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Single and dual-groove textured tools for titanium machining

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Abstract
The present study deals with the performance of the textured tungsten carbide cutting tools for titanium machining. In order to simplify the tool-chip interaction with textured tool rake surface, a single and dual-groove texturing method has been adopted. Nd: YAG nanosecond laser has been used for fabricating single and dual-groove textures. Further, the textured tools have been PVD coated with nitride-based coatings. The developed tools were employed for turning aerospace-grade titanium alloy under a dry cutting environment. Cutting forces, average interface friction, and adhesion behavior of the different textured and coated textured tools have been recorded and presented. Variable interface friction associated with single and dual-textured tools changed the adhesion behavior and chip undercutting. Uncoated dual groove has offered the highest resistance to the chip flow and registered maximum friction coefficient. AlTiN single and dual-groove textured tools have reduced friction by 7.3% and 23.3%, respectively.

Keywords Titanium; Textured tools; PVD coating; Machining

1. Introduction

Ti6Al4V alloy is one of the most widely used materials for the aerospace, automobile, and biomedical sectors. The final product manufacturing phase needs machining of Ti6Al4V alloy. Machining of titanium alloy has been a challenging task for metal cutting researchers. High yield strength, lower thermal conductivity, and high chemical reactivity of Ti6Al4V cause major tool degradation during machining [1]. Newer surface engineering methods have been developed (laser texturing, PVD coatings, surface treatment, etc.) to reduce the rate of tool degradation and improve machining performance [2].

Laser texturing on tungsten carbide cutting tools has been widely investigated in the last decade; however, a balance between the cost-effectiveness of texturing and tool performance is yet not achieved. Texturing of tungsten carbide tools might increase the cost of manufacturing as additional laser processing is desired after the final tool manufacturing stage. Although textured cutting tools have obtained the reduction in cutting forces, tool wear, and the cutting temperature [3–6], the chip adhesion inside textures and resulting influences on friction coefficient during machining are highly complicated. Some studies have reported that textured cutting tools improve surface finish however there is no correlation between texture parameters and surface finish parameters [7]. Uncoated textured tools have suffered severe chip adhesion during machining [8]. The microtextures undercut the thermally softened chips, which get deeply impregnated inside the space offered due to the presence of microtextures. The phenomenon is often termed derivative cutting [8] or interfacial multipoint microcutting $(IMP-\mu C)$ [9]. The occurrence of this behavior is independent of different tribological conditions relevant to engineering applications (depending on loading, temperature, and sliding conditions). In order to reduce the chip undercut and consequent $IMP-\mu C$ phenomenon, PVD coatings can be one of the methods to mitigate the frictional heat at the secondary tool-chip zone. Similar to texturing, PVD coating is another additional process for tool manufacturing and shall be justified with the tool performance. Due to widely available methods of industrial coating, its cost and processing are convenient for cutting tool industries.

The present research is an attempt to analyze the friction and adhesion behavior for textured cutting tools during titanium machining. For the sake of simplicity, single and dual-groove textured tools have been fabricated (owing to the maximum probable contact length at a selected machining condition).

2. Materials and method

The straight-grade tungsten carbide tools (WC-6Co, WIDIA CNMA120408) have been used for texturing and final machining experiments. Nanosecond (solid-state Nd: YAG) laser has been used for texturing of carbide cutting tools. The laser processing parameters are kept the same as in previous research conducted by our research group [7,10]. Laser pulses hit the tungsten carbide to eject the metal binder from the surface. The molten binders (Cobalt) loosen the WC grains and eject the WC grains with subsequent laser pulses. The texture parameters are kept to Width of texture = $\mathbf{120\ \mu m}$, depth of texture $\sim\mathbf{30\ \mu m}$, the distance of texture from the cutting edge = $\mathbf{150\ \mu m}$ with two variations along the contact length (single and dual groove). The microgroove has been fabricated to sufficiently cover the zones parallel to the tool nose region, principle cutting edge, and auxiliary cutting edges. Textured tools have been polished before depositing PVD coatings. AlTiN coating has been deposited on the untextured and textured cutting tools using the PVD coater (Oerlikon Balzer, India). Commercially available AlTiN coating has been administered on the polished tool surfaces with a thickness of $\sim\mathbf{1.5\ \mu m}$. The coating morphology, cross-section, growth, and chemical stoichiometry of the PVD-coated untextured cutting tools can be seen in our research [11].

