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Effect of Rake Face Reinforcement on Cutting Tool Life of Cemented Carbide Tools during Turning of a-Titanium Alloy

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A B S T R A C T

Key words:

This study analysed the wear mechanism of different cemented carbide tool and the effect of reinforcing the rake face of the best wear resistant cemented carbide tool during the turning of α-titanium alloys as a means of determining the most appropriate cutting tool and optimum tool geometry for the cutting operation. Three titanium alloys: BT1.00, BT3-1 and BT-5.1 were used as the work piece materials. The cutting tools used are cemented carbide tools BK8, BK6, BK60M, BK100M, BK10X0M, T5K10 and T15K6. The cemented carbide tools come under the Russia standard (GOST). The cutting operations were carried out dry for the three work piece materials used. Cutting conditions chosen are; cutting speed, v, between 40-60m/min; cutting feed, s, 0.3mm/rev; and cutting depth, t, 1.5mm. The peculiarity of contact flow process and the wear tendency of the cemented carbide tools account for the necessity to reinforce the rake face with a negative fascia. In respect of this, the fascia has the following parameters: rake face=00, supporting fascia= -150, width of supporting fascia= 0.20-0.25mm. Results of the experiment helps to determine the optimum cutting speed and parameters of type of tool materials that suit different types of production.

1. Introduction

Metal cutting is one of the most extensively used manufacturing processes, and its technology continues to advance in parallel with the developments in material science. The productivity and accuracy of the metal removal operations depend on machining process parameters, cutting conditions and cutting tool geometry as well as the workpiece material and material of the tool. An important aspect in manufacturing and machining process is to obtain the desired final dimensions and surface finish quality (Isik, 2007). Rapid progress in the science and technology of materials has resulted in the development of a wide range of advanced engineering materials. These materials are customized to attain special characteristics of the required applications such as high strength-to-weight ratio, high strength at elevated temperatures, excellent wear resistance etc. An example of these materials is titanium-based alloy. Although these materials are being used in a wide variety of engineering applications (e.g. aerospace, medical, petroleum), they are considered difficult-to-cut and their properties impose a lot of constraints on their machinability. Also their machinability imposes a lot of constraints due to their properties (Ezugwu and Wang, 1997; Dandekar et al, 2010; Hong et al, 2001a). The relative ease with which a material can be machined is referred to as its machinability (Ezugwu, 2005). There is no exact definition of this term but machinability is generally assessed in terms of particular process responses such as tool life, surface finish and power required to cut (Kalpakjian and Schmid, 2006; Ezugwu, 2005; Isik, 2007). The tool life obtained is considered to be the most important factor in machinability (Kalpakjian and Schmid, 2006; Ahsan et al., 2012). One way of achieving cost-effectiveness in machining advanced material is by elongating tool life by reducing replacements of tools and the resources used in the machining process. Tool wear causes degradation of the shape and efficiency of the tool cutting edge and this influences the surface quality and dimensional accuracy of the finished product.

Titanium and its alloys have been increasingly used in a wide range of applications such as aerospace, automotive, and medical industries. Titanium is extensively used due to its superior properties of low density, high strength to weight ratio, good temperature resistance and corrosion resistance (Ezugwu, 2005). These properties harden its machinability so it is classified as a "difficult-to-cut" material (Ezugwu, 2005; Dandekar et al, 2010;

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Hong et al, 2001b). Short tool life is the main challenge while machining titanium alloys (Dandekar et al, 2010). This has limited the cutting tools to coated carbide and ceramics tools (Ezugwu, 2005; Ezugwu and Wang, 1997) and prevents the use of high cutting speeds (Dandekar et al, 2010). The poor machinability of titanium alloys is due to their low thermal conductivity which increases the temperature at the cutting tool and the workpiece creating a very high temperature cutting zone (Ezugwu and Wang, 1997). Additionally, the interface between titanium chips and cutting tools is usually quite small, which results in high cutting zone stresses. There is also a strong tendency for titanium chips to pressure-weld to cutting tools (Dandekar et al, 2010; Ahsan et al., 2012).

