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# EFFECT OF TEXTURED CUTTING INSERTS IN MICRO-TURNING OF TI-6AL-4V ALLOYS

## VPLIV TEKSTURIRANIH REZALNIH VLOŽKOV NA MIKRO STRUŽENJE ZLITIN VRSTE Ti-6Al-4V

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There is an increasing demand for higher machining quality and service life of the cutting tools used for the machining of high-strength alloys. Various studies revealed that textured cutting tools could improve the cutting performance by enhancing the tribological characteristics of the cutting regime. Advances in precision machining enabled the creation of micro/nano-textures on tool surfaces with excellent dimensional control. In this work, distinct micro designs, viz. horizontal line, vertical line and cross-hatch, are made, varying the pitch on the rake faces of coated carbide cutting inserts (CCMT060202LF KC5010). An in-house micro-turning machine was utilized to perform all the experiments in dry-cutting conditions. Micro-turning operations were performed using plain and textured inserts and varying the cutting parameters under dry conditions. The effectiveness of micro-scale textures at a contact interface was evaluated based on the cutting forces, tool flank wear and surface roughness. Compared to non-textured inserts, the machining using cross-hatch textured inserts with 100 µm pitch resulted in 50 % lower cutting forces, a 45 % improved surface finish and 37 % reduced tool flank wear. When machining with horizontal-line textured inserts with a 100 µm pitch, cutting forces are reduced by 46 %, the surface finish is enhanced by 34 % and the tool flank wear is lowered by 30 %. Similarly, when machining with vertical-line textured inserts with a 100 µm pitch, cutting forces are minimized by 38 %, the surface finish is improved by 20 % and the tool flank wear is lowered by 26 %. Additionally, a durability test was conducted for the inserts, and the results showed that the cross-hatch textured tool life improved by 80 %, the life of the horizontal-line textured tool increased by 50 % and the life of the vertical-line textured tool increased by 40 % compared to plain inserts. The heat dissipation and tool-chip friction during machining are thus significantly influenced by the texturing, namely by its design, dimensions and orientation.

Keywords: micro-texturing, micro-turning, femtosecond laser, titanium alloy, surface roughness, wear

V svetu so se močno povečale zahteve po kakovostni mehanski obdelavi in povečanju dobe trajanja rezalnih orodij med mehansko obdelavo zlitin z visoko trdnostjo. Izvedene so bile številne študije, ki so pokazale, da teksturirana rezalna orodja lahko izboljšajo kakovost rezanja zaradi izboljšanih triboloških lastnosti režima rezanja. Napredek pri precizni mehanski obdelavi je omogočilo kreiranje mikro oziroma nano teksture na površinah orodij z istočasno odličnim nadzorom dimenzij. V tem članku avtorji opisujejo posebne mikro horizontalne in vertikalne linijske dizajne teksture s prečnimi šrafurami z variranjem prečnega nagiba vrha rezalnega orodja oziroma rezalnega vložka (ploščice) iz prevlečene karbidne trdine s komercialno oznako CCMT060202LF KC5010. Na domači mikro stružnici so avtorji izvedli vse preizkuse v pogojih suhega rezanja. Uporabili so ploske (gladke) in teksturirane rezalne vložke in pri tem spreminjali pogoje suhega rezanja. Učinkovitost mikro tekstur na meji kontakta so ovrednotili z določitvijo sil rezanja, bočne obrabe vložkov in površinske hrapavosti. Primerjava mehanskih obdelav med neteksturiranimi vložki in vložki s 100 µm korakom šrafirano teksturo je pokazala 50 % manjše rezalne sile, 45 % izboljšanje kakovosti (gladkosti) površine in njihovo 37 %-no manjšo bočno obrabo. Mehanska obdelava s horizontalno 100 µm korakom linijsko teksturo rezalnih vložkov je pokazala 46 % zmanšanje rezalnih sil, 34 % izboljšanje kakovosti površine in 30 % zmanjšano bočno obrabo. Podobno so se pri uporabi vertikalno 100 µm teksturiranih rezalnih vložkov rezalne sile zmanjšale za 38 %, kakovost površine se je izboljšala za 20 % in bočna obraba se je zmanjšala za 26 %. V primerjavi s konvencionalnimi neteksturiranimi (gladkimi) rezalnimi vložki se je življenska doba teksturiranih vložkov močno podaljšala, s šrafirano teksturo za 80 %, z horizontalno linijsko teksturo za 50 % in vertikalno linijsko teksturo za 40 %. Avtorji v zaključku povdarjajo, da pri mehanski obdelavi, tekstura rezalnega orodja, oblika, dimenzije in orientacija močno vplivajo na prenos oziroma disipacijo toplote ter trenje med ostružki in rezalnim orodjem.

Ključne besede: mikro teksturiranje, mikro rezkanje, femto sekundni laser, zlitine na osnovi titana, površinska hrapavost, obraba

## 1 INTRODUCTION

The manufacturing of miniaturized components is crucial in many industries, including precision engineering, medical technology, optics and electronics. There is growing demand for highly accurate and compact components in a wide range of industries. The limitation to a 0.05-mm feed and depth of cut is no longer a barrier in micro machining as advancements in the machine tool technology now allow for cutting depths below 0.05 mm, with exceptional precision and rigidity. Micromachining involves the manufacturing of components, features or cutting tools with dimensions that typically fall within the range of 1–500 µm.[1,2] Additionally, they can help with miniaturization, which is essential for implantable and portable devices. The micro-components made of Ti6Al4V alloys are widely used in the aerospace industries due to their high strength-to-weight ratio and great fatigue strength and in medical industries because of their exceptional wear and corrosion resistance. How-

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ever, the mechanical machining of these alloys is challenging due to their limited heat conductivity, high strength and substantial chemical reactivity with the cutting tool material.[3,4] Micro-turning is a popular machining method for producing small, precise axi-symmtric components, which can be particularly challenging for this alloy. Micromachining requires high cutting speeds, producing extremely high temperatures at the tool-chip interface. In order to increase the machining quality and tool life, removing these temperatures from the cutting zone is necessary. The heat and the cutting chips can be removed from the machining zone by applying cutting fluids such as mineral oils, vegetable oils, synthetic fluids, etc.[5,6] The use of lubrication oil during machining is an environmental hazard if not followed by proper handling and disposal procedures. Lubrication oil may include harmful substances, such as carcinogenic compounds or toxic metals or oncogenic compounds, which can pollute soil and water if they are not properly disposed of. Also, if the oil is not carefully handled while being used, the emissions of volatile organic compounds might lead to air pollution.[7,8]

