STATISTICAL ANALYSIS OF SURFACE ROUGHNESS IN HARD TURNING OF AISI 4340 STEEL USING THE MULTI-LAYER COATED CARBIDE TOOL

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STATISTICAL ANALYSIS OF SURFACE ROUGHNESS IN HARD TURNING OF AISI 4340 STEEL USING THE MULTI-LAYER COATED CARBIDE TOOL

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ABSTRACT

The present work describes the surface quality of the hard turning process using multi-layer coated carbide tool. Even though many literatures has repeated the hard turning process using polycrystalline cubic boron nitride (PcBN) tool, it became necessary to investigate the effect of multi-layer coated carbide tool due to economical concern. In this paper, the machinability of AISI 4340 steel has been evaluated by considering the different levels of cutting speed, feed and depth of cut. The experimental design is based on L_9 orthogonal array. Then, statistical approach was applied to investigate the effect of cutting speed, feed and depth of cut on surface roughness. Main effect plot of surface roughness revealed that cutting speed of 150 m/min, feed of 0.1 mm/rev and depth of cut of 0.4 mm are the optimum setting of control parameter for minimum surface roughness. Analysis of variance (ANOVA) results of surface roughness revealed that cutting speed and feed are the most significant factor affecting the surface roughness.

KEYWORDS: PcBN, ANOVA, AISI 4340 steel.

Introduction

In the highly competitive metal cutting industries, the ultimate aim in manufacturing is to produce high quality product at low cost and reduction of time constraints. To satisfy the above aim the relationship between product quality and production cost must be minutely observed. Hence, necessary corrective measures need to be employed to meet the demand of the industries. In the recent past, hard turning has been presented as a substitute of cylindrical grinding which helps to establish the quality and viability with the presence of a large variety of tools, workpiece materials and process parameters. Hard turning is an emerging metal cutting process of steel with hardness above 45 HRC, which has been explored as a profitable alternative to cylindrical grinding. This has assured various advantages more than the cylindrical grinding practice with respect to reduced setup time, greater process flexibility, increased productivity, reduced power consumption, lower production costs, improved surface integrity and insignificant environment disputes exclusion of cutting fluid Ko (2001), Tonshoff (2000), Grzesik (2008), Das (2016).

Surface rough nesses of machined parts are considered as one of the most important aspect in hard turning. Because surface roughness affects the corrosion resistance, fatigue strength, tribological properties of machined components and wear resistance. Various researches have been executed on surface roughness using several workpieces in hard turning by many researchers. The following section relates to assessment, modelling and optimization of surface roughness by varying process parameters which have been reported. In the work of Aouici (2016) evaluated the surface roughness by conducting hard turning experiments on AISI H11 hot work steel with various cutting tool materials (ceramic and CBN) and presented statistical analysis associated with RSM and ANOVA to check the validity of regression model and to determine the effects, contribution, significance and optimal settings of machining parameters (v, f, d) on roughness criteria Ra and Rt, The after effects of research work demonstrated that, the feed rate was observed to be an overwhelming factor on surface roughness, trailed by the cutting terms of surface finish with conventional insert by considering the effect of nose radius and cutting

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parameters (v, f, d) in finish turning of oil hardening non-shrinking (OHNS) steel through analysis of variance. The published that better surface finish is achieved with wiper geometry insert. The outcomes of this investigation reveal that, feed followed by depth of cut and insert type significantly affected surface roughness. Shihab (2014) performed am optimization study on surface integrity in order to investigate the effect of different cutting parameters on surface roughness and micro hardness during dry hard turning of alloy steel AISI 52100 steel with coated carbide inserts applying RSM and sequential set of experimental runs using CCD. Results revealed that good surface integrity could be achieved when feed rate and depth of cut are their low levels, whereas cutting speed at high level. During turning of martensitic stainless steel (AISI 420) with coated carbide tool, the FFD, ANOVA and RSM methods were utilized for the optimization of surface roughness by Bouzid (2014). They analyzed the results of an observation regarding the effect of cutting speed, feed and depth of cut on the surface roughness criteria.

