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"A COMPREHENSIVE STUDY ON COEFFICIENT OF FRICTION PERFORMANCE OF UNTEXTURED AND TEXTURED TOOL STEEL"

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ABSTRACT

Tool steel finds extensive applications in tools, dies, and various manufacturing sectors; however, friction between interacting surfaces poses a challenge to its efficiency and performance across industrial applications. Laser Surface Texturing (LST) emerges as a viable solution to mitigate energy losses caused by friction and substrate wear. Bio-inspired textures have gained traction owing to their effectiveness in reducing friction and surface wear, resulting in substantial energy savings. The project initiates with an exhaustive literature review, delving into previous research on laser surface texturing and its potential to minimize friction. Honeycomb and fingerprint textures were created on the tool steel surface using varied laser power, scanning speed, and laser frequency. The coefficient of friction (COF) of these textured surfaces was evaluated under a normal applied load of 10 N using a reciprocating tribometer. Surface characterization was conducted using a 3D profilometer to validate material ablation. The findings revealed a notable 7.74% reduction in COF over a sliding duration of 1250 seconds and a distance of 50 m, underscoring the efficacy of laser surface texturing in enhancing friction reduction.

***Keyword**:* Tool steel; Hardness; Texture; Hexagon

I. INTRODUCTION

Due to the addition of alloying elements, tool steels are iron-based alloys having unique features from carbon steels. They are a part of a sizable class of steels that display high strength, high hardness, and high wear resistance in comparison to other steel kinds after being heat treated. Furthermore, a variety of tool steel types maintains their qualities to a significant depth in the material and exhibit good microstructural stability at high temperatures (red hardness). Tool steels are used extensively, such as in cutting tools, dies, and molds.

Surface texturing is used to create patterns of different shape and size on the surface of the materials. It can be used to enhance the tribological behavior of the surface, improve cell attachment and bacteria adhesion reduction in bio-interfaces, and also to improve the mechanical properties like stiffness and hardness of the surface. Texture designs are also inspired from nature like honeycomb, mosquito egg surface etc. which have characteristics to reduce friction, wear and augment the mechanical properties. Texturing has prominent applications in electrical systems of automobiles, solar cells to improve light absorption, increasing the wettability of the surface and many others and thus are not restricted to only use in tribology. The different surface texturing techniques discussed may be further divided in following groups: melting and vaporization such as EDM, ablation such as LST, forced material removal such as micro grinding, VMT, dissolution such as chemical etching. Forced material removal process like micro grinding have an advantage of establishment of contact between tool and work piece resulting in an excellent geometrical contact between surface to be machined and the tool is established. Forced material removal process affects geometrical precision due to machining force and limits the texture size due to elastic deformation of work piece and cutting tool. In

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melting and vaporization process of texturing, very little machining force is required and machining characteristics are influenced by thermal properties like; boiling point, melting point, heat capacitance and conduction efficiency. Tool and work piece does not come in contact in this process which may lead to inaccuracy in texture dimensions and has a disadvantage of generation of heat affected zone. Ablation also generates the heat affected area on the substrate but using the femtosecond and excimer laser, heat affected area can be reduced to a larger extent producing textures with a greater accuracy. Chemical etching, another texturing process, with no requirement of machining force does not modify the mechanical characteristics of the surface. When compared to LST and other texturing methods chemical etching leaves very few irregularities along with a minimized roughness but it restricts the usage due to consumption of time in printing the mask and etching. Thus selection of a texturing technique is very important for a particular application to achieve the higher degree of accuracy with the cost in the limits. Further, compatibility with the dimensions of work piece, required shape of textures, safety of substrate material are some of the minimum criterion which needs to be satisfied while choosing the texturing technique. Among the different texturing technique discussed micro grinding is the lowest in cost and easy to operate. But a large number of researchers have used LST to create textures since the process is environment friendly and possess accuracy in shapes and size of textures. It is also taken into consideration that the surface textures are highly application dependent and firstly be evaluated for the use in the tribological system. The number of texturing parameters are huge in quantity thus they need to be simulated further under the frictional regime to optimize the texture parameters to overcome "trial and error approaches" of expensive and time consuming texturing. Due to environment friendliness and higher rate of accuracy LST edges over other techniques in various applications.

II. LITERATURE REVIEW

Pathak et al. (2019) revealed that the tool steel is generally used for the machine tool parts, blades, punches and forging dies. The use of fuzzy logic and the Taguchi approach to optimize the machining settings for dry turning TOOL STEEL tool steel with carbide inserts is covered in this article. Analysis of variance (ANOVA) was used to study the combined effects of the cutting parameters, including cutting speed, feed rate, depth of cut, and nose radius, on the surface roughness and cutting force components. Fuzzy logic was also used to optimize the process parameters. For optimization, a Multi Response Performance Index (MRPI) was applied. The correlation between the results demonstrates that cutting speed and feed rate have the biggest effects on the entire operation.

