Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

Study of Surface Roughness During Machining of Alloy Steel AISI 4340 Using PVD and CVD Coated Tools in a Dry Environment

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Abstract:
The machining of AISI 4340 alloy steel will be done utilising PVD and CVD coated carbide tools under dry and wet machining conditions in the current experimental investigation. It will be investigated how rough the surface of the machined object is and how chips behave. The morphology of the chips, including their colour and different types of chip formation (continuous, fractured, helical, straight, etc.), provides information on the state of the machining process. The chip generation mechanism is also influenced by the types of machining tools used, the tool nomenclature, and the machining environment. We come to the conclusion that the PVD carbide tool is more effective than the CVD carbide tool in creating better surface finish. Both CVD and PVD carbide tools can produce higher surface finishes under wet conditions. Moreover, the PVD tool performs better than the CVD tool in terms of giving a superior surface finish. For the creation of superior surface quality, cutting speed has been proven to be more beneficial than feed and depth of cut. Continuous chips are created while milling with a PVD-coated carbide tool while it is wet. Continuous chip creation during machining is another sign of producing a high-quality surface finish.

1. Introduction

A subtractive manufacturing method utilised in a wide range of sectors is machining. Due to the ongoing development of materials, it is now crucial to choose the right machining conditions and cutting tool materials. Depending on their qualities, various steel grades are becoming more important in various applications. Among the various steel grades, AISI4340 alloy steel is a grade that finds extensive use in aircraft landing gear, power transmission gears and shafts, and other structural components. Turning operations are believed to be the most often employed machining procedure among all those used for the manufacturing of these valuable components. To achieve the required or desired surface quality in terms of surface finish and better tool life, it is crucial to choose the right cutting tools, the right cutting environment, and various cutting parameters. In recent years, numerous studies have examined the machining characteristics of AISI 4340 alloy steel. In their study of the experimental analysis and investigation of machining parameters in finish hard turning of AISI 4340 Steel, Khan and Bhivsane (2018) discovered that the nose radius and cutting speed play a crucial role in the experimentation to achieve the lowest surface roughness, while the feed and depth of cut have played a minimal role in the experimentation to achieve desirable surface roughness.Suresh et al. (2012) studied the hard turning of AISI 4340 Steel using a multilayer coated carbide tool ($TiC/TiCN/Al_2O_3$) and found that the optimal combination of low feed rate and low depth of cut with high cutting speed is beneficial for reducing machining force. Higher values of feed rates are necessary to minimize the specific cutting force. Suresh et al (2012) studied some studies on the hard turning of AISI 4340 steel using a multilayer coated carbide tool and found that machining force initially increases with an increase in feed rate and depth of cut and decreases with an increase in cutting speed. Anshuman et al (2019) studied the performance appraisal of various nanofluids during hard machining of AISI 4340 steel and the surface finish of machined parts improves with the change in nanofluid from aluminum oxide-based nanofluid to copper oxide-based nanofluid. Because the viscosity of copper oxide-based nanofluid is lower compared to the aluminum oxide-based nanofluid, this results in proper settlement of the nanofluid in the work tool interface, hence, which provides the cushioning effect which may induce low machine chattering and vibrations. The application of nanoparticles in minimum quantity lubrication technique has shown promising results in improving the performance of the hard turning process concerning cutting tool life due to the superior cooling and lubrication properties which enhanced the interface bonding between the tool and workpiece surfaces. Gunjal and Patil (2018) studied the experimental investigations into the turning of hardened AISI 4340 steel using vegetable-based cutting fluids under minimum quantity lubrication (MQL) and concluded that an increase in cutting speed led to rapid wear of tool flank. At a higher cutting speed (240 m/min) sudden failure is observed in the MQL cutting environment, which is due to extreme temperature generated during higher speed. The surface roughness of the material is not significantly affected under varying cutting speeds, as the feed rate was constant throughout the experimentation.

According to the literature, MQL is a suitable option for improving tool life and surface polish when employing coated carbide inserts. The MQL setup is not well-accepted to machining in the traditional sectors. Moreover, thermal shock is not a strong indicator of enhanced machining performance for carbide inserts. Perhaps a better option for general use is the dry machining scenario with carbide inserts. There is hardly much literature on this topic. The current study focuses on turning AISI 4340 alloy steel employing coated (PVD and CVD) materials in a dry environment. The machined component's surface finish has been examined.

