Key Insights into Performance of Textured Single Point Cutting Tool towards using Metal Matrix Composite: A Conceptual

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Abstract:- - Cutting tools play a crucial role in manufacturing industries. Currently, research is being conducted on using textured tools on various metal matrix composites to enhance tool life and improve machining quality. Experimental studies are being carried out by creating textured patterns such as grooves, dimples, concave, linear and convex textures on carbide tips. These studies demonstrate that textured single-point cutting tools exhibit improved tool life, reduced cutting forces, and enhanced lubrication capabilities. Good machining performance has been achieved using textured single-point cutting tools with various parameters. This study will be beneficial in improving tool life and enhancing cutting performance on aluminium metal matrix composite alloys using carbide-tipped tools.
Keywords: *Cemented carbide cutting tool, texture on tool surface, metal matrix composite, minimum quantity lubrication.*

1. Introduction

Cutting tools play a crucial role in the manufacturing industry and perform a wide variety of machining operations. To improve machining quality, the rake surface of cutting tools is textured, and cutting operations are performed. Comparing textured tools with non-textured tools, it was found that textured tools perform better than non-textured tools and also reduce cutting forces. They have also been found to improve machinability [1], [4]. For example, dimple textures improved crater wear resistance and enhanced the lubrication environment. Controlled surface textures on cutting tools have the potential to reduce cutting force and tool wear [4], [31].

Texturing of carbide tools can improve machining performance if the orientation of the texturing is parallel to the main cutting edge. In such cases, the texturing form allows the cooling-lubrication fluid to penetrate the cutting zone more effectively and can act as a micro-reservoir for continuous replenishment of the emulsion. This results in better cooling and lubrication, which manifests as reduced cutting forces [2].

Based on the review mentioned above, it has been observed that to achieve the desired tool life of carbide materials, it is crucial to control a wide range of performance parameters and experimental factors. Nowadays, many researchers are giving due importance to the texturing of the rake face, cutting tool parameters, and minimum quantity lubrication methods [4], [30].

When a machining operation such as turning or facing is performed using a single-point cutting tool, several factors affect the machining operation. In a machining operation, the operation should be completed in the shortest possible time and should have a good surface finish at the best possible cost. Therefore, to achieve these qualities, studies should be conducted on single-point cutting tools, and some modifications should be made to the tool on the rake face [2], [4]. Micro textures are produce to the rake face surface of carbide inserts tips. These textured surfaces significantly reduce heat and cutting forces, with the texture width being the most influential parameter [30]. Different micro textures on the carbide inserts affect the stress distribution, leading to reduced wear and improved tool life. The purpose of the textures in single-point cutting tools, as analysed using the Finite Element Method (FEM), is to enhance cutting performance by optimizing the tool-workpiece interaction [4]. This includes reducing cutting forces, temperature, and wear rate, ultimately improving tool life and machining efficiency on metal matrix composites [2], [4].

1.1 **Construct of cutting tool with textured on rake face surface**:

For experimental analysis, carbide tools are fabricated with different textures and varying combinations of width and depth, and the forces acting on the tool are calculated. The forces involved, namely the cutting force and feed force, are measured. This will reveal that micro-textured tools generate lower cutting and feed forces [1], [31].

