Effect of textures on machining of carbon steel under dry cutting condition

Rajesh Ruban S1*, P Jayaseelan 1, M Suresh1, Sumanth RatnaKandavalli1
1Department of Mechanical Engineering, Karunya Institute of Technology and Sciences, Tamilnadu, India.

*Corresponding Author: rajeshruban@gmail.com

Abstract

The effect of cutting performance was investigated using uncoated plain and texturized tungsten carbide tools in dry machining of carbon steel. Texture namely straight line, zigzag and plus profiles was created on flank face of the uncoated tungsten carbide tool. This textured tool was designed and fabricated by Neodymium-doped Yttrium Aluminium Garnet Nd-YAG laser machine. Also it was evident with scanning electron microscopy analysis. In further design of experiment was carried by taguchi method by using L9 orthogonal array for varying cutting speed, feed rate, depth of cut to perform the machining experiment. The cutting force, surface roughness and cutting temperature were measured in which it depicts that microscale textured tools improves the machining characteristics to a greater extent when compared with untreated tool. It can be effective in all manufacturing industries provide an eco friendly environment since no coolant is required due to which it becomes pollution free.

Keywords: Texture tool design and fabrication, Dry machining characteristics, Taguchi method

1. Introduction

Kawasegia et al.,[1] The production of high performance and intelligent tool are required for higher speed, efficiency at a higher rate and trouble-free cutting. Testing is undergone for different structured cutting tool grooves and carbon steel for the flank face. Tatsuya Sugihara et al., [2] established various textured surface to enhance cutting tool life. The process involved in suppressing crater wear on surface tool and correlation between wear resistance and texture dimensions have been examined in order to provide guidance for designing instruments with textured surfaces. Hence to improve flank wear resistance the textured surfaces of cutting tools was introduced into a flank face. Flank wear was decreased by invented tool with flank face textured by experimenting on face milling of the steel material along with which cutting conditions as well as the influence of texture dimensions on flank wear resistance is covered. Toshiyuki Enomoto et al [3] has worked to enhance the life of cutting tool, prior implementation shows that the stripe-grooved surfaces have been established on a cutting tools which was coated by TiAlN-coated. The surface of the coating and texture tool has reduced tool wear by experimenting with face milling on steel materials. Toshiyuki Obikawa et al., [4] depicts the tool rake face’s lubrication conditions and the effect on micro surface texture in machining aluminium alloy. Because of this reason, 4 categories of microtexture surface was produced by photolithography, wet etching and spattering on tool faces coated by diamond like carbon in turn resulted improving the effect of lubrication condition due to the square-dot and parallel type micro textures as the pater of the texture was deeper and smaller while machining in aluminium alloy A6061-T6. Dong Min Kim et al., [5] cutting tools produced with a femtosecond laser long with micro or nano scale textures have
been developed to improve machinability process of cutting. Textures permitted to reduce the friction on tool surfaces, reducing the required cutting force. This effect was largely due to the contact length difference between the tool and the workpiece. Due to difference in adherability in material at enhanced cutting speeds there was observed a reduction in cutting force when machining aluminium alloys. The influence of textures was mainly apparent in better lubrication conditions, when cutting forces were at higher cutting speed of 200 m/min were reduced to 21.2-34.7%. Wu Ze et al.,[6] Grooved that acted as a same liquid replenishment micro-reservoir were largely responsible for the beneficial impact of surface texturing. The beneficial effect of extended surface texture cutting tools of the cutting performance even in a worst lubrication conditions was small whenever the existence of grooves resulted in lower cutting forces on interface of the tool chip solely 2% to 8% aimed at highest speed about 200 m/min. Analysis revealed that wear debris trapping function and secondary lubrication effect generated by the textures was smaller.

From the literature study it was found that very less work is carried out in machining carbon steel as the workpiece with textured tool so there are plenty of scopes for further works.

