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Wear behaviour of coated carbide tools during machining of Ti6Al4V aerospace alloy associated with strong built up edge formation

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ABSTRACT

In the machining of Ti alloys, it is challenging to optimise the cutting tool life and process productivity. It is not a trivial task to find an efficient strategy to improve the tool life during machining of Ti alloys using surface engineered tooling. In the case of rough turning operation with strong built up edge formation we establish that it can be achieved through the application of self-lubricating TiB_2 PVD coating. It has been shown that the application of a TiB_2 coating results in tool life improvement by over 60% compared to the uncoated tool and over 70% compared to the TiAlN coated tool. Comprehensive characterization of the coated vs. uncoated cutting tool wear performance was performed using optical 3D imaging, SEM/EDX and XPS methods. Various micro-mechanical characteristics of the TiB_2 coating were evaluated. It was determined that tool life improvement using the TiB_2 coating is mostly related to the ability of the coating layer to provide self-lubrication effect and in this way, very efficiently dissipate frictional energy. The coating also exhibited less substrate exposure as it fails indicating better protection of the coated tool surface. This is of particular importance for machining of materials like Ti, which have strong sticking intensity. It has been demonstrated that the TiB_2 coating combines beneficial micro-mechanical characteristics and self-lubricating properties due to the formation of B-O tribo-films on the tool surface under operation. These tribo-films serve as a liquid lubricant formed in-situ on the tool surface under the elevated temperature of cutting. The formation of liquid tribo-films is an effective way to address intensive adhesive interaction followed by built up edge formation at the tool/chip interface, which is typical for roughing operations during Ti machining.

1. Introduction

Titanium alloys are regarded as difficult-to-cut materials for the following reasons [1–8]: 1) their high-temperature strength; 2) a relatively small contact area is created that leads to high stresses at the tool edges; 3) the strong chemical affinity of titanium to the cutting tool materials, including the coating leads to intensive adhesive interaction at the chip/tool interface resulting in built up edge formation. The temperatures generated in titanium machining are much higher than those of steel machining [6]. These phenomena are responsible for the rapid wear of carbide tools [1,3,6]. To achieve a reasonable tool life, the cutting speeds in titanium machining using carbide inserts are kept low [9] and therefore, the productivity of machining is reduced. Thus, it is of utter importance to consider ways to improve the tribological performance during machining of Ti alloys. Two major strategies are: (i) application of coolant/lubricants that can be efficiently supplied to the cutting zone. This could be solved through high pressure coolant supply to the cutting zone [10] (ii) machining with surface engineered tooling, mostly with PVD coated tools [11]. Two major categories of PVD coatings that are widely used for Ti machining are hard coatings [11] and self-lubricating coatings [12]. In current practice the most dominant hard coatings are TiAlN-based [13], which is also true for Ti machining [11]. However due to intensive sticking of the titanium to the tool surface a severe cohesive debonding of the hard coating layer could take place [12,14] so that quite often uncoated tools behave better than coated tools in this application [14]. This situation could be better tackled by considering other coating compositions. Amongst newly designed coatings, borides have shown some promise for machining of Ti [15]. TiB_2 is known to have high hardness, chemical and thermal stability at room and elevated temperatures [15–19]. This combination of properties makes TiB_2 a very promising material for cutting tools application

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Table 1
Cutting data for the experiments performed.

Cutting data						
Machining operation	Cutting tool substrates	Workpiece material	Hardness, HRC	Speed, m/min	Feed, mm/rev	Depth of cut, mm
Turning	Kennametal CNMG432 Grade K 313 Turning inserts	TiAl6V4 alloy	37–38	45	0.15	2

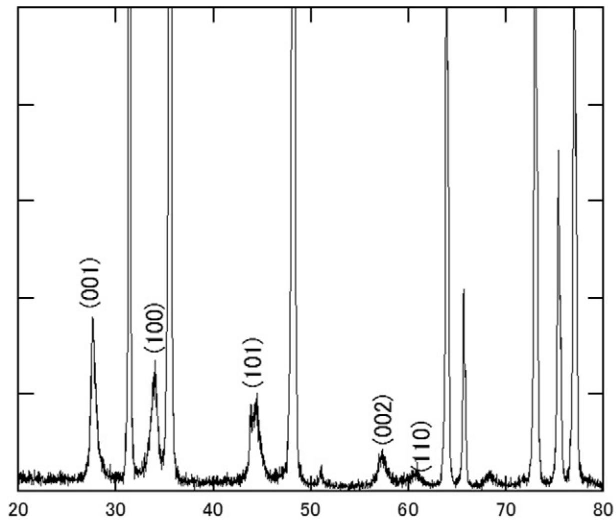

Fig. 2. XRD data on the monolayer TiB_2 coating.

