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The Analysis of Coating Performance on Stainless Steel in High Speed Machining

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ABSTRACT

This paper describes the performance of coated tools inserts (TiAlN, Al_2O_3 and TiCN) when machining stainless steel AISI 416 at high cutting speed. The effects of cutting speed and feed rate on the surface roughness and tool life were studied experimentally. The settings of machining parameters were determined by using general full factorial design method. For tested range of milling conditions, the result shows that the surface roughness is highly affected by the feed rate, while tool life is highly affected by combination of cutting speed and feed rate. TiAlN coating performs better followed by Al_2O_3 coating and TiCN coating. Slow wear rate were observed at the combination of cutting parameters which are low cutting speed (260m/min) and feed rate (0.24mm/rev). Meanwhile, interaction between low value of feed rate (0.24mm/rev) and high value of cutting speed (320m/min) that produce good surface finish. Generally, TiAlN coated tool perform better than another coated tools, in terms of surface finish and tool life with current parameters.

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INTRODUCTION

Coated tools widely used in today's metal cutting industry, which bringing about significant improvements in tool performance and cutting economy through lower tool wear, reduced cutting forces and better surface finish of the work piece. Coated tool has high strength and toughness but it generally abrasive and chemically reactive with tool material. Because of their unique properties, coated tools can be used at high cutting speed, thus reducing the time required for machining and costs. In practice, it has been observed that coated tools can improve tool life as much as 10 times of uncoated tools (Kalpakjian, S. and Schmid, S.R. (2008).

In the present paper, (Al_2O_3) Aluminum Oxide, TiCN (Titanium Carbonitride) and TiAlN (Titanium Aluminum Nitride) as coated tools are used to measure the coating performance during machining of Stainless Steel AISI 416 under a specific machine conditions. The effectiveness of different coatings are evaluated in term of effect of cutting speed, feed rate, machining time, tool life and wear, and surface quality (surface roughness). The study was carried about by simultaneously varying the cutting parameters such as cutting speed and feed rate by fitting the value in standard orthogonal array design by Full Factorial.

2. Experimental Techniques:

The experiments were carried out on a Center Mori Seiki NV4000 DCG High Precision Vertical Machining in dry condition, as recommended by the tool supplier for the specific workmaterial. The workmaterial that used was stainless steel AISI 416. Table 1 shows the chemical composition of workmaterial in percentage by weight. The insert used were Al_2O_3, TiCN and TiAlN coated carbide tools. The tool wear was analyzed using the Tool Maker Optical Microscope. Meanwhile, the surface roughness of the workpiece was measured at six several locations along the length of the cut using portable surface roughness tester model Mahr Perthometer PGK.

Table 1: Chemical composition of workmaterial in percentage by weight

C	Cr	Si	Mn	P	S
0.15 %	12.0 – 14.0%	1.0%	1.25%	0.04%	0.15% Min

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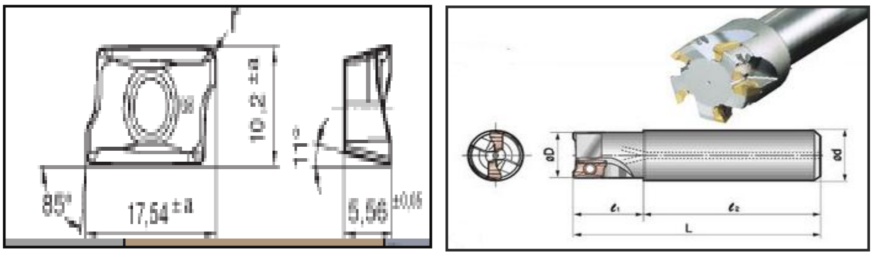

Fig. 1: The dimension of insert and tool holder

Table 2: Detail dimension of tool holder

Dimensions (mm)					Ramp Angle	Insert Qty
D	d	L	l_1	l_2		
40	32	170	50	120	2^0	4

2.1 *Design of experiment:*

Design of experiment (DOE) is used to reduce the number of experiments and time. The control factors are cutting speed and feed rate, as recommended by the tool supplier for the specific work material. Table 3 shows the factor to be studied at 2-levels and has 3-replication. Two levels of cutting speed and feed rate were selected to investigate the machinability of the coated tools at high-cutting speed. The two levels of each factor are represented by ‘1’ and ‘2’ in the matrix. So, the design was chosen a full factorial design with 12 experimental runs.

Table 3: Recommended cutting speed and feed rate for the experiments.