The cutting tools with different textures are advised to use for conventional machining to minimize the usage of hazardous cutting fluids. The patterns on different faces of the cutting tools improve the tribological features at the tool-chip interface and maximize the heat dissipation from the machining region. Therefore, texturing of the cutting tool enhances the machining quality and prolongs the tool life.[9] Coated carbide cutting tools perform better with titanium alloys as they do not react with them and prevent the diffusion of ingredients of the machining materials.[10] In micro-turning the surface quality improves with an increase in the cutting speed because of the thermal softening of the work material at high speeds. The depth of cut should be larger than the edge radius of the cutting inserts, otherwise ploughing occurs instead of shearing and it results in a poor surface finish.[11] Several studies[12–14] concentrate on comprehending the cutting abilities of textured tools in terms of modifying their dimensions and form, creating new coatings, modelling with the finite element method, machining under multiple lubrication conditions and fabricating textures using various techniques. Devraj et al. investigated the effectiveness of micro-dimple-pattern inserts in a turning process by altering the dimple size, depth and pitch. They revealed that the size of a dimple influences localized stress and chip development while the depth of the dimple influences friction, and the pitch of the dimple influences lubrication and chip breakage.[15] Vasumathy and Anil Meena examined the efficacy of line-pattern-textured WC-Co inserts. They discovered that the lay angle has a significant impact on the tool-chip contact area and lubrication.[16] Arulkirubakaran et al. investigated the performance of linear textured inserts for dry machining Al-Cu/$TiB_2$ composites and identified reduced cutting force, specific energy and tool wear.[17] Prasad and Ismail investigated the effect of protruded textured HSS tools made with a reverse EDM method for turning operations. They discovered that these tools had a 110-% longer tool life and better machining quality than untextured tools.[18]

From the previous studies, it is evident that surface texturing has the capability to enhance the tribological features at the tool-chip interface by lowering the friction, cutting forces and heat generation. However, literature shows that there is a need for studying different sizes, shapes and orientation of textures, which is essential for understanding the chip flow and heat-dissipation behaviour that are crucial in deciding on the friction and temperature at the tool-chip interface. Also, relatively few researchers focused on how the form, dimensions and orientation of texturing on cutting tools influence the machining quality and tool life in micro turning.

In this study, a femtosecond laser facility is utilized to create different patterns, such as horizontal lines, vertical lines, and cross-hatch patterns, on the rake face of the coated carbide cutting inserts. Such textured inserts and non-textured inserts were employed in the micro-turning of the Ti6Al4V alloy under dry cutting conditions. The experiments were conducted by varying the cutting parameters, and the performance parameters such as cutting force, surface roughness and tool wear were measured. The effects of different textures on the rake face in terms of performance parameters were investigated and compared with the results of conventional cutting inserts. Also, durability tests of various textured inserts were performed for further analysis of the longevity of the textured and plain tools.

## 2 EXPERIMENTAL STUDY

The experiments were carried out using an indoor table-top micro-turning machine that was built in the lab, as illustrated in **Figure 1**. The machine tool consists of a bed with the size of 600 mm × 600 mm made of cast iron, mounted on an antivibration optical table. An air-cooled bearing spindle of 24,000 $min^{-1}$ is mounted onto the base with clamps, controlled by a variable frequency drive (VFD) with a resolution of 6 $min^{-1}$, which can be operated manually or automatically. The X-Y stage with a precision of 1 µm and maximum speed of 4 mm per second is installed to control the feed and depth of cut. A Kistler mini dynamometer is attached under the tool holder with the support of a tool post to measure the cutting forces during a machining operation. This dynamometer with a piezoelectric sensor has the capability of measuring forces from 1–200 N.

All the experiments are carried out in dry conditions. The tool holder is mounted onto the X-Y stage with the help of the tool post to accommodate the cutting insert. Titanium nitride (TiN) coated carbide cutting inserts with a nose radius of 100 µm (CCGT060201LF) are utilized for all the experiments. Various line textures and

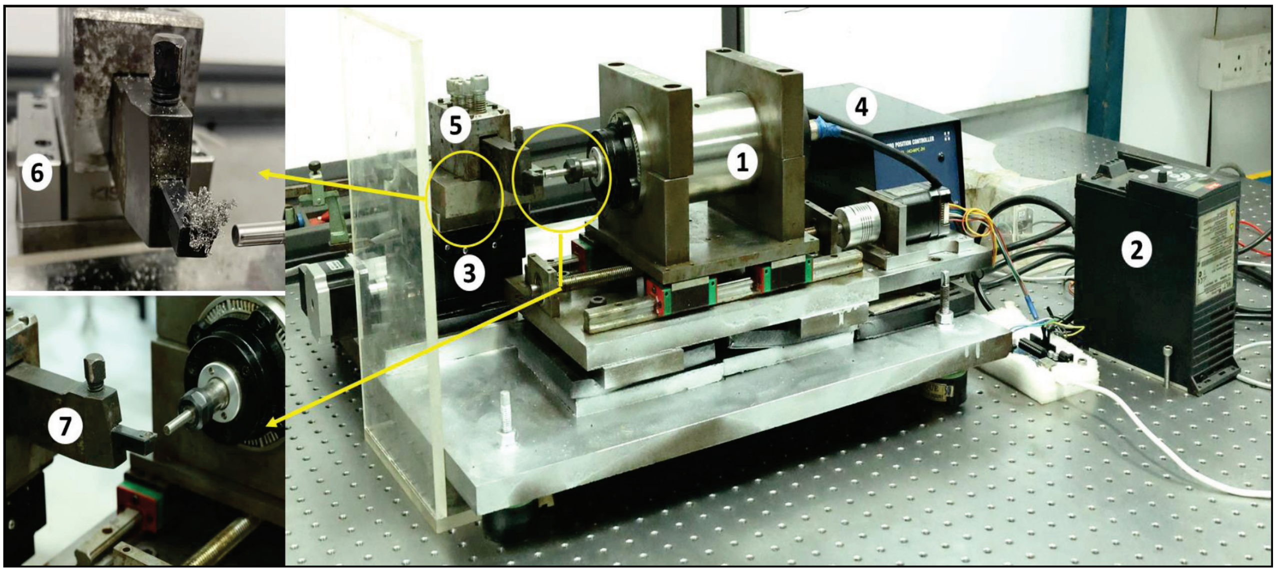


**Figure 1:** Micro-turning machine – 1. spindle, 2. VLT drive, 3. X-Y stage, 4. micro-motion controller, 5. tool post, 6. mini dynamometer, 7. tool holder

**Table 1:** Parameters that are established during the laser operation

| Parameter | Range | Parameter | Range |
|---|---|---|---|
| Wavelength | 1030 nm | Repetitions | 100 |
| Power | 20 W | Spot diameter | 20 µm |
| Pulse energy | 40 µJ | Lens | 1064 nm |
| Pulse duration | 500 fs | Beam quality, $M^2$ | <1.2 |
| Repetition rate | 2 MHz | Scanning speed | 100 mm/s |

cross hatch are designed in AutoCAD and then imported to the Kyla software, used to operate the femtosecond laser. **Table 1** shows the parameters established during the laser machining process. The horizontal-line, vertical-line and cross-hatch patterns fabricated by varying the pitch in the range of (100, 150 and 200) µm by keeping a stand-off distance of 500 µm from the cutting tool nose are depicted in **Figures 3a** to **3i**. **Figure 3j** illustrates the plain tool, featuring a nose radius of 100 µm. The line width and depth of the texturing achieved are 30 µm and 40 µm, respectively. Because of the limitations in manufacturing, the stand-off distance of 500 µm could not be achieved due to manual positioning. As a result, a tolerance of ±25 µm has been taken into consideration. All the experiments are performed by varying the feed (20 and 40 µm) and depth (20, 40 and 60) µm of the cut while keeping the cutting speed constant at 12,000 min$^{-1}$. The experiments were carried out with untextured and variously textured inserts, including horizontal line, vertical line and cross hatch with different pitches of (100, 150 and 200) µm. With a combination of speed, feed and depth of cut, six experiments were conducted with each insert, a new insert being utilized in each experiment. A total of 60 experiments were conducted, with each experiment being repeated three times for a more comprehensive analysis.

