An experimental Investigation to Augment the Performance Characteristic in Hard Turning of AISI 4340 Steel with CBN Insert Based on Taguchi

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Abstract: The aim of this research is to investigate the effects of process parameters (cutting speed, feed rate and depth of cut) on performance characteristics in finish hard turning of AISI 4340 steel.The effect of machining parameters has long been an issue in understanding mechanics of turning. Machining parameters has significant influence on chip formation, heat generation, tool wear, surface finish and surface integrity during turning Therefore, an effort has been made in this research to evaluate the effect of machining parameters on surface roughness when turning with CBN tool. Machining trials are performed based on full factorial design under dry condition. The combined effects of the process parameters on performance characteristics are investigated using ANOVA analysis.Taguchi methodology is used to find out the optimal cutting parameters in hard turning. The orthogonal array, the signal- to-noise ratio, and analysis of variance (ANOVA) are employed to study the performance characteristics in turning operation of AISI 4340 steel bar.

Keywords: Hard Turning, Orthogonal Arrays, Cutting Force, Surface Roughness, ANOVA, FEA, Tool wear, Taguchi, SEM

1. Introduction

Hard turning technology has been gaining acceptance in many industries throughout the last two decades. The trend today is to replace the slow and cost-intensive grinding process with finish hard turning in many industrial applications such as bearings, transmission shafts, axles, and engine components, flap gears, landing struts and aerospace engine components. Hard machining means machining of parts whose hardness is more than 45HRC but in actual case hard machining process involves hardness 60HRC and higher. The work piece materials used in hard machining are hardened alloy steel , tool steels , case – hardened Steels , nitride irons , hard – chrome – coated steels and heat – treated powder metallurgical parts. In orderto withstand the very high mechanical and thermal loads of the work piece and cutting materials with improved performances, such as ultra-fine grain cemented carbides, cermet’s, ceramics, cubic boron nitrides (CBN), polycrystalline cubic boron nitride (PCBN) and have been developed and applied. Hard turning is a developing technology that offers many potential benefits compared to grinding, which remains the standard finishing process for critical hardened steel surfaces.

2. Literature Review

In real world steel has gained wide application in industrial fields for its magnificent characteristics. So, in this research work AISI 4340 steel is considered and effect of various process parameters are investigated. Various related works are studied and illustrated below.

Maghodiya et al. [1] investigated the effect of process parameters nose radius, feed rate and cutting speed on the performance characteristics like surface roughness in finish hard turning of H-11 steel hardened at 60 HRC with CBN tool. **Gajera1 et al. [2]**observed that both the cutting speed and the feed rate play equally important roles in the effect on the feed force. **Sowjanya et al. [3]** investigated that the tool life is more when the speed is moderate, depth of cut is minimum and the feed rate is moderate. **Ahmedet al. [4]** described an experimental investigation on machining turning parameters on the cutting forces while machining AISI 1020 steel. Experimental results revealed that the increase in depth of cut d influenced the cutting forces more when compared to changing the feed rate f and cutting speed v. **Dasetal.[5]** tested the performance and concluded that Cutting force shows an increasing trend with the increase in feed rate and depth of cut on the other hand they show a decreasing trend with cutting speed. **Kabaso et al. [6]** studied and indicated that PCBN tool suggests a good wear resistance regardless of the aggressiveness of the 42CrMo4 at 62HRC. At 200 m/min, the machining system becomes uneven and results in significant sparks and vibrations just after a few minutes. **Asilturk et al. [7]** have studied on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. **Nayak et al. [8]** have studied the influence of different machining parameters such as cutting speed (Vc), feed (f) and depth of cut (t) on different performance measures during dry turning of AISI 304 austenitic stainless steel. ISO P30 grade uncoated cemented carbide inserts was used a cutting tool for the current purpose. L27 orthogonal array design of experiments was adopted.**Das et al. [9]** have studied on surface roughness during hard machining of EN 24 steel with the help of coated carbide insert. The experiment has been done under dry conditions. The optimization of process parameters have been done using Grey based Taguchi approach.

