An Experimental Study on Machining of AISI H-13 Steel Using Dimple-Textured and Non-Textured Tungsten Carbide Cutting Tools

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Abstract. Fabrication of micro-dimples at the rack surface closer to the cutting region of the tungsten carbide tool will induce the tribological modifications at the tribo-contact surfaces. The motive of this work is to find the influence of micro-dimples fabricated on the cutting tools during turning operations. Linear arrays of dimple-textures with various geometrical aspects (dimple diameter and depth) and area density ratio were prepared using laser marking technique. The influence of surface-texture pattern is experimentally analysed through dry machining of AISI H – 13 steel using a dimple-textured tungsten carbide cutting tool. The responses of cutting temperature and cutting force generated during the turning operation were analysed. It shows improvement in machinability in terms of wear rate reduction in dimple-textured tools. Optimizing the dimension of micro-dimples (diameter of 90μm, depth of 60μm) results in a 10% reduction in tool wear rate.

1. Introduction

In the machining area, dimple textured surfaces play a significant role in the tribological phenomenon. The essential thing about dimple texture in the machining area is the variation in frictional parameters that improve machinability. Dimple texture forming over the cutting inserts has several benefits attained by varying frictional factors at the tribo-contact surfaces. Alagan et al. [1] applied a laser ablation technique to produce dimple texture on the uncoated tungsten carbide round inserts (Grade H13A) for machining of superalloy 718. They suggested that micro-dimples on the sintered carbide round inserts increases the wear resistance without affecting the mechanical properties [2]. Darshan et al. [3] fabricated the dimple-shaped texture of an uncoated carbide insert using a multi-diode fiber laser technique. They found that micro-texturing on cutting inserts delivers the good lubricating phenomenon at tribo-contact surfaces [4]. Guarani, K.K et al. [5] compared the dimple-textured and coated dimple-textured inserts with the conventional device and they concluded that coated cutting tools performed better in the aspect of reduction in cutting force and friction coefficient. Lei, S et al. [6] analyzed the insert wear and chip morphology for the micro-textured inserts, and they found that a 20% reduction in friction force and coiled chips are produced. Li et al. [7] applied a fibre laser marking technique to make the micro-hole surface modification of PCBN cutting inserts. They stated that the surface quality of the workpiece was improved [8]. Niketh and Samuel [9] fabricated micro-dimples on the tungsten carbide drill bit using a laser ablation technique. Solid-powdered MoS2 filled in the dimple-textures to make a coated drill tool. They observed that tool wear and cutting torques are reduced in the coated device compared with the uncoated tool [10]. Rajbongshi and Sarma [11] compared different samples of dimple-texture (dot and groove) on the flank surface in the machining of AISI D2 steel. They concluded that heat produced at the tool-work contact surface of the point-textured drill tool was exhibits better performance than the groove textured...
drill tool [12]. Sawant et al. [13] experimented on the influence of spot and dimple textured HSS insert in the turning of titanium alloy. Using spot-textured insert, thrust and cutting forces, cutting temperature and tool wear were reduced [14-15]. Vignesh et al. [16-17] experienced the influence of dimple textured inserts in the turning of aluminum alloy. They found that chip adhesion was suppressed when the dimple-textures were fabricated straight to the cutting region. Xing et al. [18] fabricated three samples of dimple-textures (circular, linear, and rectangular) of the carbide inserts using a laser marking method for turning of aluminum alloys. They concluded that, among three kinds, circular textured inserts showed machinability improvement in cutting forces, frictional co-efficient decrement, and low surface region of the machined region [19].

It is found that the dimpled-texture on the rake surfaces of the inserts improves the cutting quality, and hence machinability is improved. The objective of this work is to analyse the dimple-textured coated and uncoated cutting tools over non-textured cutting tools. Furthermore, the effect of the dimple-texture dimension and the tool wear rate were also analysed.

2. Materials and Methods

2.1. Preparation of cutting inserts with dimple-textured surface

Tungsten carbide (WC) insert is selected as the cutting insert for dimple-texturing and machinability study. The tungsten carbide tool is used for turning rigid materials. The dimple-texture are formed on the rack face of the cutting tool using a fibre laser ablation technique. Figure 1. shows a tungsten carbide tool with a topography of the micro-dimples pattern. The dimple textures having a circular shape with various geometrical patterns were fabricated in the tungsten carbide cutting tool.