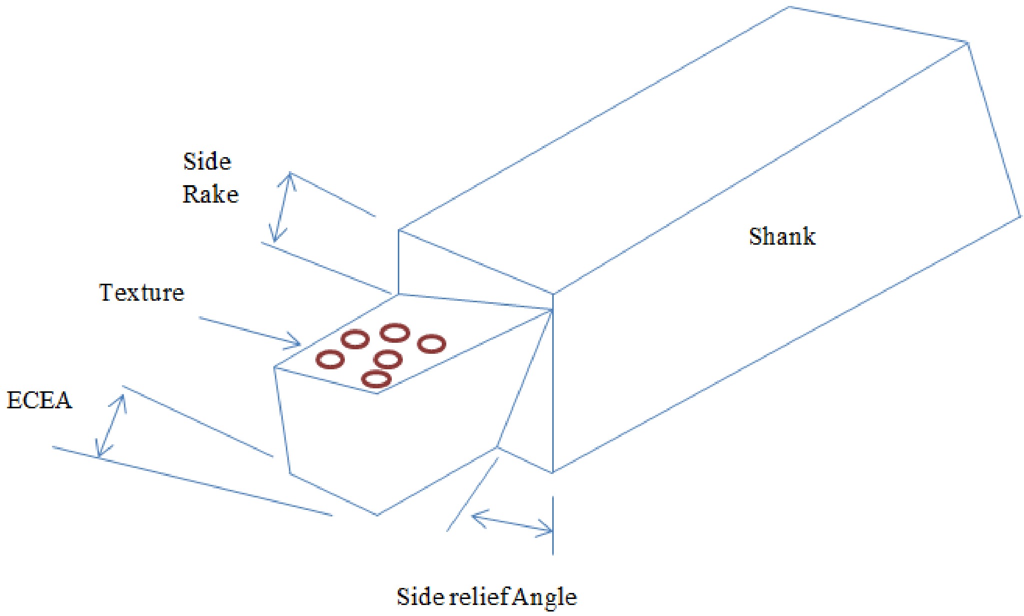

Fig. 1: Textured Single Point Cutting Tool

1.2 **Performance of cutting tools with different textures shape**:
Surface texturing is a method in which specific patterns are designed on the rake surface to improve the quality of the operation, such as reducing friction, retaining lubricant, and providing self-cleaning properties [8].
Laser surface texturing is one of the most popular techniques used to create various micro-textures on a surface, as it offers advantages such as less waste, high precision, satisfactory machining rates, and repeatability compared to other texturing processes [9].

Fig. 2: Dimple Shape

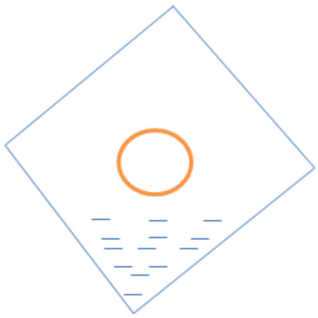

Fig. 3: Linear Slot Shape

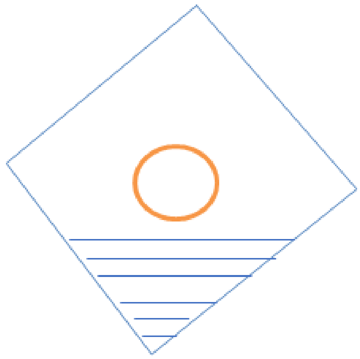

Fig. 4: Straight Groove Texture

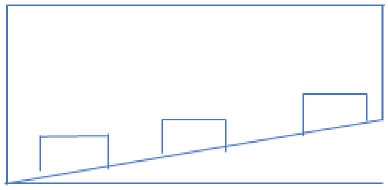

Fig. 5: Micro Square Pit Texture

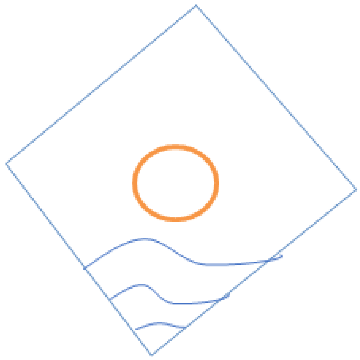

Fig. 6: Wave Groove Texture

2. Literature Review

The rake surface texture of single-point cutting tools has the potential to reduce cutting forces, tool wear, and other factors. A study was conducted on carbide tools with different rake face textures, examining the cutting forces, chip shape, and surface roughness [1].Texturing of cutting tools can improve machining performance. In such cases, the textured surface allows the cooling-lubrication fluid to reach the cutting zone more effectively and can act as a continuous micro-reservoir. This results in improved cooling and lubrication, which manifests as reduced cutting forces. On the other hand, no significant difference was observed in chip shape and surface roughness among the different textures [35]. The negative impact of cutting chips on surface texture and cutting performance has been discussed, particularly when using micro-textured tools with grooves perpendicular to the cutting edge. This phenomenon can degrade cutting performance, making it a crucial area of investigation. Challenges in experimental observation: The authors state that observing and characterizing cutting chips in situ through experimentation is challenging. This lack of experimental data has resulted in a limited understanding of the mechanisms and effects of cutting chips on specific cutting forces and tool wear. The finite element method is used to simulate the cutting process with micro-textured tools. This method allows for a more detailed analysis of cutting dynamics and chip effects, which cannot be easily captured by traditional experimental methods [33], [34].

