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Optimization of Machining Parameters in Turning EN-45 Steel Using Plain Carbide Tools

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ABSTRACT

In this Study, Taguchi method and regression analysis has been used to optimize the machining parameters during the turning of EN-45 spring steel by plain carbide cutting tool. Experiments were designed and conducted by L_{16} orthogonal array. The surface roughness, material removal rate and tool wear were optimized by considering cutting speed, feed rate and depth of cut as machining parameters. The analyzed results revealed that the feed rate was the most dominating factor for surface roughness and the cutting speed is the most dominating factor for material removal rate and tool wear.

Keywords: EN-45 spring steel, Taguchi method, Material removal rate (MRR), Surface Roughness (SR), tool wear (TW), Speed (V), Feed (F), Depth of cut (DOC) and L_{16} orthogonal array.

I. INTRODUCTION

Manufacturing process can be categorized as machining and non-machining processes. The machining processes are the cutting process in which the material is removed from the metal through cutting action. Almost 90 % of the engineering components require machining. Turning process is the most commonly used cutting process. It is very important to maintain the quality of components in terms of surface finish. Speed, feed and depth of cut are the input parameters which directly affect the performance of the cutting tool. During metal cutting, heat is generated which causes thermal softening of the cutting tool and thus becomes phenomena for tool wear. The surface roughness and tool wear also depends on input parameters of speed, feed rate and depth of cut. Hence it is very important to choose the accurate combination of cutting speed, feed rate and depth of cut so that tool life, material removal rate and surface texture of the component can be improved. For this purpose, optimization of cutting parameters, cutting speed, feed and depth of cut are performed for maximum tool life and material removal rate, and minimum surface roughness of the component.

Spring steel grade EN-45 steel is a commonly used material. The motivation for choosing this topic of optimizing cutting parameters in case of machining of EN-45 Spring steel on lathe machine came mainly from the literature survey. The turning process and optimization of parameters for EN-45 steel material is very important as this material is used in a number of industries including the automobile industry. This paper presents the turning operation on EN-45 spring steel with plain carbide for optimizing the input parameter for surface roughness, MRR and tool wear using Taguchi L_{16} method.

