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International Journal of Engineering Technology Research & Management (IJETRM)
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INFLUENCE OF MQL COOLING ON CUTTING TEMPERATURE, SURFACE ROUGHNESS AND TOOL WEAR DURING TURNING OF AISI 316 STEEL MATERIAL WITH DIFFERENT TOOLS

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ABSTRACT:
Textured tools performance significantly influenced by the geometry of the textured tool and texture design type. In this context, the new textured tools were fabricated in the present work and its performance will be evaluated and compared with untextured tools in terms of cutting temperature, surface roughness and tool wear during turning of AISI 316 steel grade material under Minimum Quantity Lubrication (MQL) cooling conditions respectively.
Turning process variables such as cutting speed, feed rate and depth of cut will be considered as input variables. Results of the current study indicate that textured tools under MQL significantly reduced the cutting zone temperature, tool wear and surface roughness respectively when compared to untextured tools. As a whole, parallel slot microgrooves present on the textured tools act as lubrication storage sites and provide additional cooling during machining of AISI 316 stainless steel material.

Keywords:
AISI 316 Steel, MQL, Textured Tools, Surface Roughness, Cutting Temperature, Tool Wear.

INTRODUCTION

Nowadays, industries involved in the metal cutting operation focused on minimizing conventional cutting fluid usage because of stringent regulations imposed by the different governments to meet eco-friendliness. In this con text, machining of AISI304 material is difficult under the conventional cooling method since this method involves in the disposal of a huge amount of chemically contaminated coolants into the atmosphere. Poor product performance has been the result of AISI 316 material products produced in dry machining operation due to high cutting temperature. Surface texturing of tools has emerged as an eco-friendly and efficient machining technique that satisfies the stringent environmentally friendly regulation. This technique is effective even in the absence of cutting fluid due to this derivative cutting mechanism. Recently, few studies were carryout on different grades of material with textured tools having different texture designs on the rake of the tool and MQL environments as follows.

Das et al. conducted experiments on hardened steel material under MQL condition with nanofluids and noticed superior results due to efficient heat transfer capacity.

Kulandaivel and Kumar Performed turning experiments on Monel K500 alloy and observed paramount results with MQL condition due to more temperature reductions compared to dry and wet conditions. In literature, it is noted that the use of surface texture tools significantly affects the performance of chip removal processes while machining different hard-to-cut materials.

Sugihara and Enomoto compared the machining performance during milling of medium carbon steel with two different surface texture designs namely micro dimple and microgrooves on the rake face of the tool under dry, wet cooling environment respectively. From results, paramount performance was obtained with the micro dimple-shaped textured tools when compared to microtextured grooves under both machining conditions respectively. In wet machining condition, dimple shaped textures serve two purposes it acts like a micro reservoir for coolant as well as a provision to trap the chip during machining these factors leads to obtaining beneficial results in micro dimple shaped textured tool over micro-textured grooves.

Niketh and Samuel made micro dimples on the tungsten carbide drill tool and found improved performance in the drilling of grade 5 Ti-6Al-4V material in MQL cutting condition when compared to flood and dry cutting conditions respectively due to reduction in friction at the cutting zone.

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Hao et al. fabricated textured tools with lyophilic/lyophobic wettabilities and studied their effect in the MQL environment during the turning of Ti-6Al-4V alloy. From results, it was observed notable reduction in the cutting force, average friction coefficient and cutting tool wear with textured tools in comparison of untextured tools and micro-grooved tools respectively.

Zhang et al. applied conventional cooling methods on the pit hole texture pattern textured tools and found higher turning performance compared to untextured tools in the machining of AISI 1045 material.
Khan et al. supplied nanofluids through the MQL technique on the textured tools in turning of titanium alloy and found beneficial results over conventional cooling because of effective cooling.

Zhang et al. pyramid-shaped textured tools were made on the tool and noticed positive results were observed with textured tools under dry and MQL conditions over untextured tools while machining of titanium alloy.

Pang et al. applied coolant using a conventional cooling technique on conical-shaped textured tools in turning of AISI 1045 material and found improved machinability index due to efficient coolant supply to cutting zone over untextured tools respectively.

Feng et al. fabricated microgrooves parallel and perpendicular to the chip flow direction and examined its effect by filling the grooves with solid lubricants on cutting temperature, tool wear and cutting force during turning of AISI 1045 steel at increasing cutting velocity condition respectively. Spread out of solid lubricant over the rake face of the tool is a responsible mechanism for contributing superior results with texture tools when compared to untextured tools respectively. However, the tool with perpendicular microgrooves showed superior results when compared to the other texture tool due to the significant reduction in tool-chip contact length. Furthermore, FEA- based analytical study revealed that texture tools produced beneficial results when compared to untextured tools respectively.