Experimental procedure

The work material was AISI 4340 steel in the form of round bars with 60mm diameter and 120mm long were heat treated (quenching and tempering) to reach a hardness of 47 HRC. AISI 4340 is high tensile strength general engineering steel used in automotive and aircraft components, axles, arbors, extrusion liners, magneto drive coupling, shaft & wheels, pinions, etc. The chemical composition of AISI 4340 steel is given in Table 1.

Table 1. Chemical composition of AISI 4340 steel (in %)

Elements	C	Mn	Cr	Mo	Ni	Si	Fe
(%)	0.39	0.77	1.1	0.17	1.55	0.38	Balance

The cutting tool was CVD (TiN/TiCN/Al_2O_3/ZrCN) multilayer coated carbide with an ISO designation of CNMG120408TN7015. TN7015 is a thick alumina-coated carbide grade with a moderately hard, deformation resistant substrate and it is CVD coated with TiCN under layer, followed by Al_2O_3 intermediate layer and ZrCN outer layer. The inserts were clamped on the tool holder with a designation of PCLNR2525M12. The combination of the insert and tool holder resulted in 6° clearance angle, 6° negative rake angle and 95° major cutting edge angle.

The experiment has been conducted to analyze the effect of depth of cut, cutting speed and feed on surface roughness (Ra and Rz). The experiments were carried out with three parameters at three levels each, as shown in Table 2.

Table 2. Process parameter and their levels

Parameters	Unit	Levels		
		1	2	3
Cutting speed(v)	m/min	90	120	150
Feed (f) mm/rev	0.1	0.15	0.2	
Depth of Cut (d)mm	0.3	0.4	0.5	

The experiments were planned according to Taguchi's L_9 (3^3) orthogonal array as shown in Table 3. The turning experiments were carried out in order to obtain experimental data in the dry condition on CNC lathe machine (Jobber XL, AMS India) which has a maximum spindle speed of 3500 rpm and a maximum power of 16kW. In attempts to evaluate the effects of machining parameters on surface roughness (Ra) in hard turning by using experimental data, the working range was decided on the basis of data given in the handbook. The surface roughness of the turned specimen was measured using a portable 'Mitutoyo surface roughness tester' (Taylor Hobson, Surtronic 25) in terms of arithmetic average roughness (Ra).

Table 3. Experimental data of cutting speed, feed and depth of cut.

Run	Coded values			Actual setting			Experimental results of Surface roughness (Ra)
	v	f	d	v	f	d	
1	1	1	1	90	0.10	0.3	0.772
2	1	2	2	90	0.15	0.4	0.98
3	1	3	3	90	0.20	0.5	1.43
4	2	1	2	120	0.10	0.4	0.44
5	2	2	3	120	0.15	0.5	0.762
6	2	3	1	120	0.20	0.3	0.852
7	3	1	3	150	0.10	0.5	0.39
8	3	2	1	150	0.15	0.3	0.742
9	3	3	2	150	0.20	0.4	0.91

Result and discussion

The experimental data of cutting speed and surface roughness have been shown in Table 3. These experimental data were analyzed using MiniTAB software in order to obtain the main effect plot, probability plot and ANOVA results. The main effect plot of average surface roughness (Ra) has been shown in Fig. 1 which indicates the optimum setting of surface roughness at cutting speed of 150 m/min, feed of 0.1 mm/rev and depth of cut of 0.4 mm. Further, the regression model of surface roughness was also developed using MiniTAB software at 90 % confidence level which indicate the R-Squared = 86.5% and R-Squared (adjusted) = 78.4%. The high R-squared value indicates the effectiveness of the developed mathematical model as shown in Eq. (1). Further, the model was checked for their adequacy, which indicate that predicted value are closely following the experimental value. Moreover, probability analysis also has been conducted on experimental data as shown in Fig. 2. The probability plot indicates that most of experimental data points are lying on a straight line which means that experimental results having good agreement with the predicted results.