Kannan et al. [11] CBN tool insert are considered to be one of the most suitable materials for machining hardened steel because of their high hardness, wear resistance and chemical inertness. In this experimental investigation regarding about heat partition, tool life and develop Merchant circle and tool wear of CBN cutting tool and analyzed while turning of AISI316 steel rods. **Patel etal. [12]** investigated the effect of process parameters (cutting speed, feed rate and depth of cut) on the performance characteristics (tool life(wear), surface roughness) in finish hard turning of D2 steel hardened at 55 TO 57 HRC with CBN tool.**Karthik et al. [13]** conducted experiment on hardened EN31 steel using Hardinge hard turning machine using CBN tools under dry conditions to study the effect of cutting parameters on surface roughness and to obtain optimum cutting parameters for minimizing surface roughness by using Taguchi L9 Orthogonal array method and ANOVA. **Geetha et al.[14]**performed turning of AISI 4340 material using uncoated tungsten carbide at varying cutting parameters. Graphene nanofluid as well as hybrid nanofluid showed the least flank wear. Hybrid nanofluid showed the least cutting temperature at higher depth of cut and higher feed while copper nanofluid showed the least cutting temperature at higher cutting velocities.**Jaykumar et al. [15]**utilized Taguchi technique with an L9 orthogonal array and for ANOVA the Grey Relational Analysis (GRA) has been used. The results were obtained by performing Surface Defect Machining on hardened AISI 4340 steels. For this typical Surface Defect Machining, the grey relation grade is used with the thought of machining force and Surface Roughness (SR) as the level of variables and the best combinations has found as 0.05 of feed mm/rev, 0.5 mm depth of cut and 900 rpm of cutting speed.

From through survey of literatures we found that, though various research works have been carried out on steel but still extensive analysis is required in relation to AISI 4340 steel. So, in this research effect of various parameters on AISI 4340 steel along with optimization techniques like ANOVA and Taguchi is used to obtain the optimal cutting parameters.

3.Experimental details

In this experiment AISI 4340 hardened steel is the work material. It is heat treated to make its hardness reach up to 52HRC.The work piece is AISI 4340[EN24] hardened steel with 41mm diameter, 245 mm long which is shown in Fig.1 and the chemical composition of the specimen is shown in Table1.

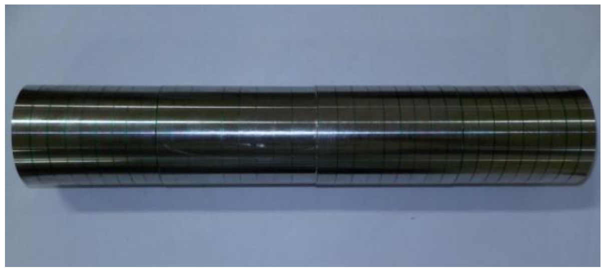


Fig.1: Workpiece used

Table1: The chemical composition of AISI 4340 steel

Sl No.	Name of Component	Percentage
1	Carbon	0.04%
2	Silicon	0.25%
3	Manganese	0.70%
4	Nickel	1.85%
5	Chromium	0.80%
6	Molybdenum	0.25%

CBN tools sometimes enables to skip the grinding process completely in particular cases. CBN do not react chemically with most metals.CBN inserts are specifically for machining high temperature alloys. The insert is cubic boron nitride [CBN] has two no of cutting edges in diagonally, but only one cutting edge is used for 9 experiments. The specification of insert is CNMX 120408EN TA201 [CERATIZIT]

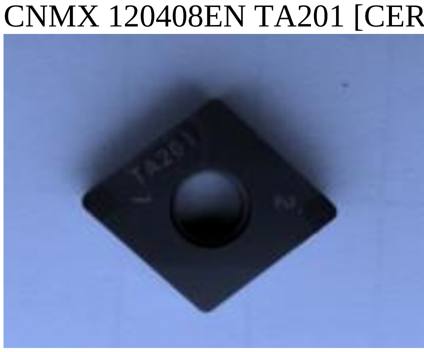


Fig.2: CBN insert

The type of machine used for hard turning is high speed precision lathe machine with high rigidity. Cutting tests were carried out under dry cutting condition. Dry machining has been considered as the machining of the future due to concern regarding the safety of the environment.

Fig.3: High speed precision lathe

Table 2: Conditions of operation

Operating condition	Description
Work specimen	AISI 4340 steel
Insert	Cubic boron nitride(CBN)
Diameter of w/p	41mm
Length of w/p	245mm
Cutting speed	106-202m/min
Feed	0.08-0.16mm/rev
Depth of cut	0.2-0.6
Cutting environment	Dry condition

3.1 Cutting force measurement

Cutting Forces were measured for the CBN tool. The three force components which are, the main feed force (Fx), radial force (Fy) and tangential force (Fz).The measuring signal output was recorded by the data acquisition with interface between amplifier and the PC which is allowing all settings and queries to be made in the instrument.

