = 0.001$ µm using surface grinding machine. The surface roughness was measured using stylus profilometer (Perthometer S2, Mahr). The friction force was measured using a calibrated strain gauge which is fixed on the load lever holding the specimen and the measurements were averaged over the steady state range. Hence, the coefficient of friction was determined as the ratio of friction force to normal force applied on the pin specimen against the counter-disc. The surface contact temperature was recorded using an infrared thermometer (MT-4002, Proskit) that was positioned at approximately 15 cm away from the specimen trailing edge. The weight loss was calculated by measuring the weight difference using 0.1 mg electronic balance (SHIMADZU AW-220).

All experimental tests were carried out at the ambient temperature and humidity environment (around 27 °C, 89%RH) under oil-lubricated conditions with increasing sliding speed in the range of 0.5–7.8 m/s and at nominal contact pressures from 0.08 to 0.30 MPa. Every speed was maintained for 120 s. Syntium 1000 SAE 15W-50 engine lubricant was used for the entire tribological test, and its properties are shown in Table 3. About 25 ml of engine oil (without relubrication) was meted out in the contact zone of counter-disc surface in each test using a syringe. The counter-disc was then rotated at a speed of 1300 rpm for 30 s in order to obtain a uniform thin film of lubricant on the disc. The morphologies of worn surfaces were examined using metallurgical microscope (MT-8530, Meiji) and scanning electron microscopy (MiniSEM, SNE-3000M, SEC).