THE PERFORMANCE OF LOW COST CUTTING TOOLS WHEN MACHINING HARDENED STEEL OF 60 HRC

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ABSTRACT: Hard turning is a topic of great interest in today's industrial production and scientific research. The hard turning technology has the potential for improving productivity against grinding in the manufacturing process. Today, tool manufacturers are constantly developing new combinations of coatings and substrates to precisely match different workpiece materials and operations. Nevertheless, the suitability of coated mixed ceramic (AI2O3 + TiCN) cutting tools when hard turning AISI D2 cold work tool steel (60 HRC) is yet to be investigated. An understanding of the tool life and wear mechanisms, surface integrity produced by coated mixed ceramic cutting tools will give an alternative to the manufacturing industries to exploit low costs cutting tools in hard turning of AISI D2 (60 HRC). The noticeable trend of the tool life was observed at test conditions where the cutting speed is at 100 m/min instead of 140 m/min or 200 m/min. The wear mechanism of coated mixed ceramic cutting tools with TiN is subjected to abrasion, adhesion, chipping and notching, especially when machining at high cutting speed of 200 m/min.

KEYWORDS: Hard turning, Low cost cutting tools, Tool life, wear mechanism.

1.0 INTRODUCTION

Hard turning is a topic of great interest in today's industrial production and scientific research. The hard turning technology has the potential for improving productivity against grinding in the manufacturing process. There are two kinds of super hard materials in the past which $A = \pi r^2$ diamond and cubic boron nitride (CBN). Man made diamond, and CBN were manufactured by the middle of the 20th century. The commercialization of cubic boron nitride tools, since1970s, has resulted in a rapid advanced in hard machining technology. Hard turning is a machining operation that is complex nonlinear and coupled thermo mechanical process. The complexities are due to large strain and high strain-rate in the primary shear zone and due to the contact and friction between the chip and cutting tool along the secondary shear zone. In addition, complexities are also caused by local heat generation through the conversion of plastic work in the chip during chip formation and the frictional work between the tool and chip. An undesired by-product of the metal-cutting process is the creation of residual stresses and strains in the freshly cut work piece, which is known to affect the integrity of the newly finished surface, including shortened creep and fatigue lives of the machined component under service loads.

Hard turning is a topic of great interest in today's industrial production and scientific research. For a metal-cutting tool, wear processes conspire to make a tool fail. CBN inserts have been proven to produce as good or better tolerances than conventional grinding processes (Liao *et al.,* 1995). Potential process benefits of hard turning over grinding have been reported including short cycle time, process flexibility, part longevity, and less environmental impact (König *et al.,* 1993). Tools used in hard turning are required to have high strength, high abrasive wear resistance and chemical stability at high temperatures. Currently, CBN cutting tools are still relatively expensive compared to ordinary carbide and ceramic cutting tools. In order to attain sufficiently high production rates at minimum cost, the uses of cheaper cutting tools at the same performance are necessary.

Cutting tools are subjected to an extremely severe rubbing process. They are in metal to metal contact, between the chip and workpiece, under conditions of very high stress and at high temperatures. The situation is further aggravated (worsened) due to the existence of extreme stress and temperature gradients near the surface of the tool. During machining, cutting tools remove the material from the workpiece to achieve the required shape, dimension and surface roughness (finish). However, wear is also occurring during the cutting action, and it will result in the failure of the cutting tool. An understanding of the wear mechanisms and tool life of coated mixed ceramic cutting tools will give an alternative to the manufacturing industries to exploit low costs cutting tools in hard turning of AISI D2 (60 HRC).

2.0 EXPERIMENTAL SETUP

2.1 Work Material

The work material selected for this investigation was AISI D2 cold work tool steel (60 HRC). This is due to its availability and prominent use in tool and dies industrial applications. The diameters of the bars were 90 mm, and they were cut to 250 mm in length prior to heat treatment. The material has through hardened to 60 HRC. AISI D2 cold work tool steel is a high carbon. High-chromium tool steel alloyed with molybdenum and vanadium. It is characterized by: high wear resistance, high compressive strength, and high hardness after hardening, good through-hardening properties, and excellent dimensional stability in hardening. Its toughness and machinability are considered to be low (Kalpakjian and Schmid, 2003). The abundance of carbon (1.55 %) combined with the presence of 11.6 % of a chromium element in AISI D2 cold work tool steel allows the formation of complex alloy carbides, which provides for some special mechanical properties, but is very difficult to machine with conventional cutting tools.

Table 1: Typical Physical Properties of AISI D2.

