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Effects of Surface Texturing on Cutting Tool Performance

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Abstract

Cutting tools with micro-textures on cutting face have shown notable improvements in reduction of wear, cutting forces, and friction. However, these benefits are entirely dependent on the various parameters of a micro-texture. The primary objective of this study is to analyze the effects of micro-textures while orthogonal cutting of AISI 1018 Mild Steel. Micro-textures were imparted on the rake surface of coated and non-coated tungsten carbide (WC) cutting tools by using Ytterbium laser. Micro-cavities of circular shape were machined on tool surface. Circular shaped micro-cavities were selected as they are axisymmetric and unimpacted by the flow direction of the chip unlike triangular and rectangular micro-cavities. Also, the parameters like dimple size, pitch, depth, and distance from the cutting edge were varied during experiments. The study reveals the optimal parameters which have substantial effects on cutting force, shear angle, cutting vibration and also chipping effect. Taguchi estimation was conducted to determine the most optimal parameter configuration. To demonstrate the influence of individual texture parameters on resultant cutting forces, a main effect plot was charted, and its evaluation was done to validate the effectiveness of micro-texturing. Thus, the most effective permutation of texture parameters has been found considering all the responses and assortment of parameters. The micro-textured tools have shown reduced cutting forces, enhanced tool life and lesser tool vibrations as compared to non-textured tools.

Keywords: Laser Surface Texture, Cutting tool, Wear, Friction, Tribology, Micro-texture.

1. Introduction

Cutting tools during machining experience high thermal stresses which leads to face wear. Machining zone is always deprived of ample quantity of lubricant to reduce the tool-chip friction. These effects result in high cutting forces, wear, and tool failure. Wear of tool during machining is inevitable, but with proper tool geometries and with a usage of lubricants it can be reduced. Consistent efforts are being undertaken to enhance performance of the cutting tools and to lengthen their operational life. This is generally done by using chip breakers, alteration in tool geometry, coating the tool and surface texturing to facilitate efficient separation of the chips from the workpiece material[1]. Uncontrolled tool wear results in tool chatters, surface roughness, and increased tool conditioning costs. Texturing of a tool includes surface modification which will help to reduce the frictional and wear effects.

Surface texture imparted on the tool reduces the friction and wear by creating sites to hold the lubricants between tool interfaces. Nano and micro scale dimples created by suitable process such as femto-second laser improves the tribological behaviour of cutting tools. Various patterns of textures can be created by controlling laser parameters [2].

During a machining process, the friction resulting within the tool–chip interface performs a vital role during the cutting operation. Reduced machining forces were observed while using textured tools[3]. Also, lower coefficient of friction was observed for textured tools. Highest decrement in values of cutting forces was observed for perpendicular and diagonal grooved micro textured tools[4]. Also, significant increase in heat exchange rate has been observed for textured tools[5]. Surface roughness of components machined with coated dimple textured inserts is far less as compared to uncoated and non-textured inserts[6].

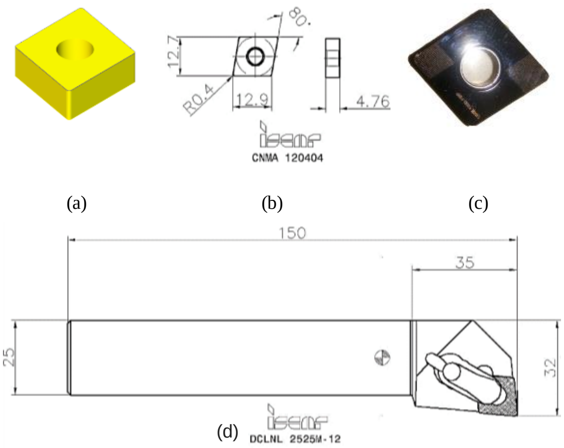

Fig. 1 (a) 3D view of cutting tool, (b) Schematic diagram with dimensions, (c) Textured tool of WIDIA® Carbide turning insert CNMA 120404 GRADE CJ215K and (d) Cutting tool holder DCLNL 2525M12 R-clamp tools with 95° lead angle carrying the 80° negative rhombic inserts. (All dimensions are in mm).