2. Materials and Methods

2.1 Workpiece Material

In the present study the AISI4340 alloy steel has been used and workpiece material. The grade steel has wide range of applications in structural and machine building industries. The composition of AISI4340 steel is given in Table 2.1.

Table 2.1: Chemical compositions of AISI 4340 alloy steel

Element	Fe	Ni	Cr	Mn	C	Mo	Si	S	P
Content (wt%)	95.1 – 96.3	1.65 – 2.00	0.7 – 0.9	0.6 – 0.8	0.37 – 0.43	0.2 – 0.3	0.15 – 0.30	≈ 0.04	≈ 0.035

2.2 Cutting tool material and tool holder

The coated carbide tools (PVD and CVD) have been used for the present study (Figure 2.1). The CVD coated tool has the two layers of coating of TiCN and Al_2O_3. The PVD coated tool has the coating of TiAlN. The coatings provide better wear resistance during cutting of steel. Both the tools have chip breakers for easy breaking of chips during machining. These tool inserts are recommended for medium to high-speed cutting operation for medium to high surface finish operations.The tool holder ACLNR

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ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

2525M12 has been used for this experiment (Figure 2.2). This tool holder gives the following tool signature for cutting operation to the tool insert: Tool cutting edge angle=95°; Tool lead angle = -5°; Orthogonal rake angle = -6°; Inclination angle = -6° Tool shank= 25 × 25 mm cross section. The machining has been carried out in a CNC Lathe (FANUC Series o*i*-TF) at CIPET, Ranchi.

	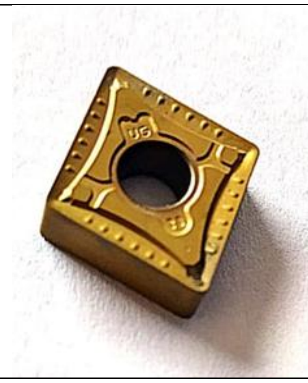
CVD Cutting Insert	PVD Cutting Insert

Figure 2.1: PVD and CVD tool inserts

Figure2.2: Tool holder (YG make)

The present experiments have been carried out using Taguchi design of experiments of L9 orthogonal array. For both dry and wet lubrication machining using PVD and CVD tool inserts, three level of machining process parameters have been used (Table 2.2).

Table 2.2: Levels of machining parameters

Parameters	Level 1	Level 2	Level 3
Cutting speed (m/min)	70	140	210
Feed (mm/rev)	0.05	0.1	0.15
Depth of cut (mm)	0.05	0.075	0.1

The selection of the levels of machining parameters is based on the literature. After each experiment the workpiece was allowed to cool for some time and then the surface roughness was measure using Mitutoyo surface roughness tester. For every experiment, one edge of insert was used. The flank wear was measured using metallurgical microscope. After each experiment, the chip was collected for study of chip morphology analysis purpose.

3. Results and Discussion

This section deals with the results and discussion of machining of AISI 4340 steel using PVD and CVD coated carbide tool inserts under dry condition. For machining under dry condition, the L9 orthogonal array has been used. Table 3.1 shows the nine experiments to be carried out using machining parameters (speed, feed, and depth of cut of different levels. The machining length was 150 mm for all experiments.

Table 3.1: machining parameter of L9 orthogonal array DoE

Experiment No.	Feed(mm/rev)	Cutting speed(m/min)	Depth of cut (mm)
1	0.05	70	0.05
2	0.05	140	0.075
3	0.05	210	0.1
4	0.1	70	0.075
5	0.1	140	0.1
6	0.1	210	0.05
7	0.15	70	0.1
8	0.15	140	0.05
9	0.15	210	0.075

3.1. Surface roughness Analysis

Surface finish of the machined component is very important for quality aspect of the finished part or product. The cutting tool and different machining parameters along with the cutting environment affect the quality of the machined surface. In general, the acceptance level of surface roughness upto 2.5 micron. Moreover, in finishing machining operation, the surface roughness is expected to be much less. During machining of hard metals like AISI4340 steel, the selection of tool, process parameters decide the surface finish of the machined part. Table 3.2 and 3.3 show the surface roughness values obtained during machining of AISI 4340 steel using CVD and PVD tools respectively.