Titanium poses considerable problems in its manufacturing due to its poor machinability. Cutting of titanium alloys is characterized by low cutting speeds and high tool wear. Up to the present moment, the rough turning process of titanium alloys, where the determining factor of the tool life is the mechanical characteristics of the tool, is well studied unlike the semi-finished turning of the alloys, especially α- titanium alloy (Awopetu et al. 1995). Titanium and its alloys present many problems, though the cutting forces are lower than that for iron and nickel alloys of comparable hardness. This may be associated with the relatively small tool contact area developed and the consequent high stresses (Alexander et al. 1987).

The American Society of Metals (ASM) recommends the use of the general purpose carbide tool with classification C2 under the commonly used industry code classification of carbide tool materials for the cutting of titanium and its alloys (Metals Handbook 1989). Straight tungsten carbide (WC-Co) cemented carbide cutting tool have longer life with titanium alloys than the steel cutting tungsten-titanium carbide (WC-TiC-Co) or tungsten-tantalum carbide (WC-TaC-Co) grades, but speeds may still be limited to 30m/min (Alexander et al., 1987). Also, Trent (1984), submitted that, with cemented carbide tools, longer life is achieved with the use of the titanium carbide (WC-Co) alloys than the steel cutting grades containing titanium carbide (TiC) and tantalum carbide (TaC). Moreover, the introduction of TiC, which is so strikingly successful in combating diffusion wear when cutting steel, has an adverse effect in relation to diffusion wear when machining titanium and its alloys. Therefore, the resistance to diffusion wear and resistance to deformation at temperatures make the straight carbide (WC-Co) grades of carbide cutting tools more useful for cutting titanium alloys (Trent, 1984).

A significant amount of research has been based on the measurement of cutting forces since it has direct effect on the machining accuracy and surface finish (Choudhury and Ratch, 2000; Zhang et al., 2012; Kannan et al., 2009). Cutting forces can be measured by mounting a dynamometer or force transducer on the tool (Kalpakjian and Schmid, 2006). There are others who have done tremendous work in the area of titanium cutting and its wear mechanism; they are, among others, Komanduri and Hou (2002), Findes et al., (2013), Sugihara and Enomoto (2015) as well as Talantov (1992).

It can be seen from the above review that investigation of tool wear mechanism in metal cutting is an important field of study. Developing a wear process of different types of cutting for machining titanium, will help in optimizing the geometry of the cutting tool to minimize wear.

This paper is looking into the investigation of wear mechanism of different type of cemented carbide tools in the machining of difficult-to-cut titanium alloys. The main objective of this work is to study the influence of cutting conditions in the tool wear in the turning process of titanium alloys.

2. Methodology

The experiment was carried out in the Department of Advanced Manufacturing Technology, Faculty of Manufacturing Technology and Machine Tools, Volgograd State Technical University, Volgograd, Russia. Cutting operations were carried out on an industrial lathe machine thereby making turning operation the basis for the experimental works. Three titanium alloys: BT1.00, BT3-1 and BT-5.1 were used in the state in which they were supplied. The workpieces are of diameter 100 – 200 mm and length 600 – 800 mm. Cutting conditions chosen, as shown in Table 1, are: cutting speed, V, between 40 – 60 m/min; cutting feed, s, 0.2 mm/rev, cutting depth, t, 1.5 mm, cutting condition, dry (no coolant used).

Table 1: Chosen Cutting Conditions

S№	Parameter	Range of Values	Unit
1	Cutting Speed (v)	40 – 60	m/min
2	Cutting Feed (s)	0.2	mm/rev
3	Cutting Depth (t)	1.5	mm
4	Coolant	None (Dry Cutting)	

The cutting tools used are cemented carbide tools BK8, BK6, BK60M, BK100M, BK10X0M, T5K10 and T15K6. The cemented carbide tools come under the Russia standard (GOST) 2209-69 as insert forms 0227A which are bolted (fixed) mechanically on the tool body. Regrinding of the inserts is carried out on a universal tool grinding machine with abrasive disc AYK-ACP 100/80.51.100. Since the properties of the cemented carbide tools (inserts) are not homogenous, the inserts to be used are chosen to be having the same thermal electromotive force (emf) after such tests have been performed on all acquired inserts.

