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An Experimental Investigation on Effect of Cutting Fluids in Turning with Coated Carbides Tool

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The major needs in machining are high material removal rate, good work surface finish and low tool wear. These objectives can be achieved by reducing tool wear using proper cooling system of the tool during machining. The work aims to seek conditions in which dry cutting is satisfactory compared with the flood of fluid usually used. The cutting tool used in this research is CVD coated carbide $TiC+Al_2O_3+TiN$ insert (ISO P25). The type of inserts is DNMG 150608. During the experiments flank wear, cutting force and surface roughness value were measured throughout the tool life. The results have been compared with dry and wet-cooled turning. The results of the present work indicate substantial reduction in tool wear, which enhanced the tool life; this may be mainly attributed to reduction in cutting zone temperature and favorable change in the chip-tool interaction.

Keywords: flank wear, tool life, cooling, cutting forces, tool wear

0 INTRODUCTION

In metal cutting process, the condition of the cutting tools plays a significant role in achieving consistent quality and also for controlling the overall cost of manufacturing. The main problem caused during machining is due to the heat generation and the high temperature resulted from heat. The heat generation becomes more intensified in machining of hard materials because the machining process requires more energy than that in cutting a low strength material. As a result, the cutting temperatures in the tool and the work-piece rise significantly during machining of all materials [1]. At such elevated temperature the cutting tool if not enough hot hard may lose their form stability quickly or wear out rapidly resulting in increased cutting forces, dimensional inaccuracy of the product and shorter tool life. The magnitude of this cutting temperature increases, though in different degree, with the increase of cutting velocity, feed and depth of cut, as a result, high production machining is constrained by rise in temperature. This problem increases further with the increase in strength and hardness of the work material [2] and [3].

In dry cutting operations, the friction and adhesion between chip tool tend to be higher, which causes higher temperatures, higher wear rates and, consequently, shorter tool lives. Up to this moment, completely dry cutting is not suitable for many machining processes. Since cutting fluid is necessary to prevent the chips from sticking to the tool and causing its breakage [4].

High temperature in cutting zone has been traditionally tried to control by using cutting fluids. The coolant effect reduces temperature in cutting zone and the lubrication action decreases cutting forces. Thus the friction coefficient between tool and chip becomes lower in comparison to dry machining [5] and [6]. The aims of cutting fluid applications were determined as cooling and lubrication in metal cutting. In addition, cutting fluids can help to disposal of the chips from hole and control chip formation. Because they decrease contact length between chip and tool, and this situation has a positive effect on chip breaking. Thus, they can help to achieve better tool life [7] and [8]. The cost of cutting fluids is approximately 7 to 17% of the total cost in machining process [9]. As cutting fluid is applied during machining operation, it removes heat by carrying it away from the cutting tool/work-piece interface [10]. This cooling effect prevents the tool from exceeding its critical temperature range beyond which the tool softens and wears rapidly [11]. Cutting fluids are used throughout industry in many metal cutting operations and they are usually classified into 3 main categories: neat cutting oils, water-soluble fluids and gases [12].

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The major needs in machining are high material removal rate, good work surface finish and low tool wear. These objectives can be achieved by reducing tool wear using proper cooling system of the tool during machining. The main objective of using cutting fluids in machining operations is the reduction of temperature in the cutting region to increase tool life. The cutting fluids are used in machining operations in order to

(i) Reduce friction at the tool-chip and tool-work-piece interfaces,
(ii) Cool both chip and tool, and
(iii) Remove chip.

Furthermore, they have a strong effect on the shearing mechanisms and, consequently, on the work-part surface finish and tool wear [13] and [14].