2. Work material and cutting tool used
For the proposed work the workpiece is chosen as Carbon steel (EN3B) grade which has good machining properties. EN3B Steel is able to withstand higher stress levels, especially at small diameters. Tungsten Carbide Insert which has been used as cutting tool is been used in turning applications. Geometric specification are orthogonal rake and inclination at an angle of -6°, Orthogonal clearance at an angle of 6°, auxiliary cutting edge at an angle of 15°, principal cutting edge at an angle of 75°, finally the nose radius is taken as 0.8mm. Compared with other metals Tungsten carbide which has hardness value to be 1600 HV make it a very hard metal due to the equal amount of carbon atoms and tungsten. Therefore generally it is viewed as an appropriate material for the production of turning tools.

3. Design and fabrication of micro textured tools
The design of micro texture is done by using design software Creo as shown from Figure [1-12], if we look at the design we can observe that the grooves have a width size of 50µm and the distance between each groove is 100µm, the distance from the cutting edge is 150µm these dimensions. The dimension specification of straight line profile tool is taken with the width of the slot to be 0.05mm(50µ) and the distance between the slots is considered as 0.1 (100µm) and the depth of slots is taken as 0.02mm(20µm), finally the distance from the cutting edge is 0.15m (150µm). The dimension specification of zigzag profile tool is taken with the width of the slot to be 0.05mm(50µ) and the distance between the slots is considered as 0.1 (100µm) and the depth of slots is taken as 0.02mm(20µm) and the distance from the cutting edge is 0.15m (150µm). The angle is set to be 45° and finally the length of micro texture from corner is set as 2.4mm (2400µm). The dimension specification of plus profile tool is taken with the width of the slot to be 0.05mm(50µ) and the distance between the centre of slots is set as 0.1 (100µm) and the depth of slots is taken as 0.02mm(20µm) and the distance from the cutting edge is 0.15m (150µm) and finally the length of micro texture from corner is set as 2.64mm (2640µm). Arul et al.,[7] have conducted a similar experiment to find out the performance of the tool on the work piece material and most of their experiments have shown positive results. Here we are using WC tool for our experiment to conduct test on the hard Carbon Steel EN3B.
Nd-YAG laser machine have been used on cutting inserts to produce of 1064nm wavelength slot-shaped structures. The above specified laser system produces 3 kHz repetition rate, 0.001m pulse width and 250mJ/sec pulse energy and energy stability accounted for about ±12% of the average value. Cutting insert were analysed in SEM Scanning electron microscope to check micro texture and also dimensions. There are 3 different types of micro textures were fabricated using this laser machining process with distortion in the dimensions of ±10 μm.

4. SEM analysis of fabricated micro textured tools

The SEM analysis for straight line profile tool are captured at a magnification of 64x/269x to measure the dimensions of the micro texture is shown in Figure 13. The SEM analysis for zigzag profile tool are captured at a magnification of 97x/232x to measure the dimensions of the micro texture is shown in Figure 14. The SEM analysis for zigzag profile tool are captured at a magnification of 102x/247x to measure the dimensions of the micro texture is shown in Figure 15. From the SEM analysis it can be observed that three different textures namely straight line, zig zag and plus profile was fabricated according to the design made in pro e software which is shown on the figures listed below.
5. Experimental procedure

5.1 Machining of Carbon steel with textured and Untextured tool

For turning operations three primary cutting parameters are cutting speed, feed rate, and depth cut. In order to establish non-linearity, cutting parameters across three levels were varied for the simulation trials. Experiments were performed based on L9 design of experimental approach as mentioned in Table 1 by using various textured cutting tools for machining carbon steel material. The output parameters are selected so as they give us an overall idea of the relationship between the quality characteristic and the selected factors. Kirloskar Turn master-35 lathe as shown in Figure 16 was used to carry turning operation. A Kistler multi-component dynamometer of type 9257B and Surface roughness tester named as Mitutoyo-SJ 210 as shown in Figure 17 were equipments used for measuring cutting force and surface roughness. An optical pyrometer as shown in Figure 18 was used to gauge cutting temperature. These responses were recorded and further analysis by using plain and textured uncoated tungsten carbide tool.