4. Experimental design

The following parameters were kept fixed during the entire experiment.
Work piece material: AISI 4340
Work piece condition: Hardened to 52HRC
Insert material: cubic boron nitride (CBN)
Cutting condition: Dry

Table 3: Factors and levels used in the experiment

factors	level		
Cutting speed (mm/min)	106	138	202
Feed rate (mm/rev)	0.08	0.12	0 .16
Depth of cut (mm)	0.2	0.4	0.6

5. Selection of orthogonal array

The total degrees of freedom (DOF) for three parameters, each at three levels, are six (Ross 1996). So, a three level OA with at least nine DOF has to be selected. The L9 OA (DOF=8) was thus selected for the present case study. The L9 OA is given in table below. This array specifies nine experimental runs and has four columns. Speed, feed, DOC are assigned to columns respectively.

5.1 Taguchi experiment design

The Taguchi experimental design method is a well-known, unique and powerful technique for product or process quality improvement. It is widely used for analysis of experiment and product or process optimization.

5.2 Experimental results and discussion

Table 4: L_9 Orthogonal array

SI NO.	SPEED (m/min)	FEED (mm/rev)	DOC (mm)
1	106	0.08	0.2
2	106	0.12	0.4
3	106	0.16	0.6
4	138	0.08	0.4
5	138	0.12	0.6
6	138	0.16	0.2
7	202	0.08	0.6
8	202	0.12	0.2
9	202	0.16	0.4

Table 5: Result analysis with various process parameters

SI. No	Speed (m/min)	Feed (mm/rev)	Doc (mm)	Fx	Fy	Fz	Ra	Rz	Rt
1	106	0.08	0.2	74.46	109.84	165.34	0.61	3.5	5.5
2	106	0.12	0.4	102.85	150.58	248.05	0.69	4	6
3	106	0.16	0.6	184.23	318.46	425.34	0.95	5.5	8.12
4	138	0.08	0.4	98.34	125.21	211.32	0.56	3.5	5.5
5	138	0.12	0.6	134.34	196.91	252.45	0.67	4	6.57
6	138	0.16	0.2	82.57	116.12	160.93	0.82	4.5	7.39
7	202	0.08	0.6	126.48	172.98	215.72	0.52	3.35	4.9
8	202	0.12	0.2	50.5	88.54	132.59	0.53	4	6.45
9	202	0.16	0.4	111.36	165.94	219.45	0.76	4.36	5.9