These cutting tools and their compositions and properties are presented in Tables 2 and 3 in the following categories:

i. Tungsten carbide cemented carbide tools category, this comprise of cutting tools with mostly plane (or straight) tungsten carbide (WC) by composition, this group has a designation which starts with "BK", and

ii. Tungsten-titanium carbide cemented carbide tools category, this comprise of tools with tungsten-titanium carbide (WC-TiC) major composition. The cutting tools in the category have their designation starting with "TK". Component cutting forces are registered on an apparatus YDM-600.

The dynamometer YDM-600 comes as a complete set consisting of dynamometer sensor, four-channel amplifier TA-5, oscilograph H-700, the power block and the voltage stabilizer. The signal of the changes of the component force is fixed on the oscilograph. The speed of pulling of the special photo paper, covered with ultraviolet film, for instant analysis of results of experiment, equals 5000m/sec with time indication marks at every 0.002sec. The temperature during cutting is measured with the aid of thermal EMF by the natural thermal couple method. The tool wear is observed on an instrumental microscope.

Micro metallographic specimen guarantees the best and authentic information about the contact process during cutting and tool wear. The chip root, consisting of the chip and a beak-off of the tool, is contained in the micro metallographic specimen. A micro metallographic specimen of this type alloys the study of the mechanism of the contact relationship, in any pre-determined section, in particular the way they have been even during cutting process.

The thermal conductivity of the tools was also monitored; this is to ensure that all the cemented carbide tools used were in the same thermal conductivity range. The tool holder had been constructed in such a way that it could be connected to a voltmeter, to an amplifier and then to the oscilograph, H700, in order to monitor the thermal conductivity of each tool throughout the cutting period.

The wear process and mechanism of the used cemented carbide tools were studied during the cutting process using cutting speeds, V=40, 50 and 60m/min. Then the discovered best wear resistant tool, BK6, was then further experimented to determine ways of improving the durability and reliability of the tool for any type of production. In doing this, the rake face of the tool was reinforced with negative fascia. In this respect, the fascia has the following parameters: rake face = 00, supporting fascia = -150, width of supporting fascia = 0.20 – 0.25mm.

Table 2: Chemical composition, grain sizes, proportional limits and ISO equivalents for tungsten carbide and tungsten-tantalum cemented carbide tools used (Poduraev 1974, ISO 2004).

Code	Chemical compositions (per weight), in percentages				Grain size microns (μ)	Proportional limits (compressive) GPA	ISO equivalent
	WC	TaC	Cr_2C_3	Co			
BK6OM	91.9	2.0	-	6.0	Up to 0.5	1.20	K05-K10, M05
BK6	94	-	-	6.0	1 to 2	1.50	K20
BK8	92	-	-	8.0	1 to 2	1.70	K30-K40, M30
BK10OM	87.8	2.0	-	10.0	Up to 0.5	1.40	M30
BK10XOM	89.2	-	0.8	10.0	Up to 0.5	1.50	M30

Table 3: Chemical composition, grain sizes, proportional limits and ISO equivalents for tungsten carbide and tungsten-titanium carbide cemented carbide tools used (Poduraev 1974, ISO 2004).

