Investigating the friction reduction capability of dimpled surface using CNSL as lubricant

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Abstract. This work investigates the friction reduction capability of dimple – textured steel surface created using a vertical milling machine. A suitable geometry for creation of dimples was chosen and cashew nut shell liquid (CNSL) was used as lubricant. A L9 orthogonal array was created using Taguchi design of experiment where load, speed of disc and duration of the test were chosen as the parameters. A pin – on – disc tribometer is used to find the coefficient of friction (COF) between an EN 24 steel pin and the dimple – textured steel disc made of low carbon steel. ASTM G99 standard was used for the test and the lubricant was supplied intermittently. Optimization was carried out using Taguchi method, where the optimized condition of the input parameters influenced a substantial change of 32.38% in COF as compared to the non – textured disc surface. The lubricant retention capacity of the dimple was the primary cause for the decrease in COF.

1. Introduction

Surface texturing is a method of enhancing the tribological properties of a surface. They help in decreasing the coefficient of friction. It is a process of modifying the surface and is made using various technology, such as chemical etching [1], laser texturing [2-5], lithography [6], and pellet pressing [7]. They have applications in the areas of thrust bearings [8], journal bearings [9], piston rings [10,11], mechanical seals [12] and bio-implants [13] to name a few of them. Yu, et al. [14] investigated about the geometric shape effects of surface texture on the generation of hydrodynamic pressure between conformal contacting surfaces. Successive over relaxation method was used to find the hydrodynamic pressure generated by texture pattern with the dimples in shapes of circle, ellipse and triangle at different orientations to the direction of sliding. The observed results indicated that the geometric shape of orientation has influence on the load carrying capacity of contacting surfaces. Wakuda et al. [15] studied surface texturing effect between steel and ceramic surfaces and investigated the effect of micro-dimple on friction. It was reported that effect of textured micro-dimples is retained even under severe friction conditions. It was further concluded that a sufficiently lubricated sample with appropriate surface morphology reduces coefficient of friction without forming undesirable tribochemical films.

Concerning environmental factors, disposal of non-biodegradable mineral oil leads to the damage of an ecosystem. Hence, there is always a need for bio-degradable lubricant [16]. As an alternative to
minerals oils, researchers are now resorting on cashew nut shell liquid (CNSL) as a bio-degradable lubricant. It is a waste product obtained in the processing of cashews and is also obtained as a predecessor in the production of cardanol [17]. The current work focusses on the effect of CNSL as a lubricant on steel-to-steel contact in the condition of dimple surface texturing.

2. Materials and methods

2.1. Materials
A low carbon disc (carbon content less than 1%) was used for the test. Its counter surface was an EN 24 pin.

2.2. Surface texturing using dimples manufactured by vertical milling machine
The optimized dimple condition investigated by Bhaumik et al. [18] was used as the geometrical parameters for manufacturing the dimples on the low carbon steel disc. A vertical milling machine (Make: BFW; Model: Gaurav BMV 35 T12) was used. The created dimples have had the next geometrical parameters: diameter of 1.5 mm, depth of 0.6 mm, and pitch of 10 mm.

2.3. Measurement of surface roughness
A contact type surface roughness machine of SurfCom make was used to measure the surface roughness of the pins before conducting the test for coefficient of friction. The value of surface roughness was kept in the range of 0.2-0.3 µm for all the samples.

2.4. Measurement of coefficient of friction using pin-on-disc tribometer
The test for coefficient of friction was conducted on a pin-on-disc tribometer using ASTM G99 standard. The lubricant used was CNSL and it was supplied intermittently (at a rate of 1 ml/s).

2.5. Surface characterization
The tested samples were cut to cylinders of 2 mm length using a hacksaw. The worn out surfaces were then studied under an Olympus optical microscope.

3. Results and discussions

3.1. Test for coefficient of friction
An L9 orthogonal array following Taguchi design of experiments were used to create the Design of Experiments (DOE) using Minitab 16. The factors to be studied were applied load (N), speed of the disc (rpm), and duration of the test (minutes). The L9 orthogonal array is shown in table 1.

| Load (N) | Speed of the disc (rpm) | Duration of test (min.) |
|----------|-------------------------|------------------------|
| 100      | 400                     | 20                     |
| 100      | 700                     | 40                     |
| 100      | 1000                    | 60                     |
| 120      | 400                     | 40                     |
| 120      | 700                     | 60                     |
| 120      | 1000                    | 20                     |
| 140      | 400                     | 60                     |
| 140      | 700                     | 20                     |
| 140      | 1000                    | 40                     |
The tests were conducted on a pin-on-disc tribometer where CNSL was added intermittently. The results of the experiments are shown in figure 1.

![Figure 1. Results obtained by L9 design of experiments.](image)

The results were then obtained using Taguchi method and Minitab 16 software. The factors attained by optimization are a load of 140 N, speed of 1000 rpm and a test span of 20 minutes, as shown in figure 2. Figure 3 shows the comparison of results of a non-textured disc surface and a dimple-textured disc surface under the optimized condition of load, disc speed and duration of the test. It was observed that a decrease of 32.38% in coefficient of friction was reported in case of dimple-textured surface as compared to a non-textured surface.

![Figure 2. Results obtained by optimization.](image)
3.2. Surface characterization

The worn surfaces of the pins used to determine the coefficient of friction for the non-textured and the dimple-textured discs under optimized condition of load, speed of disc and duration of test were analyzed under an optical microscope (see figure 4). It can be said that less wear has occurred on the surface of the pin that was used on the dimple disc surface as compared to the non-textured disc surface. This is due to the less number of grooves present on the dimple surface.

This proves that dimpled disc has the ability to retain lubricant forming a lubricant film at the interface of the dimple and the pin surface [19,20].

4. Conclusions

From the above work, it can be concluded that CNSL is an effective biodegradable lubricant, which can be used to reduce friction. It can also be observed that dimple surface texturing is an effective method of friction reduction. The lubricant film, which is formed at the interface of the pin and the dimple, is mainly responsible for friction reduction. Due to the absence of surface textures, lubricant
film cannot be formed at the interface of the pin and non-textured surface. This leads to inefficient lubrication and to an increase of coefficient of friction.

5. References

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