IMPACT OF LASER MICRO TEXTURED CUTTING TOOL INSERTS FILLED WITH GRAPHITE IN REDUCING CHIP ADHESION DURING THE TURNING PROCESS OF ALUMINIUM ALLOY AA2025

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ABSTRACT

Chip adhesion is a major problem in the dry machining of aluminum and its alloys. Laser textured Tungsten carbide (WC-Co) insert filled with chemically inactive solid lubricant (micro- sized graphite) was used to reduce tool and chip contact and to promote lubrication on the rake face of the cutting tool. The sliding friction behavior of the tool and chip interface was simulated using a pin on disc apparatus. The performances of the insert when untextured, textured and textured rake surface filled with graphite were investigated by dry turning process on aluminum alloy AA2025. A surface finish of the machined surface and microscopic observation of the tool under different conditions were considered as performance indicators. Laser textured insert filled with graphite outperformed in reducing the aluminum chips by dry turning process. Further, the roughness of the finished work surface were reduced by 40% and 20% when compared with untextured and textured tool respectively.

KEYWORDS: Micro-Texturing, Aluminium, Chip Adhesion, Graphite & Surface Finish

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1. INTRODUCTION

Chip adhesion to the tool rake face is the major problem when machining soft and ductile materials like aluminum. Chip adhesion on the tool can form built up edge or built -up a layer or combination of both depending on the cutting conditions. The built up material affect the actual cutting process resulting in deterioration of surface finish, tool wear by variation in tool geometry and adhesion, fluctuation in cutting force, changing the chip flow direction and chip shape (R. M. Rashad and El-Hossainy, 2006). Machining of ductile materials with an uncoated or coated cemented carbide tool under dry environment will increase the friction between the tool and chip, lead to the generation of heat at the tool -chip interface. This high temperature accompanied by the pressure along the rake surface, cause the adhesion of work material in the vicinity of the cutting tool. Different research groups attempted to arrest the chip adhesion by various approaches such as modification in tool geometry, higher cutting velocity, flood cooling, and diamond tooling (Skingle and Thompson, (1980)). However, such attempts were only successful in a particular regime of the working domain (Iyappan and Ghosh (2015)).

Laser Texturing is an emerging technique for tribological surface modification and cost -effective method for generating micro -reservoir for solid lubricants and hard coatings (A. A. Voevodin et al., (2006)). Their application in internal combustion engines was attempted by researchers in the past (Etsion and Sher, (2009)). However, their application in the metal cutting industry was not investigated in depth. Laser texturing has been proposed by different research groups in metal cutting to reduce chip adhesion to provide reduced tool -chip

contact and reservoir for lubricant. Laser Texturing pattern plays a vital role in improving the tribological behavior of tool substrate. From the work of Enomoto and Sugihara, (2010) it was found that the texture patterns parallel to the cutting edge had less coefficient of friction. Jianxin et al., (2012) studied the effect of different laser textured surface in the dry cutting of steel. They observed that the laser patterns with elliptical hole pronounced lower cutting force, cutting temperature and coefficient of friction when compared with grooves normal and parallel to the cutting edges. Further, the coefficient of friction of the tool was reduced by filling those grooves by solid lubricants.

B. S. Yilbas et al., (2007) experimented the tools with surfaces of WC, TiC, TaC and evaluated the thermal stress developed due to temperature gradients in the laser treated zone. They found that there are high-temperature stress gradients developed below the surface of the titanium and tantalum carbide substrates which had caused the crack initiation below the surface cracks and it was extended over the entire laser treated region. Ling et al., (2013) found that Texturing on the drill bit enhanced the drill bit life and reduce the built -up edge in dry drilling of titanium. There are at least 66% of the improvement in tool life with the textured tool when compared to an untextured tool.