In dry cutting, especially when machining titanium alloys like Ti-6Al-4V, which are known for their high specific strength and low thermal conductivity. The absence of cutting fluids leads to rapid tool wear and high cutting temperatures, necessitating innovative solutions to enhance tool performance. Surface Texturing Benefits like various studies have shown that surface texturing on cutting tools can significantly improve their performance. For instance, micro-pit arrays on textured surfaces can store lubricants and capture wear debris, which helps in reducing tool wear and improving cutting efficiency [10].

The surface texture of cutting tools can significantly reduce the heat generated and the cutting forces during machining. This is a crucial area of study because it directly impacts the efficiency and effectiveness of the machining process. This study identifies three main factors influencing cutting performance: texture width, depth, and spacing. Of these, texture width was found to have the most significant impact, followed by depth and spacing. Surface texture of cutting tools can significantly reduce cutting heat and force [16].

Finite element analysis was used to simulate the cutting process and analyze the distribution of cutting temperature, pressure, and stress. This approach helps in understanding how different surface textures affect cutting dynamics, providing insights into the mechanical behaviour of the tool during the operation. The Taguchi method was also employed to assess the impact of three main factors—texture width, depth, and spacing—on cutting performance. This method helps in systematically varying parameters to minimize cutting forces and improve overall efficiency. The methods used in this paper include finite element analysis for simulation, the Taguchi method for optimization, and orthogonal array design for structured experimentation, all aimed at understanding the influence of tool surface texture on cutting performance [17].

This approach allows for a detailed examination of the interaction between the drill tool and the material, providing insights that are not easily obtainable through purely experimental methods. Further research into micro-textured drilling technology is highly necessary, particularly for aluminium alloys. These results highlight the potential benefits of optimizing drill texture to improve cutting efficiency and reduce cutting forces during the drilling process [18].

A material can only be machined if conditions, such as cutting speed and feed rate and depth of cut are satisfied., It's a means to determine how well one kind of tool material interacts with another so that the tool lasts a long time and the components have a high surface quality and functioning. Tool life, surface quality, and power usage are all important considerations when it comes to machining [19].

The severe deformation occurs in local small area of tool tip during high speed turning process. In order to simplify the research work, the finite element model of orthogonal turning has been studied using DEFORM software. In turning process, the plastic deformation occurs in the tool tip, which makes stress gradient, strain gradient and temperature gradient of the blade bigger, so the mesh of these zones should be fine [18].

When the thrust force and feed force an increase in cutting speed, feed, and depth of cut machining forces is also increased. With increase in cutting speed there is increase in cutting forces, this is due to increase in temperature in tool chip contact zone and relatively softening of workpiece material which results in reduced shear strength [20].

This paper discusses tool wear in turning operations. It focuses on uncoated carbide tools for machining. A FEM-based procedure is used to predict the progression of tool wear. Experimental tests were conducted with AISI 1045 steel to validate the FEM model. The model analyzes the effect of rake angle and stress on tool wear. The aim of this study is to improve the reliability of tool wear simulations. Some discrepancies were observed, mostly at higher cutting velocities and feed rates [21], [33].

2.1 **Methods for produced texture**:

There are different types of methods for producing texture on the race face of single point cutting tools. Manufacturing texturing on rake face or flank by electric discharge machining (EDM), laser beam machining, photo chemical machining, abrasive jet machining, ultrasonic machining and additive manufacturing [12].