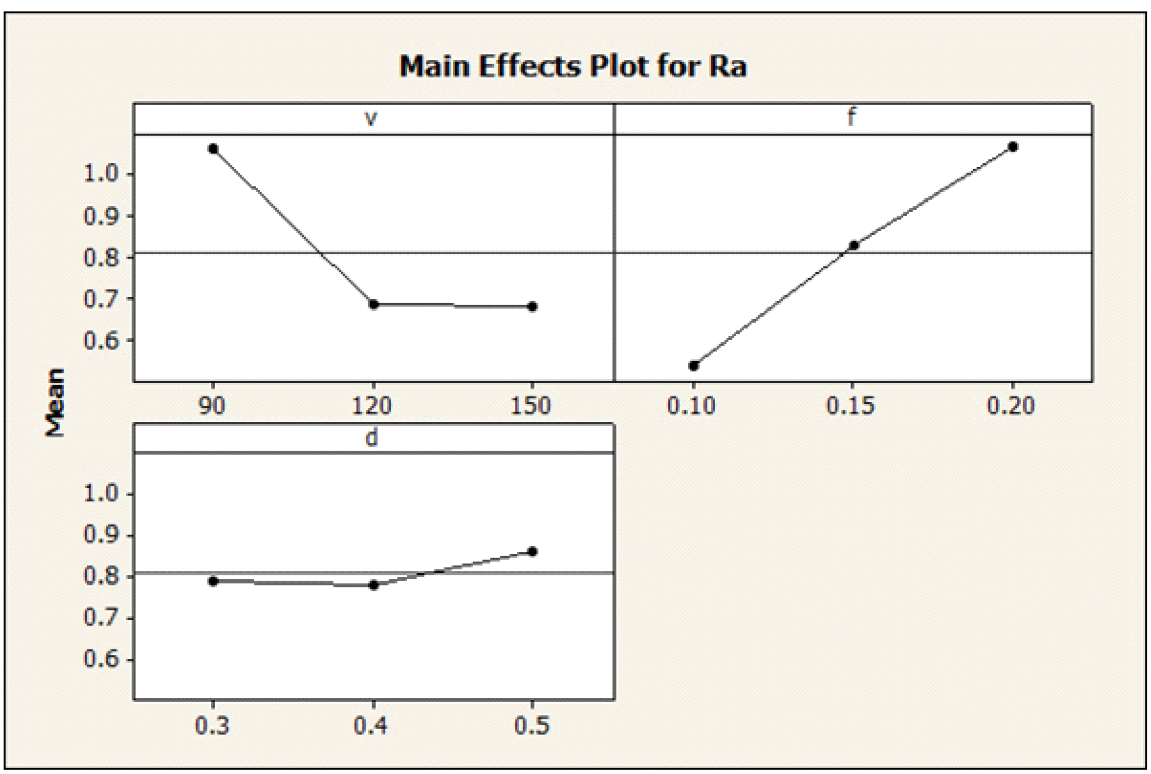

Fig. 1. Main effect plot of surface roughness (Ra).