**Table 2:** Design of Experiments

| Design of texturing | Pitch (µm) | Speed (min$^{-1}$) | Feed (µm/rev) | Depth of cut (µm) |
|---|---|---|---|---|
| Plain | 100<br>150<br>200 | | 20<br>40 | 20<br>40<br>60 |
| Vertical line | 100<br>150<br>200 | 12000 | 20<br>40 | 20<br>40<br>60 |
| Horizontal line | 100<br>150<br>200 | | 20<br>40 | 20<br>40<br>60 |
| Cross-hatch | 100<br>150<br>200 | | 20<br>40 | 20<br>40<br>60 |

Ti-6Al-4V alloy samples of 5 mm in diameter and 50 mm in length were utilized for all the experiments, and the workpiece was held in the spindle using an ER 11 collet. The work material was initially measured to have a hardness of 364 ± 2.4 HV using the Vickers hardness test. During each experiment, the cutting force was measured using a Kystler mini dynamometer, mounted under the tool holder with the help of a tool post, as shown in **Figure 1**. The cutting force data were collected by applying a drift allowance and operating an amplifier for three hours prior to the measurement, which allowed the drift to be eradicated. The cutting force data was analysed using the Dynoware software, as shown in **Fig-**

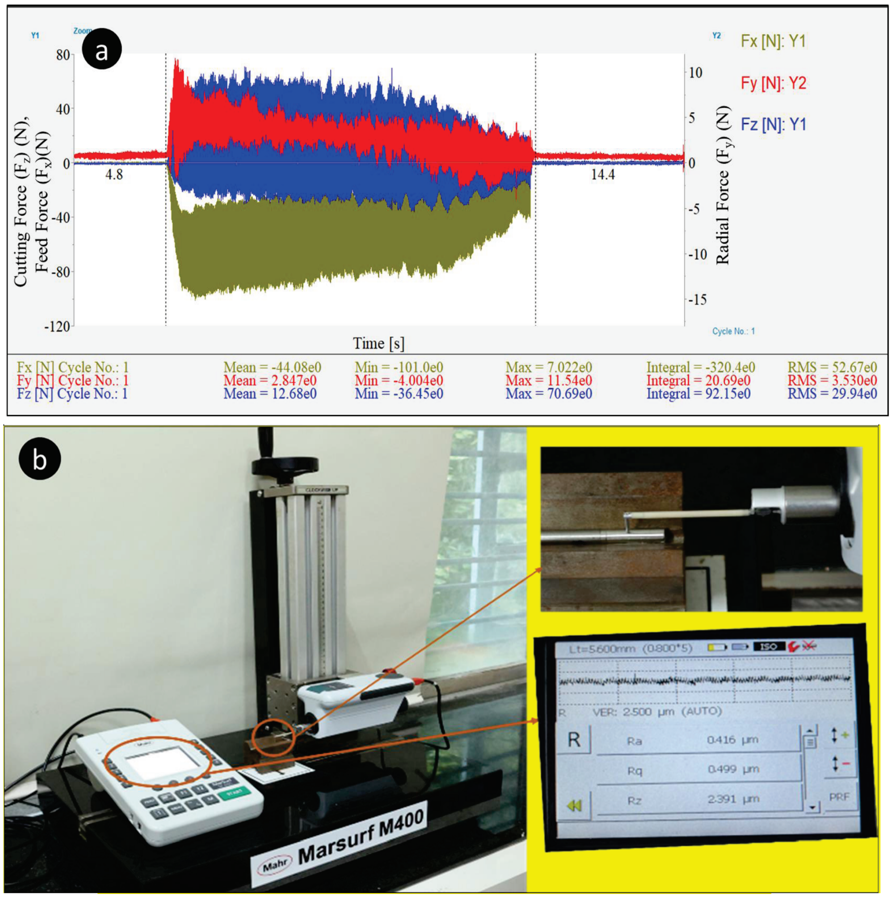


**Figure 2:** a) cutting force measurement, b) surface roughness measurement

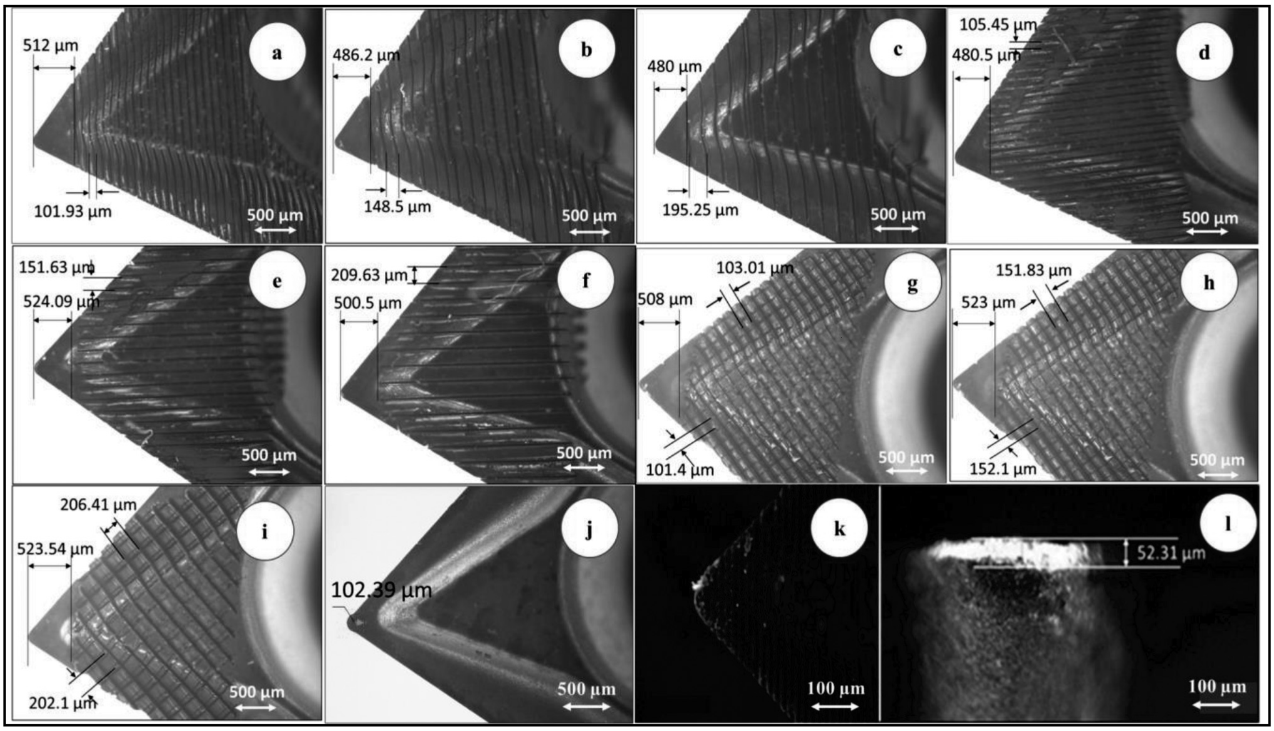


**Figure 3:** Horizontal-line (perpendicular to the chip flow direction) textured insert: a) 100 µm pitch, b) 150 µm pitch, c) 200 µm pitch, vertical-line (parallel to the chip flow direction) textured insert: d) 100 µm pitch, e) 150 µm pitch, f) 200 µm pitch; cross-hatch textured insert: g) 100 µm pitch, h) 150 µm pitch, i) 200 µm pitch; j) plain insert; k, l) tool wear measurement

ure 2a. The average surface roughness (Ra) of a machined sample was measured using a contact-type surface roughness tester Mahr surf M400 with a stylus radius of 2 µm. After each experiment, readings were collected at three different places on the circumference of each sample and the average of these readings was recorded as the actual Ra of the respective sample, as illustrated in **Figure 2b**.