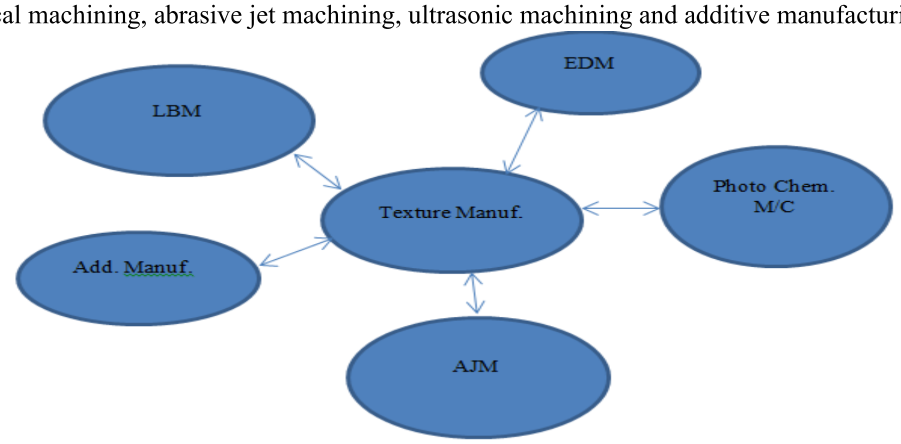

Fig. 7: Classification of texture manufacturing

2.2 **Metal Matrix Composite with Reinforcement**:

A metal matrix composite (MMC) made of aluminium (Al) with graphite reinforcement is a hybrid material that combines the lightweight and ductile properties of aluminium with the excellent lubricating and thermal properties of graphite [28], [29]. This type of MMC is especially useful in applications where low friction, wear resistance, and good thermal conductivity are required. In practice aluminum reinforcing material Al2O3 , SiC, B4C, graphite, Boron, etc.

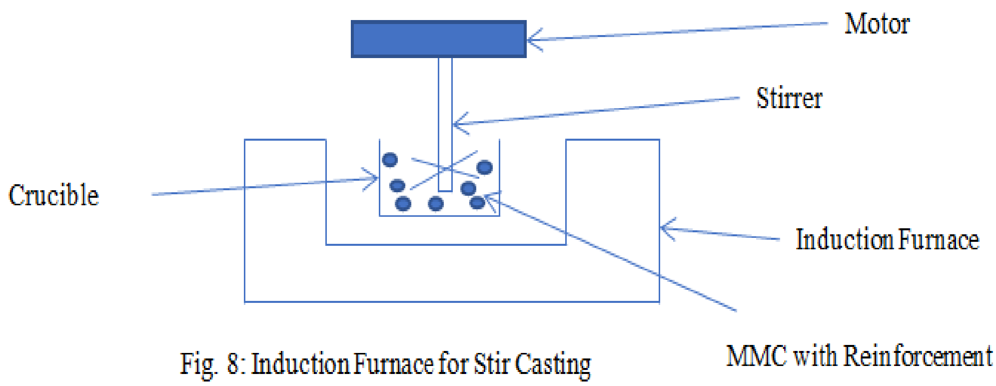

Fig. 8: Induction Furnace for Stir Casting

3. Minimum Quantity Lubricant Method:

The current trend in the metal-cutting industry is to find ways to reduce cutting fluid use; the use of coolants in machining is thought to be undesirable for economical, health, and environmental reasons. The minimization of cutting fluid leads to economic benefits by saving lubricant costs. Workpiece, tool and machine cleaning time are reduced. The MQL technique consists of misting or atomizing a very small quantity of lubricant [14], [34].