Table 3.2: Surface roughness values obtained during machining with CVD tools

EXPT. No.	FEED (mm/rev)	CUTTING SPEED (m/min)	DEPTH OF CUT (mm)	Ra (Dry)
1	0.05	70	0.05	2.11
2	0.05	140	0.075	0.6
3	0.05	210	0.1	1.2
4	0.1	70	0.075	3.34
5	0.1	140	0.1	0.65
6	0.1	210	0.05	0.35

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ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

7	0.15	70	0.1	2.47
8	0.15	140	0.05	0.92
9	0.15	210	0.075	1.08

Table 3.3: Surface roughness values obtained during machining with PVD tools

EXPT. No.	FEED (mm/rev)	CUTTING SPEED (m/min)	DEPTH OF CUT (mm)	Ra (Dry)
1	0.05	70	0.05	1.29
2	0.05	140	0.075	2.03
3	0.05	210	0.1	1.33
4	0.1	70	0.075	2.13
5	0.1	140	0.1	0.52
6	0.1	210	0.05	0.96
7	0.15	70	0.1	2.75
8	0.15	140	0.05	1.03
9	0.15	210	0.075	1.04

With the use of CVD tools and in both dry and wet lubrication, the cutting speed and feed are the most influential parameters for lower surface roughness values during machining. Moreover, machining under wet condition, the surface roughness values are found to be less. Higher cutting speed was found to be better for getting lesser surface roughness values. The MINITAB has been used to establish the correlation between the process parameters and the surface roughness values.

