Optimization of Roughness Value by using Tool Inserts of Nose Radius 0.4mm in Finish Hard-Turning of AISI 4340 Steel

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Abstract: **- Increasing the productivity and the quality of the machined parts are the main challenges of high strength and heat resistant materials in aerospace, automotive, steam turbines and nuclear applications. This requires better management of the machining system corresponding to cutting tool-machine tool- study piece combination to go towards more rapid metal removal rate. In this work, a L9 Taguchi standard orthogonal array is adopted as the experimental design. The combined effects of the cutting parameters on roughness value are investigated. The relationship between cutting parameters and roughness values through the regression analysis is found out. The different correlations are developed between tribological parameters and roughness value for mm of tool nose radius with 9 runs.**

Keywords: L9 Taguchi, Roughness Value, Cutting Parameters, Regression Analysis, Tribological Parameters.

1] INTRODUCTION:

The hard turning is performed on materials with hardness within the 41–68 Rockwell range using a variety of tipped or solid cutting inserts, preferably CBN. Although grinding is known to produce good surface finish at relatively high feed rates, hard turning can produce as good or better surface finish at significantly higher material removal rates and also allowing the machining of more complicated geometries than the aforementioned process. Although the process is performed with small depths of cuts and feed rates, estimates of reduced machining time are as high as 60% for hard turning as compared to grinding.

Machined surface characteristics are important in determining the functional performance such as fatigue strength, corrosion resistance and tribological properties of machined components. The quality of surfaces of machined components is determined by the surface finish and integrity obtained after machining. High surface roughness values, hence poor surface finish, decrease the fatigue life of machined components.

In turning, there are many factors affecting the cutting process behavior such as tool variables, work piece variables and cutting conditions. Tool variables consist of tool material, cutting edge geometry (clearance angle, cutting edge inclination angle, nose radius, and rake angle), tool vibration, etc., while work piece variables comprise material, mechanical properties (hardness), chemicals and physicals properties, etc. Furthermore, cutting conditions include cutting speed, feed rate and depth of cut. The selection of optimal process parameters is usually a difficult work, however, is a very important issue for the machining process control in order to achieve improved product quality, high productivity and low cost. The optimization techniques of machining parameters through experimental methods and mathematical and statistical models have grown substantially over time to achieve a common goal of improving higher machining process efficiency.

As finish hard turning has experienced significant growth due to the need for continuously improving productivity and decreasing the processing cost, it is a potential alternative to conventional mechanical grinding for small and medium numbers of work pieces. Finish hard turning offers high geometric flexibility, reduced machining sequences, options for dry machining, improved surface integrity, and significantly enhanced fatigue life. Since, high hardness work pieces are involved in finish hard turning, high toughness and wear resistance for the tools are required along with an imperative need for optimum tool geometry.

2] Present Theories and Practices**:** Many researchers have worked on hard turning of metals with the help of single point inserts. Some of the notable works relevant to our study are summarized below:

A. Agrawal et. al. [1] has studied in their article, Prediction of surface roughness during hard turning of AISI 4340. In his study, 39 sets of hard turning experimental trials were performed on a AISI 4340 material hardened up to 60 HRC to study the effect of cutting parameters in influencing the machined surface roughness. The machining outcome was used as an input to develop various regression models to predict the average machined surface roughness on this material.

The effects of the cutting parameters and tool materials on surface roughness were evaluated by the analysis of variance. N. Gore et. al. [2] has studied the Optimization of Roughness Value from Tribological Parameters in Hard Turning of AISI 52100 Steel. The experimentation was performed on CNC machine and the CBN insert was used to optimize the roughness value of AISI 52100 steel which has hardness between 41 to 65 HRC under the tribological parameters like speed, feed and the depth of cut. The Taguchi L9 (OA) was utilised and the performance of roughness value was optimized by the regression analysis.

P. Campos et. al. [3] has stated in their published paper about Modeling Life of Tool and Roughness in Turning Hard Steel AISI 52100. They have studied the interrelationship between the life of tools, average roughness of the machined surfaces and the process factors such as cutting speed, feed, depth of cut in a single context. They have applied a statistical approach to derive a mathematical relationship between the influencing factors and a mathematical modeling tool life (T) and surface roughness (Ra, Rq) of the part in the process of turning of hardened steel.

B. K. M. Paul et. al.[4] has published in the article, Optimization of Cutting Parameters in Hard Turning of AISI 4340 Steel. Their paper investigates the effects of parameters such as cutting speed, feed and depth of cut on the surface roughness, tool wear and cutting force during the hard turning of AISI 4340 alloy steel using ceramic wiper tool and the effect of various process parameters on hard tuning and optimize the cutting parameters.

