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STUDY OF DIMPLE TEXTURE WEAR CHARACTERISTICS BY EXPERIMENTAL METHOD

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ABSTRACT

Various approaches has been proposed in order to improve tribological behavior, some of which are lubrication, coating, and surface modification such as texturing, which is the center of attention of this work. Dimple Texture Forming is the proposed area of study. Dimple Texture Forming in friction pairs is one of the wear reduction techniques. In most of the contact mechanisms, the materials chosen for two contacting parts are different; the reason behind this is wear happens on both the parts since they are of same material. For example, in case of shaft and bearing, it is difficult to replace the shaft since it is cost effective, whereas bearing can be replaced easily; so shaft is made of different material compared to bearing. But if we can use dimples texturing on any of the mating parts, same material can be used for both the contacting parts, and this is the main area of study in this work. By texturing the surface with Dimples, the value of surface roughness throughout the surface remains constant at peak; this eliminates the surface roughness variations on the surface of an un-textured surface, since it will be peak only at some places and varies throughout. In this work, different geometries of the Spherical and Elliptical Dimple Textures were formed using Laser Surface Texturing. The tribological performance of the sliding pair mainly depends on shape geometry and density of the patterned micro-texture features (dimples).The effect of these micro-dimples on friction properties were experimented by using Pin on Disc Tribometer ASTM G99 for a Brass disc mated with Brass pin (same material for both pin and disc). Concurrently, Un-textured surface frictional properties were also tested using Pin on Disc Tribometer ASTM G99. Compared to a smooth surface without texturing, some textured surfaces successfully indicated the Reduction of coefficient of Friction. Spherical dimples with 150 microns diameter and 75 micron depth provided the minimum coefficient of friction from the experiments. There was valid evidence proving that dimple shape and geometry was the optimum texturing solution to increase tribological properties. Results also indicted that optimum texture density might exist at which the surface shows the best Friction and Wear behaviour.

Keywords: dimples, dimple texture forming, tribology, tribometer, wear behavior, friction.

INTRODUCTION

Friction is involved in thousands of applications in our daily lives. In some applications high friction is desirable, as in vehicles' tires on the roadways, brakes, clutches, and frictional power transmission systems. In other applications, friction reduction is a constant demand which reflects on energy efficiency, component durability, and system reliability. For example, the energy loss due to friction in automobiles is estimated to be 40% of the total energy generated by the internal combustion engine. In all cases, understanding the mechanisms involved in friction and the means to control it are necessary. Various approaches have been engaged in order to improve tribological behavior, some of which are lubrication, coating, and surface modification such as texturing, which is the center of attention of this work. Lubrication, whether hydrodynamic, boundary, or mixed is one solution to control friction, however, lubrication in some operating conditions is not applicable. In addition, surface coating is another effective means of reducing friction. High strength and low friction coating materials have been employed in a wide range of applications, yet surface coating sometimes faces the challenges of de-bonding and fractures of the coating layer, which may result in more catastrophic results. Therefore, researchers have been searching for a more reliable approach that can control friction in all operating conditions. Three decades ago, attention was drawn to surface patterning, or surface texturing, as an effective means to improve the tribological performance. The idea of surface texturing is inspired by nature. Shark skin, for instance, boosts swim speed by cutting the drag force; therefore, the skin suits of Olympic athletes have v-shaped grooves called riblets which mimic the texture of shark skin. The gecko foot is another example from nature that inspired many adhesive systems. Many studies have investigated the effect of surface texturing on the performance of a variety of mechanical systems. It was found that surface texturing has great potential for improving the tribological performance in terms of reducing the wear, friction, and lubrication consumption. In the following sections, a review of the surface texturing effect on friction is presented. This includes a discussion of the surface texturing parameters, the different benefits of the textured surfaces based on lubrication regimes, the various methods which are used to fabricate the textured surface, and the applications that widely employ micro-surface texturing.

Tribology: Tribology is the science and technology of friction, lubrication, and wear, derived from the Greek tribos meaning "rubbing". Formally, it is defined as the science and technology of interacting surfaces in relative motion and all practices related thereto. Webster's dictionary defines tribology as "a study that deals with the design, friction, wear, and lubrication of interacting surfaces in relative motion (as in bearings or gears)."