Ti6Al4V alloy has been used as a workpiece material for turning in a dry environment. Machining parameters have been kept constant to $v_c = 90\ m/min, f = 0.12\ mm/rev, a_p = 0.5\ mm$. All experiments were run for 1 min cutting time. The cutting forces were recorded using a piezoelectric dynamometer (Kistler 9129AA) and used for calculating the apparent friction coefficient(μ_{app}). Adhesion of work material over the tool and inside the grooves was analyzed under a scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDS: Bruker-ASX QuanTax200).

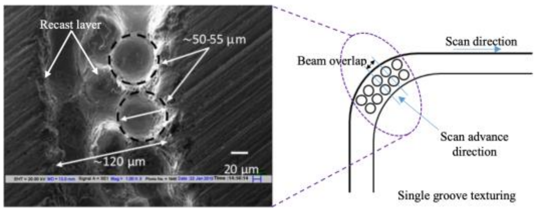

Fig. 1 Laser processing on tool rake face for groove generation

3. Results and discussion

The results pertaining to the apparent friction coefficient are shown in Fig. 2. Amongst various tools, dual groove textures have significantly reduced friction coefficient for coating conditions. In the case of the dual-groove uncoated tool, high interaction of chip-underside with texture edge cause heavy undercutting, which causes high friction. Fig. 3 shows the adhesion on the coated tools with different textures.

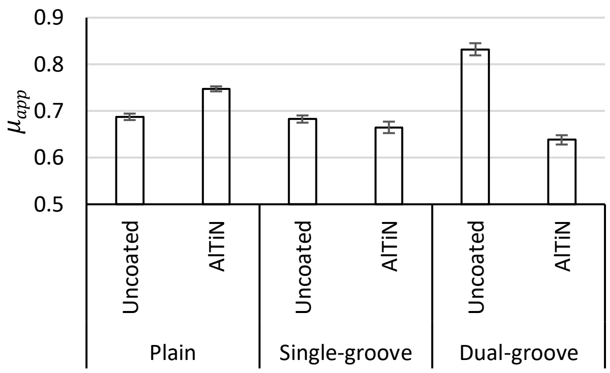

Fig. 2 Apparent friction coefficient for different cutting tool conditions

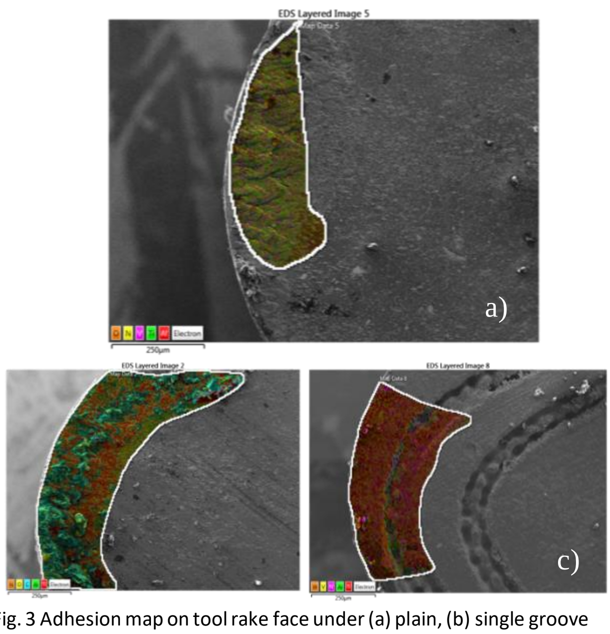

Fig. 3 Adhesion map on tool rake face under (a) plain, (b) single groove and (c) dual groove AlTiN coated tools

Adhesion area for different tools remain similar and mostly concentrated to the tool nose. A high concentration of titanium is evident on plain tool (no texture) (Fig. 4), which suggest heavy adhesion of work material due to consecutive stacking of the flowing chips. The concentration of titanium is reduced for single and dual grooved cutting tools. The results support the reduction in the adhesion characteristics of work material due to the combined effect of texturing and coating over the cutting tools.

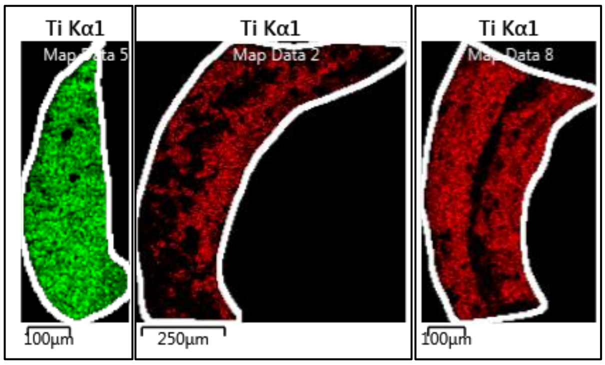

Fig. 4 Titanium adhesion on the tool rake face

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