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Performance of Coated Carbide Tool in Green Turning of FCD 700 Ductile Cast Iron

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Abstract— **This paper presents the performance of carbide coated cutting insert in turning FCD700 ductile cast iron in various dry machining conditions (without air, using air and chilled air). The turning parameters studied were, cutting speed of 120m/min., feed rate of 0.15mm/rev - 0.4mm/rev, and depth of cut of 0.6 mm-1.0 mm. The results show that the tool life was significantly controlled by the type of air coolant used, whereas the cutting force and surface roughness were not influenced by these coolants. Chilled air was found to be significantly improved the tool life by about 30% and 40% respectively when compared with normal air and without air conditions. The wear mechanism was predominantly controlled by the flank and crater wears on the flank and rake faces respectively. Due to the low cutting speed used in the experiment, both flank and crater wears were uniformly formed along the cutting edge and no catastrophic failure was observed under the scanning electron microscope (SEM).**

***Index Terms*— FCD700 ductile cast iron, carbide tool, wear mechanism, dry machining**

I. Introduction

Metalworking fluids are a double-edged sword. They can be effective for lubricating and cooling the tool/workpiece interface and flushing chips, but maintenance, safety, fluid disposal and air quality can create pricey headaches. As a result, a growing number of U.S. manufacturers shift to dry or near-dry machining, seeking benefits ranging from coolant cost savings to improve tool life to higher value for recycled chips without having to buy fluid-extraction equipment [1]. Holemaking, however, is an exception. In traditional machining, the fluid that cools and lubricates the cut also helps evacuate chips from the hole, workpiece and fixture. When cutting dry, only the spindle's motion will work to evacuate chips.

In manufacturing automotive components, grey cast iron continues to occupy a notable place in the area of materials. Cast iron is in direct competition with cast aluminium, although the mechanical properties of the former find their place in the market in making certain components such as cylinder blocks, and to a lesser extent, cylinder heads [2]. Cast iron is a ferrous alloy containing a carbon content of 2.14% to 6.67%. It is classified roughly into two types depending on the morphology of graphite in the Fe matrix. One is gray cast iron (also called Ferrum Casting or FC) and the other is ductile cast iron (also called Ferrum Casting Ductile or FCD) [3].

Cutting temperature is an important factor in the machining operations as it strongly influences the cutting forces, tool life and the workpiece surface integrity. Higher cutting temperatures decrease the yield strength of the workpiece material, making it more ductile. This results decrease the cutting forces and hence improve the machinability of the material. However, increased workpiece surface temperatures cause problems like white layer formation. Most importantly, the tool life is affected by increasing cutting temperatures [4].

In this investigation, an industrial carbide coated cutting insert was used to perform turning on FCD700 high tensile ductile grey cast iron. This particular difficult-to-machine cast iron material was selected for this study because of its wide application in automotive industry. The main objective of this study was to evaluate the performance of carbide tool in chilled air condition interms of tool life and wear mechanism.

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II. Experimental Work

The machining trials were carried out on a Colchester model Tornado 600 CNC turning machine in dry condition. The FCD700 (JIS) grade ductile cast iron with spherical graphite and ferrite was prepared in D100mm x 160mm round bar. The Brinell hardness and tensile strength are in the range of 241 HB and 845MPa respectively with elongation of 6%. Table 1 shows the composition of cast iron grade FCD700 used in the experiment.

The AC700G grade coated Al_2O_3 carbide cutting insert was used in these experiments. The technique of CVD coating applied for the insert is suitable for machining ductile gray cast iron material [5]. Table 2 shows the mechanical properties of the coated carbide insert AC700G.

Table I
Composition of cast iron grade FCD700 [6]

Element percentage (%)							
C	Si	Mn	P	S	Cu	Mo	Mg
3.32	2.68	0.46	0.028	0.018	0.85	-	0.09

Table II
Geometry and coating of coated carbide insert

Nose radius, r_ε	Clearance Angle, β	Rake angle, α	Main coating material
0.8	0°	-5°	Al_2O_3 + TiCN

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Chilled air coolant was supplied using vortex tube EXAIR Spot Cooler System Model 3825 during the experiment. Minimum temperature was set at -2 ^{o}C at the same supply of air pressure use for non-chilled air coolant. The cutting speed was kept constant at 120 m/min. The temperature of non-chilled air coolant was set at 28 ^{o}C.