The positive effect of the use of fluids in metal cutting was first reported in 1894 by F. Taylor [15], who noticed that by applying large amounts of water in the cutting area, the cutting speed could be increased up to 33% without reducing tool life. Since then, cutting fluids have been developed resulting in an extensive range of products covering most work-piece materials and operations. According to Kress [16], the costs associated with the use of cutting fluids represent approximately 17% of the finished work-piece cost against 4% spent with tooling. Kwon [17], studied flank wear by incorporating cutter temperature and physical properties of coating and work materials. The objective of this paper is to investigate the effects of internal cooling on the tool flank wear in orthogonal metal cutting. Diniz and Micaroni [4], carried out other experiments in turning operations of AISI 1040 steel, also using coated carbide tools and cutting conditions typical of finishing operations. Their goal was to compare dry cutting with cutting with abundant fluid at different feeds, cutting speed and tool nose radius.

The present work deals with experimental investigation in the role of cutting fluids on cutting temperature, cutting forces, tool wears, and surface roughness value in machining AISI-1050 steel at industrial speed-feed condition by CVD coated carbide TiC+AI_2O_3+TiN insert as compared to completely dry machining. This study indicated that cutting fluid did not show a significant improvement on surface roughness particularly when cutting tests with 0.8 mm nose radius were considered. In fact, the roughness similarly deteriorated under wet machining in some of tests.

1 EXPERIMENTAL DETAILS

1.1 Cutting Tool Materials

Carbides are the most common tool material for machining of castings and alloy steels. These tools have high toughness, but poor wear characteristics. To improve the hardness and surface conditions carbide tools are coated carbide with hard materials such as TiN, TiC, TiAlN, and TiCN by chemical vapor deposition (CVD).

Currently, the most popular CVD coatings are titanium carbide (TiC), titanium nitride (TiN), titanium carbon nitride (TiCN), and alumina (Al_2O_3). The first successful CVD coating, TiC offers high hardness and excellent wear resistance. A later development, Al_2O_3 coatings, offers superior thermal stability, oxidation wear resistance, and high-temperature hardness. High-temperature characteristics of Al_2O_3, when it's deposited as a single layer or alternating multi-layer, provide increased productivity in high-speed machining of steels and cast irons.

DNMG 150608 (with an ISO designation) carbide inserts, clamped on tool holders CSBNR 2525 M12. As cutting tools, CVD coated carbide TiC+AI_2O_3+TiN insert (ISO P25) were used in the experiments. Inserts possesses, a coating consisting of a TiCN under layer, an intermediate layer of Al_2O_3 and a TiN out layer, all deposited by CVD (Fig. 1).

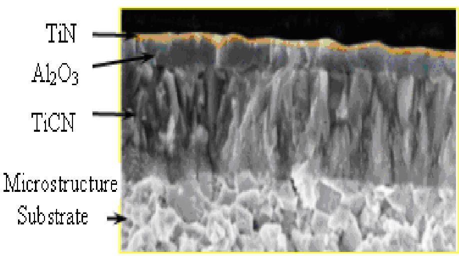


Fig. 1. *CVD coating layers of insert*

1.2 Work-piece Material

The work-piece material is AISI 1050 steel. The chemical composition of work-piece material are 0.52%C, 0.86%Mn, 0.040%P, 0.050%S. Cylindrical work-pieces (Ø80×340 mm) were fixed between the chuck and the tailstock and were pre-machined by using a separate insert.

1.3 Machinability Test

Machining tests were carried out according with Standard ISO 3685 [18] which involves turning of a bar at a constant cutting speed (*V*c) and the identification of the cutting time (*T*c) necessary to obtain a specific value of tool flank wear. Since conventional 5.5 KW TOSS lathe was used in the tests, in order to have a constant cutting speed, in the turning operation 190 to 260 m/min of various cutting speed, 0.14 mm/rev of feedrate, 0.5 mm and 1 mm of depth cut values were used in all cases. As the tool life criteria, a value of 0.3 mm of average flank wear land (I_B) that was established by ISO 3685, was used (Fig. 2). Coated carbide inserts, ISO DNMG 150608 (K10), clamped on tool holders CSBNR 2525 M12 were used in the tests, Cutting forces, flank wear and surface roughness values were measured until the tool expires.

