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A BRIEF REVIEW ON IMPORTANCE OF SURFACE TEXTURING IN MATERIALS TO IMPROVE THE TRIBOLOGICAL PERFORMANCE

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Abstract. Surface texturing in materials is one of the current process that satisfying the industrial needs and providing ample support to the production managers in machining. During machining for producing various products the major task is the reduction of materials waste, assessment of tool wear and its happening. Tool wear affects the production cost severely also incurring the material waste. One of the effective methods to reduce this problem and improving the tool life considerably is the surface texturing process. This can be carried out in work piece material neither the tool also. Surface texturing done on the surface of the tool or the work piece material to give aesthetic look also mainly enhances the performance in various aspects. Many industrialists and researchers carried out the surface texturing process for various machining applications such as lathe, milling with various surface texturing techniques. This article present a detail review about the need for surface texturing in materials, its importance and its role in tool life enhancement had been discussed and reported.

1. INTRODUCTION

In the modern scenario the industrialists face many kind of obstacles during the machining. One such major issue is the tool wear assessment and the tool life. This play a vital role in affecting the production process cost. Several methods adopted for the tool wear reduction but the effective one is the surface texturing concept to enhance the tool life with affordable low cost. Townsend et al. [1] conducted a review study on recent industrial trend that is the additive manufacturing concept wherein the surface texturing of metal parts were thoroughly discussed. Also strongly justified that the surface-texturing process was more important in additive manufacturing compared to conventional machining processes. Another review study by Upadhyay et al. [2] present the effect of the surface-texturing process on hard machining materials such as titanium and nickel-based alloys. They focused on the microsurface texturing, through which the tool-chip area is reduced, and the textures help in reducing the wear by acting as lubricants. Surface texturing had been done on both the rake surface and flank surface of the cutting tool to know the tools wear rate and performance. Since the tool wear is mostly affected and measured by the rake surface effect only there is no detailed consideration on the other ones but to rectify the same Anshu Anand et al[3] done studies on the effect of surface texturing in the flank surface with special reference to the cutting forces and surface roughness. Also reported that the tribological properties improved by surface textur-

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ing in the flank side of the tool. One of the major factors that characterize the tool wear is the built-up edge (BUE) and the effect of surface texturing on the BUE had been studied by Kummel et al. [4]. By means of laser surface texture different texture formed on the rake face of the tool to know the BUE behavior. Further it is reported that the textured pattern tool possess better wear resistance as well as controlled BUE when compared to the un textured pattern tool.

The main success in the manufacturing sectors depends on the good quality product in a predefined cost. For the same one of the things to be considered is the analysis of surface roughness for the machined materials. Theoretical and artificial intelligence [5] are the most important effective methodologies to measure the roughness even though other techniques have its own merits and demerits. Surface texturing improves the surface roughness of the materials also to a greater extent. In the surface texture analysis the surface roughness measurement had been carried out by the machine vision methodology offers more merits and better optimized results be obtained [6]. Surface texturing also had significant impact on the boundary lubricated sliding surfaces which had been studied by Ulrika Pettersson and Staffan Jacobson[7]. Also reported that the wear property of the sliding surfaces be greatly improved by the surface texture that can be done using silicon wafers with lithography and etching methods. The impact of surface texture studied in two cases with TiN coated surface against steel and DLC coated surface against steel and noted that the wear in steel ball is more in the case of textured ones for the TiN coated and much lower for the DLC coated case. The coefficient of friction decreases much on both the cases by means of lubrication.

Kovalchenko [8] carried out a thorough review studies on the importance of surface texturing with special reference to the increase in the friction values/units. In this he emphasis that surface texturing alone not simply improve the wear properties it also depends on other factors such as materials used and the design problems for providing the better geometry. Various mathematical models had been proposed to analyze the same by more researchers.

Further work on surface texturing had been carried out on mostly usable AISI316 stainless steel [9] material. Here the surface texture done by means of plasma nitriding duplex treatment with the experiments done on pin-on-disc rotary vibrometer. Various parameters such as coefficient of friction, weight loss and the surface morphology study for wear damage has been analyzed and tested for the samples. From the results it is noted that the tribological performance of the materials show improved performance in the case of textured ones. Wu Wei et al. [10] carried out the surface texture studies on ASTM 1045 steel with parameters such as rise in temperature, coefficient of friction and wear. They compare the results of texture with untextured ones and found to be better in case of all the parameters.