Present study focuses on analyzing the impact of microtexture features like dimple size, pitch, depth, and distance between the texture and the cutting edge (DFE) through statistical analysis. AISI 1018 alloy is the material used for the workpiece. It was observed in certain cases that, cutting fluids prove detrimental to the environment, are tough to dispose or recycle and also lead to extra costs during the manufacturing process[8]. Hence, more preference is given to minimum lubricated machining and dry machining.

The textures on the cutting tool surface can play a very important role in reduction of coefficient of friction, adhesion and also cutting vibration.

2. Methodology and Experimentation

This section briefs the method adopted for texture fabrication, sample preparation and the conditions set during experimentation.

2.1. Micro dimple fabrication

Experimentation is done using cutting tools made of non-coated and coated tungsten carbide, (WIDIA Carbide Turning Insert CNMA120404 Grade CJ215K and THM), Refer Table 1 for the specifications of tools. The cutting tool has a plain rake face lacking a chip breaker, a characteristic knowingly chosen to facilitate texturing on the tool and to examine the effects of individual texture parameters. The schematic of the tool and its arrangement in the tool holder is depicted in Fig. 1.

2.2. Laser Characteristics

The laser used in this study, is capable of high speed texturing, and it can encompass a wider area in a single cycle as compared to Electric Discharge Machining (EDM)[9]. It produces several ultrashort pulses within a time in nanoseconds, this fabricates textures with shallow depth of heat-affected zones. The laser settings used to generate the requisite dimples are wavelength of 1064 nm, 50 m/s marking speed, pulse frequency of 20 kHz and power of 20 W. The dimples formed have ≈20 µm depth.

The dimple shape chosen for the experiments was circular due it's symmetry on all sides (Fig. 2). Considering a random shape instead for patterning, like a star-shaped or square shaped dimple may create an impact integrity issue if the cutting tool meets the workpiece at the texture edges. Kümmel et al. observed that dimpled micro-textures as opposed to channel/groove/pillar structures were more effectual in wear reduction [10]. It was noted that the contact area was larger for the channel/groove textured tool and the texture edges in fact contributed to wear by acting as secondary cutting edges.

Table 1
WIDIA Carbide Turning Insert CNMA120404 Grade CJ215K and THM.

Features	Grade	
	CJ215K	THM
Type	Turning Insert	Turning Insert
Material	TiCN-Al2O3-TiN CVD Coated Carbide	Non coated Tungsten Carbide
Material Compatibility	Cast Iron	Cast Iron
ISO Designation	CNMA120404	CNMA120404

Arrangement of the dimples on the cutting tool and their size are a key factor, as the optimum configuration of these features will result in maximum efficacy of the texturing effect during the cutting process. Hence, three texture parameters were selected namely dimple diameter, pitch, and distance from the edge of the cutting tool. Fig. 2 shows the profile of the circular micro-dimpled surface and the distribution of the micro-dimples over the cutting tool.

The parameter 'pitch' defines the smallest distance between the centres of two neighbouring micro dimples. The distance between the bordering array of dimples and the cutting edge must be optimized, as textures in extremely close proximity to the cutting edge will obstruct the cutting process and

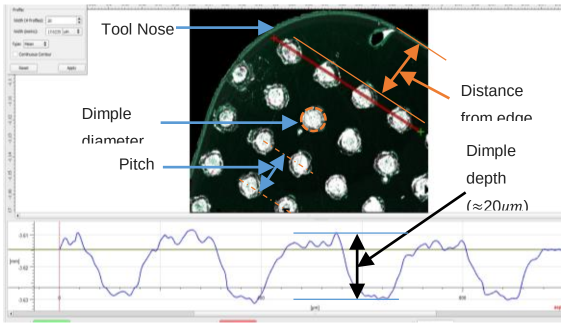

Fig.2 3D optical profile of circular micro dimple having depth of $\approx 20\mu m$.

also reduce the strength of the cutting edge. On the contrary, if the textures are located very far from the cutting edge, it will lessen the efficiency of the textures. The textured tools in this study were manually polished to mirror smoothness ($R_a = 0.05$ µm), and later cleaned in an ultrasonic bath.