TABLE III
EXPERIMENTAL DETAILS OF THE MACHINING TRIALS

Trial no.	Dry Condition	Feed rate, *f* (mm/rev)	Depth of cut (mm)
1	without air	0.4	0.6
2	without air	0.3	0.8
3	without air	0.15	1.0
4	normal air	0.4	1.0
5	normal air	0.3	0.6
6	normal air	0.15	0.8
7	chilled air	0.4	0.8
8	chilled air	0.3	0.6
9	chilled air	0.15	1.0

The tool wear on the flank face was measured after the first path using a tool maker's microscope equipped with graduated scale in mm. The wear measurement requirement would then depend on the rate of wear growth. The measured parameter to represent the progress of wear was the maximum tool wear $VB_{max.}$ The machining was stopped when VB_{max} reached 0.3 mm. The cutting forces in X, Y, and Z directions were measured online during the turning operation using Kistler dynamometer model 9275B. The surface roughness of the work piece was measured at several locations along the length of the cut using a portable surface roughness tester Mahr Perthometer.

III. RESULT AND DISCUSSION

A. Experimental Results

Table 4 shows the tool life of AC700G grade carbide tools in minutes when machining ductile cast iron in dry cutting condition. The longest tool life of 17.63 minutes was recorded in trial no. 8 at feed rate of 0.3 mm/rev and depth of cut of 0.6 mm with chilled air coolant application. The longest tool life was achieved when using chilled air as coolant. According to the present work [7], when cold wind at low temperature was supplied during the cutting process, the degree of high temperature at cutting point could be lowered, therefore delay the tool wear.

The lowest tool life of 6.7 minutes was obtained with trial no. 2, at the feed rate of 0.3 mm/rev and the depth of cut of 0.8 mm without air coolant. However, increase the feed rate to 0.4 mm/rev and reduce the depth of cut to 0.6 mm would further increase the tool life as in trial no. 1. Reducing the feed rate to 0.15mm/rev in the chilled air condition had doubled the tool life, i.e. double than without air condition. Normally, tool life is influenced mostly by the cutting speed, then by the feed rate, and least by the depth of cut. When the depth of cut is increased to about 10 times greater than the feed, a further increase in the depth of cut will no longer affect the tool life [8]. Conversely, if the cutting speed or the feed is decreased, the increase in the tool life will be proportionately greater than the decrease in the cutting speed or the feed. Generally the chilled air was found to be significantly improved the tool life. The tool life was increased by about 30% and 40% respectively when compared with normal air and without air conditions.

According to Anselmo and Ricardo [17], longer tool life will be achieved as compared to dry cutting, but at higher feed rate reduces the difference in tool life between wet and dry, this is due to the fact that when the feed increases, the heat generated increases, therefore increased the area on the tool to dissipate the heat.

Crater wear, flank wear and chipping of the cutting edge affect the performance of the cutting tool in various ways. The cutting forces are normally increased by wear of the tool. Crater wear may, however, under certain circumstances, reduce forces by effectively increasing the rake angle of the tool. Clearance-face (flank or wear-land) wear and chipping almost invariably increase the cutting forces due to increased in rubbing forces [9], [10]. As shown in Table 4, low values of cutting force and surface roughness were obtained at low feed rates for trial 3, 6 and 9. In this case chilled air coolant does not influence the machining performance. However it may give a better result in term of finishing process.

The surface finish produced in a machining operation usually deteriorates as the tool wears. This is particularly true for a tool worn by chipping, and generally in the case of a tool with flank wear - although there are circumstances in which the wear land may burnish (polish) the workpiece and produce a good finish [9], [10].