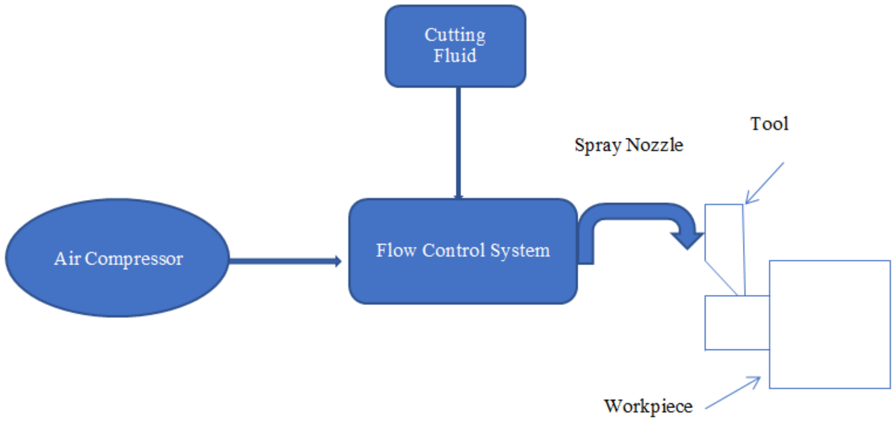

Fig. 9: Minimum Quantity Lubricant Method

2.4 **Recent experimental with texture cutting tool:**

2.4.1 Microstructures and functional properties: Texturing is commonly used to describe a fabricated pattern with systemic basic micro-textures, such dimples, linear or grooves. Most recently, surfaces structured with laser processing provided a high range of possibilities, including periodic, regular, or irregular shape or patterns on the surface topography of cutting tools [10].

2.4.2 Wear resistance in wet cutting conditions:

In machining processes, consistently higher forces are required to reduce adhesive properties and improve the wear resistance of cutting tools, thereby extending tool life. Various cutting tool technologies have been developed, involving different materials, tool geometries, surface coatings, and surface finishes. However, these technologies often fail to meet current demands in experimental settings, particularly in steel cutting, because the high mechanical stress and heat generated on the tool surfaces, coupled with inadequate lubrication, lead to excessive tool wear [11], [35], [36]. To improve the tool life and properties of cutting tools, we need to adopt a surface engineering approach, specifically the functionalization of the tool surface through texturing. Diamond-like carbon-coated cutting tools with micro-textured surfaces were developed to investigate the role of textured tool rake faces in retaining cutting fluid and reducing the contact area between the tool surface and the chip. In milling operation on aluminium alloys showed that textured surfaces improve the lubricating and anti-adhesive properties at the tool-chip interface. The most significant effect of surface texturing is the creation of lubricant reservoirs, as the lubricant trapped between the tool-chip interface during machining spreads into these textured cavities [1], [2].

2.4.3 **Effect of texturing on cutting forces:**

The effect of cutting process depends on the metal removal rate of generation of cutting forces are dependent on the cutting tool parameters tool material, work material parameters and cutting parameters. Generations of surface textures on the cutting tool are reduced cutting forces then increase the tool life and the surface finish of work material [33].

Table 1: Summary of literature review /Finding:

S. No.	Author & year	Tool Utilise	Processing Parameters	Result
1.	S. Dhanraj, Ramakrishna Malkapuram, B. Singaravel ,2020	**Tool**: Carbide insert **Material** : Al MMC (Al 6061) with reinforcement silicon carbide	**Texture**: Dimple texture Hole dia., Hole depth, Pitch between hole 1) Micro texture produces by laser. 2) Material produced by steer casting	1. flank wear reduce 21% 2. 19% Power consumption
2.	D. Arulkirubakaran, V. Senthilkumar, V. Chilamwar, P. Senthil ,2019	**Tool:** Carbide insert **Material:** Al MMC AL 4 Wt.% CU with 6%TiB2	**Texture**: Areal, Parallel and perpendicular textured tool 1)Micro texture tool produce by Wire EDM	1) Force reduction 21% to 27% 2) Specific cutting energy is reduced 25% in dry and 30% lubrication condition.
3.	Priya Ranjan, Somashekhar, S. Hiremath, 2019	**Tool**: Carbide tool insert **Material**: AL2O3/Tic	**Texture**: Micro Groove tool 1)Different technique to produce textures 2) Minimum quantity lubricant (MQL) technique	1) Reduce cutting force 23% 2)Nano texture tool is better performance compare to micro texture tool
4.	Jianfeng Pan, Kai Feng, Lihua He, Kai Zhuang, Jing Ni, and Junjie Lv	**Tool** : milling tool, **Material** : Aluminium Alloy	**Texture:** linear, Wave and micro pit, Milling tool 8 mm dia. and work piece 40mm X3 0mmX 10 mm 1) Speed -3000 rpm, feed-200, depth-2, width-8, cooling method-dry	1)Milling Load reduced 10.7% 2) surface roughness improve 23.8% by wave texture Found milling load, top burr and surface quality.