2. SURFACE TEXTURING IN MATERIALS VARIOUS METHODS

With the growing significant impact of the surface texturing process usage in industries that satisfying many needs with enhanced performance the researchers focuses on the usage of different techniques for making the surface texture which improves the tribological behavior of the sliding surface. A detailed review done by Arslan et al. [11] on the different types of manufacturing techniques used for surface texturing. The Various methods to create surface texture such as laser method, micro-EDM, ECM, CNC-ultrasonic method, Focused Ion Beam machining, AJM, Vibromechanical texturing, Micro grinding, Micro casting and chemical etching were used commonly. Among all each one has its own merits and demerits compared to other but used for different kind of applications. Also these techniques are opted for the creation of micro textures and improve the cutting performance of the tools used in turning, milling and drilling. One of the main factors that the production managers look into is the cost effectiveness of the surface texturing process. In this aspect a review study done in which three new surface texturing method with low cost and high processing speed be reported. The three methods are PCT, MECT and ink jet printings [12] are best suitable for steel surfaces texturing. PCT is very simple and cheap method widely used in electronic industries. MECT is very fast, simple and cheap too but offers limitation due to the minimum size feature.

Electrically Assisted Manufacturing (EAM) process involves the passage of electric current into the material which has the ability to produce deformation either permanently or temporarily. A review had been done on the different electroplastic behaviors of various metals and metal alloys reported by Huu-Duc Nguyen-Tran et al. [13]. Electrically assisted indentation for surface texturing and its effects had been analyzed by Hyun-Seok Oh et al. [14]. The

hardness measurement had been done with the Vickers hardness setup and by passing the electric current the variations is observed. It is noted that the hardness is proportional to the electric current. Another most widely used method is the laser surface texturing where more researchers focuses on due to its various parameters with high quality texture applications. One such work had been done using tool steel in which the laser surface texturing performed on a five axis dynamic laser precision machining center [15]. From the results it is inferred that the qualitative characteristics in terms of the dimension, shape and surface morphology of the texture gets enhanced by means of the laser surface texture. An improved texturing method known as Vibromechanical Texturing Method (VMT) had been introduced for conventional turning process by Aaron Greco et al. [16]. This method offers various advantages such as low cost of equipment, quick process time and easy adaptation to the manufacturing scenario. They performed the experiments successfully on aluminum and steel material by means of controlled vibratory motion of the tool dimples formed on the workpiece surface. Further studies on laser surface texturing had been done by de Lima et al. [17] in which to enhance the performance of the high speed drills, the texturing had been carried out using laser and physical vapour deposition method. The same textured drill tool been used for cutting the carbon and stainless steel materials using a CNC machine. From the results they strongly inferred that the laser textured possess better tool wear than the untextured ones but also noted that the wear behavior mechanism was same for the both materials used. The studies on surface texturing had been continued with the micro EDM process along with high frequency vibration used on cemented carbide cutting tools. Micro holes and Linear grooves were made with more accuracy and waste formation reduced using the surface textured tool made by the microEDM process [18].

Remarks:

This section discusses the various techniques proposed and used by various researchers for the surface texture preparation. Among all the non conventional machining process mostly preferred by the researchers than the conventional ones due to the low cost, high accuracy, better finish and design flexibility. In spite of all every process have its own demerits in that aspect in few cases the conventional machining offers more advantage for making the surface texture which is still in use till now.

3. SURFACE TEXTURING EFFECT IN TRIBOLOGY BEHAVIOUR

One of the main features in the machining process is the effective performance of the tool and its wear since the tool wear affects the complete process drastically which in terms reflect in the final product quality. Surface texturing had straightaway influence on the tool wear. The tool wear assessment is a very critical factor and the different methods for same had been reported by various researchers and discussed in the below section in detail.