especially when we are dealing with intensive built up edge formation. But at the same time, TiB_2 coatings are usually brittle, with high residual stresses and low adhesion to substrate [16,17] which is not desirable for machining of titanium alloys. However, such issues can be altered through the variation in deposition conditions [19,20]. Magnetron sputtering in an inert atmosphere seems to be the most suitable method of depositing this compound for cutting tool applications [19,21]. It has been shown that TiB_2 can be successfully used for coating metal cutting tools where it is necessary to address both built up edge formation during operation and high abrasion resistance such as machining of high Si (around 16%) Al 319 alloy [22,23], where it outperforms TiAlN coating [22]. Using TiB_2, it is possible to consider another coating design strategy that aims at improving the self-lubricating properties within the cutting zone [12]. Self-lubricating properties of the coating layer develop thorough formation of tribo-films on the friction surface in operation. In general, there are two major categories of beneficial tribo-films that are forming on the coated tool surface: thermal protective and lubricious [12,24]. Due to intensive adhesive interaction typical for machining of Ti alloys that results in intensive built up edge formation, it is of highest importance to enhance lubriciousness during Ti machining [12]. Moreover it is also very important that the tribo-films formed in-situ on the tool surface transform to liquid under the high operating temperature [25]. In this way the efficiency of lubrication is strongly enhanced and the machinability of Ti6Al4V alloy is improved. The prime novelty of this approach is the development of the coating with enhanced self-lubricating abilities combined with optimised structure and properties to better sustain very challenging operating conditions of Ti alloys machining. The main goals of this paper are to compare wear performance of coated vs. uncoated carbide tools and outline the ways for future coatings development under heavily loaded rough turning operations during machining of Ti6Al4V alloy associated with intensive built up edge formation.

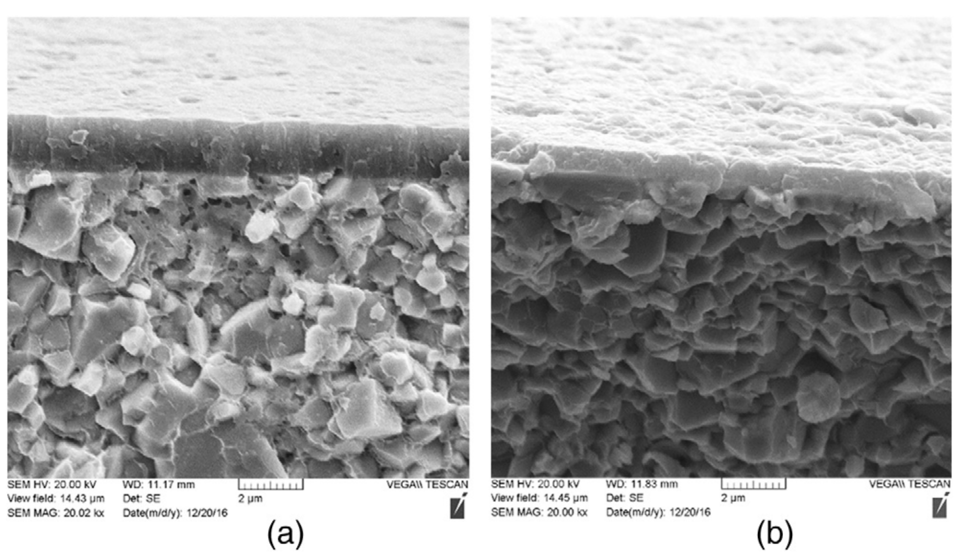

Fig. 1. SEM images of fracture sections of studied coatings: a) TiAlN; b) TiB_2.

Table 2
Micro-mechanical properties of the coatings studied.

Coatings	Architecture	Properties						
		Thickness, microns	Hardness, GPa	Elastic modulus, GPa	H/E	H^3/E^2	Plasticity index	Residual stresses, GPa
TiAlN	Monolayer	1.7	30.1 ± 8.4	550 ± 82	0.055	0.090	0.52	-2.391 ± 0.292
TiB_2	Monolayer	1.1	15.5 ± 4.3	510 ± 77	0.030	0.014	0.62	-0.633 ± 0.0838