Code	Chemical compositions (per weight), in percentages				Grain size microns (μ)	Proportional limits (compressive) GPA	ISO equivalent
	WC	TiC	Cr_2C_3	Co			
T15K6	79.0	15.0	-	6.0	2 to 5	1.15	P10-P20
T5K10	85.0	5.0	-	10.0	2 to 3	1.50	P30

4. Results and Discussion

At the cutting speed, V=60m/min, BK6 better resists wear on the clearance face (flank wear) as seen in Fig. 1. However, it is faced with micro-breaks and pull-offs of the cemented carbide particles from the rake face of the cutting tool as presented in Fig. 2 and Fig. 3. BK8 just better resists the micro-breaks and pull-offs of the cemented carbide particles from the rake face but it is much weaker in the clearance face wear. BK100M and BK10X0M showed highest resistance to micro pull-offs of the cemented carbide particles. Comparing them with BK6 and BK8, more intense rake face and clearance face wear were observed. T15K6 practically cannot stand the test of turning titanium alloy at cutting speed, V = 60 m/min because of micro and macro pull-offs right from the first seconds of cutting. T5K10 showed the best result of the resisting wear of the rake face but the wear of the clearance face is too intense compared to BK8 and Bk6.

The durability of the best wear resistant cemented carbide tool, BK6, with wear criteria of 0.7 mm, was found to be 1.5 min at average, which is clearly not economical. Reduction of the cutting speed by 30% (v = 40 m/min) enables increase in durability to up to 40 min but this is coupled with a drop in productivity. In order to work out ways of improving the durability of the optimal type of cemented carbide tool, BK6, while cutting with speed 60 m/min, experiments were further carried out on the process of wear (characterized with micro break-offs and pull-offs of the cemented carbide grains) in the very first minutes of cutting since it is intense in this period, by reinforcing the rake face of the cutting tool. The cutting speed used are 50 and 60 m/min. Results of the experiments show that tools with negative angles in the reinforcement fascia (as shown in Fig. 4) are faced with a more intense wear, mainly diffusion, which 'dissolves' the defective surface layer fast, with no traces of micro break-offs and pull-offs and the durability is not more than 15 min. Wear of tools with a positive rake face at the beginning was less intense (as shown in Fig. 4) but becomes very intense after 10 min which is acceptable for majority of production. Further variations of the tool geometry do not bring about a better durability.

Fig. 3 shows the results of cutting titanium with BK6 at 50 and 60 m/min with no, with negative and with positive reinforcement fascia of the rake face.

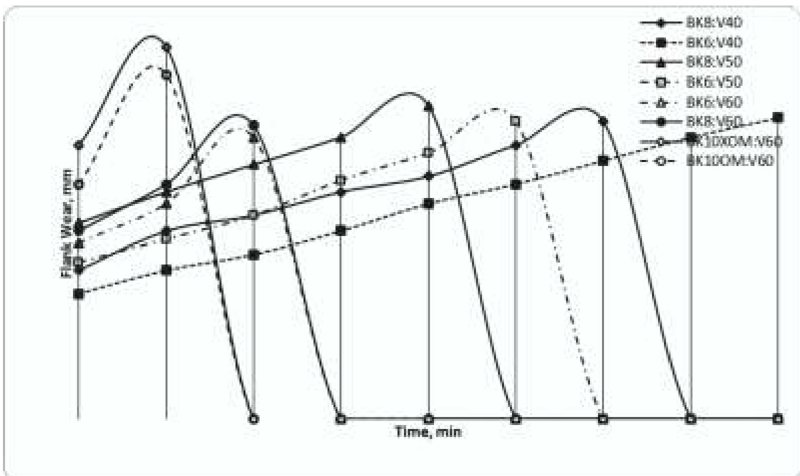

Fig. 1: Wear mechanism of different cemented carbide tool during turning of α-titanium alloy at different speeds

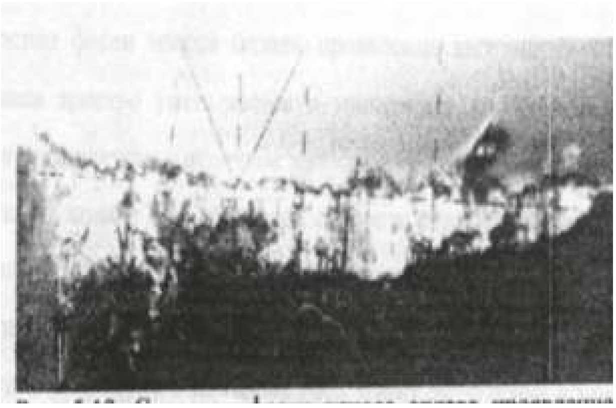

Fig. 2. Clearance face of cutting tool showing micro cracks, micro breaks and pull-offs