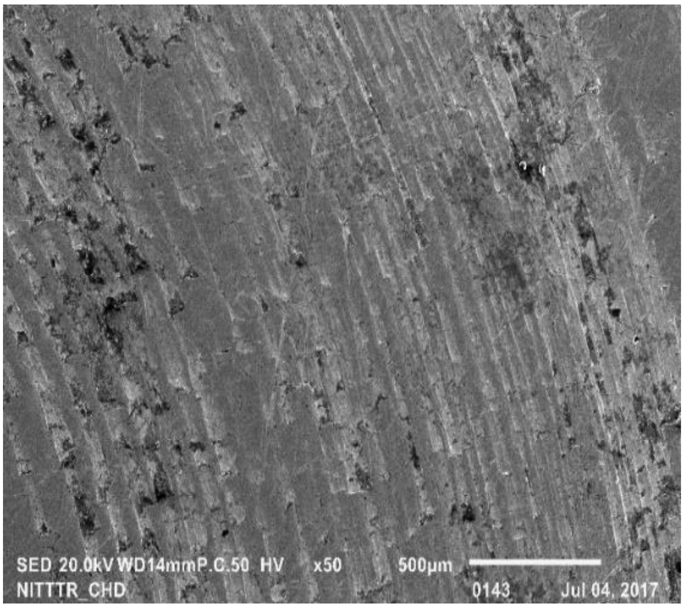
II. LITERATURE REVIEW

Turning is the machining operation in which cutting tool is held parallel to the direction of rotating workpiece [1]. Surface finish of machined part is desirable requirement for the customer [2]. A better surface finish is helpful for improving the corrosion resistance, fatigue strength and aesthetic look of product [3]. Surface finish plays very important role in the specification of produced components [4]. Singh et al. optimized the parameters of speed, feed and depth of cut for response of material removal rate (MRR) and surface roughness (SR) [2]. Das et al. experimentally studied AISI 4340 steel using coated inserts and optimized the surface roughness (SR) in hard turning [5]. The production of the component with increased quality is the main challenge of industries [6]. Bhateja et al. conducted the experiment on CNC turning of EN-24 Alloy steel and optimized the cutting parameters like speed, feed and depth of cut for material removal rate, surface roughness, and tool wear [7]. Panda et al. experimentally examine the hard turning of EN 31 steel using coated carbide insert and investigated the SR characteristics [8]. Muley et al. optimized the material removal rate and surface roughness during turning of AISI D2 steel [6]. Mohanty et al. conducted the experiment on surface roughness (SR), material removal rate (MRR) and microstructure during electrochemical machining of Inconel 825 [9]. Mehmet and Ilhan studied the surface roughness (SR) of the medical alloy $Co_{28}Cr_6Mo$ during turning at different speed, feed and depth of cut [10]. Samya et al. conducted experiments to study the machining parameters of AISI 1042 steel at different speed, feed and depth of cut for surface roughness (SR) during turning [11]. Kumar et al. optimized cutting parameters during turning of EN-45 alloy steel and studied the effect on surface roughness (SR) by response surface methodology (RSM) technique [12]. Xavierarockiaraj and Kuppan studied the surface roughness (SR), cutting forces and tool wear (TW) during Laser machining of SKD11 tool steel [13]. Kumar and Bidyadhar experimentally studied the surface finish during hard turning of AISI 4340 steel using plain carbide insert and multilayer coated carbide inserts [14]. Umesh and Amit investigated the surface roughness AISI 4340 steel using coated carbide insert during dry lathe turning [15]. From literature review it is revealed that limited work is done on the optimization of TW, SR and MRR during machining of EN-45 spring steel at different speed, feed and depth of cut by Taguchi method and using plain carbide as cutting tool.

III. EXPERIMENTAL PROCEDURE

3.1. Work-piece material

The work material EN-45 spring steel in round bar of size 32×100 mm was purchased from Steelmart Mumbai, India. The applications of EN-45 steel lies mainly in making springs for automobiles as well as bolts and nuts. It is often required to undergo threading and cutting processes on lathe machine. The hardness of EN-45 steel is observed to be 34 HRC and 335 HV. The chemical composition of EN-45 steel was checked on EDS (Energy Dispersive Spectroscopy). The EDS test confirmed that the purchased material was EN-45 spring steel and also confirmed the presence of various alloying elements like Fe, C, P, Cr, Ni etc. Fig.1 (a) shows the Scanning Electron Microscopy (SEM) of EN-45 steel. Chemical composition (wt%) of EN-45 steel is shown in Fig.1(b). The physical and mechanical properties of the EN-45 steel are demonstrated in Table1.



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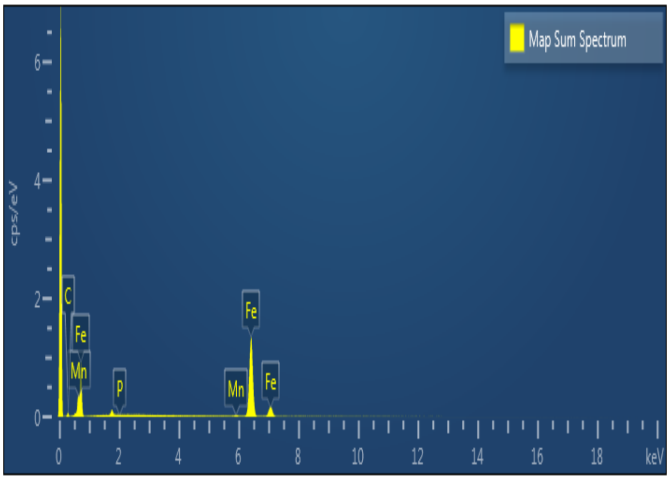