Surface texturing: In general, surface texture may be positive, in that it protrudes out of the surface, or negative, such as dimples or holes. It can also be made up of continuous grooves, channels, or undulations. It can be discrete shapes, such as circular, square, triangular, or hexagonal, that is distributed evenly or randomly. Positive surface textures are used extensively in micro-electrical mechanical systems (MEMS), and magnetic hard disks to decrease the friction by decreasing the area of contact. Negative texturing, which is the focus of the current study, is mostly employed in automotive components, and in machining tools and punches for metal forming processes. Different texture parameters, such as shape, size, density, depth, and orientation, or a combination of these parameters, control the effectiveness of the surface texture on tribological performance. The role of the surface texturing in improving the tribological properties varies based on the contact conditions, whether they are hydrodynamic (full), mixed, boundary, or dry conditions. In the case of the full or mixed lubrication conditions, the micro-craters serve as micro-hydrodynamic bearings that increase the hydrodynamic pressure due to asymmetric pressure distribution, therefore the load carrying capacity increases. In mixed lubrication conditions, this additional lift in hydrodynamic pressure alters the balance between hydrodynamic and boundary lubrication, consequently the number of the asperities in contact decreases, and friction and wear decrease.

Laser Surface Texturing (LST): Laser Surface Texturing orLST developed by Surface Technologies has successfully resolved some of the severest mechanical seal performance problems and is now available as an integral part of these high performance seals. This unique treatment designed to overcome the effects of marginal lubrication has shown it can help combat the most common causes of seal failure such as dry running, media vaporization and contamination. LST generates high precision micro pores or dimples, usually in the face of the stationary ring, that are optimized to trap scarce lubricant whatever the medium. Each pore acts as a micro-hydrodynamic bearing generating an improved lubricant film and pressure differential. Face friction can be more than halved with corresponding reductions in face temperature. Typically LST can more than double seal life in poorly performing applications, or if seal life is not an issue it can greatly enhance security against unforeseen operating conditions such as loss of media flow or sudden pressure peaks. Surface texturing has been used in various applications for different purposes. Mainly, it is used to enhance tribological performance which includes decreased wear and friction. Most of these applications are automotive components, tools and punches of metal forming processes, and micro-electrical mechanical systems (MEMS).

RELATED WORK

In this thesis, Dimple Surface Texturing is proposed as the wear reduction techniques, and its effect on the frictional properties are proposed to be tested without any mixed lubrication systems [1][4]. The fabrication method for Laser Surface Texturing needs to be finalised with top most priority since it can completely alter the results. LPT is chosen as since some of the studies, it is proved to be the best texturing method when it is compared to other methods [16][9]. In this study the material proposed is Brass unlike the Co Cr-Mo Alloy surfaces [14]. Brass is chosen for its lower load applications. Experimentation work is made as the basis for this work, since Surface texturing is proved to reduce Frictional parameters analytically by Finite Element Methods [2] [5]. Dimple Texture shapes were selected as Spherical and Elliptical and are proposed to be tested unlike other shapes in [8]. Dimple Texture geometry parameters are chosen in range of 100 to 200 μm and the depth of dimple is chosen from the 50 to 100 μm [3][6][10]. The pitch of the dimples were chosen as 0.6mm as friction reduction will be more effective if we can chose the optimum density distribution.

Based on the referenced literature, micro surface texturing has proven to be an effective means of enhancing tribological performance. Most of the studies investigated the effects of micro surface texturing in wet conditions with a very limited number of studies tackling the dry sliding condition. Most of the studies concluded that texturing with 40 μm dimples had no beneficial effect on friction reduction under the above test conditions, whilst lower friction coefficients were obtained for the larger dimples. Most of the studies verified that the circular shape shows the most stable wettability among three regular layout dimples. Most of the studies concluded that LST is an effective technology to fabricate controlled micro-dimple array on specimen surface. Most of the studies verified the beneficial effect of multi-scale dimples becomes higher with increasing dimple depth and sliding speed. Most of the studies showed the potential benefits of adding micro surface texturing to one surface only of the contact pair in different sliding conditions. Moreover, micro surface texturing plays different roles based on the lubrication regime. In full (hydrodynamic) lubrication mode, the dimples develop pressure differences, thus they act as bearings. In the boundary lubrication mode, the texture pores provide a continuous lubricant supply to the contact interface, which decreases surface to surface contact. In the dry condition, they act as traps for wear debris so that plowing decreases.