Factors	Levels	
	Low (1)	High (2)
Cutting Speed, v (m/min)	260	320
Feed rate, f (mm/rev)	0.24	0.7

RESULT AND DISCUSSION

The results for tool life, Flank wear (Vb) and surface roughness (Ra) is shown in Table 4. All of the tools failed primarily on the flank face to wear. For all machining conditions, the machining was stopped when the flank wear land (VB) reached about 0.3mm. Previous researchers find the feed rate influence surface roughness. Feed rate was the most significant machining parameter in milling process to predict the surface roughness (Mike, S.L. *et al* (1998). Martelloti (1941) state that the surface roughness produced in milling operation depends on feed rate where, surface roughness increased with the increase in feed rate. The feed rate provides primary contribution and influences most significantly on the surface roughness (Lalwani, D.I. *et al*. (2008). Increasing the feed rate value resulted in higher cutting force, which requires more power consumption to remove the material and consequently more heat generated at the tool edge, which in turn promotes increased of surface roughness and tool wear (Ghani, J.A. *et al*., (2004). There are interaction between surface roughness (Ra) value and flank wear where the roughness of machines surface increases in proportion to the damage suffered by the worn cutting edge and unevenness of the flank wear. This support the earlier discussion about the effect of increasing feed rate on the surface roughness of the machined workpieces. So, the feed rate is most significant machining parameter used to predict the surface roughness.

Table 4: Result for tool life, Flank wear (Vb) and surface roughness (Ra)

Test	Coated Tools	Speed, v (m/min)	Feed rate (mm/rev)	Depth Of Cut (mm)	Tool life (min)	Flank Wear, Vb (mm)	Mean Ra (μm)
1	Al_2O_3	1	1	1.4	49	0.302	0.325
2		1	2	1.4	35	0.310	0.398
3		2	1	1.1	38.5	0.300	0.269
4		2	2	1.0	25	0.313	0.431
5	TiCN	1	1	1.2	42	0.302	0.379
6		1	2	1.1	27.5	0.310	0.434
7		2	1	1.0	35	0.317	0.358
8		2	2	0.8	20	0.317	0.602
9	TiAlN	1	1	1.8	63	0.336	0.293
10		1	2	1.8	45	0.310	0.328
11		2	1	1.6	56	0.305	0.257
12		2	2	1.6	40	0.308	0.363

Meanwhile, Figure 4 shows that general longer tool life could be achieved by using low values of feed rate (0.24mm/rev) as in Test 1, 3,5,7,9, and 11 for each type of coating tools. Che Haron (2001) observed that low feed rates inserts provides better tool life than with high feed rates. Refer to the Table 4; the effect of high feed rate on tool life is significant when Test 2, 6 and 10 shows low value of tool life. However, the shorten tool life or rapid tool wear occur when combined with high cutting speed in Test 4, 8 and 12. This is because, by increasing the cutting speed while keeping the feed rate at high value it further shortens the tool life.

The effect of interaction between high cutting speed and feed rate is most significant in shorten tool life as compared with interaction of low cutting speed and high feed rate at Test 2, 6 and 10. This observation is actually same as the earlier claims by previous researches. Urbanski (2000) found that tool life decrease drastically as cutting speed is increased because at high cutting speed high temperature will be generated, which accelerates tool wear and consequently shortens the tool life.

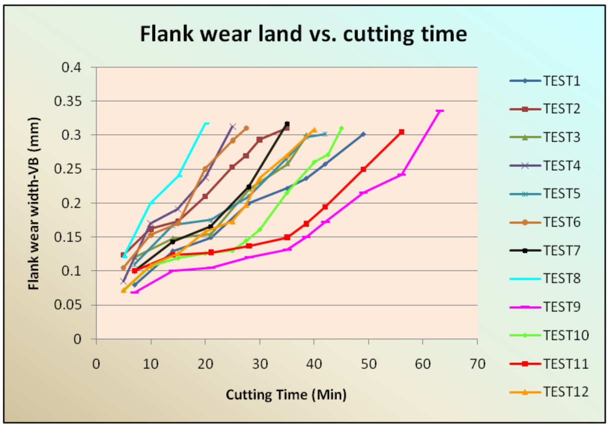

Fig. 4: Graph of flank wear land vs. cutting time

Study of the progress wear shows the longer tool life when using combination of low cutting speed and feed rate was observed as in Fig. 5 at Test 9 using TiAlN. The using lower cutting speed and feed rate resulted in longer tool life at 63 minutes. While, Fig. 6 shows the rapid wear at Test 8 using coating type TiCN. The rapid wear occurs when the cutting tool fail after 20 minutes of machining. The milling parameters such as cutting speed and depth of cut and coating type may influences the tool life. However, when a very high speed is used, more heat will be generated. Ghani (2004) stated when the temperature exceeds a certain limit, it will cause total failure of the cutting edge as high temperature and periodic tool movements in and out of the workpiece cause the temperature fluctuations. Thermal cycling combined with thermal shock causes the thermal fatigue. Besides, Koshy (2002) also found that the effect of cutting speed on the tool life is minimal over the range of speeds tested (50–150 m/min) when they employed indexable inserts of PCBN coated with TiCN when high-speed end milling of AISI D2 (~58 HRC).