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Figure 1. (a) SEM of work material (b) EDS of work material

Table 1: Physical and mechanical properties of EN-45 steel

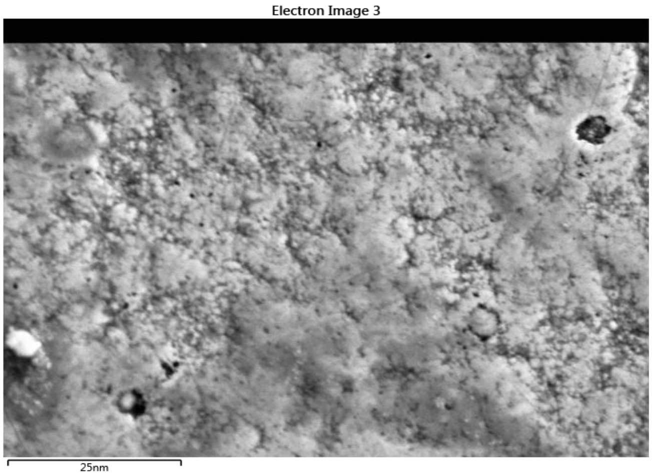
Density	Hardness	Tensile strength	Possion's ratio	Modulus of Elasicity
7850 kg/m^3	44 HRC	1034 N/mm^2	0.3	204 G Pa

3.2 Machine Tool

The machining were performed on a lathe machine with plain carbide tool (PCLNR 2020 K 12) of Okuma make. The machine is equipped with cutting speed of 525 rpm to 1800 rpm under dry environment.

3.3 Cutting inserts

The plain carbide inserts (CNMG 120408) was used for turning operation to perform experiments. Fig. 2 demonstrates the details of cutting tool. The Scanning Electron Microscopy of plain carbide tool is shown in Fig. 2 (a) and Energy Dispersive Spectroscopy of plain carbide tool is shown in Fig. 2 (b) respectively.



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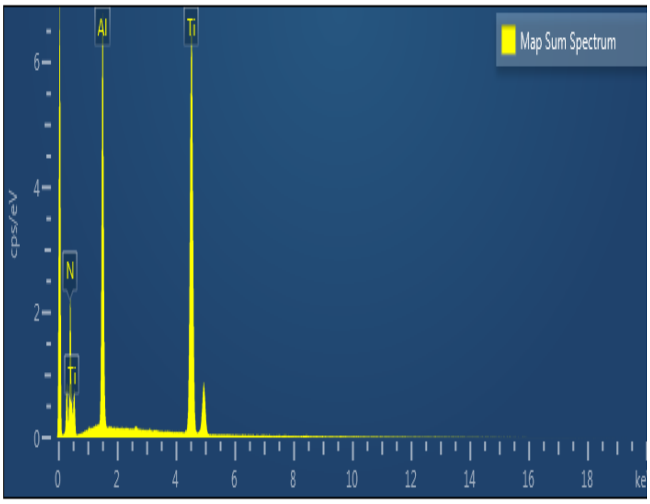


(b)

Figure 2. (a) SEM of Plain Carbide Tool (b) EDS of Plain Carbide Tool

3.4. Experimental setup

Each of the experiment were performed on the lathe machine, schematic diagram of exploratory work of which appear in Fig. 3. Three machining parameters were considered as controlling variables with each parameter varying at four levels. Table 2 shows details of machine tool, work specimen materials and cutting inserts used for experimentation. Table 3 shows cutting parameters along with their levels.