Temperatures	20 °C (68 °F)	200 °C (390 °F)	400 °C (750 °F)
Density kg/m^3 Ibs/in^3	7 700 0.277	7 650 0.276	7 600 0.275
Modulus of elasticity N/mm^2 kp/mm^2 tsi psi	 193 000 19 700 12 500 26 × 104	 188 000 19 200 12 200 25 × 104	 173 000 17 600 11 200 24 × 104
Coefficient of thermal expansion /°C from 20 °C /°C from 68 °F	 - -	 12.4×10^{-6} 6.7×10^{-6}	 13.4×10^{-6} 7.4×10^{-6}
Thermal conductivity W/m °C Btu in/(ft^{2}h °F)	 20.0 139	 21.0 146	 23.0 159
Specific heat J/kg °C Btu/Ib °F	 460 0.110	 - -	 - -

Table 2 : Chemical Compositions of AISI D2.

Element	C	Mn	Cr	Mo	V	Si
% Volume	1.55	0.4	11.6	0.8	0.9	0.3

2.2 Cutting Tools Material

All cutting operations require tool materials that can withstand the difficult conditions produced during machining. There are primarily three problems all cutting tools face: wear at the cutting edge, heat generated during the cutting process, and thermo mechanical shock. Characteristics that allow tool materials to stand up to the cutting process include hardness, toughness, wear resistance, and chemical stability. Cutting tool's material used in this investigation are commercially available mixed ceramic cutting tools (Al2O3 and TiCN) with TiN coating which available in the market. These tools are considered competing grades of ceramic tools. Table 3 shows the specifications of cutting tools.

Newly developed cutting tool grades are intended to permit a versatile use in roughing and finishing applications for a broader spectrum of work piece materials. The new improvements and developments in coating technology have produced new and more wear resistant tool materials. Coated tools used for metal cutting must have a combination of abrasion wear resistance and chemical stability at a high temperature to meet the demands of the application. The use of coated cutting tools to machine various materials now represents the state-of-the art technology. Cutting tools suitable for hard turning such as CBN are relatively expensive. So, it is important to investigate mixed ceramic (AI2O3 + TiCN) cutting tool performance in order to assure the economic justification for hard turning.

Table 3: Specifications of Cutting Tool and Tool Holder used.

Tool holder	MCLNL 2020H 12
Insert	CNGA120408T01020
Nose radius, R	0.8 mm
Chamfer angle	200
Side rake angle, α_s	-50
Side cutting edge angle, α_s	-50
Back rake angle, α_b	-50
Relief angle, α_p	50

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3.0 MACHINING EQUIPMENT AND METHOD

The machining operations were carried out on a 5.5 KW MAHO Graziano GR200 CNC slant bed lathe machine with a 432T control unit under dry cutting conditions. Every work material was centre-drilled to give a 1/4 inch minimum centre hole with 120 degree chamfer to provide adequate support and minimize the potential for vibration and chattering. After every cutting test performed, a thin layer of 0.5 mm was machined (0.25 mm depth of cut per pass) with a new coated carbide cutting edge in order to remove the uneven surfaces due to the previous operation and to ensure consistency. In addition, a paper (0.2 μm) was used to do cutting tool touch-off setting to determine the depth of cut. The major concern was to reduce the depth of cut error introduced during the cutting tool touch-off setting procedure. The tool life criteria selected are based on the literature survey and considering the recommendation set forth in ISO 3685. The cutting was stopped when the flank wear of the cutting tool comes to 300 microns.

4.0 RESULT AND DISCUSSIONS

4.1 Tool Lifes

In order to investigate the possibility of using higher tool wear values for the criteria considered, first the cuttings were performed at the highest cutting of speed 200 m/min. A low tool life value of 10 min is obtained. For this reason, it is decided that the tool wear values for the tool life criteria be maintained. At a low cutting speed of 100 m/min, the longest tool life of 29.5 min is achieved when cutting is performed with mixed ceramic coated with TiN. Low speed would result in high cutting forces, in particular, the friction force due to the lesser degree of softening of the work material. This will lead to severe abrasion of the rake face by the hard carbide particles in the work material; and thereby removes the binder of coating.

At a cutting speed of 140 m/min, Mixed ceramic coated with TiN still gives the longest tool life of 12 min. At the highest cutting speed 200 m/min, tool life is 10 min. The noticeable trend of the tool life data is shown in Fig. 1. The tool life improves dramatically at test conditions where the cutting speed is at 100 m/min instead of 140 m/min or 200 m/min. It can be clearly seen that the tool life decreases with increasing in cutting speeds. When the cutting speed is increased from 100 to 200 m/min, there is a significant change in the tool life.