The cutting forces were measured by a three-dimensional force dynamometer, Kyowa TD-500. The flank wear of the tool was measured by means of Nikon104 microscope with a magnification of X10 and the cutting process was paused in every 60 mm and the average flank wear was measured. The work-piece surface roughness was measured by a profilometer (Taylor Hobson Talysurf Series 10). Oil based coolant was pumped at rate of 3 liter/min on the tool-work interface, so as to flood the cutting zone along with surrounding area in wet turning tests. The process parameters as indicated in Table 1 were selected on recommendation of tool manufacturers for machining AISI 1050 steel.

In the experiments, CVD coated carbide $TiC+AI_2O_3+TiN$ cutting tool was taken into consideration throughout the tool life at certain cutting conditions. Parameter on tool life, was determined with respect to the recommendations advised by the tool manufacturers for the coated tools. For all tools, only the flank wear was taken into consideration in the comparisons. The result of experimental data is given in Table 2.

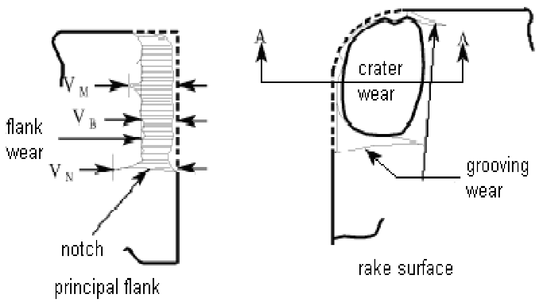
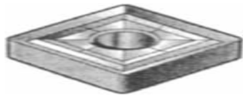


Fig. 2. *Geometry of wear of turning tools [19]*

Table 1. *Experimental condition*

Machine tool	: TOSS, 5.5 KW, Lathe
Work specimens materials	: AISI-1050 steel (0.52%C, 0.86%Mn, 0.040%P, 0.050%S.)
Size	: (Cylindrical workpieces Ø80×340 mm)
Cutting tool	: CVD Coated carbide, DNMG 150608(K10)
Coating	: $TiC+AI_2O_3+TiN$
Tool holder	: CSBNR 2525 M12 (ISO specification),
Working tool geometry	: Inclination angle: 6, rake angle: 6, clearance angle: 6, cutting edge angle:
75	
Principal nose radius: 0.8mm	



Force dynamometer	: Kyowa TD-500,
Microscope	: Nikon104 with a magnification of X10
A profilometer	: Taylor Hobson Talysurf 10
Process parameters	
Cutting velocity, V	: 190, 220, 240 and 260 m/min
Feed rate, f	: 0.14 mm/rev
Depth of cut, a	: 0.5, 1.0 mm
Environment	: Dry, and wet cooling

Table 2. *Results of experimental data*

Flank wear [mm]	The rate of flank wear [mm/min.]	The volume of material removed [cm^3/tool life]	Tool life [min.]	Cutting parameters			Cutting condition
				Cutting speed [m/min]	Feed rate [mm/rev]	Depth of cut [mm]	
0.35	0.0173	783.65	20.13	260	0.14	1.0	Dry
0.33	0.0146	814.35	22.55				Wet
0.35	0.0080	627.20	43.60			0.5	Dry
0.37	0.0063	705.63	58.27				Wet

2 RESULTS AND DISCUSSION

2.1 Tool Wear and Flank Wear

Cutting tools may fail by brittle fracture, plastic deformation or gradual wear. Turning carbide inserts having enough strength; toughness and hot hardness generally fail by gradual wear. With the progress of machining, the tools attain crater wear at the rake surface and flank wear at the clearance surfaces [19], the principal flank wear is the most important because it raises the cutting forces and the related problems.

Flank wear is a major form of tool wear in metal cutting. When machining using tools under typical cutting conditions, the gradual wear of the flank face is the main process by which a cutting tool fails [20] to [22].

According to ISO standard 3685 to tool life testing, the life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value (V_B) of its principal flank wear reaches a limiting value of 0.3 mm [24]. In tool life evaluation turning processes were paused in every 60 mm and the average flank wear was measured. If the tool was not expired (which means it does not reach to a value of 0.3 mm of average flank wear land) at the end of the first bar, second bar of the same structure was used for the rest of the process. This was necessary for the constant cutting speed as explained previously.

