



Tribological aspects of various geometrically shaped micro-textures on cutting insert to improve tool life in hard turning process

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ABSTRACT

The present study investigates the effect of three different geometrically shaped micro-textures, namely horizontal micro-texture (WH), vertical micro-texture (WV) and elliptical micro-texture (WE) impregnated with MoS₂ dry lubricant on the rake surface of the cutting inserts on the machining performance of hard turning. The results of the experiments carried out with and without micro textures were compared. Experimental results showed the improvement in reducing coefficient of friction resulting into reduction of cutting force and increase in shear angle when machining with horizontal, vertical and elliptical micro textures impregnated with MoS₂ as compared to the results of machining without micro textures or without solid lubricant. Reasons for micro-textures reducing the tribology action at the chip-tool interface were investigated. The theoretical model developed here to determine the coefficient of friction by incorporating actual chip-tool contact length confirms the patterns of improvement observed during the experiments and offers a basis for explaining the reasons for it. Novelty of the study involves in predicting actual chip-tool contact length corresponding to forces in cutting speed direction, feed force in axial direction. This study has taken care of validating the theoretical model with experimental results. Errors in the results of chip-tool contact length was within 12% and that of chip reduction coefficient was within 5%. Optimum value of shear angle for maximum chip reduction coefficient was found to be approximately 39°. A maximum reduction of 11.9% in coefficient of friction was obtained using vertically oriented micro texture.

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1. Introduction

In the process of metal cutting, it is important to improve tool life by decreasing temperature generated during machining at the vicinity of tool-work or at the tool-chip interface. The rise in temperature generally results into thermal deformation of the tool and adherence of chip on the faces of the tool thereby reducing tool life. The tool life can be improved by reducing either the friction-coefficient at the mating surface or the shear force and contact pressure. For improvement of cutting performance researchers in the past had tried implementing optimal cutting conditions under dry environment with multi-coated inserts. But their effort had led to higher machining cost and high tool wear. Therefore, for reducing friction coefficient various cooling techniques, such as MQL, air/gas or cryogenic and surface coating/treatment were used.

In recent years, micro texturing has gained popularity in reducing the tool-chip contact area and to obtain uniform contact stress. In view of this, micro-patterning has been introduced on the rake face of the cutting tool to improve tribological characteristic of the sliding surfaces resulting in improvement in load capacity, tool wear resistance and friction coefficient in hard turning process. Micro-patterning on cutting tool was adapted in this paper as a novel technique to bring sustainability in hard turning.

It may be noted that most of the papers published on hard turning so far are based on investigation of cutting force, chip morphologies, MRR etc. Researchers [1–10] have shown improvement in cutting process in terms of better surface quality and enhanced tool life by using textured cutting tools or making micro holes, filled with solid lubricant on the rake and flank face of the tool. The resulting force of the micro-patterned insert was reduced up to 10.5% due to the reduction in friction up to 34.5% at varying feed rate. Similarly, tool wear of micro-patterned insert was improved up to 11.4%. Koshy and Tovey [11] observed that textures overlapping each other on the rake surface are more effective in reducing the machining responses than the linear texture. Ze et al. [12] proposed an innovative technique to reduce cutting force, cutting tempera-

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Nomenclature

A_r	real or true area of contact (mm^2)
d	depth of cut (mm)
f	feed rate (mm/rev)
F_d	frictional force of dry contact (N)
F_m	frictional force developed due to MoS_2 as medium (N)
F_f	total friction force developed at chip-tool sliding contact on rake surface (N)
F_r	resultant force (N)
F_x, F_y, F_z	axial feed force in x-direction, radial force in y-direction, main cutting force in z-direction (N)
g_{width}	groove width (μm)
h_c	chip thickness (mm)
h	uncut thickness (mm)
l_{act}	actual chip-tool contact length (mm)
$l_{\text{chamfered face}}$	tool chamfered face length (mm)
m	mass of chip (gm)
MH	horizontal micro-texture on cutting insert impregnated with MoS_2 dry lubricant
MV	vertical micro-texture on cutting insert impregnated with MoS_2 dry lubricant
ME	elliptical micro-texture cutting insert impregnated with MoS_2 dry lubricant
MRR	material removal rate (mm^3/min)
R_a	average surface roughness (μm)
T	temperature ($^\circ\text{C}$)
V	cutting speed (m/min)
V_{bc}	flank wear (mm)
WH	horizontal micro-texture cutting insert
WV	vertical micro-texture cutting insert
WE	elliptical micro-texture cutting insert
WOT	cutting insert without texture
w	width of cut (mm)
K	chip thickness ratio (no unit)
ζ	chip-reduction coefficient (no unit)
ρ	density of chip (gm/mm^3)
n	number of micro-texture
α, α'	fraction of dry contact area and due to MoS_2 as medium
τ_d, τ_m	average shear strength of dry contact and due to MoS_2 as medium
μ	coefficient of friction (no unit)
θ	shear angle (degree)
γ	rake angle (degree)
η	friction angle (degree)
c_s	principal cutting edge angle or approach angle (degree)