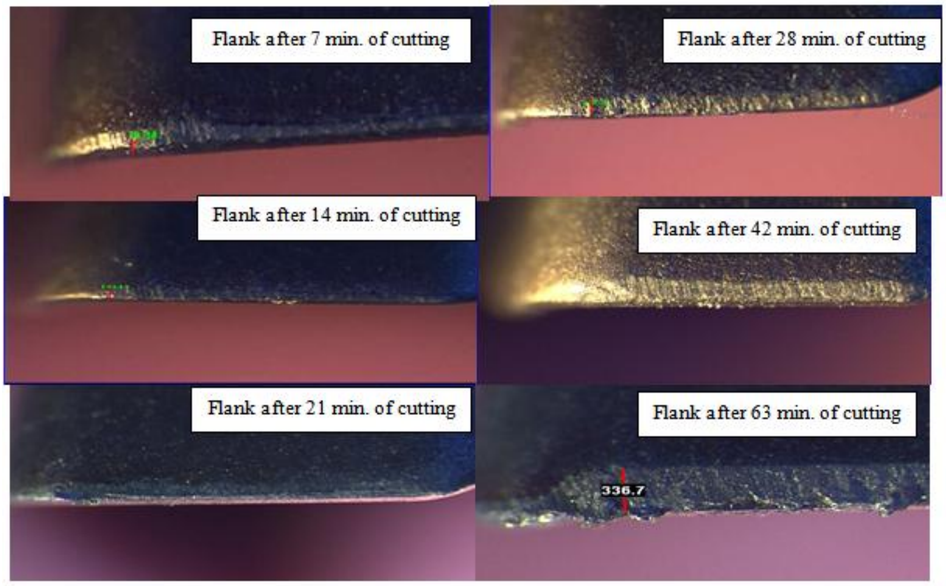

Fig. 5: Progressive wear of Test 9

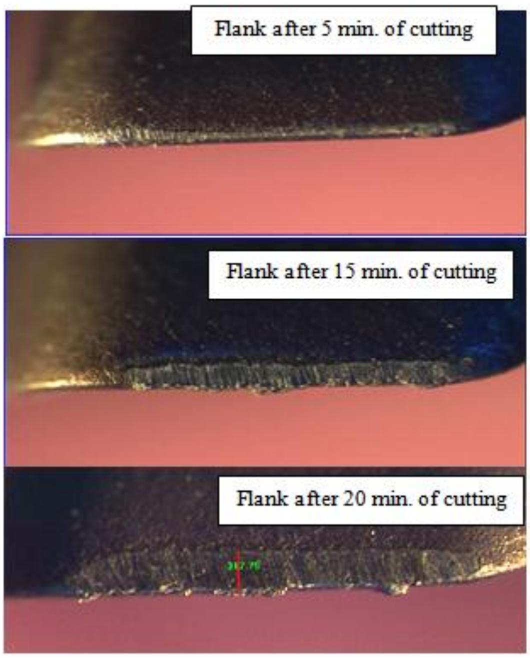

Fig. 6: Progressive wear of Test 8

Conclusion:

i. Results show that the TiAlN coating performs better compared followed by Al_2O_3 coating and TiCN coating when machining stainless steel AISI 416.

ii. It is recommended to use TiAlN coating for finishing operation due to its capability to produce good surface finish, longer tool life and high value of depth of cut.

iii. The feed rate is most significant machining parameter used to predict the surface roughness. Interaction between low value of feed rate (0.24mm/rev) and high value of cutting speed (320m/min) will produce good surface finish.

iv. The cutting speed also gives a significant influence on the surface roughness. As the cutting speed increases, the higher temperature is generated which results in an increase of the surface roughness and reduces the tool life.

v. Tool life depends more on cutting speed and feed rate. The tool life is decrease with the increase of cutting speed and feed rate. Interaction between high cutting speed and high feed rate value will rapidly increase tool wear and surface roughness. The optimum value for tool life which corresponds to design variables: cutting speed = 260m/min and feed rate = 0.24mm/rev.

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