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MACHINABILITY OF FCD 500 DUCTILE CAST IRON USING COATED CARBIDE TOOL IN DRY MACHINING CONDITION

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ABSTRACT

Machining is the most important manufacturing process in these modern industries especially for producing automotive component. In this study, ductile cast iron grade FCD 500 was machined using carbide cutting tool in dry end milling condition. The end milling parameters used were cutting speed of 180 m/min, 210 m/min dan 260 m/min. The feed rate of 0.10 mm/tooth, 0.25 mm/ tooth and 0.40 mm/ tooth, and the depth of cut of 0.30 mm, 0.60 mm dan 0.90 mm. Orthogonal L_9 array in Taguchi method was employed to carry out the experimental work. The results were analyzed using Analysis of Variance (ANOVA) to determine the effect of end milling parameters on the tool life, cutting force and surface roughness measured. From the analysis it was found that the depth of cut and feed rate are the most important parameter influencing the tool life. The optimal tool life was found at cutting speed of 180 m/min, feed rate of 0.10 mm/tooth and depth of cut of 0.30 mm. A good surface finish was obtained at cutting speed of 260 m/min, feed of 0.10 mm/ tooth and depth of cut of 0.90 mm. Whereas, at cutting speed of 210 m/min, feed of 0.10 mm/ tooth and depth of cut of 0.30 mm, the lowest cutting force was measured. Wear mechanism at the tool surface such as crater wear, cracking and chipping were observed. These optimum parameters obtained will help automotive industry to have a competitive machining operation from the economical and manufacturing perspective.

Keywords: FDC500 ductile cast iron, carbide tool, Taguchi Method, Wear mechanism, machining performance.

1. INTRODUCTION

Cast iron usually refers to grey cast iron, but identifies a large group of ferrous alloys, which solidify with a eutectic (Trent, 1981). Casting of gray cast iron has relatively few shrinkage cavities and little porosity (Kalpakjian & Schmid, 2001). Generally, white cast iron is hard and brittle, which is difficult to machined (Gonzalez & Bhadeshia, 2001). In addition, the casting process is never perfect especially when dealing with large components (Gonzalez & Bhadeshia, 2001). Instead of scrapping the defective castings parts, repaired can be also done by welding. Very high carbon concentration in the typical cast iron causes difficulties due to the brittle martensite in the heat-affected zone of the weld. In order to avoid cracking, it is therefore necessary to preheat the cast iron to the temperature of about 450ºC followed by slow cooling after welding (Goodrich, 2007).

Goodrich (2007) discussed that the machining problems of cast iron is not necessarily foundry-related. Machining problems associated with cast iron were drilling, milling, turning and other machining processes. Most of the problems were due to the microstructure formation/changes during the machining process itself. As an example, during the high pressure drilling operation, the matrix structure of the cast iron was actually being changed due to stress transformation of the high carbon-retained austenite in the matrix into martensite (Griffin et al, 2007). This transformation produces a much greater wear, and machining-resistant matrix-martensite. Hence, the drilling nearly stops and soon the drill was "fried." The solution suggested to overcome the problems were to increase the feed rate and reduce the turning rate so that any material that was transformed will be removed as the transformation was occurring. Thus, a hardened layer would not be developed under the tool (Goodrich, 2007). Cast iron is comparatively brittle material; therefore it is not suitable for product where a sharp edge or flexibility is required. It also has a property which is strong under compression but not under tension (Gonzalez & Bhadeshia, 2001).

FCD 500 is widely used in automotive industry such as for fuel pump and oil pump, engine cylinder and cranks shaft. This material has a great potential due to good mechanical property, easy to cast and cheap. Carbide tool is important in machining application due to availability and cheap as compared to other cutting tool material such as CBN, eventhough it is preferred in machining cast iron. Dry machining is becoming important due to the awareness towards the environment and worker's health (Gundlach & janowak, 1985). Cutting fluid also add another 16-20% of manufacturing cost (Gundlach & janowak, 1985), therefore optimum use of cutting fluid is a must. According to Komanduri (1983), associated cost with the cutting fluid, sometimes exceed the cost of labour and tooling.

This paper will presents the machining factors that affecting the machinability of FCD500 interms of cutting force, surface roughness and tool life. The wear mechanism of the cardibe tool also will be discussed in detailed.