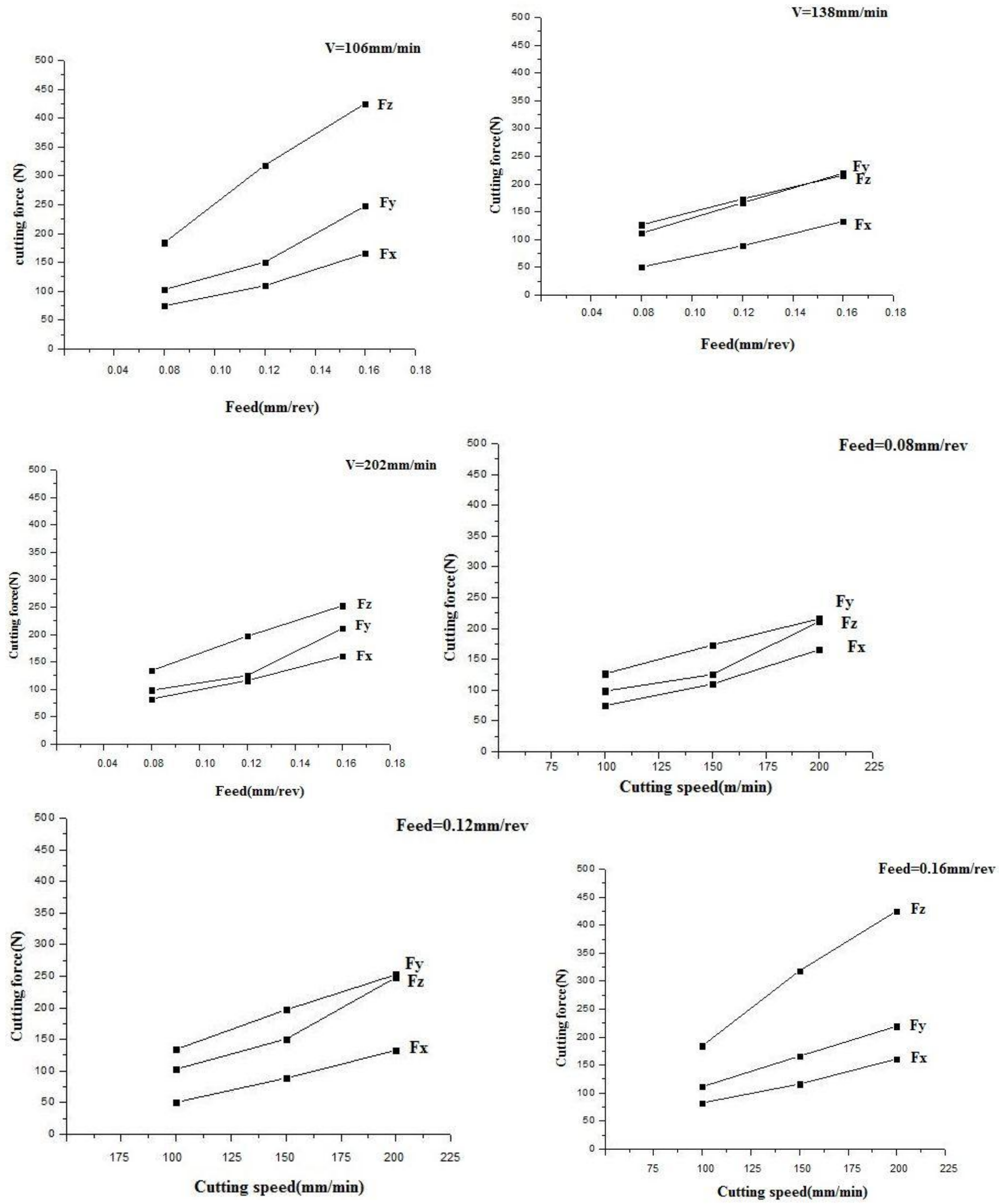


Fig. 4: Graphical representation of various process parameters

6. Analysis of variance for cutting force

According to the analysis done by the MINITAB software, if the values of probability are less than 0.05, it indicated that the factors are significant to the response parameters. Comparing the probability value (p-value) to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant.

Table 6: Analysis of variance for Fx, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Speed	2	913.9	913.9	457.0	12.04	0.076	7.60
Feed	2	1615.7	1615.7	807.8	21.29	0.045	13.40
Doc	2	9444.6	9444.6	4722.3	124.44	0.008	78.37
Error	2	75.9	75.9	37.9			
Total	8	12050.1					
S=6.16020				R-Sq=99.37%			R-Sq(adj) =97.48%

Comparing the probability value (p-value) to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant. Response Table for Signal to Noise RatiosSmaller is better

Table 7: Response table for signal to noise ratios for Fx

Level	v	f	d
1	-41	-39.78	-36.61
2	-40.25	-38.96	-40.34
3	-39.01	-41.53	-43.3
Delta	1.98	2.57	6.69
Rank	3	2	1

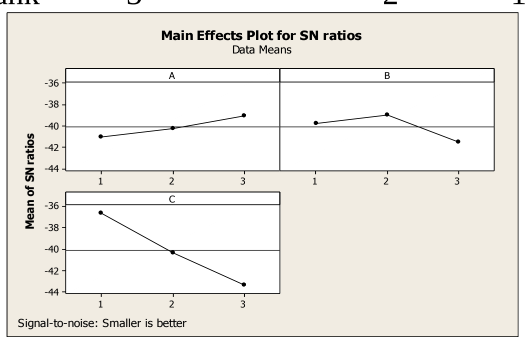


Table 8: Analysis of variance for Fy, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Speed	2	4758.2	4758.2	2379.1	3.25	0.236	12.70
Feed	2	7210.4	7210.4	3605.2	4.92	0.169	19.21
Doc	2	24085.9	24085.9	12042.9	16.43	0.050	64.20
Error	2	1466.0	1466.0	733.0			
Total	8	37520.4					
S=27.0741			R-Sq.=96.09%			R-Sq.(adj) =84.37%	

Table 9: Response table for signal to noise ratios for Fy

Level	v	f	d
1	-44.81	-42.51	-40.35
2	-43.05	-42.79	-43.3
3	-42.7	-45.25	-46.9
Delta	2.11	2.74	6.55
Rank	3	2	1