Kumar and Patel observed better turning performance with the tool having an inclined texture to the chip flow direction when compared to parallel and perpendicular direction textures to the chip flow direction since low tool-chip contact length and low adhesion of workpiece material on the tool during machining of AISI 52100 steel respectively.

Ma et al. Made microbumps on the rake face of the tool and compared its performance with the untextured tool during dry turning of steel. FEA based simulation studies have been on the considered texture designs and found better results when compared to untextured tools respectively. Further, optimum microbump parameters were identified in terms of bump height, width, edge distance and observed superior performance with texture tools over the untextured tools.

Su et al. performed dry machining experiments on Ti–6Al–4V alloy at the constant cutting velocity condition with a tool having texture surface parallel to the cutting edge and found favourable cutting conditions when compared to untextured tool because of the significant reduction in tool-chip length and low chip adhesion to the tool.

Based on the literature study, it was observed that surface texture design and geometry can affect the turning process performance. Regarding the surface texture tool literature, most of the research is investigated under dry cutting condition and countable work is available under impregnated solid lubricants. However, the literature lacks texture tools under the MQL environment. Recently, the requirement of sustainable machining of AISI 316 material has been increasing to meet the conspicuous environmental regulation. Therefore, the target of the present work is to evaluate the turning process performance with textured tool during machining of AISI 316 material and results were compared with untextured tools under minimum quantity lubrication (MQL) technique. In the present work, novel parallel slot micro grooves have made on the rake face of the tool and investigated the developed tool performance during turning of AISI 316 material under MQL condition. Further, the considered microgroove design specifications are different when compared to the literature design.

EXPERIMENTAL WORK

In the experimentation procedure, AISI 316 steel material is selected as the workpiece material and carried out experiments in turning operation using a CNC lathe with textured and untextured tools respectively under MQL condition. AISI 316 stainless steel is widely used in industries such as chemical processing, marine and medical applications due to its excellent corrosion resistance and mechanical strength. The fiber laser machining process was used to fabricate the proposed textured tools as shown schematically in Figure 1. Turning experiments were conducted on AISI 316 steel using CNC lathe machine. During machining, MQL mist was supplied on the rake face of both textured and untextured tools with a flow rate of 100 ml/hr with a nozzle having 1 mm diameter as depicted in Figure 2. In MQL condition, Castrol cool edge oil-water emulsion

ISSN: 2456-9348
Impact Factor: 8.232

iJETRM
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was used in the ratio of 1:10. An experimental design called one factor at a time approach was used to carry out the experiments. The cutting conditions used to perform the experiments are shown in Table 1. Every experiment was conducted three times and the average was considered in each response to provide the accuracy in the data. Machined product average surface roughness was measured using Talysurf roughness tester. Tool wear analysis and measurement were done by using a metallurgical microscope. Infrared thermometer was used to measure the cutting zone temperature during machining.