After the completion of each experiment, the worn area on the rake face of the cutting tool was captured using an inverted GX 200 microscope at a magnification of 10×, as shown in **Figures 3k** and **3l**. The width of the worn area was then measured from the acquired images of the cutting tool tip and considered as the tool wear. The image magnification range of this microscope is 5–200×.

In order to gain a more comprehensive understanding of the durability of textured inserts, further experiments were undertaken using new inserts for machining the Ti64 alloy at dry conditions. It is found that 100 µm pitch textured inserts have demonstrated superior performance compared to 150 µm and 200 µm pitch inserts. Hence, various textured inserts with a 100 µm pitch and a plain insert were utilized in these additional experiments. The experiments continued until the tool reached the state of failure. Each experiment involved turning a Ti64 workpiece with a diameter of 5 mm and a turning length of 25 mm, with a total of 14 passes made for one sample with a 100 µm depth of cut, 30 µm feed and 12,000 min$^{-1}$ speed. This process was repeated until the tool failed. The determination of tool failure was based on the measurement of the cutting forces during the operation. If the cutting forces exceeded 100 N and emitted flames were observed during cutting, it was considered an indication of tool failure. Upon a closer examination, it was observed that a taper had formed at the end of turning after multiple passes. The taper on a sample was measured for all the samples, machined with both textured and non-textured inserts.

**Figure 4** exhibits the measurements of the cutting force, average roughness and tool wear for each experiment. In order to evaluate measurement uncertainty, each experiment was repeated three times. Error bars were plotted for all these measurements, providing a visual representation of the variability or uncertainty associated with each data point. These error bars allow for a better understanding of the reliability and variation in the measured values for the cutting force, average roughness and tool wear across the experiments. **Figure 4d** specifically showcases a clear trend, being followed in the cutting force measurement. In **Figure 4**, the error bars demonstrate a relatively low amount of error across the re-

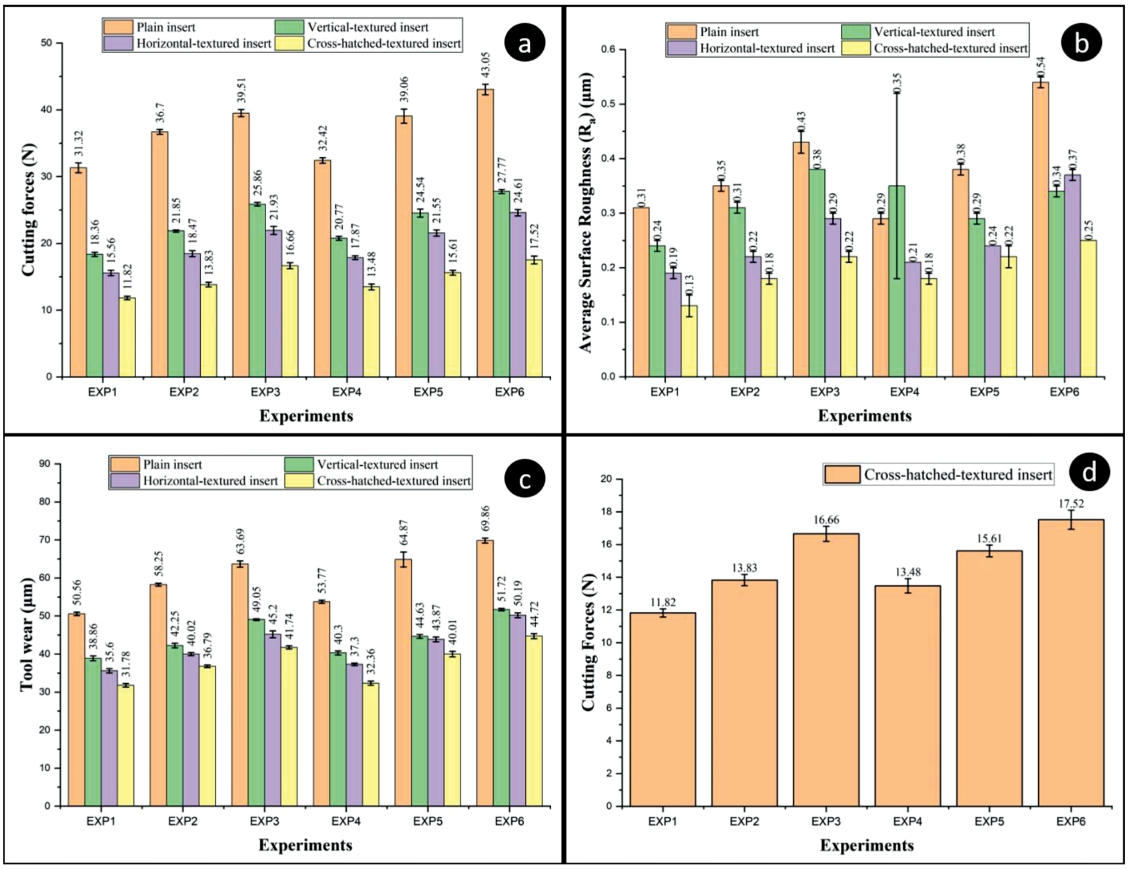


**Figure 4:** Error bar chart: a) cutting force measurement, b) surface roughness measurement, c) tool wear measurement, d) cutting force for cross-hatch tool machining

peated experiments. This indicates a consistent and reliable trend in the measured values. Based on the analysis of the error bar chart, it can be concluded that the observed variations within the measurements are within an acceptable range. This suggests that the experimental results are reliable and support the conclusion that the observed trend from **Figure 4** is valid and meaningful.

## 3 RESULTS AND DISCUSSION

The cutting force, tool wear and surface roughness were measured as performance parameters and plotted against the experiments. With this analysis, we examined how different designs, pitches and texturing orientations on a cutting-insert rake face affected these performance parameters. **Figures 5** and **6** visually represent the relationship between the performance parameter data and conducted tests, providing valuable insights into the impact of the variables mentioned above on the rake face of a cutting insert.

The influence of the pitch variation in the texture on the cutting insert was analysed based on the information presented in **Figure 5**. **Figures 5a** to **5c** show the plots of cutting forces that were measured during the turning operations using horizontal, vertical and cross-hatch textured inserts with various pitch values. The results depicted in **Figures 5a** to **5c** indicate that machining with the 100 μm pitch textured inserts led to lower cutting forces compared to machining with inserts of larger pitches of 150 μm and 200 μm. However, it was observed that there was a minimal difference between the results obtained for the 100 μm and 150 μm pitch inserts. This is because, despite a smaller pitch (100 μm) providing an increased surface area for heat dissipation, the key factors related to the chip interaction, such as chip flow direction and chip obstruction, remained consistent for both pitches. This indicates that the change in the pitch from 100 μm to 150 μm did not have a significant impact on the chip interaction, which plays a crucial role in determining the heat transfer and overall performance. Consequently, the observed similarity in the results can be attributed to the stability of the chip interaction regardless of the pitch variation.