Prajapati et al. (2018) investigated that the wire EDM is most progressive non-conventional machining process in mechanical industries. The performance of Wire EDM is influenced by a number of factors. In this study paper, a select few of them are examined. An experiment is carried out to determine the impact of process parameters such as pulse ON and pulse OFF times, voltage, wire feed, and wire tension on MRR, SR, Kerf, and gap current. The Wire EDM of tool steel uses an artificial neural network to predict the output characteristics. Using the work piece material tool steel, an experiment is conducted to collect the training, testing, and validation data set.It has been discovered that ANN is an effective tool for data prediction and that it produces results that are comparable between experimental and predicted data.

Uhlmann et al. (2018) Mass production of micro or miniature parts is increasingly based on replication technologies, such as hot embossing, micro-injection moulding, and bulk forming. These technologies rely on the applications of high thermal and mechanical loads on the forming tools and especially on the integrated microstructures. To achieve sufficient tool life, functional tool materials like hardened steel or cemented carbide are used. The mechanical properties of these materials are a limitation to the variety of structuring technologies which can be applied. Due to their non-contact thermal material removal mechanism electrical discharge machining technologies offer a suitable alternative, in terms of obtainable structure dimensions and accuracy. This paper presents an overview on the state of the art of applicable micro-electrical discharge machining.

Zhan et al. (2018) The effectiveness of laser surface texturing in reducing wear
rate was studied, with emphasis on dimple distribution angle. Experiments were performed by varying the texturing parameters to derive variational rules of the wear scar depth on laser- textured cylinder walls under starved lubrication conditions, and the optimum laser texturing dimple distribution angle was obtained. It was found that the laser texturing could result in less wear rate compared to mechanical honing.

Masuzawa et al. (2018) The resent advances in radio frequency (RF)-magnetron sputtering of hydroxyapatite films are reviewed and challenges posed. The principles underlying RF-magnetron sput- tering used to prepare calcium

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phosphate-based, mainly hydroxyapatite coatings, are discussed in this chapter. The fundamental characteristic of the RF-magnetron sputtering is an energy input into the growing film. In order to tailor the film properties, one has to adjust the energy input into the substrate depending on the desired film properties. The effect of different deposition control parameters, such as deposition time, substrate tem- perature, and substrate biasing on the hydroxyapatite (HA) film properties is discussed.

III. METHODOLOGY

3.1. Sample preparation

Commercially available tool steel was used as a substrate. A 20 mm diameter of tool steel rod was cut into discs of 20 mm diameter and 9 mm thickness. The surface of samples was then subjected to facing operation to ensure flat surfaces.

Table 1 Polishing time

S.No.	Emery papers Grit size
1	320
2	400
3	600
4	800
5	1000
6	1200
7	1500
8	2000

The samples were subsequently polished using emery papers to remove unwanted scratches and damages sustained during cutting operations to obtain a smooth specimen. Emery papers of grit sizes 320 to 2000 were used for the process. Polishing operation was completed on an automatic polishing machine till 600 grit size paper and after that polishing was done by hand. Diamond polishing was done with a diamond paste of grit size 0.5 micron and 0.25 micron to achieve minimum surface roughness and also to remove dirt and impurity from the surface.

3.2 Laser surface texturing

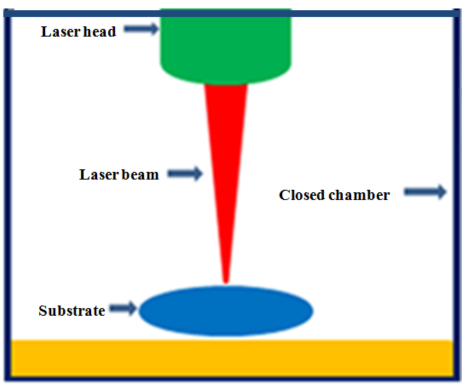

Figure 1 (a) Mechanism of Laser Surface Texturing (LST)

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Inspired by the idea of strong adsorption atcontact interfacedue to the synergistic effect of mucus and surface texture in reptiles, the regular hexagonal honeycomb textures were produced on polished tool steel substrate. Textures of side 200 µm were produced using a fiber laser of 1064 nm wavelength, 5 ns time duration.