TABLE IV
TOOL LIFE, SURFACE ROUGHNESS AND CUTTING FORCE WHEN MACHINING CAST IRON USING T150M COATED CARBIDE TOOL IN DRY CONDITION

Trial no.	Dry Condition	Feed rate, *f* (mm/ rev)	Depth of cut (mm)	Tool life (min)	Surface roughness *Ra* (μm)	Cutting force, *Fc* (N)
1	without air	0.4	0.6	8.01	6.320	562
2	without air	0.3	0.8	6.71	3.175	293
3	without air	0.15	1.0	8.98	1.777	262
4	normal air	0.4	1.0	10.45	6.202	132
5	normal air	0.3	0.6	11.91	3.622	597
6	normal air	0.15	0.8	14.27	1.827	296
7	chilled air	0.4	0.8	12.06	6.779	358
8	chilled air	0.3	0.6	17.63	4.076	682
9	chilled air	0.15	1.0	14.67	1.157	229

B. Wear Mechanism

Wear rate is defined as the volume or mass material removed per unit time or per unit sliding distance and is a complex function of time [11]. The initial period during which wear rate changes is known as the 'run-in' or 'break-in' period. Figure 1 shows the wear on the rake and flank faces at cutting speed of 120 m/min, feed rate of 0.3 mm/rev, depth of cut of 0.6 mm, and using chilled air. At this cutting condition, the longest tool life of 17.63 minutes was obtained. Examination under the SEM for Figures 1-3 show that the wear on the flank face was uniformed and the coating material of Al_2O_3 + TiCN were removed from the cutting edge. It is said so due to the presence of two layers of material observed on the cutting edge. This phenomenon was believed to occur due to the stress concentration which led to the cohesive failure on the flank cutting edge as found by Lin and Khrais [12]. Sharif and Rahim [13] found that the flank wear land increases gradually at low cutting speed. At low cutting speed wear mechanism is due to abrasion [14], and micro-attrition [15] as shown in Figures 1-3.

There is no catastrophic failure such as fracturing and chipping experienced on the cutting edge. Crater wear also uniformly formed along the cutting edge. Material deposition is observed in figures 1 and 2 on the rake face. Severe damage on the cutting edge such as plastic deformation is observed in figure 3 when machining dry without air. In addition, figure 1 shows a 'ridge-and-furrow' [16] topography at the end of the tool life, and the mechanism responsible was termed 'discrete plastic deformation'.

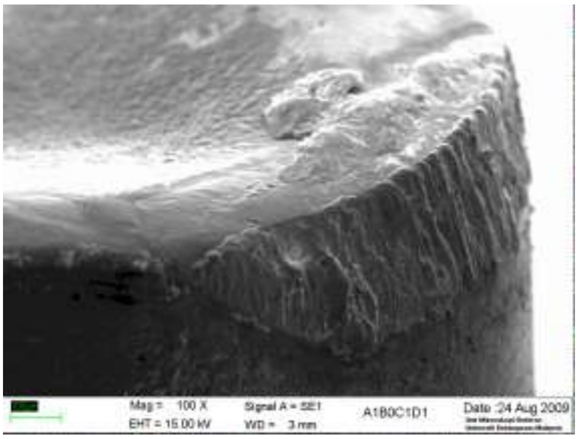

Fig. 1 Wear on the rake and flank faces at cutting speed of 120 m/min, feed rate of 0.3 mm/rev, depth of cut of 0.6 mm, and using chilled air.