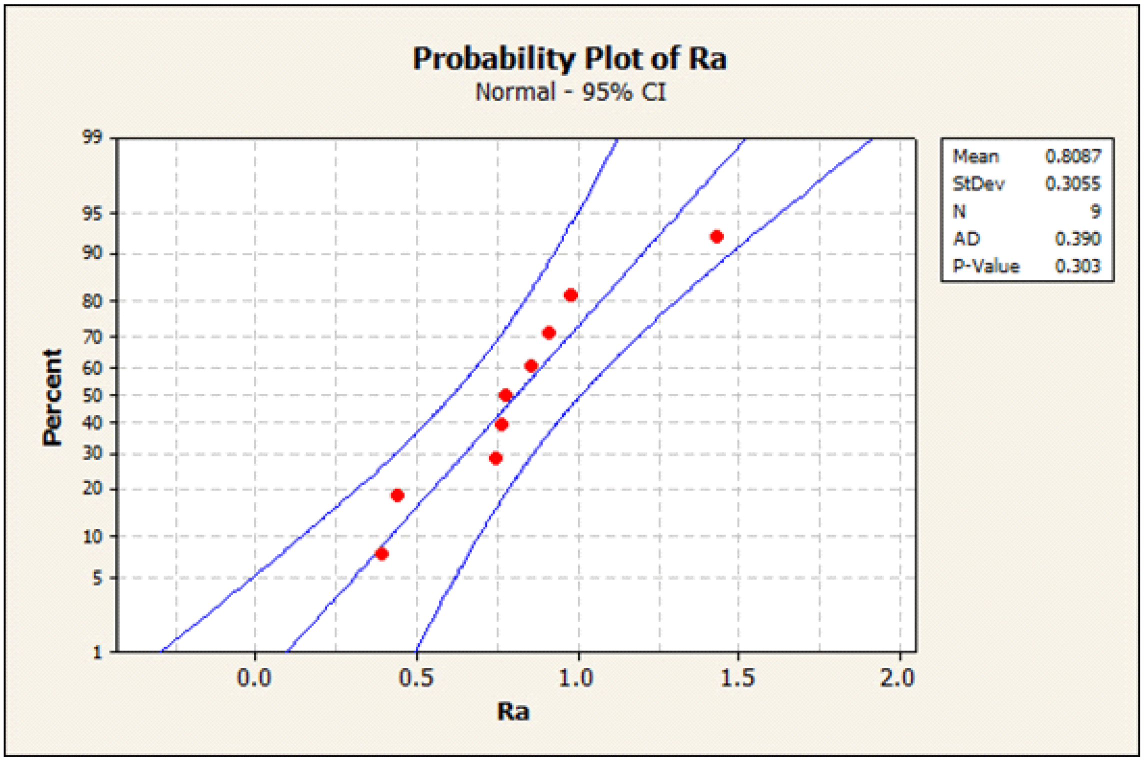

Fig. 2. Probability plot of surface roughness (Ra).

The regression equation is developed at 90 % confidence level as shown in Eq. (1).

$$Ra = 0.630 - 0.00633\,v + 5.30\,f + 0.360\,d \qquad (1)$$

The ANOVA result of surface roughness has been shown in Table 4 which indicate that cutting speed and feed are having probability value 'P' less than 0.1. It means that cutting speed and feed are the most significant factors affecting the surface roughness of the hard turned AISI 4340 steel while employing a multi-layer coated carbide tool. However, the depth of cut seems to be ineffective because probability value 'P' is more than 0.1 at 90 % confidence level.

Table 4. Analysis of Variance for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
v	2	0.28579	0.28579	0.14290	11.20	0.082
f	2	0.42303	0.42303	0.21152 16.58	0.057	
d	2	0.01238	0.01238	0.00619	0.49	0.673
Error	2	0.02551	0.02551	0.01276		
Total	8	0.74672				

S = 0.112942   R-Squared = 96.58%   R-Squared (adjusted) = 86.33%

Conclusion

In the current investigation, the effect of cutting speed, feed and depth of cut on average surface roughness (Ra) has been evaluated while turning AISI 4340 steel using multi-layer coated carbide tool. Based on experimental results, following conclusion has been derived:

- The main effect plot analysis indicates the optimum value of surface roughness for AISI 4340 steel. The average surface roughness (Ra) was found to be minimum at cutting speed of 150 m/min, feed of 0.1 mm/rev and depth of cut of 0.4 mm when utilizing multi-layer coated carbide tool in hard turning process.

- ANOVA analysis of surface roughness revealed that cutting speed and feed are most significant parameter affecting the surface quality, however the depth of cut seems to be ineffective.
- The probability plot surface revealed that all the experimental data point are lying on the straight line which indicates that experimental results having good agreement with the predicted results.

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