Table 2 Laser parameters for honeycomb and fingerprint textures

Texture Design	Laser Power (% of 20 W)	Scanning Speed (mm/s)	Frequency (kHz)
Honeycomb	30	200	30

3.3. 3-D Profilometry

A non-contact optical technique called 3D profilometry, sometimes referred to as 3D surface profiling or 3D surface measurement, is used to measure the three-dimensional shape and topography of an object or surface. To accurately depict the surface features of the item, depth information and the surface profile must be captured and examined.

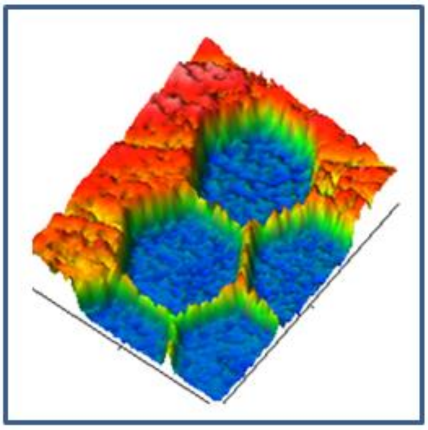

Figure 2 3D image of honeycomb textured surface

3.4 Coefficient of friction test

A ball-on-disk tribometer(RTec instruments, USA) was used to perform reciprocating or sliding tests. The counter face was the zirconia balls to wear out the polished as well as textured surface of tool steel.

Each test was carried out on a normal load of 10 N with specifications given in Table 11 as per ASTM 133 G-05 standard.

$$t = \frac{X}{0.002 \times F \times L}$$

where,

t = time in seconds

X = Sliding distance in meter

F = Frequency in Hz

L = Stroke length in mm

Table 3 Wear test specifications

Test specifications	
Load	10 N
Stroke	2 mm
Frequency	20 Hz
Sliding distance	50 m
Sliding time	20.84 min

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IV. Coefficient of Friction Results

During the test conducted over duration of 1250 seconds, with a load of 10 N, stroke of 2 mm, frequency of 20 Hz, and a sliding distance of 50 m, coefficients of friction (COF) were calculated for both textured and untextured samples. The textured sample exhibited a COF of 0.1358, whereas the untextured sample demonstrated a COF of 0.1472. This indicates a percentage variation of 7% in the COF between the textured and untextured samples.

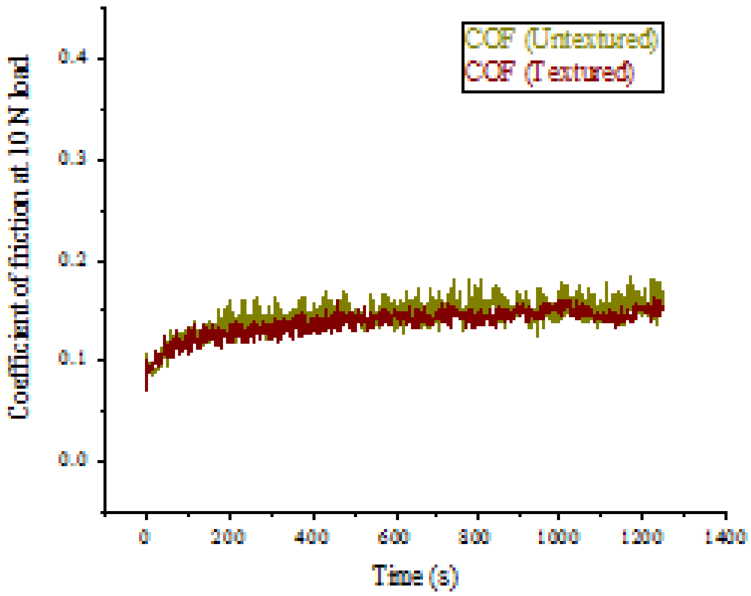

Figure 3 Coefficient of friction results

V. Conclusion Remark

Tool steel substrates with a diameter of 20 mm underwent a texturing process to investigate changes in the coefficient of friction (COF) in comparison to untextured surfaces. The texturing procedure was carried out successfully, and the substrates were subjected to testing conditions including a sliding distance of 50 m, sliding time of 1250 seconds, load of 10 N, stroke of 2 mm, and frequency of 20 Hz. Analysis revealed that the COF of untextured substrates measured 0.1472, while textured samples exhibited a COF of 0.1358. This indicates a variation of approximately 7.7% in the COF between the untextured and textured samples of tool steel. The results suggest that the texturing process has a discernible impact on the frictional behavior of the tool steel surfaces, potentially offering opportunities for optimizing performance in various applications where friction is a critical factor.

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