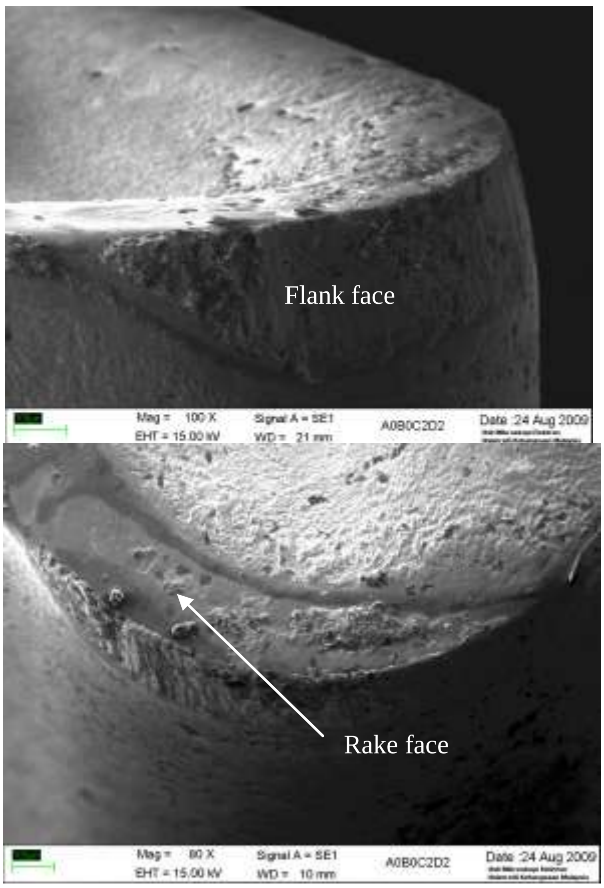

Fig. 2 Wear on the rake and flank faces at cutting speed of 120 m/min, feed rate of 0.15 mm/rev, depth of cut of 0.8 mm, and using normal air

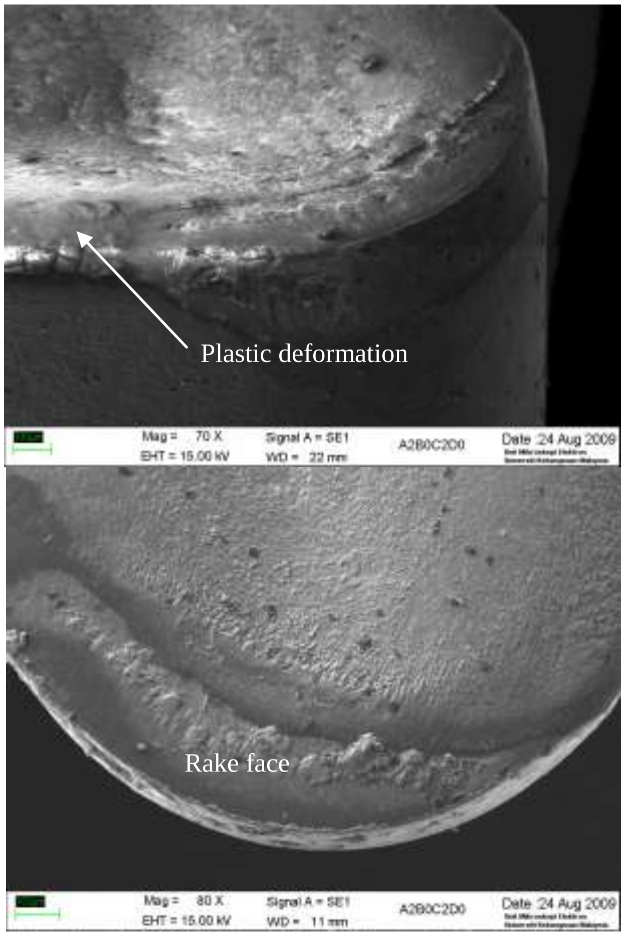

Fig. 3 Wear on the rake and flank faces at cutting speed of 120 m/min, feed rate of 0.15 mm/rev, depth of cut of 1 mm, and without air

IV. Conclusions

The application of chilled air was found significantly improved the tool life as compared with the normal and without air condition. The tool life was increased by about 30% and 40% when compared with normal air and without air conditions respectively. The medium of lubrication gave minimal effect on the surface roughness and cutting force measured. The wear mechanism was predominantly controlled by the flank wear on the flank face at all ranges of cutting speed, and crater wear on the rake face. Wear mechanisms such as abrasion, micro-attrition and a 'ridge-and-furrow' topography were observed on the flank wear. The wear was uniformly formed along the cutting edge due to the low temperature generated as low cutting speed was used in this experiment.

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