PROPOSED WORK

First, disks are manufactured with various machining process like Facing and grinding to obtain the various surface topography and the roughness value in order to investigate surface parameters that significantly contribute to the contact pressure, frictional forces, and eventually the friction coefficient, to prove that a minimum overall coefficient of friction exists. Then the surface roughness values for various machining operations are calculated by using a surface roughness tester. Finally, with help of pin on disk tribometer wear rate and frictional forces are evaluated. Design and Modeling of a dimple texture surface topography is created by using modeling software with appropriate shape and size. Then, various

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textured surfaces in contact with a rigid cylindrical indenter are fabricated in order to investigate texturing parameters that significantly contribute to the contact pressure, frictional forces, and eventually the friction coefficient, to prove that a minimum overall coefficient of friction exists. The effects of different texture parameters, such as texture size, density, shape, and anisotropy on contact pressure are addressed, and the most significant surface texture parameters at which the wear rate is minimum are determined by pin on disk tribometer. Finally, the experimental outcomes show the effect of micro surface texturing parameters on the wear rate, coefficient of friction and frictional force.

In this work, the control of the friction of dry sliding contact through micro surface texturing is the main objective. In order to reduce the sliding wear of friction pairs, the surfaces of friction pairs were textured with morphology of dimples. Finally, the optimal range of the significant surface texture parameters that minimize friction is sought. Each micro dimple can serve as a micro-hydrodynamic bearing in case of full or mixed lubrication or as a micro-reservoir for lubricant in cases of starved lubrication conditions.

System architecture diagram

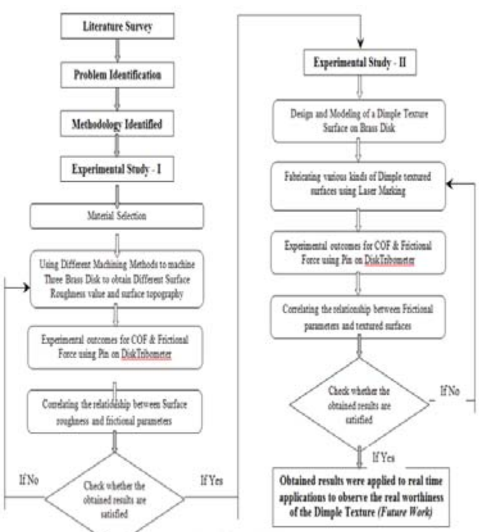

Figure 2.1 Flow chart for methodology

MATERIAL REQUIREMENTS

Material plays a major role in the frictional properties of rolling pairs. So the material selected based on it can able to withstandhigh pressure and temperature during mechanical movements. The literature survey showed that micro surface texturing has proven to be an effective means of enhancing tribological performance. Most of the studies investigated the effects of micro surface texturing in copper alloys because these metals can able to withstand high pressure and temperature. In this study Brass was chosen as specimen material to obtain frictional behavior in sliding pairs and the properties of brass as listed in Table-1.

Table-1. Material properties.

Property	Value
Young's Modulus	100000 N/mm^2
Poisson's Ratio	0.33
Shear Modulus	37000 N/mm^2
Density	8500 kg/m^3
Tensile Strength	478.41 N/mm^2
Yield Strength	239.68 N/mm^2
Hardness	192-202 BHN

EXPERIMENT MODULES

In order to carry out any experiment, we need to divide the experimentation into different phases/modules. Each and every module carries its own significant value to the experiment. The chronological order of the modules must be taken high care in order to have a perfectly planned experiment. The modules of the experiment will identify the steps to be followed. And the modules of this work can be divided in to below 4 phases:

A. fabrication and testing of untextured brass disc

B. modelling of textured dimple patterns

C. fabrication and testing of spherical dimple texture

Fabrication and testing of elliptical dimple texture

Fabrication and testing of untextured brass disc

Initially disks are manufactured by various machining process like Facing and grinding to obtain the various surface topography and the roughness value in order to investigate surface parameters that significantly contribute to the contact pressure, frictional forces, and eventually the friction coefficient, to prove that a minimum overall coefficient of friction exists.

Disk I (Facing): In machining, facing is the act of cutting a face, which is a planar surface, onto the work piece. In this method we can able to achieve the surface roughness of 0.8 - 0.9 µm. Figure-1 shows the machined surface of the brass disk using facing operation.

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Figure-1. Disk I (Facing)

Disk II (Grinding): Surface grinding is used to produce smooth finish on flat surfaces. It is a widely used abrasive machining process in which a spinning wheel covered in rough particles (grinding wheel) cuts, chips of metal or nonmetallic substance from a work piece, making a face on it flat or smooth. In this method we can able to achieve the surface roughness of 0.6 - 0.7 µm. Figure-2 shows the machined surface of the brass disk using grinding operation.