ture, friction coefficient at the chip tool interface and tool wear by combining the concept of pulsating heat pipe and surface texturing technology. Lei et al. [13] performed an experimental investigation using micro-pool lubricated cutting tool in machining mild steel. Their investigation reveals reduction of about 10–30% in mean cutting force, while chip-tool contact length was reduced by about 30%. Jianxin et al. [14] had reported that the reduction in friction was mainly due to the formation of self-lubricating film on the tool chip surface and the reduced contact length at the interface on the rake surface, but this reduction in contact length was assumed to be unity [8] which is not practical. Davim et al. [15] had characterized the machinability evaluation in hard turning of D2 steel using ceramic cutting tools to investigate the influence

of cutting parameters on machining responses such as tool flank wear, cutting pressure and surface roughness. For high dimensional accuracy surface roughness achieved was less than $0.8 \mu\text{m}$ with suitable cutting conditions. In the past, researchers [16–20] had investigated the process parameters for hard turning using ceramic cutting insert on AISI D2 steel. Their study is based on neural network to predict the machinability characteristic. Therefore, from all the research work reported it can be concluded that many of them have tried to build a micro/nano texture on the rake face of the cutting insert with the application of micro-EDM, femtosecond laser etc. to improve the cutting performance which were time consuming requiring optimality to decide the best textures. In this work, the authors have developed three different geometrical micro textures—one in the parallel direction, second in the perpendicular direction of the chip flow and the third a concentric ellipse by Epilog Laser on the rake surface of the cutting insert. With epilog laser, micro-texturing was able to keep the mega coating of $\text{Al}_2\text{O}_3 + \text{TiC}$ ceramic cutting insert for longer duration of machining, thus increasing tool life. In addition, these micro-textures were able to easily determine actual chip-tool contact length. These micro-textures were also able to withhold the liquid and solid lubricant for longer duration of turning operations. Theoretical results were validated with the experimental ones. The objective of the present study was to create micro textures on the rake surface of the cutting insert to improve tribological properties such as coefficient of friction, shear angle, chip morphology, anti-adhesive effect and area of contact at the chip tool interface. Moreover, this study aims at improving the cutting performance by incorporating MoS_2 in the textured insert that has the tool wear reduction ability. In addition, a mathematical model has also been developed to predict the coefficient of friction within the actual chip-tool contact length. This paper also proposed a force model associated with the actual chip-tool contact length and the friction on the textured rake surfaces.

2. Fabrication of cutting tool with micro-texture on rake surface

Micro-nano texturing is used to make the surface behave like hydrophobic. This concept of micro-texturing has been implemented on the rake surface of the cutting insert to investigate the tribological behaviour in the chip-tool and work-tool interfaces. Micro-texturing has biggest advantage of reducing coefficient of friction in the chip-tool interface region. Further when chip flows on the rake face, it gets obstructed in the groove of the texture and breaks resulting into short and discontinuous chips facilitating machining. During machining with textured tool the actual contact area between the chip and the rake face of the tool decreases, and hence instead of sliding along the entire length of the rake surface, chip breaks and flows out of the rake surface upon coming in contact with the geometrical texture leading to the improvement of its tool life. Most importantly, micro-texture on the rake surface may be assumed as an extended fin of uniform cross section that would help in improving heat transfer to the surrounding. In addition, it can act as a reservoir to absorb and continue to hold cutting fluid, along with the fact that it can be impregnated with solid dry lubricant, namely MoS_2 to enhance the tool life. The use of MoS_2 and its effect on machining is discussed in the subsequent section. Micro texturing was created on the rake surface of ceramic cutting insert CNGA 120408 T02025 PT 600M with the help of Epilog laser at low speed and high power by repeating number of passes to obtain desired geometry as shown in Fig. 1. Width of the texture formed was between 200 and $215 \mu\text{m}$ and the gap between the textures was approximately $150\text{--}222 \mu\text{m}$. Images of three different micro textures captured through USB-type digital microscope (Dino-lite 2.0) are shown in Fig. 2. Fig. 3 shows the 3-D surface profile image

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