Laser Texturing close to the cutting edge affect the mechanical strength of the tool when machining of high strength materials like titanium. However, machining of aluminum requires good adhesive wear resistance rather than high mechanical strength. Texturing on the rake surface enhance the chip sliding over the rake face of the cutting tool. Kümmel et al., (2015) applied different laser Texturing patterns on the rake surface of the cutting tool to reduce the built -up edge (BUE). The BUE was reduced with microtextured tools with circular holes than microtextured with channels perpendicular and parallel to the cutting edge. An Even textured tool with circular pattern to reduce the wear and BUE formation in at lower cutting velocity, it failed to arrest BUE at higher cutting velocity due to mechanical interlocking of adhering chip material to the rake surface. However, in the work of Kawasegi et al. (2009), it was observed that the micro channels parallel to the cutting edge pronounced lower cutting force when compared with perpendicular texture in turning of Aluminium alloy A5052 using WC-Co inserts. The textures with circular shape hole pronounced lesser cutting force than micro textured one with channel shape. However, their application was limited to cutting speed more than 420 m/min. Shuting and Chang, (2009) did not find any kind improvement with textured tools over untextured tools in the dry machining of mild steel. However, the microtextured inserts with the incorporation of solid lubricants pronounced 30% reduction in cutting force when compared with untextured inserts due to improved lubrication and less tool-chip contact area. Such improvement was not observed on the textured inserts with liquid lubricants.

The objective of the present work is to investigate the effect of microtexturing with different patterns filled with graphite in reducing/eliminating chip adhesion during dry, turning of aluminum alloy AA2025 using Tungsten carbide (WC-Co) inserts. Since high temperature developed due to friction is the predominant reason for chip adhesion on the cutting tool, prior to real machining experiments, the frictional characteristics of aluminum 2024 with untextured and textured WC-Co were simulated through a pin on disc test. Average surface roughness and SEM imaging of inserts after experimentation were chosen as performance indicators to quantify the chip adhesion on inserts.

2. EXPERIMENTAL PROCEDURE

The machining experiments were conducted in CNC turning center in order to investigate the performance characteristics of cutting tool inserts at three different orientations such as i. tool inserts without texture, ii. Tool insert with texture on the rake surface and iii. Tool insert having a textured surface filled with graphite as a solid lubricant. The inserts were tested by dry, turning process on aluminum alloy AA2025. To understand the tribological characteristics between the

tool and work piece, an experiment was performed on the pin on disc setup prior to machining test.

2.1 Lasers Texturing of Turning Inserts

Tungsten carbide, WC-Co is turning insert (TNMA 160408, Make: Cearatizit, Austria) was selected as a cutting tool for all experiments. Laser Texturing of the microchannel pattern was performed on the inserts using Nd-YAG laser at a wavelength of 1064 nm, cutting speed 50 mm/sec and spot diameter of 7m.

The size and shape of the pattern play an important role in chip sliding when the tool is textured. If the texture feature is too wide, the sliding motion of the chip is affected by clogging in the textured region and if it is too small does not reduce the tool-chip contact. The width and depth of the micro texturing directly influence the contact length of the chip material which is sliding over the rake face of the tool. Therefore, efforts were taken to keep the texture width to a fine value. After Texturing the inserts were polished using diamond in a polishing machine in order to remove the re-deposited layer on the surface.

The laser textured microchannels were observed by scanning electron microscope (SEM) (Make: FEI, Netherlands; Model: FEG-200) at a magnification of 500X to measure the dimensions of the microtextured feature. Figure 1 (a & b) shows the SEM image of the laser textured insert and its magnified view respectively. It reveals that the width of the microchannel is approximately 55 microns which can serve as micro-voids to facilitate reduced tool-chip contact and microreservoir for solid lubricants. Further, the laser textured insert was filled with micro-sized graphite particles having a size between 2 μ m to 5 μ m to improve the anti-frictional characteristics.