**Figures 5d** to **5i** provide insights into the effects of pitch variation on the surface roughness and tool wear. It is observed that the use of 100 μm pitch textured inserts resulted in a reduced surface roughness and less tool wear when compared to the inserts with pitches of

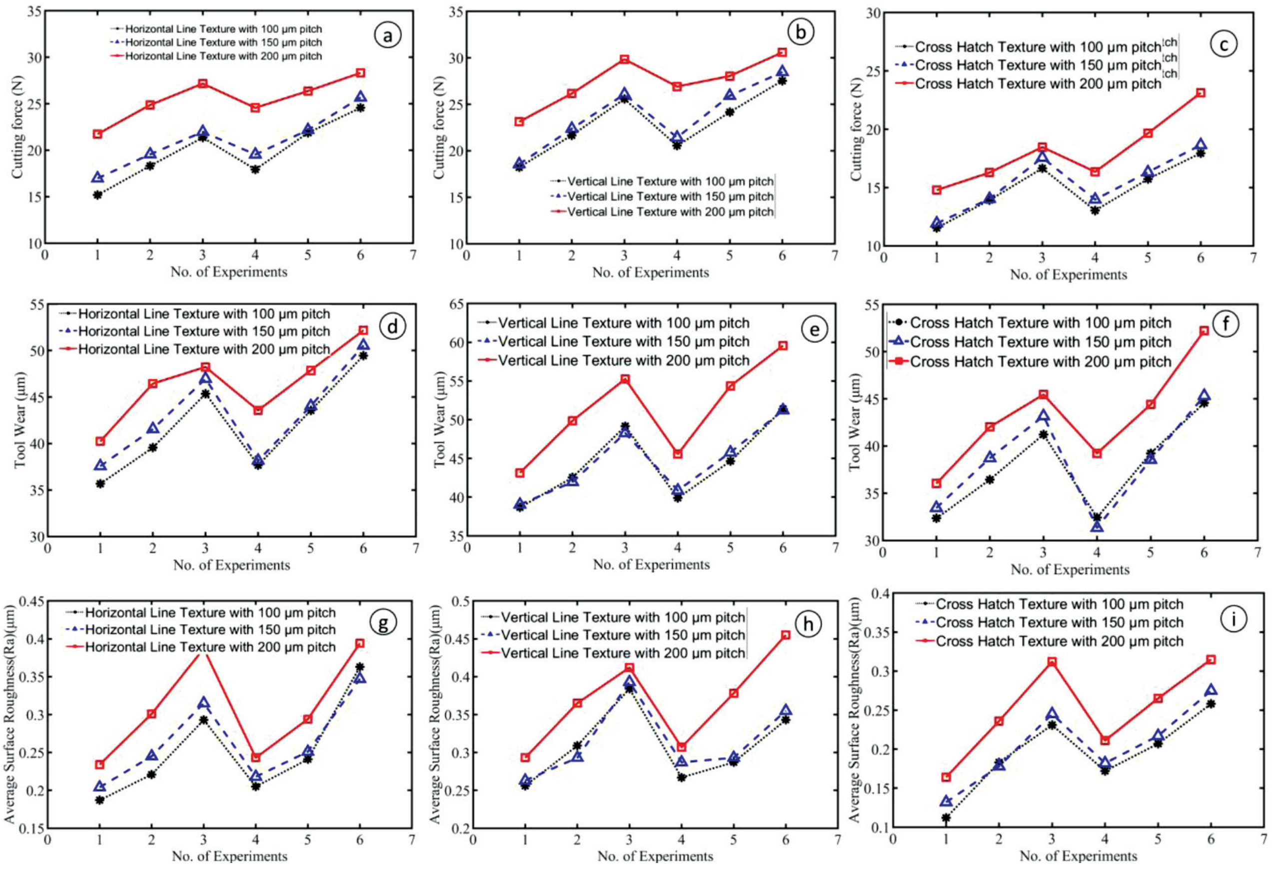


**Figure 5:** Cutting force during machining with a) horizontal-line textured inserts, b) vertical-line textured inserts, c) cross-hatch textured inserts; Tool wear after each machining pass with d) horizontal-line textured inserts, e) horizontal-line textured inserts, f) cross-hatch textured inserts; Surface roughness of the workpiece machined with g) horizontal-line textured inserts, h) vertical-line textured inserts, c) cross-hatch textured inserts

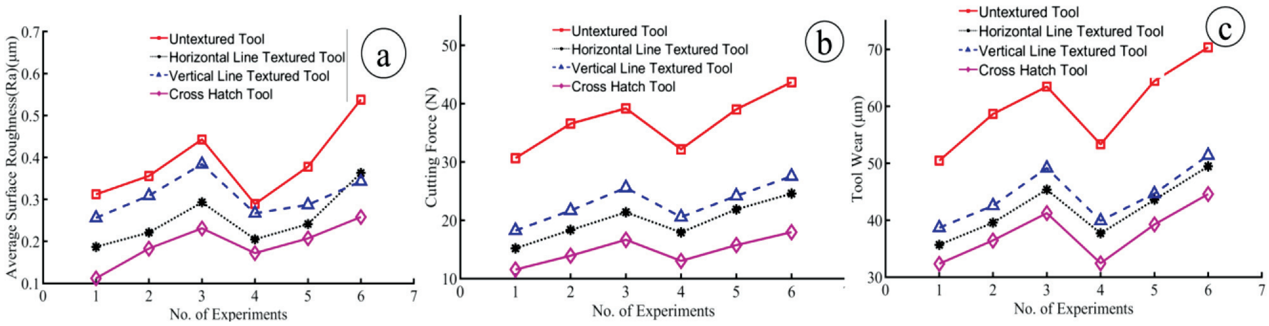


**Figure 6:** Machining with various textured and untextured inserts: a) surface roughness of the workpiece, b) cutting force, c) tool wear after each pass

150 µm and 200 µm. This indicates that finer texture patterns with a pitch of 100 µm contribute to an improved surface quality and prolonged tool life. In summary, the analysis of pitch variation in the texture, as presented in **Figure 5**, demonstrates that machining with textured inserts of 100 µm pitch on the horizontal line, vertical line and cross-hatch yields advantages in terms of reduced cutting forces, improved surface roughness and decreased tool wear when compared to the inserts with larger pitch values of 150 µm and 200 µm. The use of 100 µm pitch textured inserts leads to decreased cutting forces, tool wear and surface roughness. This is because these inserts have a larger surface area and less contact area between the chip and the tool compared to the other inserts.

As a result, heat dissipation is maximized and the friction between the tool and chip is reduced. In order to assess the impact of the texturing design on the rake face of the cutting insert, a comparative analysis was performed. This analysis involved plotting the data for the average surface roughness, cutting force and tool wear during machining with 100 µm pitch textured inserts and untextured inserts. These results can be observed in **Figures 6a** to **6c**, respectively.

