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Drilling performance of micro textured tools under dry, wet and MQL condition

S. Niketh, G.L. Samuel *

Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

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ABSTRACT

In metal cutting processes, reduction in sliding friction at the cutting regime can improve the machining performances in terms of cutting force reduction, built-up edge stabilization and improved surface integrity. However in drilling, as the cutting action occurs inside the hole, minimization of frictional effect at the contact interfaces is always a challenging task, as the reachability of cutting fluids at the machining zone is obstructed by the upward motion of chips sliding along the flute surface. This challenge can be addressed by functionalizing the drill tool surfaces with microtextures. Hence, in the present work, a novel drill tool having microtextures at the flute and margin side is used to reduce the sliding friction. The performance evaluation of microtextured drill tool was done based on the variation in thrust and torque. Margin textured tool was found to be more efficient than flute textured and non-textured tool recording a net thrust force reduction of 10–12% in dry, 15–20% in wet and 15–19% in MQL condition. Reduction in contact length, wear debris entrapment and formation of micropool lubrication effect at the cutting regime are found to be the underlying mechanisms responsible for the improved performance of microtextured drill tools.

1. Introduction

1.1. Surface functionalization for tribology enhancement

Surface engineered tools are getting wide acceptance in the manufacturing industries due to its improved cutting performances in terms of tool life enhancement, tribological characteristics, cutting force reduction, surface integrity improvements etc. Modification/functionalization of tool surfaces can be achieved by various processing techniques which include adding or removal of material from the tool substrate. Coating of tool surfaces is a usual practice followed in the cutting tool industries from the past few years and is reported to be one of the most successful methods for improving the tool performances [1]. The strength of the tool coatings depends mainly on the processing technique along with the physical/chemical properties of coating materials. Vapour deposition coating techniques like physical vapor deposition and chemical vapor deposition can precisely coat tool surfaces where the coating thickness varies from sub millimeter scale to nano scale range based on the area of application [2,3]. In metal cutting processes, coatings are mainly applied on the tool surfaces with an objective to improve the wear resistive property of the tool thereby minimizing the frictional effect occurring at the tool-chip and tool-workpiece interface [4]. The frictional force generating at the cutting zone has a predominant effect in increasing net cutting force generation along with the surface integrity of tool as well as the machined part [5]. For achieving better performances, coated tools have to be applied under wet machining conditions. Along with the wear resistance property provided by the coating material, the metal working fluid helps in faster dissipation of heat generated at the cutting zone thereby enhancing the tool life. But the application of tool coating along with cutting fluid supply system will have a high impact on total production cost. Moreover in machining processes like drilling operation as the cutting phenomenon occurs inside the hole the reachability of cutting fluids to the machining zone is a challenging task. The upward movement of chips from the helical groove will further obstruct the flow of metal working fluid to the tool tip which will lead to heat accumulation resulting in catastrophic failure of the tool. Hence there is a need to develop a technique which can retain the lubricants at the cutting zone throughout the machining processes for better heat dissipation.

* Corresponding author.
E-mail addresses: me13d038@smail.iitm.ac.in (N. S.), samuelgl@iitm.ac.in (S. G.L.).

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1.2. Complexity in drilling of titanium alloy

Drilling of titanium alloys is always a challenging task for the manufacturing industries due to its lower thermal conductivity, which results in high heat accumulation at the machining zone. This will have an adverse effect on the drill tool life and machined surface quality, which is of prime importance especially in the field of aerospace where the application of titanium alloys is found to be the most predominant. Drilling operation comprises of an overwhelming number of process parameters which determine the hole quality along with the drill tool life. Analysis of material removal mechanism during drilling is more complex than any other cutting processes as the cutting phenomenon occurs internally (inside the hole). Chips generated at the cutting lips are confined by the hole wall and flute side, creating difficulty in chip ejection. As the tool advances further into the material, more volume of chip fills the flute side which eventually gets clogged together due to extreme contact pressure at the cutting zone resulting in higher chip evacuation force [6]. Minimum chip evacuation force is always preferable for better tool life, as it has a significant contribution in the net thrust and torque generation [7]. Apart from chip evacuation force, sliding friction occurring between the margin side and drilled hole wall also have a significant contribution in net drilling forces. As the chip slides over the margin side, due to frictional effect chip adheres to the tool surface which gets squeezed along the margin, resulting in build-up edge formation. To overcome all these adverse effects researchers have formulated various techniques including flood cooling, cryogenic cooling, compressed air cooling, minimum quantity lubrication (MQL) etc. [8]. But the reachability of cutting fluids at the cutting zone while drilling at higher depths is always a challenging task due to the blockage of cutting fluids by the clogged chip.