Tool life estimation involves a number of tests to be carried out at various cutting conditions till the failure of the cutting tool. In general, as the tool life criterion, amount of flank wear is used. Flank wear (V_B) is an important factor in determining the tool life. The cutting test was started with a new cutting tool, and the machining process was stopped at certain intervals of cutting length in order to measure the width of flank wear. Flank wear rate is calculated as the average wear (mm) divided by the effective tool life [min] [23]. The major advantage of wet-cooled turning seems to be reduction of tool wear at high speed. Fig. 3 shows the progression of flank wear in dry and wet-cooled turning and volume of material removed is shown Fig. 4.

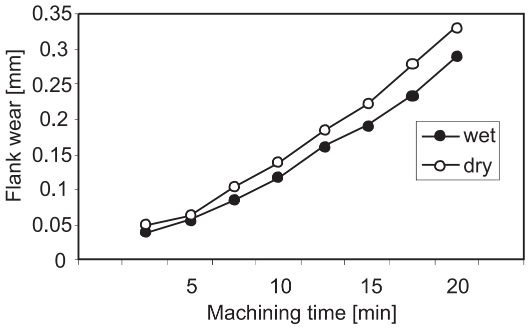


Fig. 3. *Flank wear vs. cutting time (v=260 m/min, f=0.14 mm/rev, a=1 mm)*

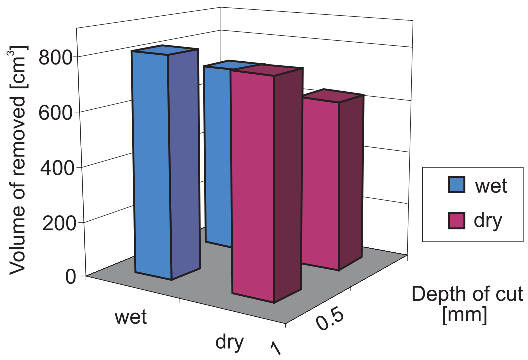


Fig. 4. *Volume of material removed (v=260 m/min, f=0.14 mm/rev, a=1 mm, a=0.5 mm)*

2.2 Surface Finish

Surface finish is one of the most stringent requirements placed on finish operations; its degradations are usually due to the tool wear. For this reason, the work-part surface finish and the tool flank wear were used to evaluate the tool performance. In particular, the wear criterion adopted in the finish turning tests was based on a maximum allowed value imposed to the average surface roughness (Ra), according to the ISO 3685 [15].

Two important performance parameters in turning process are tool life and surface roughness of the machined surface. For most tests, cutting speed and cutting fluid did not show a significant effect on surface roughness for both dry and wet machining conditions. The effect of the cutting speed is negligible. Figs. 5 and 6 shows the variation of surface roughness at different cutting speeds, and flank wear with time for dry and wet-cooled turning.