In these figures, the square with a continuous line represents the average surface roughness, cutting force and tool wear for machining with untextured tools. The triangle with a dashed line represents the average surface roughness, cutting force and tool wear for machining with vertically textured tools. The asterisk with a dotted line denotes the average surface roughness, cutting force and tool wear for machining with horizontally textured tools. Lastly, the rhombus with a continuous line represents the average surface roughness, cutting force and tool wear for machining with cross-hatch textured tools. These plots revealed that the surface roughness, cutting force and tool wear are lower with textured tools. The comparative analysis of the plain, vertical, horizontal and cross-hatch textured inserts reveals that the cross-hatch textured tools yield improved results compared to the other types. The vertically textured tools demonstrate a better performance than the plain tools but they are not as good as the horizontally textured tools. This difference can be attributed to the interaction with the chip during machining. The vertical texture facilitates a smoother chip-tool interaction, resulting in the formation of continuously serrated chips that are not prone to breaking. Also, similar to the plain tool machining, a built-up edge formation was observed with the vertically textured tools. Horizontally textured tools exhibit even better enhancements in the surface finish, reduced cutting forces and minimized tool wear compared to vertical textured tools. This improvement can be attributed to the reduced chip-tool interaction facilitated by the horizontal texture. The presence of the horizontal texture obstructs the chip flow on the tool face, resulting in a decreased tool-chip interaction and minimizing the chip flow over the rake face. Consequently, the improved results observed with horizontally textured tools surpass those achieved with vertically textured tools.

Cross-hatch textured tools exhibit superior performance in enhancing the surface finish, reducing the cutting forces and minimizing the tool wear compared to horizontal tools. This is attributed to the increased surface area created by the cross-hatch pattern, which enhances heat dissipation and reduces the friction. Additionally, the cross-hatch texture further decreases the chip-tool interaction and obstructs the chip flow on the rake face, resulting in improved machining outcomes. As a result, cross-hatch textured tools outperform the horizontal texture, vertical texture and plain tools in achieving a better surface finish, reduced cutting forces, and minimized tool wear.

In order to further study the durability of textured inserts, further experiments were undertaken using new 100 µm pitched vertical, horizontal, cross-hatch textured and plain inserts for machining the Ti64 alloy. The plain tool exhibited failure after completing ten samples. Each sample required 14 passes over a total length of 23 mm. During the machining of these samples, the minimum cutting force recorded was 115.4 N, and the maximum flame was observed during the last pass of the 14th sample. Additionally, the taper angle on the last sample, which was the 10th sample investigated, was 2.4 degrees. This presence of taper on the sample can be attributed to the thermal softening of the cutting insert caused by excessive heat accumulation at the insert's tip. As a result of this thermal softening, the depth of cut towards the end of the turning pass was reduced. This reduction in depth resulted in a taper at the end of the turning pass, leading to the observed taper on the sample. The vertically textured inserts experienced failure during the turning of the 14th sample, resulting in a maximum cutting force of 118.4 N during the final pass. Flames similar to those observed during plain-tool machining were present during the machining of the last sample. A taper angle of 1.9 degrees indicated slight dimensional changes towards the end of the turning pass. Similarly, the horizontally textured inserts failed during the turning of the 15th sample, with a maximum cutting force of 104.4 N recorded during the final pass. The flames observed were less pronounced compared to both plain and vertically textured inserts. The taper angle was 1.6 degree, indicating minor dimensional changes.

In contrast, the cross-hatch textured inserts exhibited failure during the turning of the 18th sample, with a maximum cutting force of 110.4 N recorded during the final pass. Notably, no significant flames were observed during the machining of the last sample. The taper angle was 1.2°, indicating minimal dimensional changes. Overall, these results suggest that the cross-hatch textured inserts demonstrated better durability compared to the horizontally textured, vertically textured and plain inserts. The cross-hatch textured inserts exhibited lower cutting forces, less pronounced flames and smaller taper angles, indicating their potential for longer-lasting performance in turning operations. To gain a deeper understanding of the performance and potential failure mechanisms of the textured and plain tools, scanning electron microscopy (SEM) images and energy dispersive spectroscopy (EDS) reports on the cutting inserts were collected before and after machining and illustrated in **Figures 7** to **10**. These images provide valuable insights into the presence of delamination, work material inclusions, built-up edge formation and other relevant aspects. In **Figure 7d**, the presence of workpiece inclusions on the rake face of the plain insert is clearly observed, along with an increase in the nose radius to 175 μm. Additionally, **Figure 7b** illustrates the accumulation of a built-up edge on the tool nose edge, while **Figure 7e** highlights the presence of workpiece inclusions. **Figures 7c** and **7f** provide a comparison of the material compositions before and after machining, with **Figure 7f** showing the complete extent of workpiece inclusions.

From **Figure 8a**, it is clear that the titanium coating was removed at the laser marks and other areas, resulting in only 21 % of the coating weight remaining after vertical texturing. However, the coating still provides some benefits even after texturing the vertically textured insert. **Figure 8d** displays the workpiece inclusions and an increased nose radius after machining 14 samples with 14 passes. This suggests that the machining caused the formation of inclusions and an increase of 62.5 μm in the nose radius. **Figure 8b** demonstrates the presence of a built-up edge on the edge radius and inclusions in the slots. This indicates that during machining, the material accumulated on the edge radius, resulting in the formation of a built-up edge, and inclusions can be observed in the slots. In **Figure 8e**, it is apparent that the workpiece inclusions are more prominent in the plain insert compared to the vertically textured insert. This can be attrib-