2.3. Experimental Setup

AISI 1018 Mild Steel workpieces were pre-machined with 52 mm diameter and 90 mm length and clamped in a rotating chuck. Orthogonal cutting was performed on a lathe machine (CNC TURNING LATHE, Maker- Micromatic, Model-Jobber XL, India). The experimental setup is illustrated in Fig. 3.

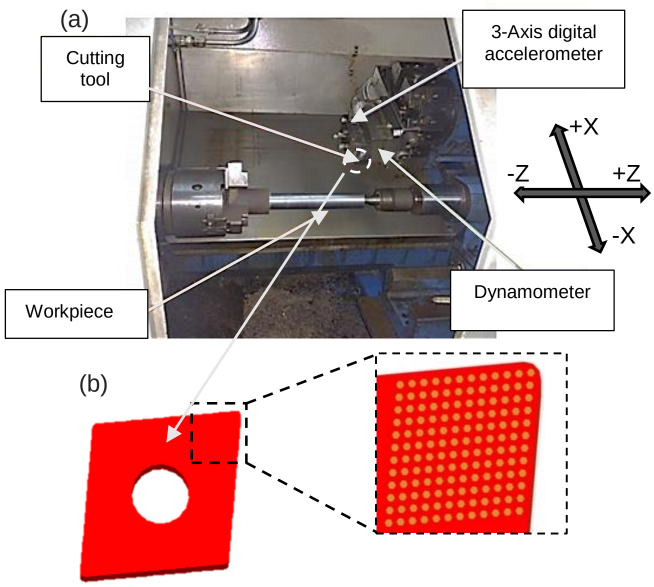

Fig. 3 (a)Experimental setup for orthogonal cutting and geometry of a turning process and (b) Schematic view of textured cutting tool.

Cutting force and thrust force are used to evaluate the cutting performance of the cutting tool directly. These forces were measured by using a dynamometer (Make & model: - Kistler 5233A1, Kistler Instruments India Pvt Ltd). This Quartz dynamometer is capable for measurement of 3 orthogonal component forces. The dynamometer was placed under the tool holder as shown in Fig. 3.

The experiments were conducted in accordance with the cutting conditions listed in Table 2. The cutting parameters chosen were as per the recommendations of the cutting tool's manufacturer. The coolant used was Servosynth 2 oil which is a synthetic grinding coolant. This coolant also has remarkable anti-rust characteristics. Servosynth 2 is widely used in cutting process of ferrous metals, titanium alloys, and high nickel. These oils meet IS: 11186 - 1985 specification. The kinematic viscosity of the lubricant is 20 mm^3/s at 24 °C.

Table 2
Cutting conditions

Parameter	Values
Revolution speed (**rpm**)	500-800
Depth of cut (**mm**)	0.5
Feed rate (**mm/min**)	25-45
Cutting length (**mm**)	90
Coolant	Servosynth 2/5
Lubricant flow rate (**cc/h**)	60

Varying textures were laser machined on cutting tool. Refer Table 3 for the texture parameters selected based on the preliminary experiments. In this research, the Taguchi L27 Orthogonal Array (3-factor, 3-level) was used to ascertain the influences of micro texture parameters on the performance of the single point cutting tool. These experiments were randomized to avoid the effect of any noise factor.

Table 3
Levels of the texture parameter

Texture Parameter (μm)	Level L1	L2	L3
Diameter	100	150	200
Pitch	150	200	250
Micro-texture distance from the cutting edge (DFE)	80	130	180

To measure vibrations of cutting tool during machining, a tri-axial accelerometer was mounted on the cutting tool holder, which in turn was connected to a data acquisition system. For ease of understanding, an 'Accelerometer' is an electromechanical sensor which calculates the force of acceleration due to gravity in g unit (i.e.: gravitational constant "g", where $1g = 9.81\ m/s^2$). The ADXL335 variant measures acceleration along X, Y and Z axes to give an analog voltage output, which is directly proportional to the acceleration along these 3 axes. The accelerometer output had been connected to Arduino™ UNO microcontrollers which can process output voltage by converting them to digital signals using ADC.

