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Experimental Study on Evaluating the Effect of Micro Textured Tools in Turning AISI 316 Austenitic Stainless Steel

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Abstract

Austenitic stainless steels show different machining characteristics as compared with the carbon steels or ferritic and martensitic steels due to their inherent properties. High ductility, low thermal conductivity, high tendency to work hardening and large built up edge formation on the cutting tools are the main reasons for the low machinability of austenitic stainless steels. The present study therefore, aims in improving the tribological characteristics at the tool-chip interface by surface texturing the cutting tools. The textures on the rake face of WC/Co carbide tools were obtained by laser machining. The effect of texture lay directions with respect to the cutting edge and chip flow was studied. The turning tests were performed using textured and conventional tools for various cutting environment. For studying the cutting performance cutting forces and tool wear were analyzed. SEM and EDS analyses were done to understand the tool surface characteristics. Results show that the textures can modify the adhesion of workpiece on the rake face as compared to the conventional tool and can help in reducing the cutting forces. Moreover, the lay direction of the groove significantly affects the tool-chip contact area and hence reduces the friction at the tool chip interface.

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Keywords: Cutting performance; Surface texture; Carbide tools; Tool wear; Austenitic stainless steel

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1. Introduction

Many industries such as food processing, petrochemical, brewing, aeronautical and naval have extensively used austenitic stainless steel for manufacturing of critical components because of their excellent mechanical properties and good corrosion resistance [1,2]. However, this steel offers challenge for machining due to its high tensile strength, low thermal conductivity and high strain hardening which causes rapid rise in cutting force, temperature and results in poor surface finish [3]. Further the chip produced while machining adheres to the cutting tool leading to BUE formation [1].

Chip adhesion can degrade the surface finish and trigger the tool wear. For solving the issue, many researchers have tried improving the surface coatings and geometry of the tool. Biermann et al. [4] tried working with different types of hard coatings such as CrN, TiN, AlCrN, AlTiN and TiAlN for micro-milling of austenitic stainless steel. They found that AlTiN and TiAlN coatings exhibited good results due to their high hardness as well as lower chemical reactivity between the workpiece and the coatings whereas CrN and TiN coated tools were subjected to spalling and chipping respectively due to their high reactivity between the workpiece and tools. For improving the anti-adhesion property, Sugihara and Enomoto [5] tried creating nano/micro scale grooves on the rake face of the tools and observed a significant decrease in chip adhesion on tool's rake face while wet cutting aluminum alloy using nano/micro textured tools. Their work highlights that the surface texturing has potential in improving the adhesion resistance.

Zhang et al. [6] has successfully fabricated micro and micro/nano scaled textured TiAlN coated tools which showed high anti-adhesion resistance compared to the conventional TiAlN coated tool while machining AISI 316. The main reason for the improved adhesion resistance is due to the presence of textures which promote effective lubrication at tool chip contact and decrease the contact area. Dimple and channel textured tools where used by kummel et al. [7] for machining plain carbon steel. Their work shows that BUE stability was improved for the dimple textured tools due to the mechanical interlock of the chip adhesion. Fatima et al. [8] tested rake flank face structured cutting tool in orthogonal turning of AISI4140 steel and found that both the friction coefficient and Iron (Fe) weight % was reduced compared to the conventional tool. Qi and Li [9] studied the orthogonal cutting of Ti6Al4V with micro textured tools under dry and MQL conditions. Their results show that the presence of grooves under MQL reduces cutting force, temperature and tool chip contact area whereas in dry condition, grooves have improved the heat transfer capability.

The benefits of textured tools compared to conventional tools are that they provide effective lubrication, break the tool chip contact, impart hydrodynamic lift and trap debris. Moreover, the structured tools results in lowering the cutting forces, tool wear and improving the anti-adhesion properties. Therefore, present work focuses on studying the influence of micro scale textures on WC-Co based uncoated insert while turning AISI 316 austenitic stainless steel. The influence of effect of groove lay directions under dry and wet conditions was studied and compared with the conventional insert in terms of the cutting forces and tool wear analysis.

2. Experimental procedure

2.1. Preparation of Textured Inserts

The tool material selected for the experiment is uncoated WC-Co cemented carbide insert with tool grade (SPUN 120308 THM08 grade). The tool is exposed to laser light from Nd:YAG laser (TEEM Photonics, France) with wavelength of 532 nm and pulse duration of 650 ps was used. Two different micro textured tool, a) Parallel to chip flow (PA) and b) Perpendicular to chip flow (PE) and c) the conventional insert (CO) are used for the study. The groove width and depth is measured using Olympus confocal microscope. The average measured values of groove width, depth and pitch are 50, 7 and 100 μm respectively. Figure 1 shows the optical image of the micro textured tool.

