Performance of Hybrid Micro Textured Drill Tool and Nanofluid in Drilling of Aerospace Alloy

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Abstract

Drilling is one of the most essential processes in manufacturing which involve in assembly of machines, equipment, and structure. Heat produced during the drilling process must be removed with the help of cutting fluid. Issue with commercial cutting fluids include environmental as well as operator health issues due to hydrocarbon oil. Researchers are attempting various approaches to avoid the above issue. Texture on cutting tool coupled with nanofluid is one of the alternative approaches. It reduces frictional coefficient which enhances the lubrication effect. Texturing with micro hole is introduced on flute as well as margin area of drill tool for drilling of titanium alloy. The result revealed that textured drill tool provides better machining performance. The combined advantage of texturing and nanofluid is reduced the surface roughness is reduced by 5 - 10% with flute textured tool and 12% with margin textured tool. Temperature of working zone by 13% and 16% with fluted textured and margin textured tools respectively.

Keywords

Drilling, Textured tools, Coconut oil, Nano alumina, Surface roughness, Temperature

Introduction

Drilling is a significant metal cutting process which has a 40 to 60 percent contribution in material removal industries. In drilling process, heat is induced due to plastic deformation which can be eliminated using cutting fluid. Cutting fluid composed of hydrocarbon oil is often used by industries, but it creates environmental impact. Micro holes or grooves are introduced on the cutting inserts rake face and embedded with solid lubricants to improve sustainability concept in machining. Textured area with solid lubrication is observed to provide lubrication effect on tool-chip interface. In the present study to achieve green economical and eco-friendly machining and to avoid issues related to mineral oil-based cutting fluid using textured drill with solid lubricants [1-3].

In general, textured tools are used by the combination of solid lubrication. Texturing is used to reduce tool chip thickness and minimize the frictional effect. Solid lubrication is achieved by producing thin lubrication film while metal cutting and heat generation. It is developed when solid lubricants are getting heat during tool-chip interface in metal cutting. It has few limitations such as chemical reaction, oxidation stability and supply of appropriate quantity. Hence the advantage of texturing is utilized with consideration of nanofluid instead of solid lubrication [4-7].
Guo et al. [8] employed internal cooling and a micro textured drill tool in order to enhance the drilling of titanium alloy. The drill bit rake and flank faces were textured. The findings were compared with traditional tools. The improved machining performance was noticed with micro texture and internal cooling in terms of chip breakability, tool-chip contact length and less co-efficient of friction. Niketh and Samuel [9] achieved tribological enhancement with sustainable machining during drilling of titanium alloy. Micro hole texture (dimple) was introduced on drill flute and margin side. The result revealed that reduced co-efficient of friction and minimum energy loss was noticed with textured drills. Ling et al. [10] used surface texturing for enhancement of machining performance during drilling process. The result indicated that reduction of chip adhesion using textured drill tool. Niketh and Samuel [11] used different cutting conditions for drilling of titanium alloy. Drill tools were applied micro textures with flute and margin area. The machining performance was assessed to that of a regular drill. The findings indicated that tool-chip contact length reduction, less adhesion and better lubrication effect with textured drill than non-textured drill.

Dheeraj et al. [12] used textured drill filled with solid lubricant for drilling of aluminum alloy. Surface integrity issue and hole geometry studies were considered. The result revealed that improved hole accuracy and spirals shape chip were observed. Pang and Wang [13] investigated the drilling process on nickel-based super alloy using textured drills. Different types of textures were considered namely pit, convex and groove. Also, 3D finite element simulation study and the results were validated experimentally. The result showed that performance was improved effectively with textured drill.

Kumar et al. [14] assessed the performance of NPMCF in grinding process. Sunflower oil was considered as base fluid and multi-walled carbon nanotube was considered as a nanoparticle. The result indicated that properties of thermal conductivity and anti-friction characteristics for the based fluid were enhanced after nanoparticle addition. Padmini et al. [15] examined the ability of nanofluids derived from vegetables during machining of steel alloy. Nano molybdenum disulfide particles were suspended in different vegetable oils. The results revealed that nanoparticle suspended cutting fluid enhanced machining. Nam et al. [16] has done micro drilling process on Al-6061 alloy. Diamond nanoparticles were mixed in base fluid to characterize the performance. The results showed that adding nanofluid made the hole better and reduced the thrust force needed. Salimi-Yasar et al. [17] investigated the titanium oxide nanofluid performance in drilling process. In their work, three different weight concentrations were considered. The result revealed that reduction of surface roughness and machining zone temperature was obtained due to the use of nanofluid.

