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Comparative study of surface roughness in milling AISI D2 steel using PVD coated and uncoated tungsten carbide insert

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ABSTRACT – This paper comparatively investigates the effect of cutting speed and feed rate on the surface roughness of AISI D2 steel using uncoated and PVD coated inserts in milling operation under dry condition. The response surface methodology (RSM) with a Central Composite Design (CCD) was employed in the experiment to determine the optimum control variables which are cutting speed and feed rate. The optimum condition required for obtaining the minimum surface roughness when milling AISI D2 steel was cutting speed of 100.38 m/min, feed rate of 0.1 mm/tooth, axial depth of cut of 1.5 mm and radial depth of cut of 2.5 mm using PVD coated insert which resulted in a surface roughness of 0.129 µm.

1. INTRODUCTION

Nowadays, various manufacturing processes in industry are capable in producing desired shapes of components within the requirements of dimensional tolerances and surface quality. R. Arokiadass et al. [1] stated that one of the most important factors in physical appearance is the surface roughness. Charles A. [2] found that surface finish influences not only the dimensional accuracy of machine parts, but also their properties. Gokkaya H. et al. [3] stated that surface roughness is affected by the cutting tool coating material, cutting speed and feed rate. A good combination of cutting speed and feed rate can provide better surface qualities.

In this research, comparative study between physical vapor deposition (PVD) coated and uncoated tungsten carbide inserts was conducted in terms of surface roughness when milling AISI D2 steel under dry condition, in order to investigate effects of cutting speed and feed rate. Furthermore, Response Surface Methodology (RSM) using Central Composite Design (CCD) was used in the experiment to determine the optimum parameter for obtaining minimum value of surface roughness.

2. METHODOLOGY

2.1 Workpiece

The material used as the workpiece in this research is AISI D2 steel. This material is widely used in mold manufacturing industry. The composition of AISI D2 steel used is described in Table 1 and the hardness is ranged from 54 to 62 of HRC.

Table 1 Composition of AISI D2 steel

Element	C	Si	Mn	Cr	Mo	Ni	V
Composition [%]	1.4 - 1.6	0.5 - 0.6	0.5 - 0.6	11.0 - 13.0	0.7 - 1.2	0.3 (max)	1.1 (max)

2.2 Machining Condition

Two types of round shape tungsten carbide insert were used in this experiment which are TiAlN/AlCrN PVD coated insert and uncoated insert. The machining conditions for the experiment are described in Table 2.

Table 2 Machining condition for the experiment

Workpiece	AISI D2 steel
Tool	TiAlN/AlCrN PVD insert and uncoated insert
Machine	Mazak CNC milling machine
Atmosphere	Dry machining condition

A Response Surface Methodology (RSM) using Central Composite Design (CCD) approach was employed in order to determine the optimum parameter. The parameter range setting was considered based on the tool maker recommendation and setting from the previous studies. Depth of cut is remained constant at 1.5 mm for axial and 2.5 mm for radial as shown in Table 3.

Table 3 Specification of cutting parameter

Control parameter	**Parameter range**	
Level	**-1**	**1**
Cutting speed, V_c	100 (m/min)	150 (m/min)
Feed rate, f_z	0.1 (mm/ tooth)	0.2 (mm/ tooth)
Constant	Axial depth of cut, a_D	1.5 mm
	Radial depth of cut, a_R	2.5 mm

3. RESULTS AND DISCUSSION

In this study, analysis on independent machining variables that includes cutting speed and feed rate was performed in order to evaluate the surface roughness of PVD coated and uncoated tungsten carbide inserts. The Ra data was measured for three points at every single pass along the workpiece. The experiment was repeated for 20 passes. Then, the value of surface roughness was calculated as shown in Table 4 and 5, respectively.