2.2 Cutting Test

The work-piece material chosen is AISI 316 austenitic stainless steel. Turning operation is carried out in VDF lathe (Heidenreich & Harbeck company) using both textured and conventional inserts and the tool holder is CSBPR 2525M12. The effect of both dry and wet cutting environment was studied. The lube named Mak sherol B was used for flood environment. The cutting speed, feed and depth of cut are chosen as 150 m/min, 0.16 mm/rev and 1 mm respectively and the cutting length is limited to 20 mm for avoiding the flank wear.

Cutting forces are obtained using Kistler 9257B dynamometer. The tool wear morphology is examined using a FEI INSPECT F50 scanning electron microscope (SEM) operating at 30 kV. The chemical composition at the worn region is identified by energy dispersive X-ray spectroscopy (EDX).

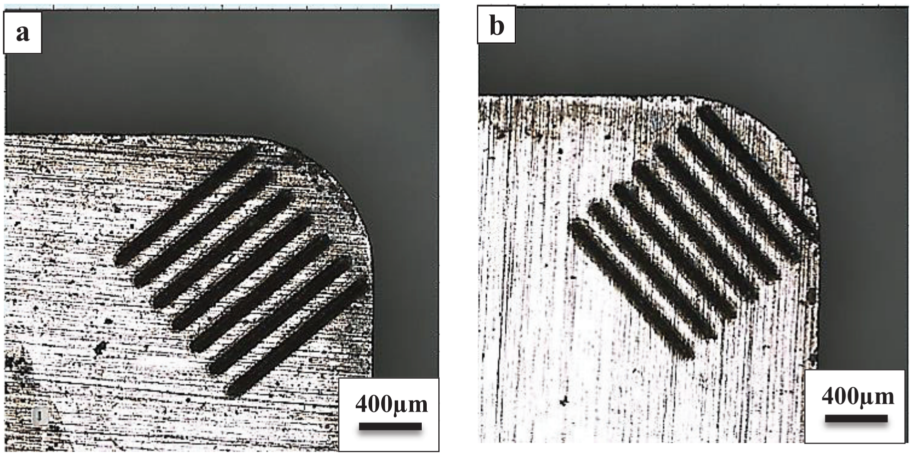

Fig.1. Optical images of micro scale textured tool a) parallel to chip flow (PA) and b) perpendicular to chip flow (PE)

3. Results and Discussion

3.1. Force

The average plots for cutting and feed force values are shown in Fig.2. The friction force (P_{fric}) and normal to friction force (P_{normal}) are calculated based on the following equations (1) and (2):

$$P_{fric} = P_{xy} \cos\alpha + P_z \sin\alpha \quad (1)$$

$$P_{normal} = P_z \cos\alpha - P_{xy} \sin\alpha \quad (2)$$

Where P_z is cutting force, P_x is feed force, $P_{xy} = P_x / \sin(90-\theta)$, α is orthogonal rake angle, θ is side cutting angle.

Under both dry and wet condition, the cutting force has got reduced for the textured tools (PA, PE) as compared to conventional tool (CO). Fig.2 shows that the lowest feed force values were obtained by PA and PE tools under dry and wet condition respectively. Moreover, it has been observed that the wet condition has favored in the reduction of forces as compared to the dry condition.

It can be clearly seen that the forces were least in case of PA tool (Fig.2). Under dry condition, the average cutting, feed, friction and normal forces were reduced by 5.1%, 5%, 4.9% and 5.2% respectively by using textured tool (PA) as compared to the conventional tool (CO). However, under the wet condition, cutting force and normal force got reduced by 4.3% and 4.7% respectively whereas feed force and friction force got increased by 3.6% and 2.1% respectively for PA tool as compared to the CO tool.