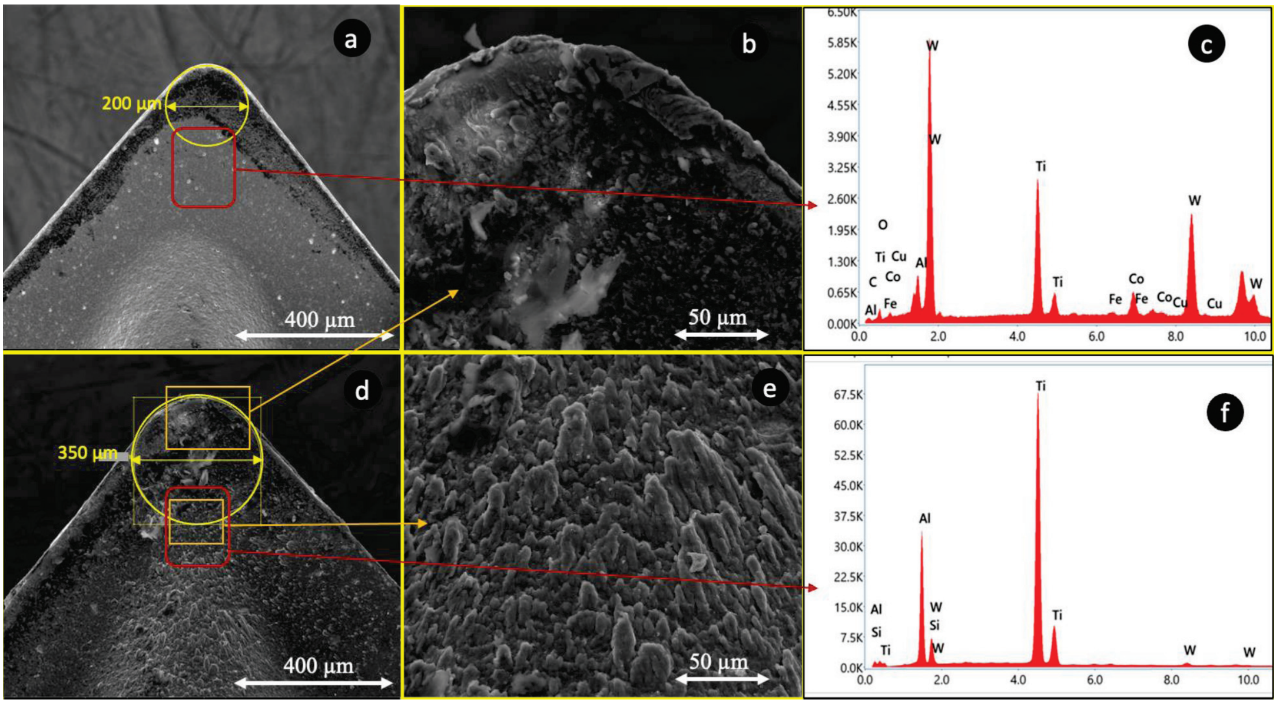


**Figure 7:** SEM and EDS details of the plain insert before and after machining

uted to the fact that more chips accumulate in the slots of the texture during machining, leading to increased inclusions. **Figures 8c** and **8f** show EDS reports before and after machining, and these figures demonstrate a 12 % reduction in the coating and an 87 % increase in the workpiece material accumulation after machining, indicating the changes that occur during the process. **Figure 9d** displays a SEM image of a horizontally textured insert after the machining of 15 samples, each undergoing 14 passes. In comparison to the vertically textured inserts, **Figures 9d** and **9b** reveal a minor increase in the nose radius that is 150.5 and a lower occurrence of the built-up edge formation. Additionally, **Figures 9c** and **9f** show that the coating was reduced to 8 % after horizontal texturing, and the workpiece material inclusions amounted to 76 % after machining, which is 11 % less than for the vertically textured inserts.

**Figure 10d** presents SEM images of a cross-hatch insert after machining 18 samples, each undergoing 14 passes. The tool nose radius is shown to have increased