Luka Cerce et al. [19] through their research developed a new model for measuring the spatial tool cutting wear for the machining tools. They pointed that this method gives the 3D view of the wear mechanism which reduce the time for wear measurement and no need for the manual inspection. Also in addition they gave a new tool life methodology using FEM modeling method. Hui Zhang et al. [20] developed an analytical model to know the tribological behavior of the surface textured regime of the tool. In their model average flow Reynolds equation and an elastic model using FEM had been used and the results show that the coefficient of friction reduced drastically in the surface textured tools. In the case of sliding elements, the wear occurs in both the sliding surfaces therefore the effect of surface texturing in both the surfaces and its improvement in the tribological properties had been reported [21]. From the results it is inferred that the surface textured both surfaces show better wear resistance in the case of small density area but not in the case of larger density area where one surface textured gave better results. On the other hand controversy arises regarding the effects of surface texturing in improving the friction and wear in all the cases. For the same an extreme assessment be carried out by Gachot et al. [22] in which the various surface textured fabrication and modeling methods had been analyzed in detail with respect to the wear improvement. Also special methods had been reported to enhance the friction mechanism. In addition to this, they compare the various surface texture techniques with respect to their cost, shape, size and wear improvement. The effect of tool geometry parameters such as rake angle, face angle, nose radius and groove plays a huge role in the tool wear and a complete review on the tool geometry with respect to this parameters had been done by Dogra et al. [23].

Another application is in bearing to compare the effect of surface texture and the slip surfaces [24] and their improvement in tribological property study

had been carried out. It is observed that both the surface texture and the boundary slip had strong matching regarding the tribological performances. The various methods related to surface texturing with special importance to the recent advanced surface characterization and evaluation studies had been done by Petropoulos et al. [25]. Various surface topography studies performed to know the behavior of the surface textured tool during machining. The optimization of geometrical parameters is another essential factor in the surface texturing process. Surface textured tool wear studies further continued by using laser form micro pores on the SiC surface [26] and the wear experiments were conducted using pin on disc wear tester for varying loads and speeds. They conclude that the texture pattern has a high influence on the friction coefficient.

The tool monitoring system is another important phenomenon in the surface-texturing process that helps monitor the machining process. The tool-cutting process was monitored in a lathe machine equipped with TiN-coated tools [27,28]. The angle and radius of the tool were used as parameters for the monitoring system. The cutting feed, speed, and tool-flank wear rate were considered. Vishal et al. [29] designed a model to determine the tool wear, which was compared with the experimental results. They proposed the model for turning operations with parameters such as cutting force, vibrations, and acoustic emission, which were compared with the experimental results. The comparison results show that the measured tool wear rate is in good agreement with the practical value. However, the model is affected by the selected data points.

Studies have been conducted on a microtextured tool with an aluminum alloy considering the effects of varying the groove pattern and response on the cutting force by varying the speed [30]. Wu et al. [31] studied the effect of groove pattern on the machinability of surface-textured materials and its response on the tribological performance. Different grooves were prepared using laser technology and their effect on the wear rate was analyzed. Marion Merklein et al. [32] carried out the studies on the change in tribological effects of the tool in the conventional and dry sheet metal forming process. By means of polishing the tool surface the friction gets increased which has significant impact in the tool life. The energy consumption in the milling process be reduced by using a new method developed with the importance to optimal orientation of the workpiece. From this various parameters relevant to the workpiece arrangements a considerable amount of energy saving obtained [33]. Baohai et al. [34] studied a circular end-milling process to predict the cutting force. They proposed a new cutting force applicable to both linear end-milling processes and circular milling processes by varying the depth and keeping it constant respectively. With the advancement in technology and the importance given to micro and mesoscale products which are more advantageous than normal ones, the micro-end-milling process is becoming increasingly popular. Accordingly, Srinivasa and Shunmugam predicted the cutting forces using a mechanistic model and reported that the same model is suitable to predict the transverse force [35].

Wojciechowski et al. [36] modeled the cutter displacements with various inclinations in a ball end-milling process. In addition, they validated this model by varying the feed per teeth, inclination angles, and run outs. The model was proposed to predict various surface textures. Shaghayegh Shajari et al. [37] performed studies to know the behavior of tool path on various parameters such as surface texture, cutting force and machining time in ball end milling process. The tool path vitally affects the quality of the product as well as the production rate hence with this note they did the experiments and reported that the radial tool path possess better results. Imani et al. simulated an end-milling process to analyze the finishing parameters such as the surface roughness as well as measure the errors [38].

Dutta et al. [39] studied an end-milling process to improve the performance of the tool by incorporating surface-texturing analysis using mathematical models, thus improving the quality of the product. They analyzed the effect of flank face using a tool-condition monitoring system. Currently, manual experimental studies on the end-milling surface-texturing process are replaced by software analyses such as finite element approach for 3D objects particularly for Ti-6Al-4V titanium alloy [40], wherein the tool wear is predicted and validated.