To analyse the effect of micro-dimple on machinability, 12 types of inserts were prepared. Figure 2. illustrates the geometrical dimensions of micro-dimples, and Table 1 lists out the dimensional details of the micro-dimples, matched with the tool designated as Textured – A to Textured – L. In this work, circular shape micro-dimples are fabricated for all samples, and the dimple distance from cutting region was fixed as 150μm. The equation calculated the micro-dimple area density $A_{dr}$ of all dimple-textured samples

$$A_{dr} = \left( \frac{A_T}{A_T + A_{UT}} \right) \times 100\%$$ (1)

$A_T$ refers to the sample area on the dimple-textured surface, and $A_{UT}$ refers to the sample area of the non-textured surface of each insert sample. The coating of MoS$_2$ (solid lubricant) on a micro-dimple plays an important role in refining the frictional performance of inserts. Nano particles of MoS$_2$ packed
in the micro-cavity to prepare a coated insert and analyses the cutting performance in contrast with the non-textured tools.

Table 1. Dimensional details of the micro-dimples

| Cutting Tool Name | Dimple Size $(D_{DIA})$ (μm) | Dimple Height $(D_{DP})$ (μm) | Dimple Distance $(D_{PIT})$ (μm) | Area Density $(D_{R})$ (%) |
|-------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------|
| Non-textured      | -                             | -                           | -                             | 0                       |
| Textured – A      | 80                            | 60                          | 135                           | 45                      |
| Textured – B      | 80                            | 60                          | 150                           | 40                      |
| Textured – C      | 80                            | 70                          | 135                           | 45                      |
| Textured – D      | 80                            | 70                          | 150                           | 40                      |
| Textured – E      | 90                            | 60                          | 135                           | 35                      |
| Textured – F      | 90                            | 60                          | 150                           | 30                      |
| Textured – G      | 90                            | 70                          | 135                           | 35                      |
| Textured – H      | 90                            | 70                          | 150                           | 30                      |
| Textured – I      | 100                           | 60                          | 135                           | 25                      |
| Textured – J      | 100                           | 60                          | 150                           | 20                      |
| Textured – K      | 100                           | 70                          | 135                           | 25                      |
| Textured – L      | 100                           | 70                          | 150                           | 20                      |

2.2. Experimental Setup

The work material of AISI H - 13 steel was selected for this work because of high wear-resistant and enormous applications like propeller shaft, connecting rod, gear shaft, camshaft, etc., Table 2 lists out the property of AISI H – 13 steel. Both the tool and work material has been purchased from Coimbatore Metal Mart, Coimbatore 641018 with the testing certificate. The machining experiments were performed on the AISI H – 13 steel (Ø50mm × 130mm) using a CNC lathe. Table 3 provides the details on machining parameters, and Figure 3. details the arrangement of the machining setup. A machining force dynamometer was utilized to measure the cutting forces. The insert wear rate of each cutting tool sample after tuning was inspected through an optical microscope.

Figure 3. Machining set-up
Table 2. Properties of AISI H – 13 steel

| Chemical Composition (%) | Mechanical Properties |
|--------------------------|-----------------------|
| Cr                       | Impact Strength (J)   |
| 4.25 – 5.15              | 60 – 74               |
| Mo                       | Yield Strength (MPa)  |
| 1.25 – 1.80              | 1000 – 1380           |
| V                        | Elongation (%)        |
| 0.90 – 1.30              | 11                    |
| Si                       | Hardness (BHN)        |
| 0.90 – 1.30              | 290 – 370             |
| C                        | Tensile Strength (MPa)|
| 0.22 – 0.63              | 1200 – 1590           |
| Cu                       |                       |
| 0.25                     |                       |
| Ni                       |                       |
| 0.3                      |                       |
| Mn                       |                       |
| 0.20 – 0.50              |                       |
| S                        |                       |
| 0.03                     |                       |
| P                        |                       |
| 0.03                     |                       |

Table 3. Machining parameters

| Workpiece                  | AISI H – 13 steel Ø50mm × 130mm |
|----------------------------|----------------------------------|
| Cutting Insert             | Tungsten carbide cutting insert  |
| Nose radius               | 0.8mm                            |
| Cutting RPM (N)           | 1500 rpm                         |
| Cutting depth (d)         | 3 mm                             |
| Cutting feed (f)          | 0.16 m/min                       |
| Machining condition       | Dry condition                    |

3. Results and Discussion

3.1. Micro-dimples on the cutting forces

Figure 4. shows the influence of various coated and uncoated dimple-textured inserts on the cutting force while turning of work material under dry turning conditions.