M. Gunay et. al. [5] has studied in Application of Taguchi method for determining optimum surface roughness in turning of high-alloy white cast iron. Their paper focused on optimizing the cutting conditions for the average surface roughness obtained in machining of high-alloy white cast iron at two different hardness levels (50 HRC and 62 HRC). Optimal cutting conditions was determined using the signal-to-noise (S/N) ratio which was calculated for Ra according to the „„the-smaller-the-better"" approach.

G. Bartarya et. al. [6] have studied the Effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI 52100 grade steel. Their present work is an attempt to develop a force prediction model during finish machining of EN31 steel hardened to 60±2 HRC using CBN tool and to analyze the combination of the machining parameters for better performance within a selected range of machining parameters. Regression models was developed to show the dependence of the cutting forces on machining parameters are significant, hence they could be used for making predictions for the forces and surface roughness.

3] Scope of work: In this study, for finished hard turning, the effect of input parameters such as cutting speed, feed, depth of cut, tool nose radius on surface roughness of hardened AISI 4340 steel material is studied by using tool with CBN inserts nose radius 0.4mm. The experimentation plan is designed using Taguchi"s technique.

4] Taguchi Design: The working ranges of the parameters for subsequent design of experiment, orthogonal array (OA) based on Taguchi"s L_9 (3^2) design has been selected. In the present experimental work, cutting speed (v), feed rate (f),and depth of cut (d) have been consider as a cutting parameters.

The cutting parameters and their associated ranges are given in the table below:

Table 1: L9 orthogonal array Taguchi experiment design with actual 9 runs

Tool Nose Radius	Runs	Taguchi Values of Tribological Parameters			Actual Values of Tribological Parameters		
		v	f	d	v	f	d
0.4	1	1	1	1	280	0.05	0.1
	2	1	2	2	280	0.1	0.15
	3	1	3	3	280	0.15	0.2
	4	2	1	2	320	0.05	0.15
	5	2	2	3	320	0.1	0.2
	6	2	3	1	320	0.15	0.1
	7	3	1	3	360	0.05	0.2
	8	3	2	1	360	0.1	0.1
	9	3	3	2	360	0.15	0.15

After that stepwise procedure is adopted for turning operation and Mitutoyo make roughness tester is used for measuring the roughness value of the machined component. The modelling has done by the regression analysis software, the regression analysis done by the Minitab software of version 16. The regression analysis is the statistical technique that identifies the relationship between two or more quantitative variables.

5] Modelling of roughness value from speed, feed and depth of cut for 0.4 mm tool nose radius: New value of roughness had estimated from the regression analysis derived formula. At last the absolute error and the percentage error calculated. The modelling of roughness value from speed, feed and depth of cut lay down in following table.

Table 2: Observation table of modelling of roughness value for 0.4 mm tool nose radius

Run	V	F	D	Exp. Ra
1	240	0.05	0.1	0.25
2	240	0.1	0.15	0.774
3	240	0.15	0.2	1.098
4	280	0.05	0.15	0.276
5	280	0.1	0.2	0.814
6	280	0.15	0.1	0.912
7	340	0.05	0.2	0.258
8	340	0.1	0.1	0.384
9	340	0.15	0.15	0.906

Regression equation:

$$\text{Est. Ra} = 0.276533 - 0.00239\ V + 7.108\ F + 2.08\ D$$

Table 3: Observation table of modelling of roughness value from speed, feed and depth of cut

Coefficients				
Term	Coef	SE Coef	T	P
Constant	0.1692	0.161378	1.0485	0.342
V	-0.00196	0.00047	-4.1508	0.009
F	7.108	0.475334	14.9537	0
D	2.08	0.475334	4.3759	0.007
Summary model				
S= 0.0582163	R-Sq= 97.72%	R-Sq(adj)= 96.98%		
PRESS= 0.0652385	R-Sq(Pred)= 92.74%			

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Analysis of variance							
Source	DF	Seq SS	Adj SS	Adj MS	F	P	C (%)
Regression	3	0.881143	0.881143	0.293714	86.664	9.9E-05	
V	1	0.058392	0.058392	0.058392	17.229	0.0089	6.49
F	1	0.757855	0.757855	0.757855	223.613	0.00024	84.26
D	1	0.064896	0.064896	0.064896	19.148	0.00718	7.21
Error	5	0.016946	0.016946	0.003389			1.88
Total	8	0.898089					100

Fits and diagnostics or unusual observation					
Observation	Exp. Ra	Fit	SE fit	Residue	St Residue
3	1.08	1.81	0.0446303	-0.083	-2.2204R

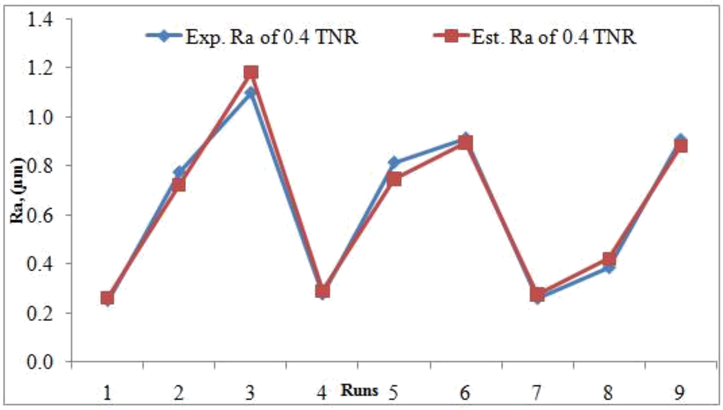
R denotes an observation with a large standardize residual.