Tae-Sung Jung et al. [41] developed an approach to analyze the cutting mode for maximum surface roughness in an end-milling process. They used bidirectional and unidirectional modes to predict the roughness and measure the machined surface. Szymon Wojciechowski et al. analyzed the various factors affecting the surface texture of a ball end mill made of hardened steel in terms of the surface-inclination angle [42]. The inclination angle was found to considerably influence the surface quality of the material, which is reflected in the surface roughness.

The surface characteristics of an end-milled AA-6061 alloy [43] were studied in terms of the surface

roughness and image texturing. The results show that the effects of energy, correlation, and homogeneity on the surface roughness are negligible. Ryu et al. analyzed the surface texture with axial depth of cuts of 0.05 mm and 0.3 mm for the same surface roughness and surface topography parameters such as tool run outs and tool errors for a flat end mill [44]. Kim and Tae Jo Ko [45] performed surface texturing on a planar surface via grinding wherein the experimental results were compared with the simulation results for the surface-textured pattern formed using a grinding wheel. In addition, they proposed a mathematical model to predict the quality of the generated pattern.

Surface texturing is to make steady pattern on a machine part with friction. The problems related to surface texturing techniques such as repeatability and environmental issues that happens in the milling process be reduced drastically by introducing new surface texture method known as micro texturing in which nanometer, micrometer parts are measured which reduce the repeatability problems[46]. Surface roughness studies on end milling machining process with the ANN model usage had been done by Azlan Mohd Zain et al. [47]. Among the various network structure formulated the combination of 3-1-1 network structure possess best result that is high for speed high, low feed rate and radial rake angle. Further studies on surface roughness of CNC face milling using neural network and design of experiments had been carried out and the optimum conditions for the surface roughness in terms of cutting forces be reported [48]. For the machining of complex geometry parts having concave and convex type surfaces three special milling methods be adopted by Ramos et al[49] with special reference to the parameters surface texture, surface roughness and reported that the 3D offset strategy possess better results.

Jiang et al. [50] carried out the surface texturing studies formed by tangential turn milling. Different shapes of surface textured formed on the materials surface and the same be simulated using MatLab. Also they inferred that the feed had impact on the surface texture in which the tooth height and the spacing increase with the feed rate. For obtaining the complex shape surface textures the CAD seems to be complicated ones and this is potentially solved by using image processing techniques. By using the same the texture formed on the surface of aluminium using micromilling process [51]. These techniques more possibly reduce the design time to form the surface texture. Ramamoorthy et al. [52] studied the different textured surfaces made by machining using the statistical techniques. Among the various techniques AVR and run length matrices best suited to study the features of the textured surface.

The analysis of surface texture itself provides clear information about the tool wear takes place during the machining operation. For the same fractal analysis be used in which the information obtained from the images of machined surface. Also in addition the hidden Markov Model [53,54] used to know the different levels of tool wear. Further studies on surface texturing continued with new techniques in which one of them is the usage of micro dimples to form patterns on different machined surfaces and the same has been performed by using micro ECM [55]. The machining studies also be performed on AISI 440C materials to know the performance of micro dimple pattern surface textured and reported that the friction reduces drastically.

Tatsuya Sugihara et al. [56] done the surface texture studies on cubic boron nitride tools which is the very hardest materials used for cutting the nickel based alloys. The major problem in this is the quick failure of the tool because of the hard tool as well as materials. It is also noted clearly from the tool wear mechanism study that the tool flank has the severe failure and for the same textures in the form of microgrooves made on the flank face which remarkably increased the life of the tool. On the other hand texturing of the rake face also done by the researchers, which has a significant impact in the friction reduction during machining. Micro scale dimples are formed using laser on the rake face of the high speed cutting tool and the machining performance be carried out on Al7075-T6 material [57].

The surface texturing process also continued on diamond cutting tool and the machining performance reported by Noritaka Kawasegia et al. [58]. Texture made on the rake face of the diamond tool and the results inferred that the friction reduced after texturing seems from the cutting force values also quality of the machined surface is good by means of texturing. Youqiang Xing et al. [59] carried out the surface textured study by means of forming two different grooved structures on Al_2O_3/TiC ceramic surface using laser. The two different groove structures with different spacing had been made in which high coefficient of friction and better wear resistance offered by means of texture. Among the two the texture with small spacing possess better results in terms of surface roughness, wear properties and friction coefficient.