Table 4
L27 Orthogonal Array

Exp. No.	DFE-Pitch-Dia.	Exp. No.	DFE-Pitch-Dia.	Exp. No.	DFE-Pitch-Dia.
1	80-100-100	10	130-100-100	19	180-100-100
2	80-100-150	11	130-100-150	20	180-100-150
3	80-100-200	12	130-100-200	21	180-100-200
4	80-150-100	13	130-150-100	22	180-150-100
5	80-150-150	14	130-150-150	23	180-150-150
6	80-150-200	15	130-150-200	24	180-150-200
7	80-200-100	16	130-200-100	25	180-200-100
8	80-200-150	17	130-200-150	26	180-200-150
9	80-200-200	18	130-200-200	27	180-200-200

3. Results and Discussion

The responses of designed experiments were measured based on each of the 27 experiments conducted for coated and non-coated textured tools. Also, required number of experiments were conducted on non-textured non-coated cutting tools. All experiments were repeated thrice for consistency. The responses measured during experiments include cutting force and cutting tool vibration.

3.1 Cutting forces.

In this study, piezoelectric sensors were used to accurately measure the dynamic cutting forces generated. The cutting forces derived from the multiple experiments conducted on various combinations (refer table 4) of textured tools are plotted in Fig. 4.

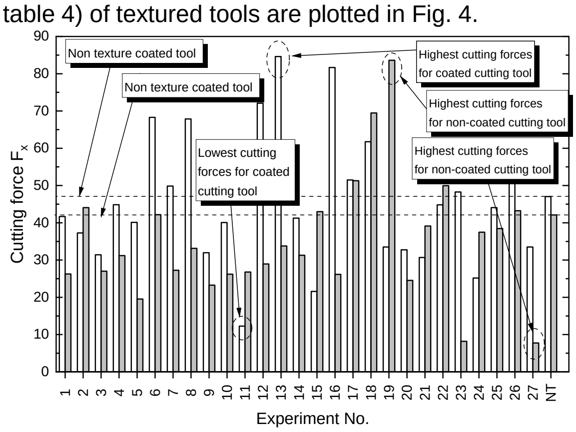

Fig. 4 Average cutting force F_x for coated and non-coated tool

Results indicate that experiment number 11, with parameters namely 150 μm diameter, 100 μm pitch and 130 μm spacing from cutting edge, has the lowest formation of cutting force as compared to all other combinations evaluated. It was observed that changes in texture parameters have an impact on the resultant cutting forces. Compared to plain (non-textured) cutting tools, for the coated textured tool used in experiment number 11, the cutting force was found to be reduced by 73.89%. For the non-coated tool used in experiment number 27, the cutting forces were reduced by 81.59%. The individual effects of micro-dimple parameters on the cutting forces are shown in Fig. 5.

Fig.5 depicts the mean effect plot charted to estimate the texture parameter majorly influencing the resultant cutting force. It was observed that increment in pitch has most impact on hike in cutting forces. Also, farther the array of dimples is from the cutting edge, lower are the values of Fx. Smaller the size of micro dimples, larger are the cutting forces generated.

3.2 Cutting vibration.

A tri axial accelerometer ADXL335 was mounted near the contact on the tool holder shaft which holds the cutting tool insert. It was noted that, most of the textured contacts having 80 μm distance from the edge

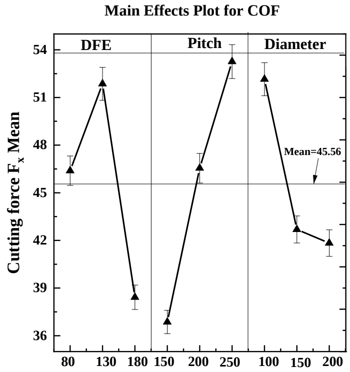

Fig. 5 Main effect plot for Cutting force Fx for distance from cutting edge (DFE), pitch and diameter of micro dimple.

and having 100 μm pitch generated low magnitude vibrations compared to the contacts formed amongst the non-textured surfaces. This happened due to the enhanced bonding of lubricant on the textured surfaces.