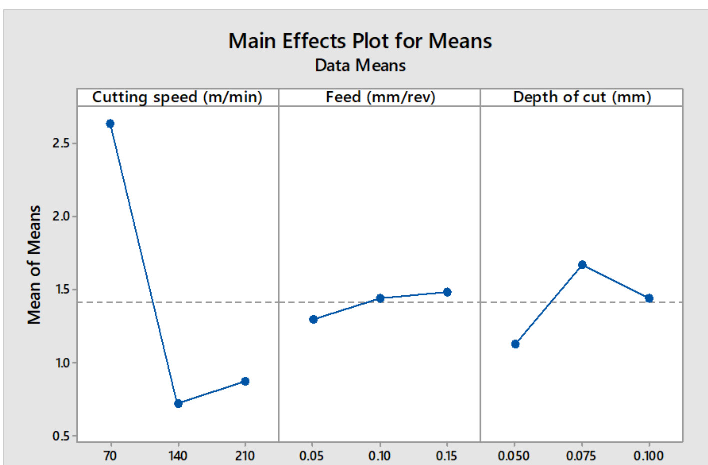

Figure 3.1: Mean effect plot for machining in dry condition using CVD tool

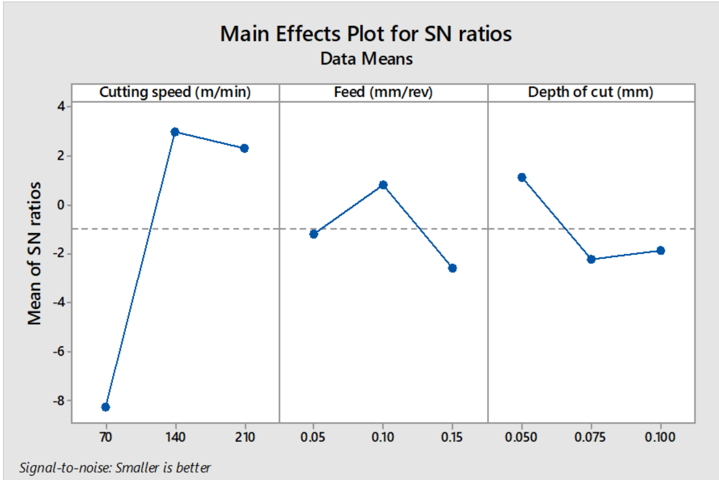

Figure 3.2: S/N ratio plot for machining in dry condition using CVD tool

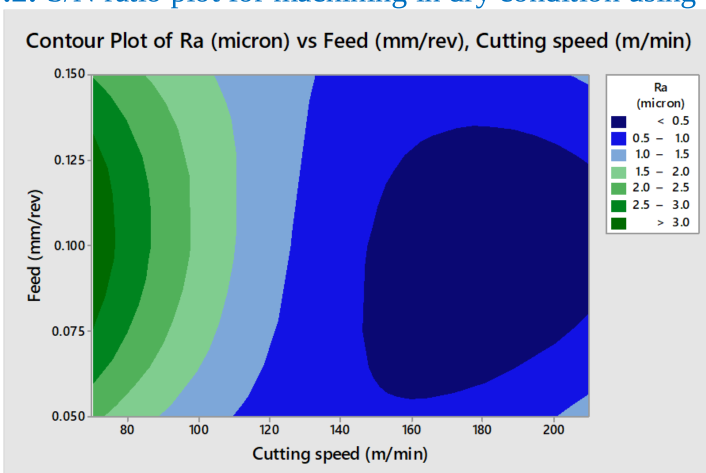

Figure 3.3: Contour plot for machining in dry condition using CVD tool considering cutting speed and feed

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Figure 3.4: Contour plot for machining in dry condition using CVD tool considering cutting speed and depth of cut

Table. 3.4: Response table for (a) Signal to noise ratio (b) Means (for CVD tool, Dry condition)

Level	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	-8.2715	-1.2108	1.1191
2	2.9677	0.7951	-2.2355
3	2.2888	-2.5994	-1.8986
Delta	11.2392	3.3945	3.3546
Rank	1	2	3

(a)

Level	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	2.6400	1.3033	1.1267
2	0.7233	1.4467	1.6733
3	0.8767	1.4900	1.4400
Delta	1.9167	0.1867	0.5467
Rank	1	3	2

(b)

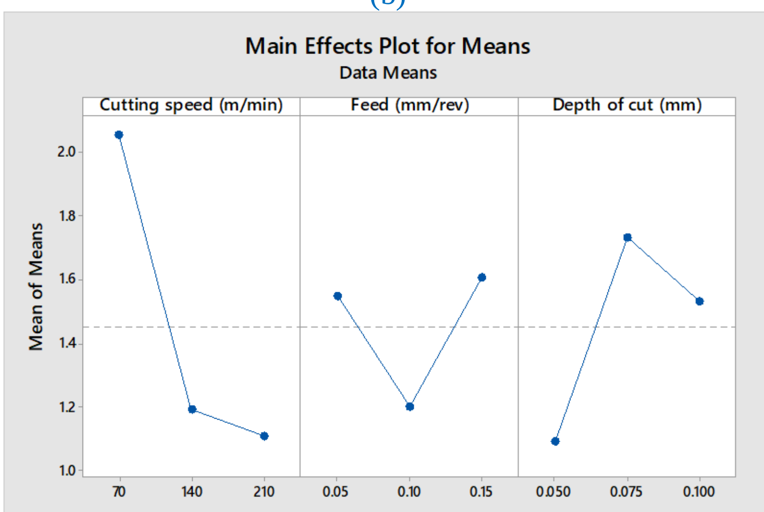

Figure 3.5: Mean effect plot for machining in dry condition using PVD tool

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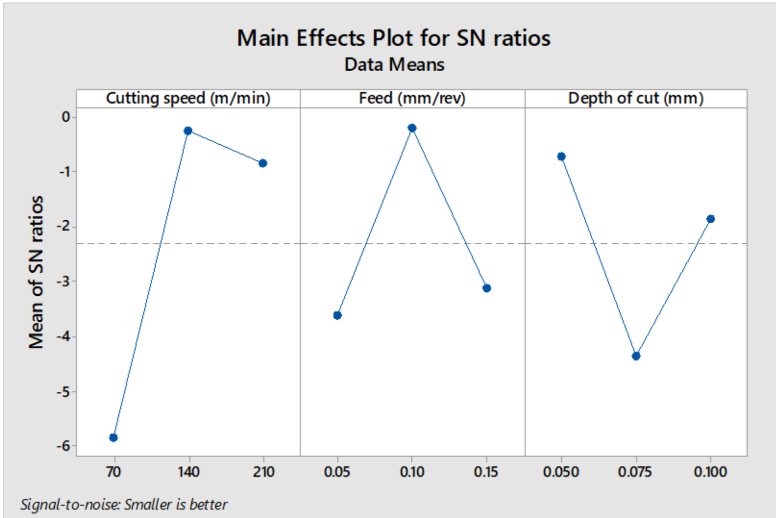