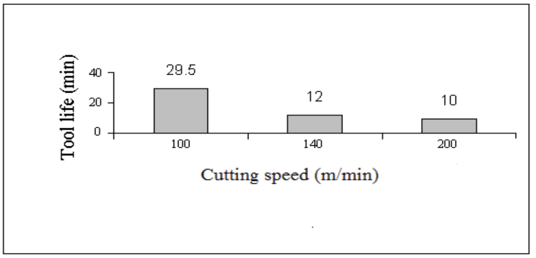

Figure 1. Tool life of mixed ceramic (AI2O3 + TiCN) coating with TiN

This can be explained by the increased in cutting speed, which has resulted in an increase in temperatures at the cutting zone. The effect of cutting speed on the tool life was previously observed by Galoppi, *et al.* (2006) in their study on hard turning of tempered DIN 100Cr6 steel with coated and uncoated CBN inserts. Their results showed that the cutting speed influences the tool life more significantly than the feed rate, and a significant reduction in the tool life is observed at high cutting speeds. Perhaps the temperature effect is the main factor affecting tool life. Wang and Rajurkar (1997) found that the temperature rise during cutting could significantly reduce the strength of the tool and hence the wear resistance of the tool. Temperature has a more harmful effect on the tool because it directly conditions the tool life by a fast evolution of wear (Ay and Yang, 1998). The dependence of the cutting temperature on the cutting speed was rather large, since an average temperature increase of two hundred degrees (from 1100 to 1300 0C has been recorded when changing the cutting speed from 400 to 600 m/min when machining steel with an alumina ceramic tools (Narutaki, *et al.*, 1997). On the other hand, hard coatings such as TiN, TiC and Al2O3 have been used and claimed to improve significantly the tool-life, enabling components to be machined at higher "economic" speeds, and able to reduce the forces and power due to the lower frictional coefficients on the rake face (Wang, 1999).

The superior tool life when hard turning hardened steel of 60 HRC by using various ceramic tools is also obtained by Kumar, *et al.*, (2006). They performed experiments at four different cutting speeds, 120, 170, 220 and 270 m/min, at a constant feed rate of 0.12 mm/rev and at a constant depth of cut of 0.5 mm, and dry cutting. Mixed ceramic with TiN and TiC obtained approximately 15.5 min of tool life at a cutting speed of 220 m/min.

4.2 Wear Mechanisms

King and Wheildon (1966) are among the earliest reports of the machining of hardened steels up to 61 HRC with geometrically defined alumina cutting tools. As a class of materials, ceramics possess high melting point, excellent hardness and good wear resistance. Unlike most metals, hardness levels in ceramics generally remain high at an elevated temperature (Narutaki, *et al.*, 1997). Major failure forms of ceramic tools are tool wear and tool fracture. Usually, tool wear is the dominant failure form in continuous machining, while a tool fracture is the main failure form in intermittent machining (Casto and Valvo, 1993; Gwidon and Stachowia, 1994). At all cutting speeds tested the early stage of cutting, initial breakdown in cutting edge with the edge rounding is observed with only a flank wear which increases rapidly. Then the flank wear becomes stable and stays constant, while a crater wear appears on the rake face which is typical of abrasive wear. Under lower speed, crack's propagation perpendicular to the chip flow direction was observed (Fig. 2). If the cutting operation continues further on, tool fracture will possibly occur.

The mechanical fatigue cracks and thermal cracks resulted from the combined action of both mechanical and thermal stresses are the dominant reasons for the late fracture of ceramic cutting tools (*Chong H.X., et al.*, 2006). Thermal shock cracks, often associated with nose or flank wear, and are caused by large temperature gradients at the cutting edge. *Chong H.X., et al.,* (2006) in their study of cutting behavior and related cracks in wear and fracture of ceramic tool materials concluded that wear and fracture of ceramic tools are significantly affected by cracks or micro cracks formed in the cutting process. The forms of fracture for ceramic tools vary with cutting conditions. Similar observation is also present by Huang (1994), micro cracks or crack-like defects inside the tool material initiate and propagate continuously under the action of thermal tensile stresses at a lower temperature. The evident to abrasion of the hard carbide particles in AISI D2 microstructure and adhesion of work piece material at the rake face was also observed. The adhered work piece particles often remain attached to the tool edge. This is believed due to chemical reaction between the work piece chip material and the ceramic tool material, and the process is activated by high temperatures at the tool-chip interface. Chemical wear (defined as the adhesion of the work piece material on the tool face) is one of the main causes of tool failure. The adhered work piece material always removes small particles of the tool when it breaks away and causes tool chipping (EI-Wardany, *et al.,* 1992). The term seizure is also used to describe the loss of tool particles from the edge or faces.