| Table 1 Input parameters and levels |
|-------------------------------------|
| **Levels** | **Level 1** | **Level 2** | **Level 3** |
| Cutting speed [m/min] | 75 | 95 | 115 |
| Feed rate [mm/rev] | 0.05 | 0.075 | 0.1 |
| Depth of cut [mm] | 0.5 | 0.75 | 1 |
L9 taguchi design was used for designing the experiment. The workpiece is fixed in the Kirlsloskar made turnmaster-35 lathe. The cutting speed (the speed of rotation of chuck) is adjusted using tachometer and the required cutting speed is set by adjusting the nob on the set up. The feed rate in voltage is set in the voltmeter in the experimental setup. Kistler dynamometer is used to measure cutting force and surface roughness tester to measure surface roughness. To measure surface smoothness the instrument was placed on the machined surface. Four average values are taken from the surface to find out surface roughness. Pyrometer was used for measurement of cutting temperature. Cutting force, cutting temperature, surface roughness is given in Table 2 for dry turning of plain tungsten carbide tool, Table 3 for dry turning of straight line profile tool, Table 4 for dry turning of zigzag profile tool and Table 5 for dry turning of plus profile tool. All the measured responses were analysed for this proposed research.

### Table 2. Tabulation of response parameters: Plain tool

| S. No | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of Cut (mm) | Cutting force (N) | Surface roughness (μ) | Cutting temperature(°C) |
|-------|-----------------------|--------------------|------------------|------------------|-----------------------|------------------------|
| 1     | 75                    | 0.05               | 0.5              | 152.3            | 3.272                 | 180                    |
| 2     | 75                    | 0.075              | 0.75             | 290.3            | 2.989                 | 176.73                 |
| 3     | 75                    | 0.1                | 1                | 303.6            | 3.403                 | 182.76                 |
| 4     | 95                    | 0.1                | 0.5              | 143.9            | 3.064                 | 179.86                 |
| 5     | 95                    | 0.05               | 0.75             | 270.8            | 2.865                 | 174.46                 |
| 6     | 95                    | 0.075              | 1                | 332.2            | 2.517                 | 182                    |
| 7     | 115                   | 0.075              | 0.5              | 130.8            | 2.113                 | 172.64                 |
| 8     | 115                   | 0.1                | 0.75             | 280.1            | 2.224                 | 170.45                 |
| 9     | 115                   | 0.05               | 1                | 390              | 2.247                 | 179.88                 |

### Table 3. Tabulation of response parameters: Straight line profile tool

| S. No | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of Cut (mm) | Cutting force (N) | Surface roughness (μ) | Cutting temperature(°C) |
|-------|-----------------------|--------------------|------------------|------------------|-----------------------|------------------------|
| 1     | 75                    | 0.05               | 0.5              | 186.8            | 2.087                 | 172.75                 |
| 2     | 75                    | 0.075              | 0.75             | 256.8            | 2.584                 | 175.89                 |
| 3     | 75                    | 0.1                | 1                | 345.7            | 3.44                  | 175.53                 |
| 4     | 95                    | 0.1                | 0.5              | 148.7            | 2.735                 | 173.83                 |
| S. No | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of Cut (mm) | Cutting force (N) | Surface roughness (µ) | Cutting temperature(˚C) |
|-------|----------------------|-------------------|------------------|-------------------|----------------------|------------------------|
| 1     | 75                   | 0.05              | 0.5              | 186.8             | 2.087                | 172.75                 |
| 2     | 75                   | 0.075             | 0.75             | 256.8             | 2.584                | 175.89                 |
| 3     | 75                   | 0.1               | 1                | 345.7             | 3.44                 | 175.53                 |
| 4     | 95                   | 0.1               | 0.5              | 148.7             | 2.735                | 173.83                 |
| 5     | 95                   | 0.05              | 0.75             | 276.1             | 2.227                | 173.25                 |
| 6     | 95                   | 0.075             | 1                | 324.4             | 2.93                 | 175.13                 |
| 7     | 115                  | 0.075             | 0.5              | 131.4             | 2.214                | 173.69                 |
| 8     | 115                  | 0.1               | 0.75             | 250.1             | 2.535                | 175.17                 |
| 9     | 115                  | 0.05              | 1                | 331.9             | 2.16                 | 176.27                 |