From the previous studies, it is understood that texturing with solid lubricant has limitations such as lubricant getting oxidized at high temperatures whereas nanoparticle mixed cutting fluid intensify the thermal conductivity, and tribological properties between the mating surfaces. Therefore, an attempt is made to study the performance of nanofluid instead of solid lubrication to utilize the advantage of textured tool. Also, limited studies are reported on texture with margin and flute region in drilling process. Temperature measurement is a difficult task during the drilling process. In this work, holes are produced on the side face of the work piece and thermocouples are inserted for accurate measurement of temperature induced while drilling. Hence, an effort to explore the machinability studies on drilling of titanium alloy using textured drill with nanofluid is done.

**Experimentation**

The drilling has been carried out on a vertical machining center (Figure 1). Titanium alloy (Grade-5) is used as a work piece (150 mm x 150 mm x 10 mm) material. It has light weight and higher strength ratio. It is preferred for automobile and aircraft industries [18, 19]. Spindle speed (600, 800, and 1000 rpm) and constant feed rate of 0.02 mm/min are selected as process parameters. Carbide drill (YG-uncoated) with 8 mm diameter as cutting tool. Experiments are conducted with plain, flute, and margin textured drills. Textured drill tool with nanofluid is attempted to eliminate hydrocarbon oil-based cutting fluid. To transport solid lubricant to the drilling area, a device is employed (Figure 2). Micro-grooves are created on the drill bit’s surface with a LASER. The textured tool’s scanning electron microscope (SEM) images are displayed in figure 3 and figure 4. Micro holes drilled on the drill tool have dimension such as diameter (100 µm), depth (60 µm), and pitch (100 µm). The results are compared for understanding output parameters such as surface roughness and temperature generated on work piece during the operation.

Nanofluid is prepared using nanoparticles and base flu-

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**Figure 1:** Machine setup.

**Figure 2:** Solid lubrication supply.
Results and Discussion

The drilling process is performed using plain tool, flute textured, and margin textured with nanosolid lubricant fluid. Taguchi steps are followed for performing the experiments and analyzing the results.

Surface roughness is an important machinability indicator. Table 2 and table 3 depict the result of surface roughness variation under different cutting conditions. Figure 8 displays the effect of process parameters, machining conditions, and drill tools on surface roughness. It is found that drilled hole surface roughness is decreased with textured tool and higher range.
of cutting speed. This occurs as high cutting rates thermally soften the work piece material. Low cutting speeds promote buildup edge which leads to machined surface deterioration. The reduced surface roughness is due to micro hole texturing on the drill bit. Texture on the drill bit has the following advantages: frictional co-efficient reduction, chip breaker and increased cooling area increased due to texturing on the drill tool [4, 9, 11]. Micro hole texture reduces the contact surface of the helical groove, making chip removal easy and adhesion low. As stated earlier, drilling is performed with plain tool, flute and margin textured. From figure 9 it is indicated that margin textured drill is performed better than other tools. It is understood that there is a higher co-efficient of friction on the flute side than margin side. The surface roughness value with margin texture drills and followed by flute textured drill are better than plain tool. It is clearly indicated that less adhesion, better cooling, and good chip breaking capability with textured drill. From the result, it is showed that dry machining of Ti-6Al-4V is enhanced by applying micro texture on drill. From this result, it is also noticed that nanofluid decreased machined hole surface roughness by 5 - 10% with flute-textured tools and 12% with margin-textured tools.

Table 2: Experimental results - Surface roughness.

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Surface roughness (µm)</th>
<th>Percentage decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non textured</td>
<td>Flute textured</td>
</tr>
<tr>
<td>600</td>
<td>4.57</td>
<td>4.40</td>
</tr>
<tr>
<td>800</td>
<td>4.18</td>
<td>3.90</td>
</tr>
<tr>
<td>1000</td>
<td>3.77</td>
<td>3.55</td>
</tr>
<tr>
<td>600</td>
<td>4.35</td>
<td>4.00</td>
</tr>
<tr>
<td>800</td>
<td>3.65</td>
<td>3.35</td>
</tr>
<tr>
<td>1000</td>
<td>3.60</td>
<td>3.30</td>
</tr>
<tr>
<td>600</td>
<td>4.45</td>
<td>4.32</td>
</tr>
<tr>
<td>800</td>
<td>3.83</td>
<td>3.62</td>
</tr>
<tr>
<td>1000</td>
<td>3.79</td>
<td>3.40</td>
</tr>
</tbody>
</table>

Table 3: Experimental results - Work piece temperature.