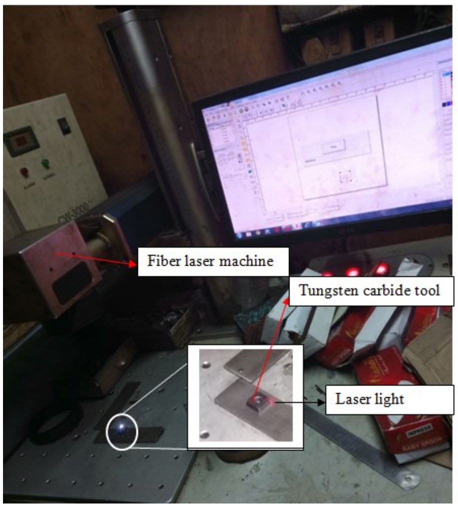

Figure 1 Fiber laser machine

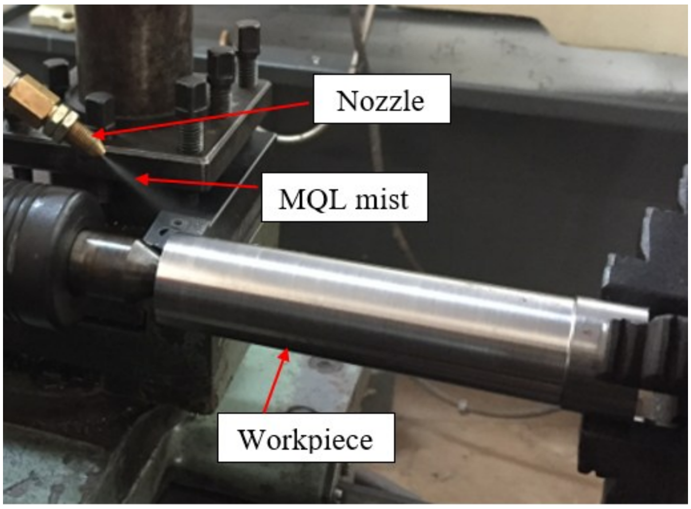

Figure 2 Machining under MQL condition

Table 1 Details of experimental conditions

Workpiece material and dimensions	AISI 316 steel round bar (⌀ 30 mm x 150 mm)
Cutting inserts	AlTiN PVD coated tungsten carbide inserts (An ISO designation of SNMG432 KC 910)
Tool holder	ISO specification of PSBNL 2020 K12, WIDIA make
Working insert tool geometry	Inclination angle: - 6°, rake angle: - 6°, clearance angle: 6°, Nose radius: 0.8 mm, major cutting edge angle: 75°
Turning Process parameters	Spindle speed (v): 1200 and 1500RPM Feed rate (f): 0.1 mm/rev Depth of cut (a_p): 0.3mm
Environmental condition and coolant used	MQL:150ml/hr (emulsion based flood cooling 1:20 soluble oil)

RESULTS AND DISCUSSION

Effect of type of tool on cutting temperature:

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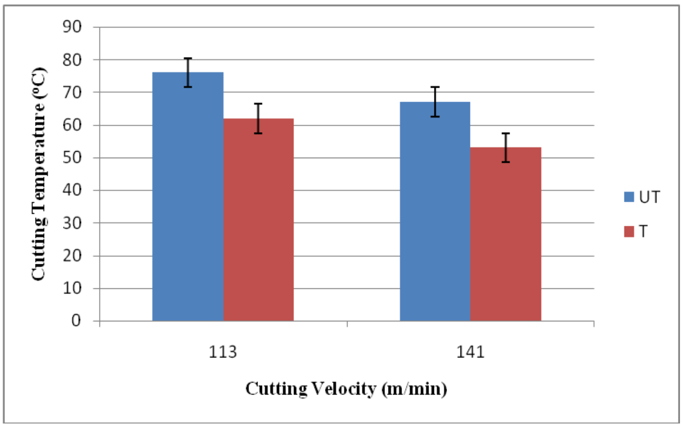

Figure 3 Influence of type of tool on cutting temperatures

Evaluation of cutting temperature is very important because the performance of the turning process significantly depends on it. Figure 3 shows the influence of cutting environment on cutting temperatures at different cutting velocity conditions respectively with type of tool. From Figure 3, it is observed that the obtained temperatures at the cutting velocity of 113 m/min with the textured tool is 60ºC and with untextured tool 76ºC in MQL cutting condition. At the cutting velocity of 113 m/min, the cutting temperature reduction observed in the textured tool is 21 % when compared to untextured tool respectively. At a cutting velocity of 141 m/min, the observed cutting temperatures are 53ºC and 66ºC respectively in textured and untextured tools repsectively. At this point, the textured tool significantly reduced the cutting temperature to 19 % over the untextured tool respectively. From Figure 3, it is clear that textured tools have outperformed in reducing the cutting temperature under MQL cutting condition when compared to untextured tool. This is because parallel slot microgrooves present in the textured tools serves as a coolant storage sites under MQL cooling condition and provides continuous coolant supply to the machining zone cause reduction of friction at the cutting zone results in low cutting temperatures. Overall, the maximum cutting temperature reductions found in textured tool is 21% over the untextured tools. The obtained cutting temperature results in the present well agreed with the literature results during machining of similar steel grade material under conventional/dry cutting condition with textured design tools.

Effect of tool type on Surface roughness:

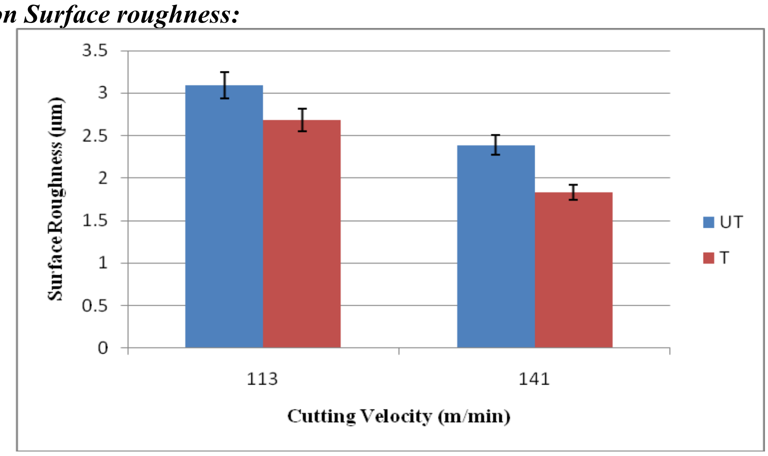

Figure 4 Effect of tool type on Surface roughness

Surface roughness is one of the important outcomes in turning process because it represents the quality of the machined product. Additionally, load-carrying capacity of the product significantly effected by the quality of the product surface. Figure 4 shows the Influence of tool type on average surface roughness. At a low cutting velocity of 113 m/min, the produced surface roughness on the machined surface is 3.09 µm and 2.68 µm respectively in untextured and textured tools. At this point, the reduced surface roughness in the textured tools is 13% compared to the untextured tools. At the high cutting velocity of 141 m/min, the observed surface roughness values are 2.68 µm and 1.83 µm in untextured and textured tools respectively. In this situation, surface roughness is significantly reduced to 32% in textured tools over untextured tools. Taken as a whole, surface roughness is significantly reduced in textured tools over untextured tools respectively at the considered

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cutting velocity conditions. This is because of microgrooves present in the textured tools promotes high lubrication effect at the cutting zone in under MQL cooling condition cause fewer tool marks on the machined surface. Further, it is noticed low surface roughness in higher cutting velocity of 141 m/min compared to low cutting velocity of 113 m/min. Low tool-chip contact length is contributed to low surface roughness at the high cutting velocity condition. The result attained in the present work well accepted when compared to the literature results during machining of AISI 316 steel with textured tools.

Effect of tool type on tool wear:

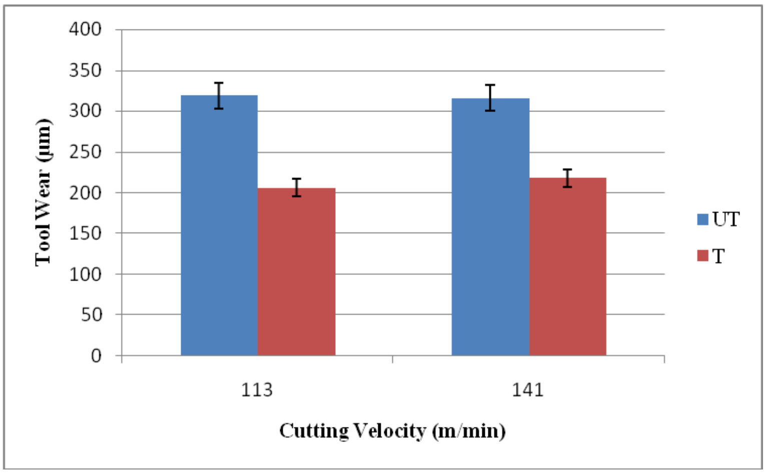

Figure 5 Influence of type of tool on tool wear

Tool wear is one of the major factors which significantly affects the quality of the machined part. Figure 5 depicts the influence of type of tool on tool rake wear at two different velocities. From Figure 4.2, it is noticed that at the low cutting velocity of 113 m/min the attained tool wears are 319 µm and 206 µm respectively in untextured and textured tools under MQL cutting conditions. At the low cutting velocity of 113 m/min, textured tool achieved 35 % reduction in tool wear when compared to the untextured tools respectively. At a cutting velocity of 141 m/min, the measured tool wears are 316µm and 218µm in untextured and textured tools respectively. In this situation, tool wear is significantly reduced by 31 % with textured over textured tools respectively. Additionally, Figure 5 shows that the MQL cooling technique significantly reduced the tool wear. Low friction due to the effective cooling at the cutting zone with a texture tool in MQL cooling is responsible for low wear. Another reason is due to the low tool-chip contact length in MQL cooling due to the favorable lubrication condition. Further, it was noticed that a large reduction in tool wear at higher cutting velocity condition over low cutting velocity condition due to the low tool-chip contact length. It is observed high edge chipping out and adhesion wears in the Untextured toolwhen compared to the textured tool at the given cutting condition.

CONCLUSION

In the present work, novel linear parallel slot microgrooves have made on the rake face of the tool and investigated the developed tool performance during turning of AISI 316 material under MQL condition. The following results were drawn based on the obtained results.

- Textured tools significantly reduced the cutting zone temperature, tool wear and surface roughness to a maximum of 21%, 31% and 32% respectively when compared to untextured tools respectively under MQL condition.
- MQL assisted textured tools significantly reduced the surface roughness owing to continuous reaching coolant through the microgrooves.
- Textured tools provide few surface defects it represents that textured tools facilitate smooth cutting action.
- Tool wear and cutting zone temperature followed an upsurge trend when the cutting velocity, feed rate and depth of cut rises.
- Surface roughness followed declined trend when cutting velocity rises. However, surface roughness rises with a rise in feed rate and depth of cut respectively.

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- Industries involved in turning AISI 316 could use developed textured tools to improve the turning performance.
- The MQL integrated textured tool machining technique meets the sustainable eco-friendly requirements which mandatory for the present industries.

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