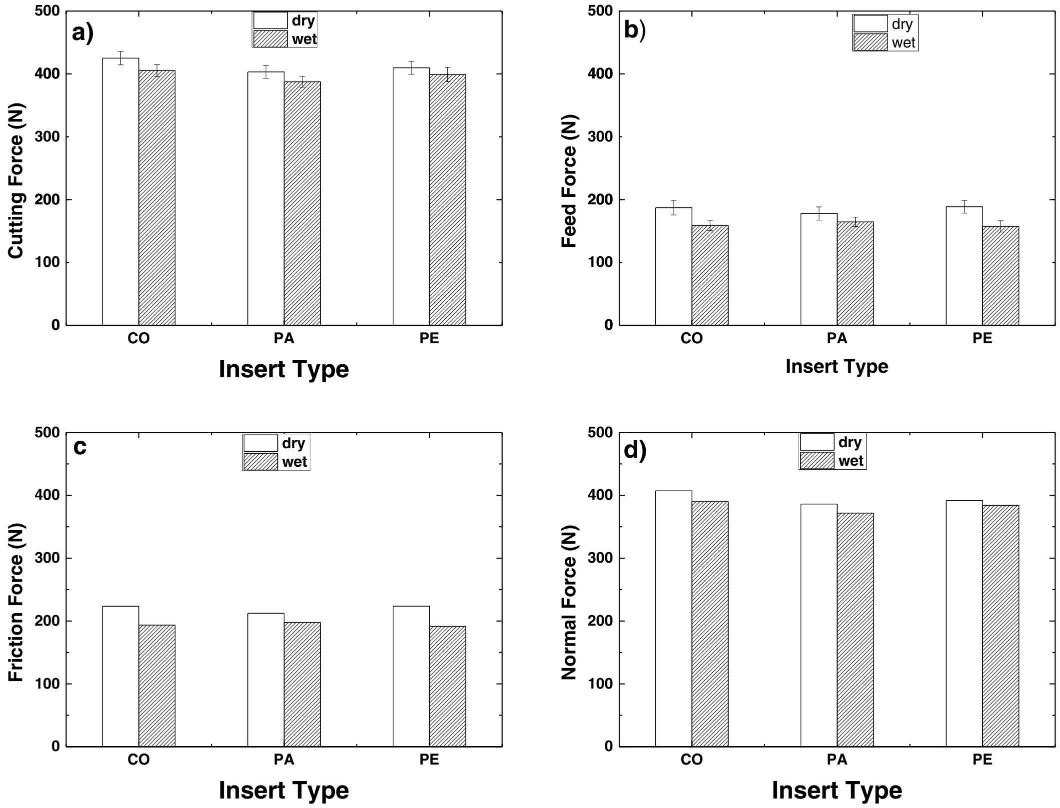

Fig.2. a) Cutting force b) feed force c) friction force d) normal force for different tools

The main reason for the reduced forces in case of textured inserts is the reduction in the direct contact between the tool and chip. The grooves help in breaking the tool chip contact and leads to lowering the adhered contact area as well as the Fe deposition (Fig.3 & Fig.4a). Therefore, the lesser contact area results in smaller friction coefficient at the tool-chip interface [9].

Also, micro groove combined with flood lube has effectively reduced the force compared to dry condition (Fig. 2). The main reason for this behavior is that the groove surface can store the lube which helps in improving the effective lubrication between the tool and the chip leading to lower adhered area and Fe deposition % as shown in Fig.3 & Fig.4a.

3.2. Tool Wear

SEM images of the inserts after machining is shown in the Fig.5, where Fe (Iron) element is shown in red color. The Fe deposition % on the rake face is plotted in the Fig.3. Further the adhered area and the sticking contact length is measured using the imageJ software. As seen from the Fig. 3& Fig. 4a, the Fe adhesion and contact area is lesser in textured inserts as compared to the conventional tool inserts. Moreover, the Fe deposition % and contact area is reduced under wet condition as compared to the dry condition for all tool inserts.

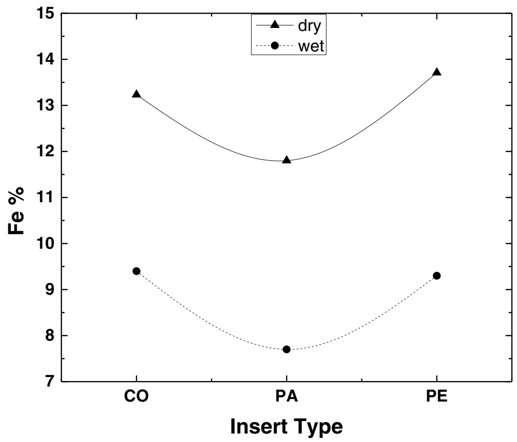

Fig.3. Fe deposition % for different cutting tool inserts

The reason for the lesser Fe deposition for textured insert as compared to the conventional insert is due to the hydrodynamic lift caused by the air or lube present in the groove which helps in breaking the direct contact between the tool and chip and leads to lowering both contact area and Fe deposition [10]. Under wet condition micro groove was able to store the oil, form lubricant film between the tool-chip interface and remove the heat away from the cutting zone whereas in dry condition the air gaps in the groove participates in heat convection only. Therefore, the effect of lubrication and cooling was improved in case of wet environment as compared to dry condition which leads to lowering the contact area and Fe adhesion (Fig.3 & Fig.4a). This is the main reason for lower forces in wet condition as compared to the dry condition (Fig.2).