Figure 1(a): SEM Image of Textured Tool Inserts (b) Magnified View of Selected Laser Textured Region

2.2. Tribological Testing of Textured Surface

A test was conducted on the pin on disc apparatus (Model: TE-165-LE, Make: Magnum Engineers) to study the frictional behaviors of untextured and textured carbide. The tribological experimental setup is shown in Fig.2. As our aim is to study the frictional behavior between the tungsten carbide tool and aluminum AA2025 during dry machining, carbide pins of 8 mm diameter and aluminum disc of 150 mm were fitted on the pin on disc apparatus. The maximum disc rotational speed of the equipment was 2000 rpm. The sliding velocity was selected as 80 m/min which is equivalent to the maximum cutting velocity used in the machining test. The normal load applied is 20N and duration of the test is 5min. All tests were conducted in a dry environment.

Figure 2: Pin on Disc Setup for Tribological Characterization

2.3. Turning Test

The turning experiments were conducted on CNC lathe (Make:MTAB Engineers Pvt.Ltd, Model: Max turn plus) having maximum spindle power of 4 kW. Aluminum alloy AA2025 which is having a more adhering tendency in machining was taken as work material for all experiments. The chemical composition of the work material and the machining conditions are given Table.1 and Table 2 respectively.

Table 1: Chemical Composition of AA2025

Element	Cu	Fe	Si	Mn	Zn	Ti	Al
Weight %	4	0.6	0.5	0.4	0.2	0.15	94.15

Table 2: Machining Parameters

Work Material	Aluminium 2025
Tool Material	WC-Co insert
Machine tool	CNC turning center (make: MTAB)
Cutting Speed (m/min)	40, 60, 80
Feed (mm/rev)	0.08, 1, 1.2
Depth of cut (mm)	0.5

3. RESULTS AND DISCUSSIONS

Experiments were carried out to investigate the performances of the tool insert when its rake surface is untextured, textured and textured rake surface filled with graphite during the dry turning process on aluminium alloy, AA2025. Tribological and machining test were conducted and results are discussed as follows.

3.1 Tribological Test

Figure 3 shows the coefficient of friction pronounced by untextured, textured and textured pin filled with graphite against aluminum disc at a sliding velocity 80 m/min in a dry sliding environment. The method of tribological test was explained in section 2.2. Results show that, the untextured carbide produced an unsteady and large magnitude of the frictional force against aluminum in dry sliding. It is obvious that there was adhesion of aluminum to untextured carbide pin due to high temperature activated diffusion which in turn increase the friction. This is called as slick-slip phenomena (jerking motion of the pin when slinging against disc) at the pin and disc interface during sliding motion. In contrast to this observation, the textured carbide pin has produced a lower magnitude of the frictional force and the random fluctuation was observed after the first few seconds of sliding. This was evident from the graph that there is a reduction in the mean value of coefficient of friction from 0.42 to 0.25 due to reduction in contact area between the pin and disc in the case of textured pin. The random fluctuation observed in the graph was due to entrapment of wear debris in the textured region,

The smooth and steady sliding of carbide pin on the disc material was observed during the entire duration of the test when the textured pin filled with graphite was used. The mean value of coefficient of friction observed was 0.21 which is slightly smaller than a pin with textured alone. The improvement in performance is due to reduced tool and chip contact and release of graphite particles from the micro-voids during sliding. This indicates that there were not much improved due to graphite filled in the textured zone. However, their suitability has to be tested in a real machining test.

Figure 3: Coefficient of Friction of Untextured Carbide, Texturedcarbide Textured and Graphite Filledcarbide pin Against Aluminium disc in dry Sliding

3.2 Machining Test

3.2.1 Preliminary Machining Test

The preliminary machining experiments were conducted on the soft and ductile aluminum AA2025 using untextured carbide insert at a cutting velocity 40 m/min for the machining length of 0.5m to reveal the challenges in machining. The SEM and Energy dispersive spectroscopy (EDS) analysis were done to investigate the post machining observation on the cutting tool rake surface and chemical composition of the tool in order to understand whether the work material has adhered to the tool surface or not. Figure. 4 (a & b) shows the SEM image and EDS of the rake face of the cutting tool after machining. From the SEM image of the tool rake face, it was found that there is a severe adhesion of aluminum over the rake face of the insert. The EDS analysis revealed that, strong bonding caused between insert and chip. Such adhered lump of material flow from rake surface to flank face, which rubs on the machined surface and increases the surface roughness by re-deposition.