1.3. Micro scale surface texturing – principle, techniques and applications

Surface texturing technique has already been proved in enhancing the tribological properties of contact surfaces. Functionalization of any surfaces can be modified or improved by creating textures in the form of dimples or grooves whose geometries varies from micrometer to nanometer scale depending on the field of applications [9]. A wide spectrum of machining processes, including both conventional (tool based micromachining) and unconventional techniques (micro electric discharge machining, abrasive flow micromachining, laser beam micromachining etc.) can be employed for creating micro/nano textures of any intricate profiles [10]. Due to fast machining rate and higher dimensional control, laser beam micromachining technique is reported to be the most efficient technique in developing micro/nano features among all the available micromachining techniques [11]. Laser textured surfaces have already applied for tribology enhancement in the fields like mechanical seals, piston rings, bio implants etc. Ryk and Etsion [12] used laser source for creating micro dimples having a diameter of 72 μm and 7.5 μm depth on the piston ring which provided a net reduction of 25% in friction when evaluated on a reciprocating piston rig. Chen et al. [13] has studied the effect of triangular textures in controlling friction in case of die steel surfaces. They reported a net reduction of 63% in coefficient of friction while using textured surfaces under lubricated sliding conditions.

1.4. Surface functionalization of cutting tools

With the recent advancements in laser micro machining technique, many researchers have extended the laser surface texturing to the field of cutting tools, where a potential enhancement in tribological properties were achieved by controlling the frictional effect occurring at the tool-chip interface. This substantial improvement is attributed to many physical mechanisms like reduction in tool-chip contact length, entrapment of wear debris, and hydrodynamic effect (retaining of lubricant in the micro cavities for improved load carrying capacity). Moreover the presence of micro textures will help in providing the anti-adhesive property. This was proved by Sugihara and Enomoto by creating micro stripe grooves (5 μm depth) using femtosecond laser for face milling operation while machining aluminium alloy [14,15]. Enomoto and Sugihara [16] further extended their experimental investigations in evaluating the wear resistant property of TiAlN coated textured tools in cutting steels and reported to be very effective with textured tools having micro-stripe grooves having a depth of 5 μm and width 20 μm. Sugihara and Enomoto [17] investigated the performance of micro textured tool in controlling the wear propagation while face milling of steel. Their experimental results proved the formation of lower crater and flank wear for laser textured cutting tools while comparing with the non-textured tools.

Application of micro scale textures were also implemented for turning operations. Kummel et al. [18] were also successful in minimizing the tool wear by stabilizing build-up edge formation by creating micro dimples of 50 μm in diameter and depth of 20 μm on the rake face of the cemented carbide tool while dry straight turning of plain carbon steel. Xing et al. [19] reported a better performance in terms of reduction in cutting forces and temperature while dry turning of hardened steel using micro scale and nanoscale textured Al_2O_3/TiC ceramic tool along with MoS_2 solid lubricant burnished into the textures. Kawasegi et al. [20] conducted turning experiments using micro and nano textured cemented carbide tool and was successful in reducing the friction while machining aluminium alloy at higher cutting speeds. The performance of micro textured tools was reported to be more efficient in wet machining conditions where the micro textures can retain the cutting fluids throughout the machining processes which can easily dissipate the heat generation on the tool surface [21]. Lei et al. [22] reported 10–30% reduction in mean cutting forces along with 30% reduction in contact length of a chip on the tool while turning mild steel under micro-pool lubricated condition.

In drilling process, Ling et al. [23] experimentally proved the tool life enhancing phenomenon by adhesion reduction while using micro textured drill tools in machining titanium alloy. Drill tool with 10% rectangular shaped micro textures at the margin side was reported to be performed better than other tool types producing 64 holes with lesser titanium build up. Till date only very few works are reported in case of drill tools with micro scale textures. Whereas drill tools with macro scale features (acting as chip breakers) were already reported in providing better cutting performances in terms of wear resistance, extended tool life, anti-adhesive properties etc. The performance of functionalized tools greatly depends on their design and geometrical characteristics. Sahu et al. [24] established a new methodology for designing and developing macro grooves on the rake face of the twist drill. From their experimental analysis it was reported that the grooved twist drills were successful in lowering chip evacuation force by minimizing the chip clogging effect, which resulted in increased drill tool life. Another research work by Degenhardt et al. [25] investigated the performance of groove type chip breakers on drill tools having different diameters (6.35 mm and 3.18 mm) and flute shapes (standard and parabolic) while drilling 1018 steel work material. Their experimental results substantiated the effectiveness of groove type chip breakers in lowering the chip clogging phenomenon. Nath and Kurfess [26] developed a new type of chip breakers in the form of ribs and pins on the drill flute surface. The pins were inserted on the flute surface by creating a blind hole using electric discharge machining process. They reported a reduction of 5%–9% in cutting forces while using modified drill tool by controlling the chip flow with minimum tool-