Figure-2. Disk II (Grinding).

MODELLING OF TEXTURED DIMPLE PATTERNS

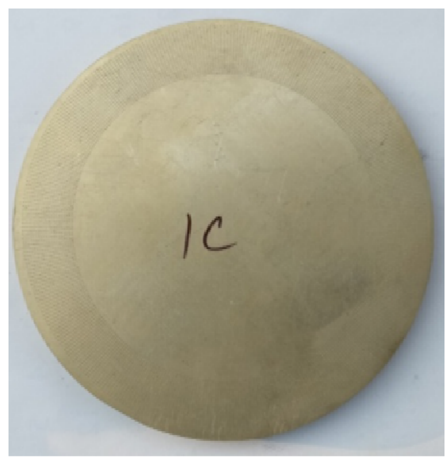
Modeling of engineered textured surface was developed to simulate the contact between a rigid surface and engineered textured surfaces. These models will be investigated with the effects of the pattern geometry, density, and shape on the friction coefficients.

Table-2. Dimple Texture Geometry.

		Dimple size (mm)		**Dimple depth** (mm)	**Dimple pitch** (mm)
		Major	**Minor**		
Spherical	Pattern I	0.1	-	0.05	0.6
	Pattern II	0.15	-	0.075	0.6
	Pattern III	0.2	-	0.1	0.6
Elliptical	Pattern I	0.1	0.05	0.05	0.6
	Pattern II	0.15	0.075	0.075	0.6
	Pattern III	0.2	0.1	0.1	0.6

FABRICATION AND TESTING OF SPHERICAL DIMPLE TEXTURE

Spherical shape, texture



a. Spherical pattern 1

b. Spherical pattern 2

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c. Spherical pattern 3

Figure-3. Spherical shapes, surface texture.

Table-3. Texture parameters for Spherical shape dimple.

Pattern no.	**Dimple starting radius** (mm)	**Total no of dimples**
I	37.5	7200
II	37.5	7200
III	37.5	7200

FABRICATION AND TESTING OF ELLIPTICAL DIMPLE TEXTURE

Elliptical shape, texture

a. Elliptical pattern 1

a. Elliptical pattern 2

c. Elliptical pattern 3

Figure-4. Elliptical shape, surface texture.

Table-4. Texture parameters for Elliptical shape dimple

Pattern no.	**Dimple starting radius** (mm)	**Total no of dimples**
I	37.5	7200
II	37.5	7200
III	37.5	7200

Pin specimens

Figure-5. Pin specimens.

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RESULTS AND DISCUSSIONS

Wear test was conducted to determine the wear behavior of the composite. Wear behavior of different composite was studied with different parameter like sliding velocity and applied loads. A computerized pinion - disc wear test machine was used for this experiment, the wear test was carried out at a constant sliding velocity with normal loads. A cylindrical pin of size 10mm diameter and 25mm length was loaded through a vertical specimen holder against the horizontal rotating disc, the principle objective of the investigation was to study the co-efficient of friction and wear.

Figure-6. Wear test apparatus.

Figure-7. Parameter setting.

Technical Specification

Normal load range	- up to 200 N
Wear measurement range	- 0 to 4 mm
Sliding speed	- 0.26 to 10 m/s (100 to 3000 rpm)
Wear disc material	- Brass with engineered texture surface
Wear disc Diameter	- 100 mm
Pin material	- Brass
Pin Diameter	- 3 to 12 mm
Pin Length	- 25 to 30 mm

SURFACE ROUGHNESS TESTER

Once the fabrication part is over the disks surface topography are tested by using surface roughness tester to evaluate the surface topography of the disks.

Figure-8. Surf test SJ-210- Series.

Technical specification

Model no	SJ-210
Drive Unit	Standard type (178-230-2)
Detector	0.75m N type (178-296)
Display unit	Compact type (178-253A)
Stylus tip radius	2μm

Roughness value for Disk I (Facing)

Table-5. Roughness value for Disk I (Facing).

Disc No.		**1**	**2**
Roughness Value (μm)	**Ra1**	**0.920**	**1.000**
	Ra2	0.940	1.000
	Ra3	0.890	0.999
Average Roughness Value (μm)		0.916	0.999

Roughness value for Disk II (Grinding)

Table-6. Roughness value for Disk II (Grinding).