Effect on main cutting force ($F_z$)

Figure 4a shows the main cutting forces are reduced with dimple-textured tools, and dimple-textured tools were exhibited 33 % of reduction in the main cutting force as compared with the regular insert. Figure 4b illustrates the main cutting forces are minimized with MoS$_2$ coated tools, and uncoated tools.
exhibited a 42\% drop in main cutting force as compared with dimple-textured inserts and 16\% of reduction in main cutting force as compared with a regular insert. A peak main cutting force of 33kgf was noted with a regular insert that was minimized to 22kgf with uncoated Texture-E and 19kgf with coated Texture-E.

**Effect on feed force (F_x)**

Figure 4a shows the feed forces are reduced with dimple-textured tools, and dimple-textured tools were exhibited 25\% of reduction in the feed force as compared with the regular insert. Figure 4b illustrates the feed forces are minimized with MoS_2 coated tools, and uncoated tools exhibited a 28\% drop in feed force as compared with dimple-textured inserts and 4\% of reduction in feed force as compared with a regular insert. A peak feed force of 33kgf was noted with a regular insert that was minimized to 24kgf with uncoated Texture-E and 23kgf with coated Texture-E.

**Effect on thrust force (F_y)**

Figure 4a shows the thrust forces are reduced with dimple-textured tools, and dimple-textured tools were exhibited 29\% of reduction in the thrust force as compared with the regular insert. Figure 4b illustrates the thrust forces are minimized with MoS_2 coated tools, and uncoated tools exhibited a 14\% drop in thrust force as compared with dimple-textured inserts and 17\% of reduction in thrust force as compared with a regular insert. A peak thrust force of 24kgf was noted with a regular insert that was minimized to 24kgf with uncoated Texture-E and 14kgf with coated Texture-F.

Micro-textured cutting tools produce minimal cutting force when compared to untextured tools due to less surface contact at the cutting tool-chip interface. MoS_2 coated textured inserts outperforms when compared to dimple-textured tools due to the capillarity property of MoS_2 on the micro-dimples of dimple-textured tools with minimal cutting insert-chip contact area. From previous work [6-7] identified that with the help of dimple-textured tool 20\% of reduction in overall cutting force but MoS_2 coated textured tools exhibits about 35\% of reduction in overall cutting force.

3.2. Micro-dimples on the heat generation

![Figure 5](image.png)

**Figure 5.** Heat generation at the cutting tool-work contacts

Figure 5. shows the heat generation during tuning operation at the tool-work contact surface for non-textured, MoS_2 coated dimple-textured, and uncoated dimple-textured cutting tools. At the spindle rpm of 1500, the low - high values of heat generated at the tool-work contacts of non-textured, MoS_2 coated
dimple-textured and uncoated dimple-textured cutting tools was observed as 90.2°C - 103.5°C, 60.2°C - 70.5°C, and 67.5°C - 77.1°C respectively. The heat debauchery in dimple-textured cutting tools was much higher than non-textured tools. The close concave surface area of the micro-dimples exhibits much higher heat dissipation.

3.3. Tool wear mechanism

Figure 6. illustrates the images of non-textured, uncoated dimple-textured, and coated dimple-textured inserts after conducting dry machining experiments. Generally, cutting tool wear was observed in the rack face due to the development of the continuous chip, generation of heat at the cutting tool-work interface, and abrasive wear in cutting tool-chip contact area. Due to minimized tool-chip contacts in the dimple-texture, cutting tools exhibit minimal cutting tool wear compared with regular inserts. Furthermore, the wear rate further reduced in MoS₂ coated textured inserts due to the effect of thin layer formation and the micro-cavity lubrication effect of the solid lubricants.

![Figure 6. optical microscope images of various cutting tools](image)

4. Conclusion

Using laser ablation technique, dimples are fabricated on the cutting tools. Machining is performed by non-textured, MoS₂ coated textured, uncoated textured cutting tools on AISI H - 13 steel in dry cutting condition. The machinability factor of the MoS₂ coated dimple-textured cutting tool is comparatively analysed with regular and dimple-textured inserts. The major findings observed through the experimental study was listed below

1. The micro-dimples influence the insert wear reduction rate as compared with regular inserts. The incremental order of insert wear as follows: MoS₂ coated dimple-textured tool < uncoated dimple-textured tool < regular non-textured tool.
2. Textured-E cutting tool (micro-dimple size of 90μm, the height of 60μm, a distance of 135μm, and density area of 35%) exhibits better performance.
3. Cutting tool wear rate further reduced in MoS₂ coated textured cutting insert due to the effect of thin layer formation and the micro-cavity lubrication effect of the solid lubricants.
4. Average machining heat generation in the coated textured cutting tool was reduced because the concave surface of the micro-dimples exhibits the much higher heat dissipation.

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