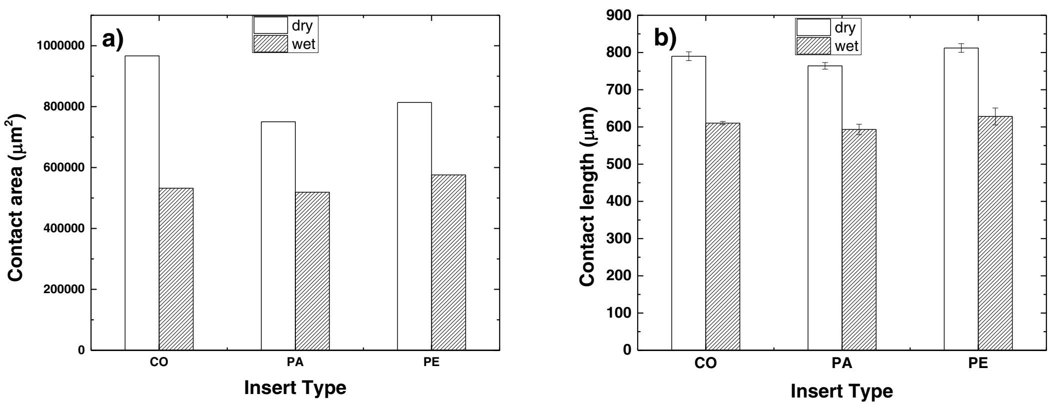

Fig.4. a) Tool chip contact area b) Sticking contact length for all the tools

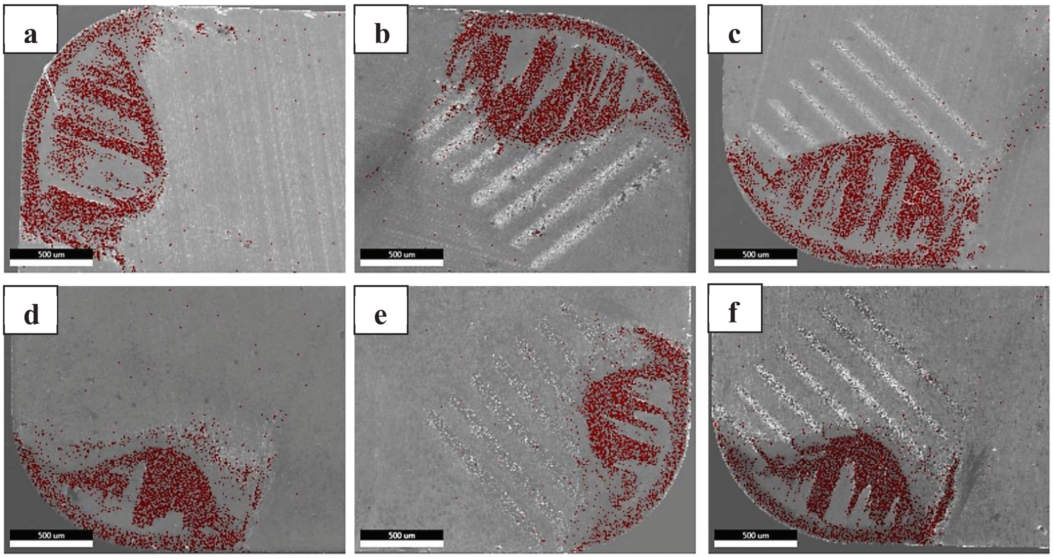

Fig.5. Fe mapping on SEM image of the machined tool inserts a) CO (dry), b) PA (dry), c) PE (dry), d) CO (wet), e) PA (wet) and f) PE (wet)

Further on close examination of the texture (Fig.6), it can be seen that, Fe adhesion is less inside the groove as compared to the outside groove. The inside area of the groove participates in hydrodynamic lift caused by the lube or air whereas the outside area of the groove is subjected to high localized stress leading to higher contact and adhesion. Therefore, the groove on the tool can break the tool chip contact leading to lesser contact area resulting in reduced Fe adhesion and thus improves the tribology at tool chip interface.