Disc No.		**1**	**2**
Roughness Value (μm)	**Ra1**	**0.675**	**0.700**
	Ra2	0.720	0.712
	Ra3	0.650	0.688
Average Roughness Value (μm)		0.681	0.700

CORRELATION BETWEEN SURFACE ROUGHNESS AND FRICTIONAL PARAMETERS

Frictional Force and COF for Disk I (Facing)

Table-7 shows the variation of frictional force and friction coefficient for Brass disk machined by facing operation. During experiment, the sliding velocity and normal load were 3.5 m/s and 40N respectively.

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Table-7. Frictional forces and COF for Disk I (Facing).

Disc No.	1	2
Material	Brass	Brass
Rpm	1000	1000
Load (N)	40	40
Time Duration	600 sec	600 sec
COF	0.1855	0.1877
Friction Force (N)	8	7

Frictional force and COF for Disk II (Grinding)

Table-8 shows the variation of frictional force and friction coefficient for Brass disk machined by grinding operation. During experiment, the sliding velocity and normal load were 3.5 m/s and 40N respectively.

Table-8. Frictional force and COF for Disk II (Grinding).

Disc No.	1	2
Material	Brass	Brass
Rpm	1000	1000
Load (N)	40	40
Time Duration	600 sec	600 sec
COF	0.1530	0.1600
Friction Force (N)	6	5.5

CORRELATION BETWEEN FRICTIONAL PARAMETERS AND TEXTURED SURFACES

Frictional Force and COF for Patterns of Spherical shape

Table-9 shows the variation of frictional force and friction coefficient for spherical shape micro dimple surface for brass-brass pair. During experiment, the sliding velocity and normal load were 3.5 m/s and 40N respectively.

Table-9. Frictional force and COF for Pattern I, II, III (Spherical shape).

Pattern No.	1	2	3
Material	Brass	Brass	Brass
Rpm	1000	1000	1000
Load (N)	40	40	40
Time Duration	600 sec	600 sec	600 sec
COF	0.16	0.1232	0.1967
Friction Force (N)	7.5	5.5	8

Frictional Force and COF for Patterns of Elliptical shape

Table-10 shows the variation of frictional force and friction coefficient for elliptical shape micro dimple surface for brass-brass pair. During experiment, the sliding velocity and normal load were 3.5 m/s and 40N respectively.

Table-10. Frictional force and COF for Disk II (Elliptical shape).

Pattern No.	1	2	3
Material	Brass	Brass	Brass
Rpm	1000	1000	1000
Load (N)	40	40	40
Time Duration	600 sec	600 sec	600 sec
COF	0.1699	0.1678	0.1573
Friction Force (N)	7.5	7.5	6.5

Frictional Force and COF for Disk III (Smooth Surface)

Table-11 shows the variation of frictional force and friction coefficient for un-textured smooth surface for brass-brass pair. During experiment, the sliding velocity and normal load were 3.5 m/s and 40N respectively.

Table-11. Frictional force and COF for Disk III (Smooth Surface).

Pattern No.	1	2	3
Material	Brass	Brass	Brass
Rpm	1000	1000	1000
Load (N)	40	40	40
Time Duration	600 sec	600 sec	600 sec
COF	0.1928	0.2119	0.1999
Friction Force (N)	9.5	9	8.5

CONCLUSION AND FUTURE SCOPE

The following is a summary of findings which have been mentioned earlier, and they would add to the current state of the art:

a) Micro surface texturing does reduce the coefficient of friction if appropriate surface texturing parameters are identified and optimized.

b) The dimensionless quantity, spatial texture density (D/L), is the most significant texture parameter because it incorporates the size of the texturing features, and the density as well.

c) The minimum coefficient of friction falls with minimum value as 0.1232 of the spherical shape texture.

d) With the circular patterning, a reduction of 14.5 % in the coefficient of friction is obtained under normal and sliding conditions with zero lubrication.

e) Spherical shape patterning outperforms the elliptical shape patterning with regard to the reduction in the friction coefficient.

FUTURE SCOPE

In this study various kinds of micro dimple arrays (Circular arrays of circular, ellipse dimples) modeled on brass surface were experimented to find the minimum coefficient of friction. In order to find the optimum geometry of the dimples, we need to carry out enormous number of experiments with different geometries. That shall be carrying forwarded in future.

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