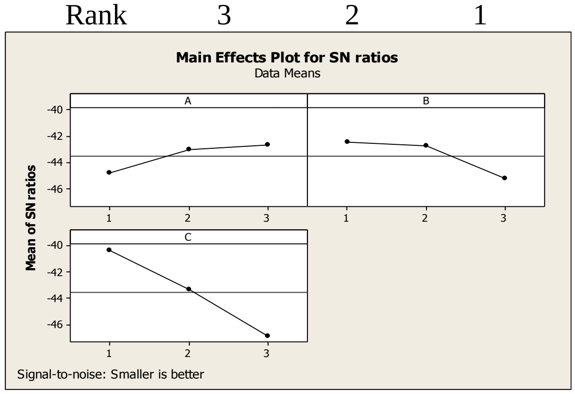


Table 10: Analysis of variance for Fz , using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
speed	2	13608	13608	6804	3.18	0.239	23.50
feed	2	8552	8552	4276	2.00	0.333	14.80
doc	2	31488	31488	15744	7.36	0.051	54.30
error	2	4275	4275	2138			
total	8	57925					
S=46.2353			R-Sq=92.62%			R-Sq(adj) =70.48%	

Table 11: Response table for signal to noise ratios for Fz

Level	v	f	d
1	-48.28	-45.85	-43.65
2	-46.23	-46.13	-47.07
3	-45.32	-47.84	-49.1
Delta	2.96	2	5.45
Rank	2	3	1

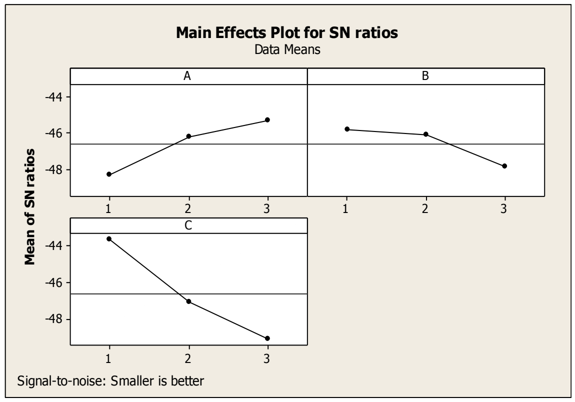
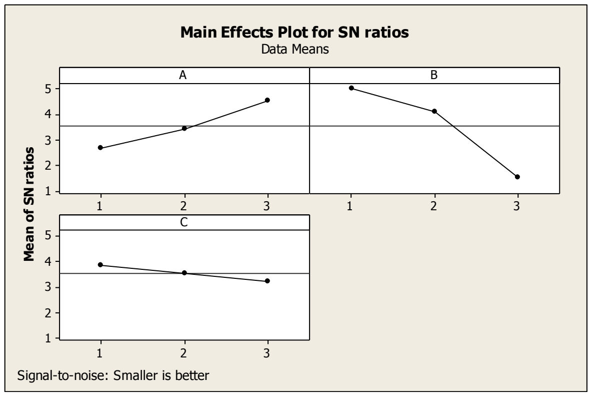


Table 12: Analysis of variance for Ra, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
speed	2	0.032356	0.032356	0.016178	1456.00	0.001	19.40
Feed	2	0.128356	0.128356	0.064178	5776.00	0.000	77.09
Doc	2	0.005756	0.005756	0.002878	259.00	0.004	3.49
Error	2	0.000022	0.0000022	0.000011			
Total	8	0.166489					
S=0.00333333			R-Sq= 99.99%			R-Sq(adj) =99.95%	

Table 13: Response table for signal to noise ratios for Ra

Level	v	f	d
1	2.654	5.003	3.844
2	3.413	4.072	3.548
3	4.526	1.518	3.201
Delta	1.872	3.486	0.643
Rank	2	3	1



7. Conclusions

From ANOVA result table it is observed that all the three parameters influencing significant role on surface roughness, whereas the largest contribution of feed is more than other two factor. The feed rate explain contribution of 77.09% the total variability. The next largest contribution on cutting speed and depth of cut. This indicates that feed has little influence on radial force.all the three parameters p-value is less than 0.05. The confidence level (CL) used for investigation is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in cutting forces is explained by the input factor. R-Sq= 99.99% which indicate that the model is able to predicate the response with high accuracy.
According to response table for signal to noise ratio smaller is better by which minimum cutting force is selected. From the table the depth of cut obtained first rank.Also the following conclusions are drawn from the research analysis.
• From main effect plot, considering cutting speed (A) the maximum mean value obtained at 202mm/min.
• Similarly for considering the feed graph (B) the maximum mean value obtained at 0.08mm/rev.
• Also for considering the depth of cut(C) the maximum mean value obtained at 0.2 which is maximum overall mean over three graphs.
• The optimum surface roughness 0.52 is obtained at spindle speed 202m/min, feed rate 0.08mm/rev and Doc 0.6mm.
• Maximum surface roughness is 0.95 at speed 106 m/min at feed rate 0.16mm/rev and doc 0.6mm.

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