Table 4. Tabulation of response parameters: Zigzag profile tool

| S. No | Cutting speed (m/min) | Feed rate (mm/rev) | Depth of Cut (mm) | Cutting force (N) | Surface roughness (µ) | Cutting temperature(˚C) |
|-------|----------------------|-------------------|------------------|-------------------|----------------------|------------------------|
| 1     | 75                   | 0.05              | 0.5              | 203.7             | 3.519                | 179.92                 |
| 2     | 75                   | 0.075             | 0.75             | 329.1             | 3.395                | 192.647                |
| 3     | 75                   | 0.1               | 1                | 407.3             | 4.22                 | 187.583                |
| 4     | 95                   | 0.1               | 0.5              | 139.4             | 3.403                | 180.5                  |
| 5     | 95                   | 0.05              | 0.75             | 230.1             | 3.398                | 193.89                 |
| 6     | 95                   | 0.075             | 1                | 334.3             | 3.105                | 201.57                 |
| 7     | 115                  | 0.075             | 0.5              | 180.4             | 1.591                | 187.11                 |
| 8     | 115                  | 0.1               | 0.75             | 256.2             | 2.159                | 197.29                 |
| 9     | 115                  | 0.05              | 1                | 347.7             | 3.336                | 205.16                 |

Table 5. Tabulation of response parameters: Plus profile tool

6. Results and Discussion

6.1 Analysis of responses by using MINITAB

The MINITAB software is used to analyse Taguchi design and generate graphs. From graphical chart as shown in Figure 19 there is a gradual reduction in cutting force, surface roughness and cutting temperature when the cutting speed was 115m/min, feed rate was 0.05 mm/rev and depth of cut was 0.5mm. The cutting force, surface roughness and cutting temperature increases as we decrease the cutting speed and increase the feed rate and depth of cut for plain uncoated tungsten carbide tool. From graphical chart as shown in Figure 20 there is a gradual reduction in cutting force, surface roughness and cutting temperature when the cutting speed was 95m/min, feed rate was 0.075 mm/rev and depth of cut was 0.5mm for straight line textured tool. From graphical chart as shown in Figure 21 there is a gradual reduction in cutting force, surface roughness and cutting temperature when the cutting speed...
was 115m/min, feed rate was 0.075 mm/rev and depth of cut was 0.5mm. The cutting force, surface roughness and cutting temperature increases as we decrease the cutting speed and increase in depth of cut and mid range for feed rate incase of zigzag textured tool. From graphical chart as shown in Figure 22 there is a gradual reduction in cutting force, surface roughness and cutting temperature when the cutting speed was 95m/min, feed rate was 0.01mm/rev and depth of cut was 0.5mm. The cutting force, surface roughness and cutting temperature increases as we increase in depth of cut and mid range for cutting speed incase of plus textured tool.

6.2 Obtain optimum parametersthrough Taguchi approach

Plain tool has an average cutting force of 264N on machining the Carbon Steel as shown in Figure 23. The cutting forces which are generated by micro textured tools (straight line and zigzag) have less cutting force while machining when compared them with the plain tool profile. But the zigzag microtextured tools have made lesser cutting forces when liken with all other profile because of anti adhesive properties and efficient transfer of heat during turning operation. Zigzag profile has better surface roughness value when compared with rest of the profiles as shown in Figure 24. The straight line micro profile has a better surface roughness value when compared with plain profile. This phenomena is because of formation of less build up edge at interface of tool chip. The temperatures generated by the Zigzag profiled tool is less than all other profiled tools as shown in Figure 25. The temperature generated by the straight line profile is better than the plain profile. The temperature generated by the plus profile is quite high compared to plain profile. The reduction in temperature is due to reduced friction in tool and machined surface due to microtexture. When the cutting speed increases there is a great reduction in BUE formation as the chips can be easily detached from the tool chip interface hence the friction reduces and hence there is gradual decrease in cutting force and