The correlation developed from the statistical analysis. The below given equation is combined correlation with roughness value,

$$\text{Est. Ra} = 0.1692 - 0.00196\,V + 7.108\,F + 2.08\,D$$

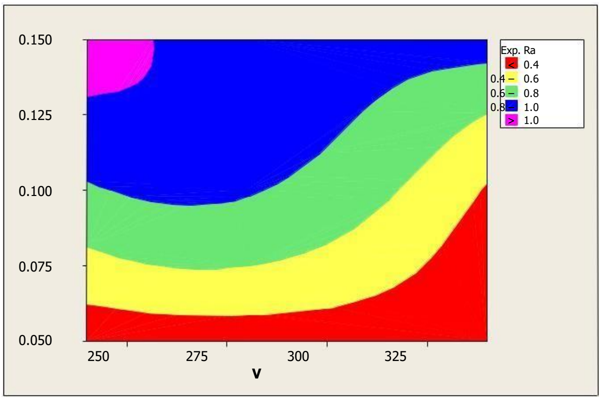
6] Experimental and estimated roughness value from speed, feed, and depth of cut for different tool nose radius 0.4mm :

The below given graphical representation show the correlation between estimated roughness value and experimental roughness value. The experimental roughness value is the actual roughness value measured by roughness tester and the estimated roughness are the values, which are estimated from regression equation and main factors cutting speed, feed, and depth of cut for 0.4mm tool nose radius.



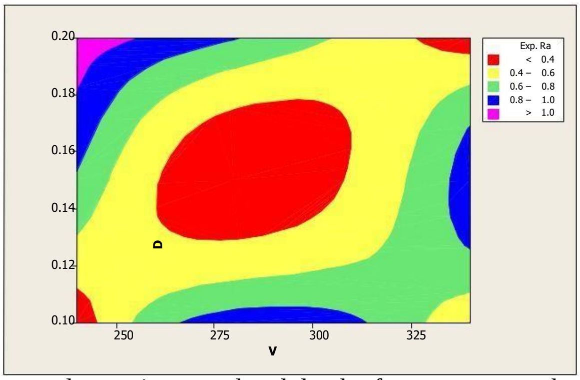
Graph 1: Number of runs versus experimental and estimated Ra from speed, feed, and depth of cut

On X-axis the cutting speed is taken and on Y-axis feed is taken, for roughness values consider the Z-axis. The different region gives the different values of the surface roughness. For example, if the point lays in the Yellow section the roughness value lie between 0.4 to 0.6 µm and similarly for subsequent section considered.



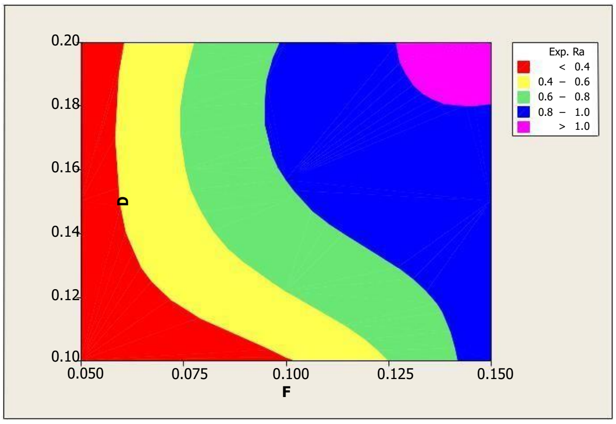
Graph 2: Counter plot cutting speed and feed versus roughness value

On X-axis the cutting speed is taken and on Y-axis depth of cut is taken, for roughness values consider the Z-axis.



Graph 3: Counter plot cutting speed and depth of cut versus roughness value

On X-axis the feed is taken and on Y-axis depth of cut is taken, for roughness values consider the Z-axis.



Graph 4: Counter plot of feed and depth of cut versus roughness value

7] CONCLUSIONS:

The conclusions drawn from the analysis are given below:

- The results show that DOE Taguchi design has proven its quality in the manufacturing and by using different tribological parameters the roughness value is optimized in the finish hard turning.
- The sources with a P value less than 0.05 are considered to have a statistically significant contribution to the performance measure. It is observed from the analysis of variance that feed is the most significant parameter followed by depth of cut and cutting speed for three different radii.
- By considering tribological parameters as a function of roughness value, the regression analysis gives an accuracy of 97.72% for 0.4 mm TNR.

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