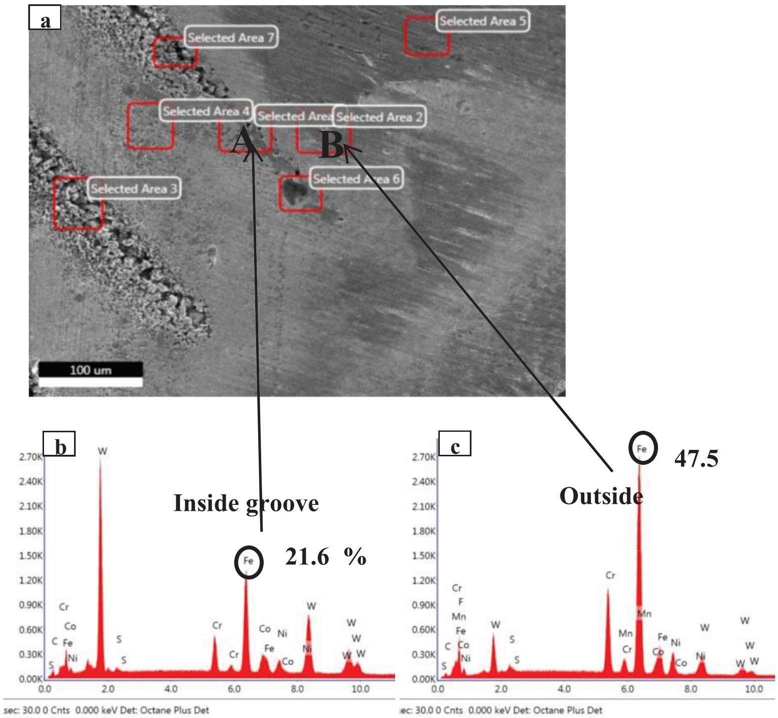

Fig.6. a) SEM image of PA textured tool (wet) and corresponding EDS analysis for (b) area A inside groove and (c) area B outside groove

3.3. Effect of Lay Direction

The relative chip flow direction is analyzed with respect to the texture direction and the Fig.7 shows the angle between the chip flow and lay direction of texture.

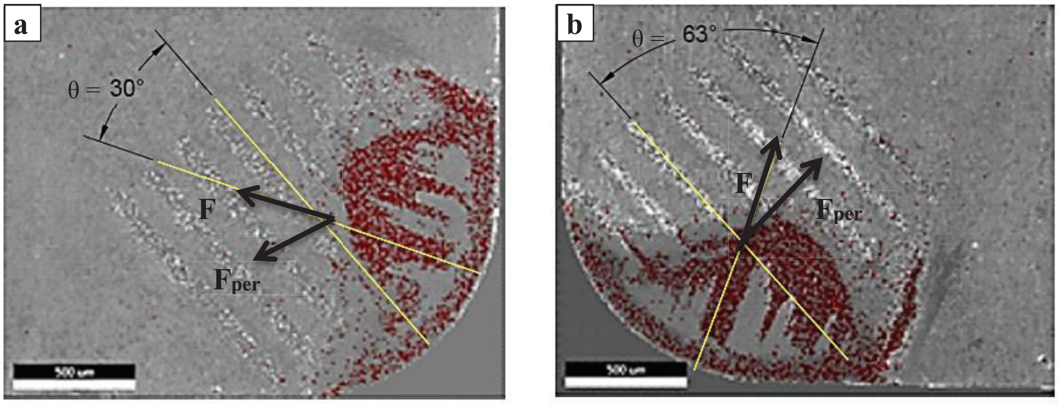

Fig.7. Relative chip flow with respect to lay direction a) PA b) PE tool

The main retarding force which is perpendicular (F_{per}) to the texture is calculated based on theory [11].

$$F_{per} = F\sin\theta \qquad (4)$$

Where F is the force along the chip flow direction and F_{per} is perpendicular to the texture which resists the chip flow and θ is angle between the chip flow and texture lay direction. Smaller the θ value results in lowering the F_{per} values. The measured relative angle for PA tool was lesser as compared to the PE tool (Fig.7). This results in lower F_{per} value for PA tool as compared to PE tool. The lower resistance offered by PA tool could be a reason for low cutting force values and reduction in Fe deposition percentage as compared with the other tools.

4. Conclusion

The cutting performance of microscale textured inserts was compared with the conventional tool inserts under dry and wet cutting environments. Based on the present study following conclusions can be drawn:

- Micro textured tools reduced the cutting, feed, friction and normal forces under both dry and wet environments as compared to the conventional tools. Maximum reduction of 5% in cutting force was obtained in case of PA tool.
- Surface texturing helps in breaking the tool chip contact that results in reducing Fe deposition on the tool's rake face.
- Under wet environment, the effectiveness of lubrication was found to be better for the micro textured tool as compared to the dry environment.
- The lay direction also affects relative angle between the chip and texture which in turn affects the F_{per} and contact area.

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