Yayun Liu et al. [60] done surface texture on the flank face of the WC/Co carbide tools and measure

the wear resistance of the same over cutting of green alumina ceramics. Results shows better wear improvement as well as protection from abrasion damages by means of texture.

Tatsuya Sugihara et al. [61] done performance studies on cutting tools with different texture patterns especially the dimple shaped surface texture and groove shaped surface texture. From the serious of cutting force measurements done it is finally concluded by them that the dimple surface texture possess better results than the groove in terms of wear resistance and the coefficient of friction.

Surface texturing concept also applicable for the polymers in which a complete review had been done by Barr et al. [62]. The scratch resistance of the polymeric gets increased by means of forming texture patterns on the surfaces. Also present a detail review on the deformation of base material, surface texturing effect on scratch damage and the impact of human vision in the scratch damage effect. In addition to know the same experimental results were also reported. Further studies on surface texturing continued on metal-polymer combination and the friction characteristics, wear performance of the pair had been reported [63].

Remarks:

This section describe in detail the effects of tool wear by means of surface texturing had been reported by various researchers. It is strongly evident from the review that the tool wear decreased drastically by means of texturing in different method. Also by using different mathematical model analysis the tool wear assessment had been reported by previous researchers.

4. SURFACE TEXTURING IMPORTANCE AND APPLICATIONS

The importance of surface texture seems to be a compulsory need for the industry peoples in today's scenario since the impact created by means of the tool wear affects the production badly. The effect of friction had been controlled by means of surface texturing. Surface texturing also vary depends on the kind of machining performed and the process be usable ones. The quality of the final product also depends on the surface texture in few cases with cost effective ones. The measurement of surface texture itself falls under the responsibility of the quality control team. There is also ample possibility to combine surface texturing with other techniques also to obtain better performance. In addition the surface texturing be made in dimples, grooves and patterns of varying angles and depth depends on the application.

Further studies continued that using various dimples [64], grooves and surface texture for the case of sliding components the friction varies for different regions. Analyze had been done for this and inferred that every region requires different kind of size, shape of dimples, groove and surface texture to achieve a better friction resistance. The usage of bearings by the industrialists for various applications is one of the essential needs in today's scenario since they afford for high load and high speed. With this perspective the improved performance of these different kind of bearings is very much essential. For the same the best option is the surface texturing process. Shahab Hamdavi et al. [65] performed the surface texturing effect studies on hydrodynamic type journal bearings and strongly justified that the surface texturing have a significant impact in withstanding the load as well as better wear resistance characteristics. By varying parameters like the speed of the shaft, bearing pressure distribution and different load conditions [66] the effect of surface texture on the hydrodynamic bearing has been studied and reported that the percentage of hydro bearing pressure increase is maximum in the case of textured surface.

Surface texturing on mechanical seals also done by researchers for the industry benefits to achieve good tribological and sealing properties. For the same microgrooves and dimples have been formed on the mechanical seals using micro abrasive jet machining and the improvement in properties had been reported [67]. Arslan Ahmed et al[68] performed studies in this aspect by taking two major applications mechanical seal and piston ring/cylinder assembly. In this they noted that the mechanical seal performance improved by means of the surface texture parameter dimple depth and for the piston rings the most essential factor is the aspect ratio. Kango et al. [69] performed the studies on importance of surface texturing in journal bearings which in terms improves the load carrying capacity and reduce the friction coefficient. The surface texture made in the form of micro cavities at various points in the bearings and the texture effects were analyzed using governing equation and strongly concluded that the friction coefficient and force decreased drastically. Romoli et al. [70] performed surface texture studies to increase the adhesive strength of bonded joints in aluminium alloys. Laser Textures were made in the form of concentric grooves.

Remarks:

Surface texturing has a very wide range of applications that involved in various sectors. The usage of surface texture in the automotive applications plays a vital role to reduce various issues. It is involved in various industrial applications especially in machining process such as drilling, milling, lathe etc., also involved in bearings, sliding surfaces and piston/ cylinder arrangements.

4. CONCLUSIONS

This review discusses in detail the current and past works carried out for surface texturing. The effect of surface texturing on different materials cutting force performance and the tool wear performance also reviewed and discussed in detail. The various methods of making surface texture its potential advantages and its suitable applications also reported in this review. In addition to the above a newly modified surface textures end mill tool presented in this review paper and also the potential of the same to be used against different materials to know the cutting force and tool wear performance.

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