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>Work piece temperature (°C)</th>
<th>Percentage decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non textured</td>
<td>Flute textured</td>
</tr>
<tr>
<td>600</td>
<td>300</td>
<td>265</td>
</tr>
<tr>
<td>800</td>
<td>350</td>
<td>325</td>
</tr>
<tr>
<td>1000</td>
<td>390</td>
<td>335</td>
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<tr>
<td>600</td>
<td>195</td>
<td>180</td>
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<tr>
<td>800</td>
<td>255</td>
<td>240</td>
</tr>
<tr>
<td>1000</td>
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<td>275</td>
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<td>600</td>
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<tr>
<td>800</td>
<td>250</td>
<td>225</td>
</tr>
<tr>
<td>1000</td>
<td>315</td>
<td>275</td>
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</table>
of the work piece by 13% (390 °C - 275 °C) and 16% (390 °C - 265 °C) with fluted texture and margin texture tools respectively. Moreover, from figure 11 it appears to be best when drilled with margin-textured tools in all cutting situations. It is noticed that micro groves on the drill bit will remove the heat produced during drilling effectively. Also, it is understood that texture can avoid minute adhesions and harsh abrasive can be seized and caught [10, 11, 13].

The contact of NPMCF on solid surface can be described by the concept of wettability. Contact angle of NPMCF influences the wettability and is followed by lubrication process. In general, smaller contact angles are capable of spread to larger regions. This will be used to decrease the friction during machining [21]. Textured surface leads to smaller contact angle and helps to better infiltration and spread of NPMCF to the groove effectively. Also, because of the lower contact of tool length at the chip-tool interface of the textured tool inserts, the contact area in between the tool-chip and rake face of tool is smaller, resulting in a drop in cutting force and temperature [22]. Texture on the drilled bit can act as a small reservoir. NPMCF creates mist cloud in the drilling zone. NPMCF has the capability to infiltrate, spread and absorb the drilling area. A rolling mechanism is obtained using NPMCF which will be used for reduction of friction induced during metal cutting. NPMCF’s higher thermal conductivity decreases the thermal deterioration of machined surfaces by lowering the temperature in the cutting zone [23]. Surface quality enhancement is based on mending effect and the nano polishing effect. Nano polishing effect is obtained through tribological properties of Al₂O₃ [24]. NPMCF are good stability, higher thermal conductivity, recyclable, non-toxic, and biodegradation. Nam et al. [16] investigated ecological investigation in terms of global warming during dry machining, wet machining and vegetable oil as cutting fluid in machining. Cutting fluid based on vegetable oil produces better results than other machining conditions. It reduces typical cutting fluid consumption. Al₂O₃ is easily available and low cost. Al₂O₃ nanoparticles have high hardness, wear, and heat resistance. It also possesses a high melting point and boiling point [25-28]. Hence, it gives better lubricity.

Conclusions
The investigation produced the following conclusions:
• Textured on flute and margin area embedded with Al₂O₃ solid lubricant is attempted for drilling of titanium alloy. Textured tools with solid lubricant achieved better machining performance over plain tools in terms of surface roughness and temperature. Textured tool enhances tool-chip interface and nanofluid induces better lubrication and followed by co-efficient of friction.
• Solid lubricant lowers machined hole surface roughness by 5 - 10% for flute-textured tools and 12% for margin-textured tools.
• Textured tools significantly lower the work piece temperature by 13% and 16% with fluted textured and margin textured tools, respectively.
• Vegetable oil is a natural product and biodegradable. To drill a hard material such as titanium alloy using textured tool with vegetable oil shown less Temperature, and good quality of the finished product. This experimental study provides that the vegetable oil is a promising candidate to use as an eco-friendly lubricant.
• NPMCF has advantages like infiltration, spreadability, and biodegradability. Further investigation is required in the area of size and type of nanoparticle. Also, a study required on disposal of nano-waste and environmental issues.

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Conflict of Interest
None.

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Chintala et al.