Plain tool   Figure.20Straight line profile tool

Figure.19 Plain tool  Figure.21 Zigzag profile tool  Figure.22 Plus profile tool
temperature. Xing et al.,[8]. At lower cutting speed the BUE formation is more because the chip will be plastically weld to the tool surface which results in increase of cutting force and cutting temperature. From the graph it can be observed that cutting speed, surface roughness and temperature is less when compared with the machining of plain uncoated tungsten carbide tool.

![Figure 23 Cutting force comparison](image)

![Figure 24 Surface roughness comparison](image)

![Figure 25 Cutting temperature comparison](image)

7. Conclusions

Three designs of micro texture namely straight line, zigzag and plus were designed and fabricated using Creo software and Nd:YAG laser machine. The effects of machinability parameters such as cutting forces, cutting temperature and surface roughness was analyzed during dry turning of Carbon
steel (EN3B). Cutting forces generated by the Zigzag profile has shown best results and Straight line profile has shown better results than plain tool. The Zig-zag profile tool has given best surface roughness and straight line has shown better results than plain tool. The temperature generated while machining of Zigzag as well as Straight line profile tool has given better results than plain tool. Textures developed on flank face structured on cutting tool inserts have shown benefits in lowering cutting forces, cutting temperature, surface roughness when compared with plain tool. It can be effective in all manufacturing industries provide an eco friendly environment since no coolant is required due to which it becomes pollution free.

References

[1] Noritaka Kawasegia, Hiroshi Sugimori, Hideki Morimoto, Noboru Moritac, Isao Hori. (2009). Development of cutting tools with microscale and nanoscale textures to improve frictional behaviour. *Precision Engineering, 33* 248–254.

[2] Tatsuya Sugihara, Toshiyuki Enomoto. (2009). Development of a cutting tool with a nano/micro-textured surface—Improvement of anti-adhesive effect by considering the texture patterns. *Precision Engineering 33, 425–429.*

[3] Toshiyuki Enomoto, Tatsuya Sugihara, Satoshi Yukinaga, Kenji Hirose, Urara Satake. (2012). Highly wear-resistant cutting tools with textured surfaces in steel cutting. *CIRP Annals - Manufacturing Technology, 61* 571–574.

[4] Toshiyuki Obikawa a,n, Akihiro Kamio b, Hidemitsu Takaoka c, Akira Osada c. (2011). Micro-texture at the coated tool face for high performance cutting. *International Journal of Machine Tools & Manufacture 51* 966–972

[5] Dong Min Kima, Ineon Leea, Sun Keel Kimb, Bo Hyun Kimb, Hyung Wook Parka. (2016). Influence of a micro patterned insert on characteristics of the tool–workpiece interface in a hard turning process. *Journal of Materials Processing Technology, 229* 160–171.

[6] Wu Ze& Deng Jianxin & Chen Yang. (2012). Performance of the self-lubricating textured tools. *Int J AdvManufTechnol, 62:943–951.*

[7] Arulkirubakaran, D., Senthilkumar, V., Chilamwar, V. L., & Senthil, P. (2019). Performance of surface textured tools during machining of Al-Cu/TiB2 composite. *Measurement: Journal of the International Measurement Confederation, 137,* 636–646.

[8] Xing, Y., Deng, J., Li, S., Yue, H., Meng, R. And Gao, P. (2014). Cutting performance and wear characteristics of Al2O3/TiC ceramic cutting tools with WS2/Zr soft-coatings and nano-textures in dry cutting. *Wear, 318(1–2), 12–26.*