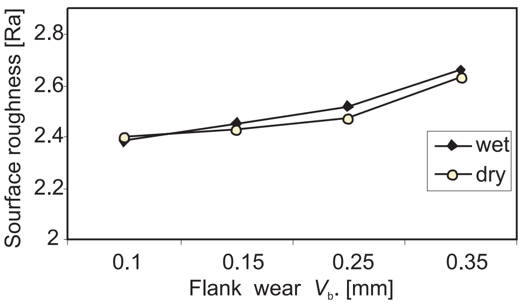


Fig. 5. *Flank wear vs. surface roughness (v=260 m/min, f=0.14 mm/rev, a=1 mm)*

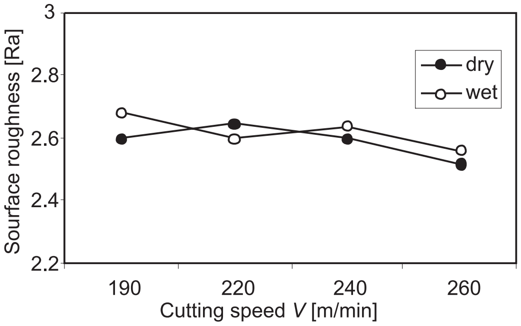


Fig. 6. *Cutting speeds vs. surface roughness*

The major advantage of using cutting fluids in machining operations is reduced of tool wear at high speed. The other advantage is the lowering of cutting forces. Fig. 7 illustrates the tool life at different cutting speeds and constant depths of cut at a feed rate of 0.14 mm/min with dry and wet-cooled turning. When cutting speed increases, Tool life decreases as is expected. But, tool life more decreases for wet cutting than dry cutting. This is because application of flood fluid reduces the coefficient of friction at the interface of the tool and chip over the rake face. This is achieved through lubrication, and by lowering the strength of welded junctions between the tool and chip.

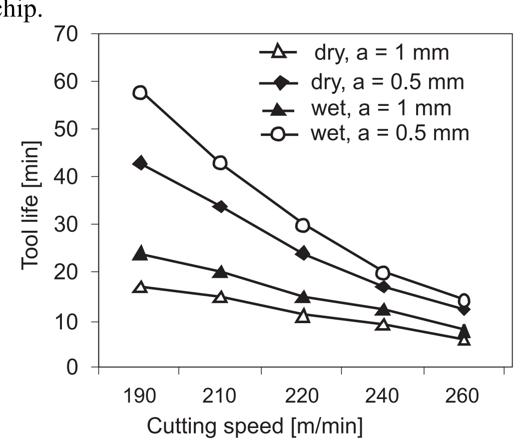


Fig. 7. *Tool life at different cutting speeds (f=0.14 mm/rev, a=1 mm, a=0.5 mm)*

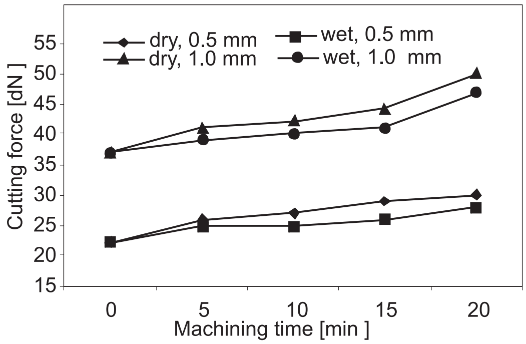


Fig. 8. *Tangential cutting force versus cutting time with dry and wet cooled condition*

2.3 Cutting Forces

The magnitude of the cutting forces is one of the most important machinability indices because that plays vital roles on power and specific energy consumption, product quality and life of the salient numbers of the machine–fixture–tool systems. Fig. 8 shows the variation of main cutting force with the machining time for certain cutting conditions. The cutting force in dry turning was found compared to wet-cooled turning. In all the cases of cutting-speed turning, the cutting force is less in wet-cooled turning due to less flank wear. The relative advantage in cutting force offered by flood fluid cooling over the dry cutting can also be seen from Fig. 8. It is very clear from the curves that cutting force in wet-cooled cutting is less than that of dry cutting.

3 CONCLUSIONS

Based on the results of the experimental investigation the following conclusions can be drawn:

1. The coolant helps breaking up chips and removing them from the cutting area more efficiently, which means the cutting tool spent less time for breaking metal chips.
2. The cutting fluid has significantly reduced the amount of heat and friction at the point where a tool cuts into a metal work piece.
3. For most tests, cutting speed did not show a significant effect on surface roughness for both dry and wet machining conditions. The effect of the cutting speed is negligible.
4. The results of the present work indicated that cutting fluid did not show a significant improvement on surface roughness particularly when cutting tests with 0.8 mm nose radius were considered. In fact, the roughness similarly deteriorated under wet machining in some of tests.
5. CVD coated carbide $TiC+AI_2O_3+TiN$ cutting tool performed better during wet machining mode.
6. The results of the present work indicate substantial reduction in tool wear, which enhanced the tool life; this may be mainly attributed to reduction in cutting zone temperature and favorable change in the chip-tool interaction.
7. The cutting fluid enabled in reducing the main cutting force due to improved and intimate chip-tool interaction.
8. It provided more efficient chip removal and heat reduction.

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