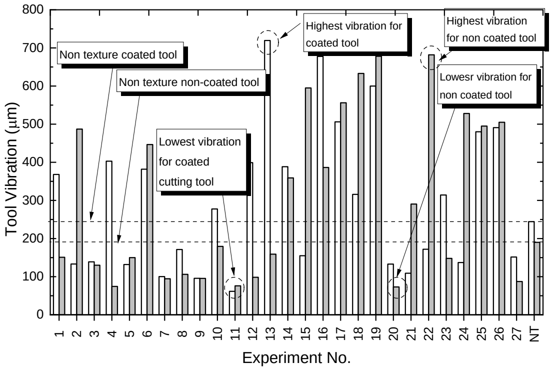

Fig. 6 Cutting tool vibration along X-axis.

Textured tools were found to increase the surface roughness while reducing the vibration. It was observed that lesser vibrations occurred during cutting process for coated as well as non-coated textured tools used in experiments number 3, 5, 7, 8, 9,11, 20 and 27 (Fig. 6), as compared to the non-textured tools. The reason being lesser cutting forces were generated and lower coefficient of friction was obtained at the tool chip interface during the cutting process. As a favorable outcome, the textured tools dampened the vibrations for a stable cutting experience and facilitated a uniform surface finish.

4. Conclusions

This study summarized the performance of micro-textured cutting tools with non-textured cutting tools while machining AISI 1018. Experiments were performed by changing the texture parameters based on estimates derived using the Taguchi method. Following valid conclusions were drawn from the research:

- The pitch of the texture is found to be the most influence inducing process parameter.
- Smearing or adhesion of mild steel is less in the textured tool as compared to the non-textured tool.
- The suitable combinations of texture parameters are identified for experiment no. 11 having DFE 130, pitch 100, diameter 150 for coated. For non-coated tool, experiment no. 27 having parameters DFE 180, pitch 200, diameter 200 with regards to all the responses are found efficient within the span of parameters considered.
- Micro-dimpled surfaces having smaller sized dimples (100μm) have exhibited lower amplitudes of vibration as compared to textured surfaces having larger size dimples (200μm).

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References

1. Ghosh N, Ravi YB, Patra A, et al. Estimation of tool wear during CNC milling using neural network-based sensor fusion. *Mech Syst Signal Process* 2007; 21: 466–479.
2. Senthilkumar V, Hari Prasath MG, Lomesh Chilamwar V. Role of surface textures on tribological behaviour of HSS. *Surf Eng* 2014; 30: 277–282.
3. Zhang K, Deng J, Xing Y, et al. Effect of microscale texture on cutting performance of WC/Co-based TiAlN coated tools under different lubrication conditions. *Appl Surf Sci* 2015; 326: 107–118.
4. Niketh S, Samuel GL. Surface texturing for tribology enhancement and its application on drill tool for the sustainable machining of titanium alloy. *J Clean Prod* 2017; 167: 253–270.
5. Vignesh G, Debabrata Barik PR, Aravind S. Experimental analysis on turning of AISI 4340 steel using non-textured, dimple textured and MoS2 coated dimple textured carbide cutting inserts at the rack surface. *Mater Today Proc* 2020; 33: 2616–2620.
6. Ahmed YS, Paiva JM, Arif AFM, et al. The effect of laser micro-scale textured tools on the tool-chip interface performance and surface integrity during austenitic stainless-steel turning. *Appl Surf Sci* 2020; 510: 145455.
7. Li K, Jing D, Hu J, et al. Numerical investigation of the tribological performance of micro-dimple textured surfaces under hydrodynamic lubrication. *Beilstein J Nanotechnol* 2017; 8: 2324–2338.
8. Kumar V, Verma R, Kango S, et al. Recent progresses and applications in Laser-based surface texturing systems. *Mater Today Commun* 2020; 101736.
9. Mastud S, Garg M, Singh R, et al. Discharge Machining (Edm) for Surface Texturing. *ASME 2012 Int Manuf Sci Eng* 2012; 1–10.
10. Kümmel J, Braun D, Gibmeier J, et al. Study on micro texturing of uncoated cemented carbide cutting tools for wear improvement and built-up edge stabilisation. J Mater Process Technol 2015; 215: 62–70.