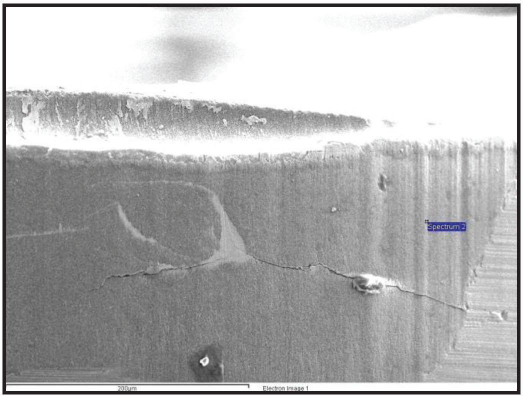

Fig. 2 The typical wear pattern of a mixed ceramic cutting tool at the end of tool life when cutting at VC = 100 m/min, f = 0.06 mm/rev and depth of cut = 0.4 mm

The flank wear of the mixed alumina tool increased with cutting speed and presenting a considerably higher tool wear rate when using a cutting speed of 200 m/min. Flank wear occurs on the tool flank, and it is generally attributed to rub of the tool with the work piece at the interface, causing abrasive wear. It was observed that the flank wear played a larger role at lower speeds and notch wear is significant at higher speeds (Fig.3). According to Kumar, *et al.,* (2006) in their study on the effect of tool wear on tool life of alumina-based ceramic cutting tools while machining hardened martensitic stainless steel (60 HRC), notch wear occurs by the rubbing process of the machined surface with the cutting tool at the boundary where the chip is no longer in contact of the tool. A machined surface may develop a thin work hardened layer which is hard and abrasive. This contact could contribute to notch wear Notch wear is mostly observed in the ceramic cutting tools, which have low toughness values (Stachowiak, 1994). The mixed ceramic cutting tools wear mechanism is subjected to not only abrasion, adhesion but also to chipping, especially when machining at high cutting speed and the morphology of high magnitude of the chipping is indicated in Fig. 4. Chipping was ever observed in a mixed ceramic tool when machining at a higher speed (VC = 200 m/min). In fact, chipping is a kind of early fracture. The most often encountered modes for brittle fracture of ceramic tools can usually be classified into four cases: chipping, flaking, breakage and cracking (Ai and Zq, 1994).

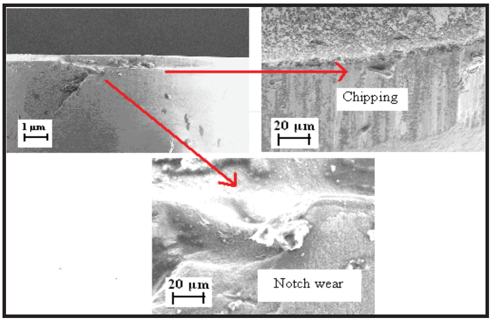

Fig. 3 Wears pattern of ceramic cutting tools at the end of tool life when cutting at VC = 140 m/min, f = 0.06 mm/rev and depth of cut = 0.4 mm

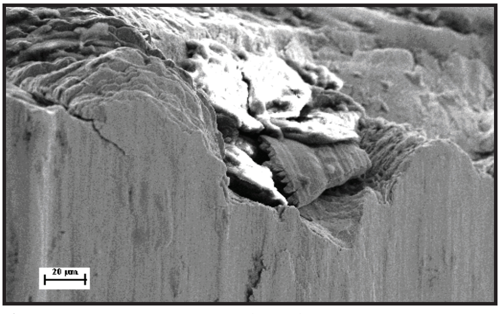

Fig. 4 Chipping of ceramic cutting tools when cutting at VC = 200 m/min, f = 0.06 mm/rev and depth of cut = 0.4 mm

5.0 CONCLUSION

In the tool life testing, it shows that mixed ceramic (AI2O3 + TiCN) coated with TiN is performed well. As a class of materials, ceramics possess high melting point, excellent hardness and good wear resistance. It seems that mixed ceramic cutting tools coated with TiN able to performed with considerable tool-life for all cutting speeds, enabling hard turning components to be machined at low costs. The wear mechanism of mixed ceramic cutting tools coated with TiN is subjected to not only abrasion, adhesion, chipping and notching, especially when machining at high cutting speed. It was observed that the tool's performance was depended mainly on the interactions of micro structures between the tool material, coating material and workpiece material.

6.0 ACKNOWLEDGMENT

Financial support from the Ministry of Science, Technology and Innovation, Malaysia through the IRPA funding vote no. 74268, Fundamental Research Grant Scheme through a vote no. F0026, and the PJP funding grant no: PJP/2009/FKP(10A)-S578 is acknowledged with gratitude.

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