Figure 3.6:S/N ratio plot for machining in dry condition using PVD tool

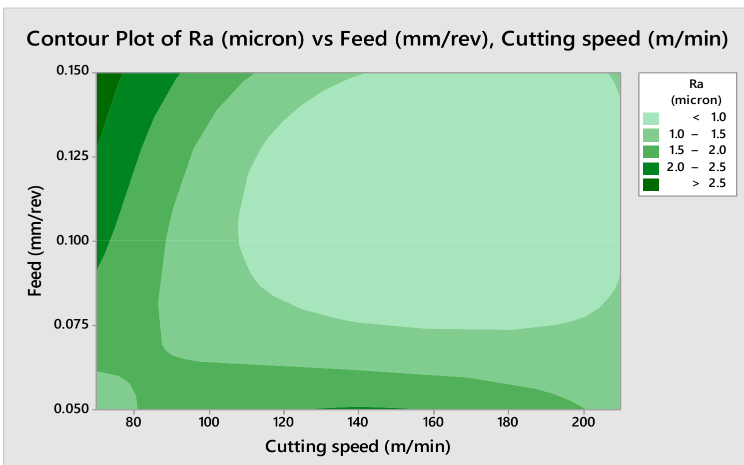

Figure 3.7: Contour plot for machining in dry condition using PVD tool considering cutting speed and feed

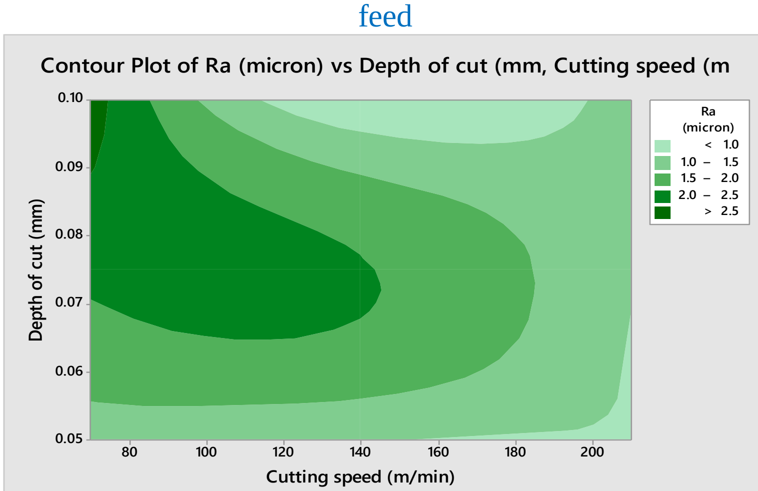

Figure 3.8: Contour plot for machining in dry condition using PVD tool considering cutting speed and depth of cut

Table 3.5: Response table for (a) Signal to noise ratio (b) Means (for PVD tool, dry condition)

Level	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	-5.8553	-3.6129	-0.7047
2	-0.2422	-0.1777	-4.3527
3	-0.8210	-3.1280	-1.8613
Delta	5.6131	3.4352	3.6481
Rank	1	3	2

(a)

Level	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	2.057	1.550	1.093
2	1.193	1.203	1.733
3	1.110	1.607	1.533
Delta	0.947	0.403	0.640
Rank	1	3	2

(b)

The surface roughness values obtained during machining of AISI 4340 steel using CVD and PVD coated carbide tools under dry and wet environment are shown in tables 3.2 and 3.3 respectively. Mean effect plot, S/N ratio, Contour plots of surface rough vs feed, depth of cut and cutting speed and response table are shown in figures 3.1-3.8 and tables 3.4 and 3.5. The followings are observed.

- The performance of PVD tool is better that CVD tool in producing better surface finish.
- In both the cases of PVD and CVD tools, cutting speed is found to be most effective machining parameter than feed and depth of cut.
- Higher cutting speed (210 m/min) is found to be most effective in generation of better surface finish than 70 m/min and 140 m/min. The high cutting speed produces more temperature, and the flow stress of the work material decreases. The cutting force also reduces. The ease of cutting operation initiates smooth machining operation and thereby produces better surface finish as well as surface quality.

4. Conclusions

The current research focuses on the dry machining of AISI4340 ally steel using carbide tools that have been PVD and CVD coated. Because of the temperature and resistance properties of PVD coated tools, their cutting performance is superior than that of CVD coated tools. A superior surface finish can be achieved with faster cutting speeds. During the machining process, feed rate and depth of cut are less effective variables for generating surfaces with a smooth finish.

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