Figure. 4 (a): SEM Image at Magnification 500x and (b) EDS of Aluminium Adhered on the Rake Face of the Cutting Tool

3.2.2 Surface Roughness

Chip adhesion to the rake face, mostly affects the surface quality of the parts produced. Figure. 5 shows the variation of the roughness of the machined surface produced by untextured, textured and textured+graphite filled carbide inserts at different feed rates 0.08, 0.1 and 0.12 mm/rev in the dry turning of aluminium AA2025. It was found that the surface roughness of the surface machined with the textured tool are lowered by 27% than that of the untextured inserts at cutting velocity 80 m/min and feed rate 0.12 mm/rev. However, with the application of graphite filled textured tools, lowest Ra value was observed by a reduction of 40% when compared with untextured inserts under the same machining conditions. Similarly, a good performance is observed from the graph drawn for the feed rate of 0.08 and 0.1 mm/rev also.

Figure.5: Variation of Surface Roughness (Ra) With Different Feed Rate and Cutting Speed 80 M/Mi

Figure 6. shows the variation of surface roughness of the surface produced by untextured, textured, textured+graphite filled inserts at cutting velocities 40, 60, 80 m/min in dry turning of aluminium AA2025. Surface roughness observed on the surface machined with textured tool produced was much lower than that of untextured one. The improvement was approximately 16% at a feed rate of 0.10 mm/rev. The variation in surface roughness was not much significant at lower cutting velocity. It is due to less heat generation in the tool -chip interface which is not enough to adhere the work material on the tool by diffusion. However, at higher cutting velocities, the textured insert produced lower surface roughness value than surface produced by the untextured insert. The Ra Value was reduced by approximately 38% at the cutting velocity of 80 m/min with the textured tool. This was due to reduced tool-chip contact in later condition as the temperature is not enough to cause the adhesion of the chip on the rake face of the tool inserts. The graphite filled textured insert pronounced lowest surface roughness when compared with untextured and textured carbide inserts. Ra value reduced approximately 40% and 20% with textured+graphite filled inserts when compared with untextured and textured inserts respectively at a cutting velocity of 80 m/min and feed rate of 0.12 mm/rev. The improved surface roughness is due to lubrication properties of layered graphite and lower tool-chip contact of textures on the rake surface. Graphite layer has been released during sliding of a chip on the rake face, which provides lubrication and act as a barrier to chip adhesion.

Figure 6: Variation of Surface Roughness (Ra) with Different Cutting Speeds and Feed Rate 0.12 mm/rev

The effect of Laser textured Tungsten carbide (WC-Co) insert and laser textured carbide inserts filled with graphite in reducing chip adhesion during machining of aluminum AA2025 was studied and following conclusions were construed.

- A simulative tribological test was carried out to investigate the frictional behavior of untextured, textured and textured inserts filled with graphite micro-sized particles. The results clearly indicated that the coefficient of friction between work material and textured+graphite filled inserts reduced approximately by 12% and 90% respectively when compared with untextured and textured inserts.
- From the SEM and EDS analysis of the tools used for machining, it was found that there is a severe adhesion of aluminum (almost 100% by weight) over the rake face of the cutting tool which deteriorates the surface finish of the machined surface.
- The microtextured surface significantly improved anti-adhesiveness of aluminum at the tool- chip interface which was established through the comparison of an average surface roughness of the machined surface. The Ra value was lowered by 27% than that of the untextured inserts at cutting velocity 80 m/min and feed rate 0.12 mm/rev.
- There is a further improvement in anti-adhesiveness of the tool by filling the micro-textured portion of micro sized graphite powder which is chemically inactive against aluminum. The performance of the graphite filled textured insert was improved at higher cutting velocities and feed rates which was construed through the surface roughness of the machined surface. Ra value reduced approximately by 40% and 20% for textured+graphite filled inserts when compared with untextured and textured inserts respectively at a cutting velocity of 80 m/min and feed rate of 0.12 mm/rev.

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