Table 4 Average values of surface roughness using uncoated insert

Run order	Factor A: Feed rate (mm/tooth)	Factor B: Cutting speed (m/min)	Ra(µm)
1	0.10	100.00	0.377
2	0.20	150.00	1.003
3	0.10	150.00	0.475
5	0.22	125.00	0.305
7	0.20	100.00	0.529
12	0.15	160.36	0.447
14	0.15	125.00	0.721
17	0.15	125.00	0.737
19	0.15	89.64	0.925
21	0.15	125.00	0.731
22	0.08	125.00	0.566

Table 5 Average values of surface roughness using PVD coated insert

Run order	Factor A: Feed rate (mm/tooth)	Factor B: Cutting speed (m/min)	Ra(µm)
4	0.10	150	0.359
6	0.08	125	0.092
8	0.15	125	0.144
9	0.15	160.36	0.13
10	0.20	100	0.199
11	0.20	150	0.146
13	0.15	89.64	0.075
15	0.15	125	0.146
16	0.22	125	0.114
18	0.15	125	0.144
20	0.10	100	0.171

3.1 Effect of Feed Rate and Cutting Speed on Surface Roughness

Figure 1 indicates the relationship between surface roughness and feed rate for uncoated and PVD coated inserts using constant cutting speed of 125 m/min. It was found that for both uncoated and PVD coated inserts, the surface roughness values increase as the feed rate increases and compared to uncoated tools, PVD coated insert produced better surface roughness.

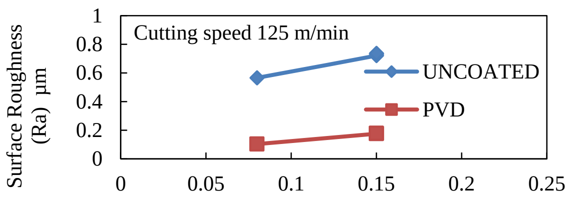

Figure 1 Relationship between surface roughness and feed rate for uncoated and PVD coated inserts

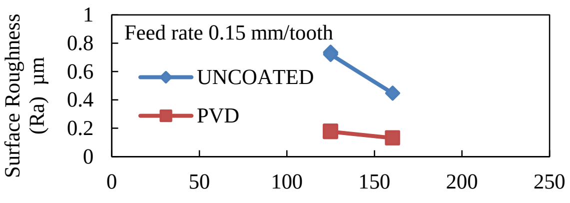

Figure 2 Relationship between surface roughness and cutting speed for uncoated and PVD coated inserts

Figure 2 indicates the surface roughness measured experimentally for uncoated and PVD coated inserts using constant feed rate of 0.15 mm/tooth. It was found that for both uncoated and PVD coated inserts, the surface roughness values decrease as the cutting speed increases and compared to the uncoated insert, PVD coated insert produced better surface roughness.

The relationship between cutting speed and surface roughness is inversely proportional. Increasing the cutting speed decreases the surface roughness. The relationship between feed rate and surface roughness is proportional. Increasing the feed rate increases the surface roughness.

3.2 Optimum parameter for surface roughness

Based on the experiment data and analysis, three cutting conditions predicted to achieve minimum surface roughness are described in Table 6. The optimum cutting condition in milling AISI D2 steel is by using PVD coated insert with cutting speed of 100.38 m/min, feed rate of 0.1 mm/tooth, axial depth of cut of 1.5 mm and radial depth of cut of 2.5 mm, which resulted in a surface roughness of 0.129 µm. For achieving good surface finish on the AISI D2 materials, the lower feed, lower depth of cut and higher cutting speed of machining parameter are preferred.

Table 6 Optimum parameter for surface roughness

No.	Feed Rate (mm/tooth)	Cutting Speed (m/min)	Coating	Surface Roughness (µm)
1	0.1	100.38	PVD	0.129203
2	0.2	150	PVD	0.158406
3	0.1	150	Uncoated	0.678511

4. CONCLUSIONS

Based on the results obtained, the following conclusion can be summarized: (1) Cutting speed and feed rate affect the surface roughness for both PVD and uncoated inserts. (2) The optimum cutting condition in milling AISI D2 steel is by using PVD coated insert with cutting speed of 100.38 m/min, feed rate of 0.1 mm/tooth, axial depth of cut of 1.5 mm and radial depth of cut of 2.5 mm, which resulted in a surface roughness of 0.129 µm.

5. REFERENCES

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