5.	Manoj Nikam, Anurag Karulkar, Aveek Chowdh (2022).	Tool : carbide inserts	**Texture:**1. Surface texturing of carbide inserts. 2. 3D Finite Element Model for stress distribution analysis.	1. Study on textured carbide inserts for improved machining performance. 2. Investigates stress distribution and wear impact on tool lifespan.
6.	Priyanka, Ghosh., Manuela, Pacella. (2020).	Tool: PCD cutting tool Material: Aluminum 6082 alloys	**Texture:** 1. Laser texturing with fiber laser for tool surface modification. 2. Characterizations using SEM, white light interferometry, and EDX spectroscopy .	1. Investigates textured PCD cutting tools for machining Aluminum 6082 alloys. 2. Examines cutting performance and anti-adhesive properties of laser-textured tools.
7.	Slyden, Rodrigues., Terrence, Pereira., Sagar, Patil., Brean, Burboz., Prasad, Bari. Tool.(2019)	Compares textured tools with non-textured cutting tools.	**Texture**: Compares textured tools with non-textured cutting tools. 1. Tool modification with micro textures on rake face. 2. Experimental analysis with strain gauges and Universal Testing Machine.	1. Study on single point cutting tool with micro textures for efficiency. 2. Analysis compares textured tools with non-textured cutting tools.
8.	Manuela, Pacella., Amir, Badiee., Priyanka, Ghosh. (2019).	Tool: PCD Tool Material: Aluminium Alloys	1. Laser surface texturing with nanosecond fibre laser. 2. Scanning Electron Microscopy and Energy Dispersive X-Ray spectroscopy.	1. Polycrystalline diamond tools improve wear resistance and reduce premature failure. 2. Adhesion issues lead to early tool breakage in dry machining. 3. Surface texturing enhances anti-adhesive properties and wear behaviour.
9.	Aniket, Roushan., Chetan. (2023)	**Tool**: Carbide Insert **Material**: pH 13–8 Mo SS alloy	1. Surface texturing using Nd:YAG laser 2. Turning experiments with textured tools on pH 13–8 Mo SS alloy	1. Surface texturing is a method to control friction and wear in tribological systems. 2. The effect of laser parameters on textured tools' machining performance is studied.

10.	TehThiam Oun, Arwinder Singh, Ooj Jia Yua, Goh Eng Hoe, Saw sor Heoh and Lee Sing (2021)	**Tool**: Dimple texture tool **Material**: AISI 1020 Steel	1. Micro dimple structure on the nitride steel tool. Micro texture produce by ion beam impact.	1. Tool not treat by DFM: 0.0041 gram wt. build of edge after machining. 2. Tool treat by DFM with tool tip 10mm: 0..37 gram wt. build of edge after machining. 3. Tool treat by DFM with tool tip 5 mm-0.0034 gram wt. build of edge after machining.

3. **Conclusion and Future Work:**

In this study, micro-textures were created on cemented carbide using laser surface micro-texturing, and this review paper presents the work done by various researchers on improving the mechanical properties of cutting tools by designing micro-textures on the rake face. This review paper discusses the different techniques used for creating textures and their effect on improving cutting performance, such as cutting temperature, cutting force, cutting chips, lubrication, surface finish, and tool wear.

It also discusses the effect of self-lubricating tools on improving machining performance. Rake face texturing affects the machining performance of carbide tools compared to untextured carbide tools. The shape of the texture affects the cutting force.

By using hybrid textures, such as dimple and rectilinear textures, we can further increase the cutting tool life and mechanical properties of textured single point cutting tool. This texturing form also helps in better penetration of the emulsion and can act as a micro-reservoir for improved cooling and lubrication.

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