2. EXPERIMENTAL WORK

The machining trials were carried out on a Cincinnati Milacron, model Sabre 750/TNC 415 Control in dry condition. The FC 500 (JIS) grade cast iron with eutectic graphite and ferrite was prepared in180mm x 100mm x 50mm block. The hardness and tensile strength are in the range of 75 - 95 HRB and 250 – 350 N/mm^2 respectively. Table 1 shows the composition of cast iron grade FCD500 used in the experiment.

The T150M 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. Table 2 shows the mechanical properties of the coated carbide insert T150M.

Table 1 The composition of cast iron grade FC500 (Sirim, 2008)

Element percentage (%)										
C	Si	S	P	Mn	Ni	Cr	Cu	Mg	Al	Co
2.77	1.26	0.11	0.036	1.24	0.26	0.27	0.18	0.127	0.063	0.073

Table 2 The mechanical properties of coated carbide insert T150M

Nose radius r_ε	Rake angle α	Main coating material
0.4	24°	AL_2O_3 + Ti (C,N)

Taguchi's design of experiment with a standard L_9 (3^4) orthogonal array was utilised (Park, 1996). The orthogonal array was chosen because of its minimum number of required experimental trials. The nine machining conditions are shown in Table 3.

Table 3 Experimental details of the machining trials

Experiment no.	Cutting speed, V (m/min)	Feed rate, f (mm/tooth)	Depth of cut (mm)
1	180	0.1	0.3
2	180	0.25	0.6
3	180	0.40	0.9
4	210	0.1	0.6
5	210	0.25	0.9
6	210	0.40	0.3
7	260	0.1	0.9
8	260	0.25	0.1
9	260	0.40	0.6

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 would be stopped when $VB_{max.}$ reached 0.3 mm. The cutting forces in X, Y, and Z directions were measured online during the milling operation using Kistler dynamometer model 9275B. The surface roughness of the workpiece was measured at several locations along the length of the cut using a portable Mitutoyo surface roughness tester.

3.0 RESULTS AND DISCUSSIONS

3.1Experimental Results and ANOVA

Table 4 shows the tool life of T150M grade carbide tools in minutes when machining cast iron in dry cutting condition. The longest tool life of 41.34 minutes was achieved in trial 1 at cutting speed of 180m/min, feed rate of 0.1 mm/tooth and depth of cut of 0.3 mm. ANOVA analysis in Table 5 shows that the effect of cutting speed is negligible as compared to feed rate and depth of cut of 30% and 70% respectively on the tool life. Generally, at the combination of low cutting speed, feed rate and depth of cut resulted in better tool life; Ghani et al. (Ghani et al, 2004) obtained similar results when machining hardened steels. The lowest tool life of 0.26 minutes was obtained with trial 3, at the biggest feed rate (0.4 mm/tooth) and the biggest depth of cut (0.9 mm). However, increase of cutting speed while keeping the feed rate at high value would further shorten the tool life as in Test 9. This was due to the feed rate which strongly influenced the range of chip thickness from tooth entry to exit (Melkote & Endres,1998) and chip area on the end mill (Sutherland & Devor,1986).

Generally, low values of cutting force and surface roughness were obtained at low combination of feed rates and depth of cut as shown in Table 4 for trial 1, 4, 6 and 8. ANOVA analysis in Table 6 shows that the feed rate and depth of cut will greatly influence the generated cutting force. These parameters contribute about 98% to the generated cutting force. The combination of feed rate and depth of cut determines the undeformed chip section and hence the amount of energy required to remove a specified volume of material.

Table 4 The tool life, surface roughness and cutting force of T150M coated carbide tool when machining cast iron in dry condition

Experiment no	Cutting speed *Vc* (m/min)	Feed rate *f* (mm/tooth)	Depth of cut *d* (mm)	Tool life (min)	Surface roughness, *Ra* (μm)	Cutting force, *Fc* (N)
1	180	0.10	0.30	41.34	1,357	290.92
2	180	0.25	0.60	10.39	1,793	845.9
3	180	0.40	0.90	0.26	1.845	1654.08
4	210	0.10	0.60	10.38	0.580	579.11
5	210	0.25	0.90	0.73	2,370	922.38
6	210	0.40	0.30	9.16	1,814	642
7	260	0.10	0.90	3.70	0.732	870.93
8	260	0.25	0.30	6.41	0.814	540.43
9	260	0.40	0.60	2.90	2,507	1067.48