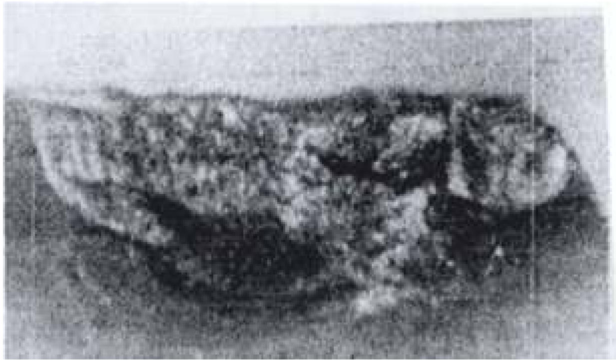

Fig. 3. Rake face of cutting tool showing micro cracks, micro breaks and pull-offs

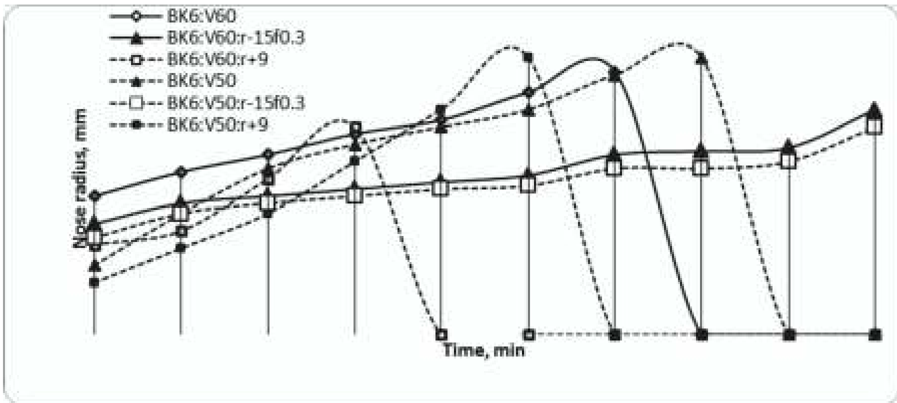

Fig. 4. Effect of rake face reinforcement on wear of BK6 during turning α-titanium alloy at different speeds

5. Conclusion

The effect of the rake face reinforcement on cutting tool life of cemented carbide tool during turning of α-titanium has been successfully investigated. The following conclusions are drawn:

i. The best wear resistant cemented carbide tool in turning titanium alloy is BK6 (and its modifications). Cemented carbide tool BK8 is only 75-80% as good as BK6 although it demonstrated higher resistance to micro break-offs of the rake face.

ii. During the period of start-off wear, all types of cemented carbide tools are characterised with intense wear. The wear value on production cutting speed for that period (about 5 min) could be as high as 0.35 – 0.45 mm. The wear of brittle double carbide tools (T5K10, T15K6) in the start-off period is catastrophic because of breaking off of the cutting edge.

iii. Micro and macro break-offs of the rake face of majority of BK6 cemented carbide grains already taking place in the period of start-off wear reduces its work reliability. To increase it and develop optimal relationship of wear fascia, it is necessary to reinforce the cutting edge by a negative fascia, average value of which is determined by the deformation process of the cutting edge of the tool in the process of cutting.

iv. Using the recommended geometry, in a semi-finished operation at cutting speed, V = 60 m/min, a generally accepted durability of 30 min was attained. If the cutting speed is reduced to 50 m/min, then the durability is increased to 45 – 50 min and a stable wear of 0.30 – 0.35 mm is maintained for about 70% of the working period.

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