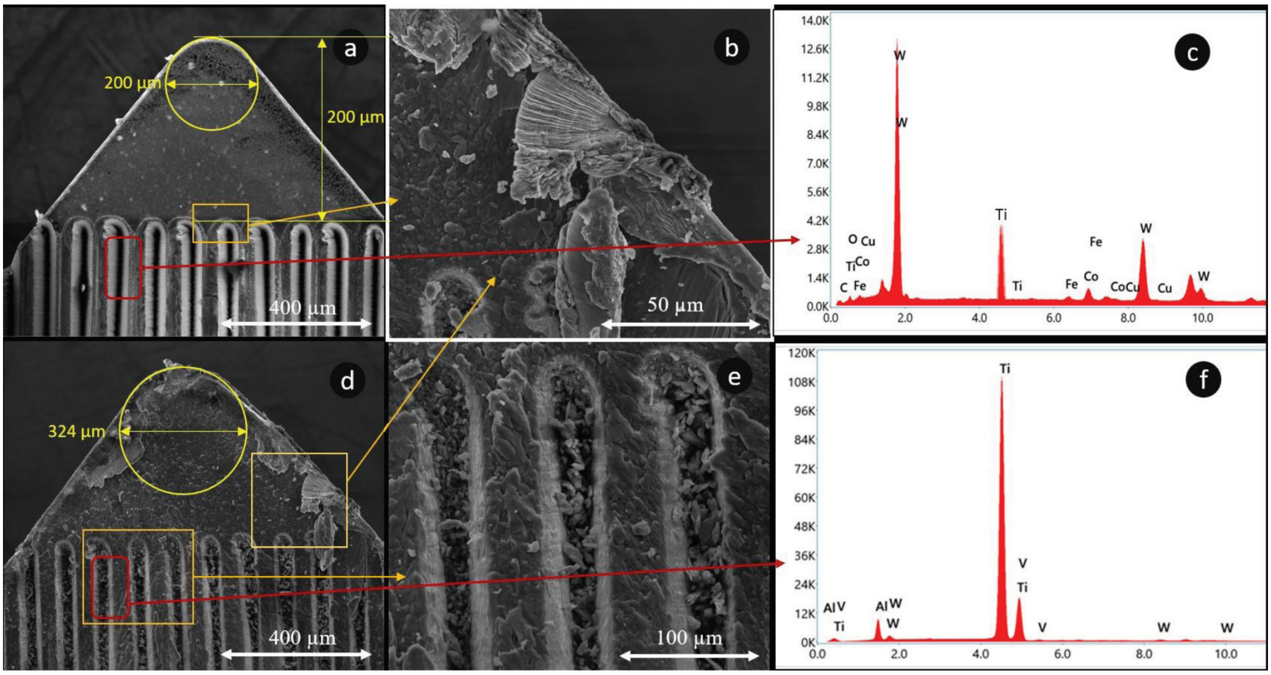


**Figure 8:** SEM and EDS details of a vertically textured insert before and after machining

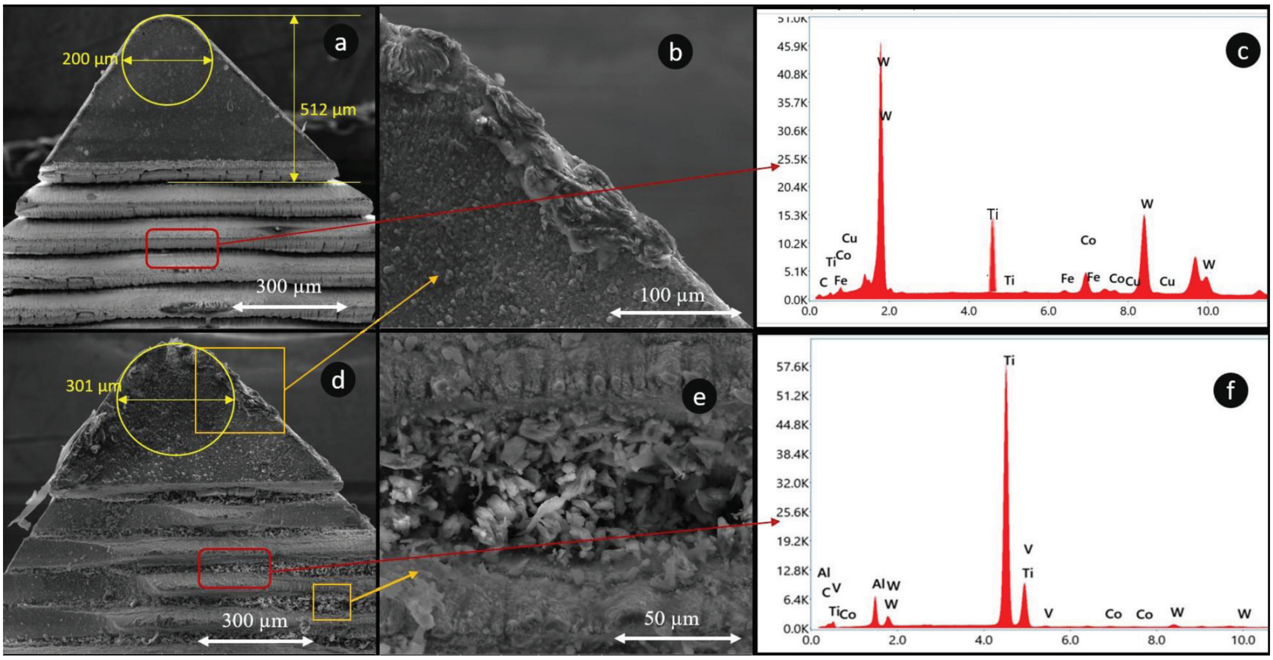


**Figure 9:** SEM and EDS details of a horizontally textured insert before and after machining

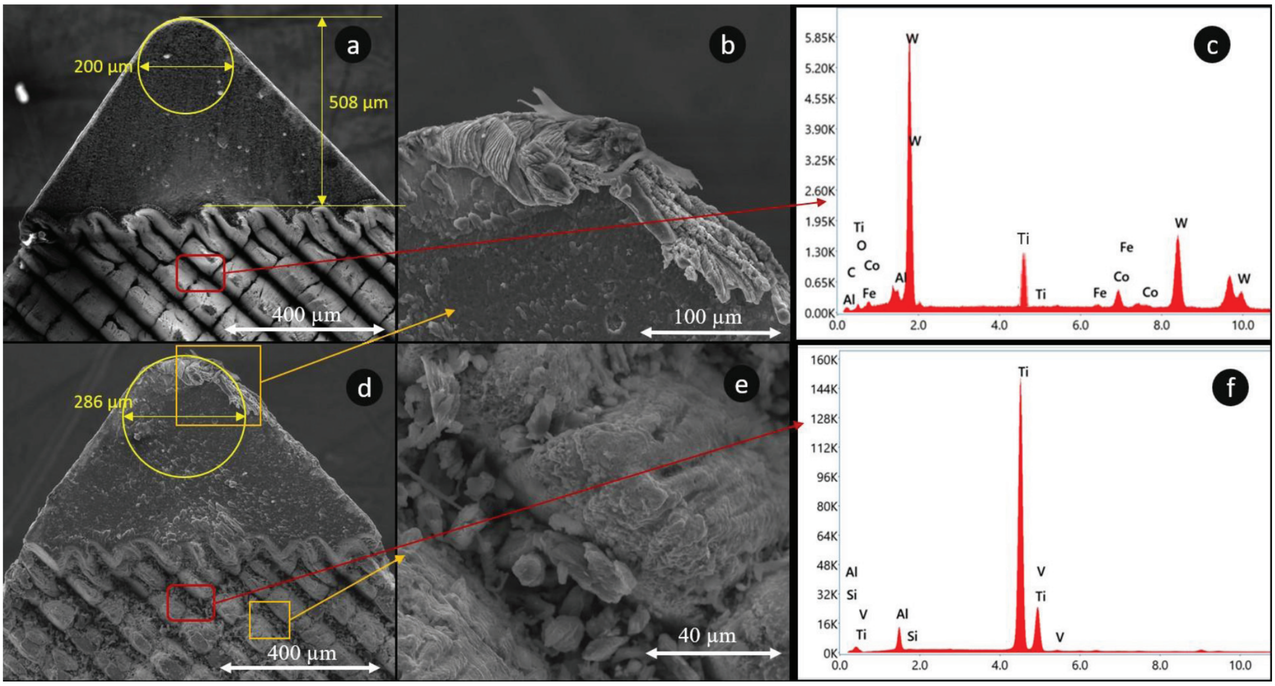


**Figure 10:** SEM and EDS details of a cross-hatch textured insert before and after machining

to only 43 µm, which is smaller than in the cases of the plain, horizontally and vertically textured tools. **Figures 10b** and **10e** demonstrate the occurrence of built-up edge and the presence of workpiece material inclusions after machining. The built-up edge is less prominent than for the horizontally textured, vertically textured and plain inserts. Additionally, **Figure 10c** shows a coating reduction by 16 % after texturing. This reduction occurs because the laser needs to machine the same plane twice to create this specific texture. Furthermore, **Figure 10f** indicates that the workpiece material inclusions after machining amounted to 88 % due to the cross-hatch texture accommodating more workpiece particles than other textures. The durability of cross-hatch textured tools is increased by 80 % compared to plain tools, 29.5 % compared to vertically textured tools and 20 % compared to horizontally textured inserts.

The wear mechanism was adhesive wear where high temperatures and pressures at the tool-workpiece interface cause material transfer between the workpiece and insert. This transfer of material leads to localized adhesion and subsequent material build-up on the insert surface, resulting in wear. Another significant wear mechanism was abrasive wear. These micro-textured inserts have small surface features, such as micro-grooves, slots and cross-hatch, designed to enhance the heat dissipation and chip interaction mechanism. However, these surface features can also act as potential sites for the accumulation of abrasive particles, such as chips or debris. These abrasive particles can cause localized wear on the insert surface. Furthermore, in dry cutting conditions, the absence of a cutting fluid or coolant can lead to increased tool wear.

## 4 CONCLUSIONS

In this work, coated carbide cutting inserts were textured based on various designs, such as a horizontal line, perpendicular to the chip flow direction, a vertical line, parallel to the chip flow direction and cross-hatch patterns with different pitches on the cutting inserts using a femtosecond laser facility. The textured inserts were utilized to perform micro-tuning operations. In terms of cutting forces, tool wear and surface roughness, the impact of varied texturing on the rake faces of the cutting inserts for the micro-turning of Ti6Al4V alloy under dry cutting conditions was compared to conventional cutting inserts. The following conclusions are drawn from the present study.

Machining with textured inserts such as horizontal line texturing with a pitch of 100 µm, vertical line texturing with a pitch of 100 µm and cross-hatch texturing with a pitch of 100 µm cause reduced cutting forces, lower tool wear and better surface finish than machining with textured inserts with pitches of 150 µm and 200 µm. 100 µm textured inserts have more surface area and less chip-tool contact area than other inserts, which helps in maximizing heat dissipation and reducing the friction between the tool and chip.

Due to machining with horizontally textured inserts with a 100 µm pitch, cutting forces are reduced by 46 %, the surface finish is enhanced by 34 % and the tool-flank wear is reduced by 30 %.

Similarly, when machining with vertically textured inserts with a 100 μm pitch, cutting forces are reduced by 38 %, the surface finish is improved by 20 % and the tool-flank wear is reduced by 26 %. The tool-chip friction during machining is thus significantly influenced by the texturing, namely by its design, dimensions and orientation.

The appropriate design and dimensions of the cross-hatch pattern on the rake faces of the cutting inserts enhance the tool life by 80 % while the horizontal texture improves it by 50 % and the vertical texture improves it by 40 %.

In the present research all the machining tests were performed under a dry condition. The effectiveness of a texture is more predominant when using cutting fluids (hydrodynamic lubrication). This will be the scope of the continuation of the present research.

The work can be further extended to study the effect of various textures on both the flank and rake faces of a cutting insert in dry and wet conditions. Also, a simulation-based analysis can be carried out to examine the influence of various designs, dimensions and orientations of the texturing as the tribological characteristics of the micro-cutting regime are challenging to be analysed in practice.

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