Table 5 ANOVA for tool life

	Factors and contribution			Net total
	A	B	C	
Sum at factor level	Cutting speed, V_c	Feed rate, f	Depth of cut d	
0	40.9592	64.0154	67.7025	172.6771
1	36.8283	33.7359	49.9042	120.4685
2	36.7492	16.7853	-3.0700	50.4645
Sum of squares (S)	34.7948	3434.8465	8131.8000	11601.44
Percentage contribution (%)	0.3	29.6	70.1	100.0

Table 6 ANOVA for cutting force

	Factors and contribution			Net total
	A	B	C	
Sum at factor level	Cutting speed, V_c	Feed rate, f	Depth of cut d	
0	-172.1930	-163.3304	-160.0810	-495.6043
1	-170.7041	-172.4994	-174.3688	-517.5723
2	-174.0216	-181.0890	-182.4690	-537.5797
Sum of squares (S)	16.5667	473.2232	770.9794	1260.7694
Percentage contribution (%)	1.3	37.5	61.2	100.0

The required force to form the chips is dependent on the shear yield strength of the work material under cutting conditions and on the area of the chip section and the shear zone. The feed per tooth and the depth of cut determine this area. The low value of cutting force is desired to cut an unsupported beam or thin sections as well as to preserve material properties against residual stress and change in micro hardness at the subsurface. ANOVA analysis in Table 7 shows that the feed rate is significantly affecting the Ra produced, followed by the cutting speed and depth of cut. The contribution of feed rate, cutting speed and depth of cut are 45%, 32%, and 23% respectively. The surface roughness produced in milling operation depends on feed rate (Martelotti, 1941), and the tool angular position depends on the depth of cut and radius of the cutter (Bornemann, 1938). The influence of the cutting speed on the work-piece surface roughness is complex and it is quite dependent on the material properties of the cutting tools. For the tools with higher hardness and fracture toughness, the work-piece surface roughness decreases as the cutting speed increases. Tools with lower hardness and fracture toughness, the work-piece surface roughness increases as the cutting speed increases (Li & Low, 1994).

Table 7 ANOVA for surface roughness

	Factors and contribution			Net total
	A	B	C	
Sum at factor level	Cutting speed, V_c	Feed rate, f	Depth of cut d	
0	-133.0431	-55.2104	-126.0368	-314.2903
1	-127.9363	-130.7791	-128.3233	-387.0386
2	-63.4858	-138.4758	-70.1051	-272.0667
Sum of squares (S)	9018.1665	12702.988	6522.9358	28244.091
Percentage contribution (%)	31.9	45.0	23.1	100.0

3.2 Wear Mechanisms

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 (Bhushan, 1999). The initial period during which wear rate changes is known as the 'run-in' or 'break-in' period. Figure 1 shows the wear mechanism on the flank face when machining at cutting speed of 180 m/min, feed rate of 0.1 mm/tooth and depth of cut of 0.3 mm. At this cutting condition, the longest tool life of 41.34 minutes was obtained. Examination under the SEM shows that the wear on the flank face was uniformed and the coating material of Al_2O_3 was 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 wedge as found by Lin and Khrais (2007). Sharif and Rahim (2007) found that the flank wear land increases gradually at low cutting speed. At low cutting speed wear mechanism is due to abrasion (Arsecularatne, 2006), and micro-attrition (Ghani et al 2004) as shown in Figures 1-3. Nose wear is also observed as shown in Figure 1. According to Ibrahim et al (2009), low depth cut and cutting speed would cause the wear formation near to the nose radius of carbide tool as observed in machining titanium alloy. Wear will deteriorate the machined part such as, machining with carbide worn tool with flank wear =0.3 mm, resulted in deeper penetration on microstructural changes of H13 tool steel, and the hardness underneath the generated surface was 30% more in relation to the hardness of the basic material (Jaharah et al, 2009).

Catastrophic falure of cutting edge is found when used high depth of cut and feed rate of 0.9 mm and 0.4 mm/tooth respectively as shown in Figure 2.

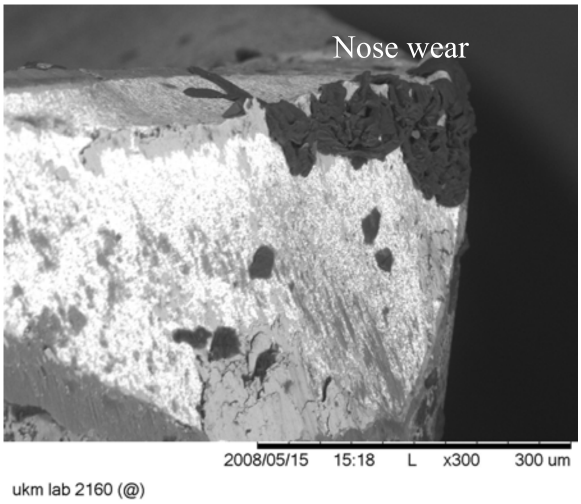

Fig. 1. Wear on the flank face when machining at cutting speed of 180 m/min, feed rate of 0.1 mm/tooth and depth of cut of 0.3 mm

Grooving and chipping are clearly observed on the cutting edge as similarly found by Ghani et al. (2004). Failure may probably due to sudden of sharpness loss at the cutting edge (Trent, 1981). Finding form Sharif and Rahim (2007) also show that feed rate and depth of cut play an important role in determining the tool life. Crater wear is also observed on the rake face as shown in Figure 3. Flaking and fracturing of the rake face occur most liely due to high feed rate of 0.4 mm/tooth. Jaharah et al (2007), found that combination of high feed rate and depth of cut would cause cracking and fracturing of the cutting edge, and led to catastrophic failure of the tool edge.

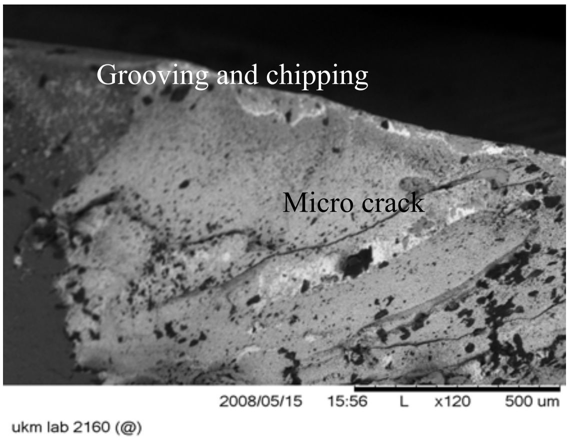

Fig. 2. Chipping and grooving on the flank face when machining at cutting speed of 180 m/min, feed rate of 0.4 mm/tooth and depth of cut of 0.9 mm

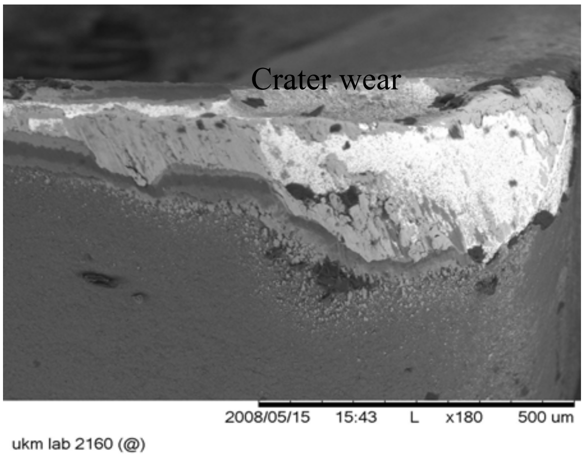

Fig. 3. Crater wear on the rake face when machining at cutting speed of 210 m/min, feed rate of 0.4 mm/tooth and depth of cut of 0.3 mm

4.0 CONCLUSIONS

The effect of cutting speed is almost negligible as compared to feed rate and depth of cut on the tool life of the carbide cutting tool. The effect of rate and depth of cut are 30% and 70% respectively on the tool life. Low values of cutting force and surface roughness are obtained at low combination of feed rates and depth of cut. ANOVA analysis shows that the feed rate and depth of cut will greatly influence the generated cutting force which contributed about 98% to the generated cutting force. Feed rate is significantly affecting the Ra produced, followed by the cutting speed and depth of cut. The contribution of feed rate, cutting speed and depth of cut are 45%, 32%, and 23% respectively. The experimental results revealed that the major contribution to wear mechanism were feed rate and depth of cut, for this range of cutting speed, feed rate and depth of cut. The wear mechanism is predominantly controlled by the flank wear on the flank face at all ranges of cutting speed, and crater wear at high cutting speed. Moreover, catastrophic failure such as chipping and grooving were observed on the cutting edge at high cutting speed of 210 m/min, feed rate of 0.4 mm/tooth and depth of cut of 0.3 mm, which then limit the tool life only up to 0.29 min. Other wear mechanism observed was nose wear at low cutting speed of 180 m/min, feed rate of 0.1 mm/tooth and depth of cut of 0.3 mm.

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