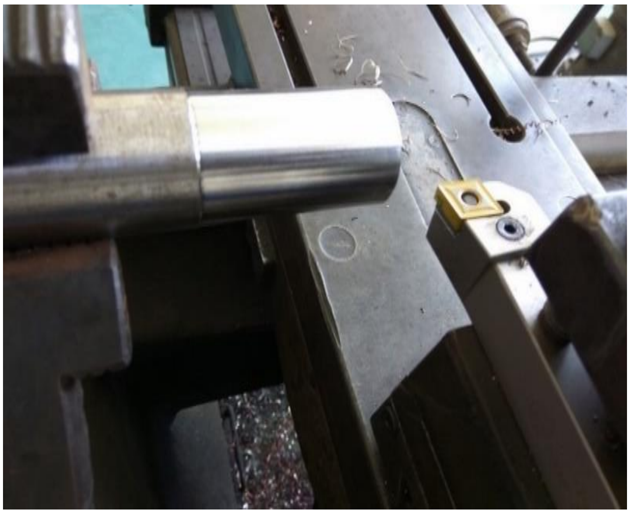


Figure 3. Schematic diagram of the experimental work using round bar

Table 2: Details of machine tool, work materials and cutting tool used for experimentation

Name of tools / equipment	Details
Work specimen materials	EN-45 Spring steel (Φ32 mm x 100 mm)
Cutting Inserts	CNMG 120408
Tool Holder	PCLNR 2020 K 12
Surface Roughness Tester	Mitutoyo, Calibration/ Measurement: range of Ra 2.94 µm - 9.3 µm
Cutting Condition	Dry Mitutoyo, Calibration

Table 3: Different Levels of Parameters

Parameters	Levels			
	1	2	3	4
Cutting Speed, m/min	52	73	97	180
Feed Rate, mm/rev	0.11	0.22	0.33	0.44
Depth of Cut ,mm	0.8	1	1.2	1.4

IV. ANALYSIS AND EVALUATION OF EXPERIMENTAL RESULTS

4.1 Investigation of the signal -to-noise (S/N) ratio

Optimisation of input parameters speed, feed and depth of cut was done by using signal-to-noise ratio in the Taguchi technique (Minitab) for maximum material removal rate (MRR), minimum tool wear (TW) and minimum surface roughness (SR).

4.2. Design of Experiments

The test was arranged according to four levels L_{16} Taguchi orthogonal array. The design of experiment was generated and analyzed by using MINITAB 16 statistical software. Three factors at three levels were considered for experimentation. Table 4 presents and run order of the experiments with values of factors and responses.

Table 4: Experimental Run Order

Run Order	Factors			Responses		
	V (m/min)	F (mm/rev)	DOC (mm)	S R (μm)	T W(μm)	MRR (mm³/sec)
1	52	0.1	1.4	1.96	65	121.0
2	52	0.2	1.2	2.46	69	208.0
3	52	0.3	1	2.94	72	260.0
4	52	0.4	0.8	5.4	71	277.0
5	73	0.1	1.2	1.15	83	146.0
6	73	0.2	1.4	1.15	65	341.0
7	73	0.3	0.8	2.52	50	292.0
8	73	0.4	1	2.67	48	487.0
9	97	0.1	1	4.79	94	162.0
10	97	0.2	0.8	2.09	77	259.0
11	97	0.3	1.4	3.58	94	679.0
12	97	0.4	1.2	3	84	776.0
13	180	0.1	0.8	0.68	69	240.0
14	180	0.2	1	1.53	43.5	36
15	180	0.3	1.2	3.15	84.5	64.8
16	180	0.4	1.4	12.5	47.5	100.8

4.3. Estimation of Optimum cutting parameters

An analysis of variance of surface roughness (SR), material removal rate (MRR) and tool wear (TW) was done with the objective of analysing effect of speed, feed and depth of cut on the results. Statically, there is a tool called an F- value, to check which design parameters have a significant effect on the quality characteristic. In this analysis, the F-value is a ratio of the mean square error to the residual, and is used to determine the significance of a factor. The P-value reports the significance level. Experimentation was done over the EN-45 work-piece and the F & P values for the cutting speed, feed and depth of cut constraints are obtained using standard Taguchi experimentation procedure. Table 5-7 shows the Taguchi method results for F&P values of surface roughness, material removal rate (MRR) and tool wear respectively. This analysis shows the 95 % confidence level of output response. From table 5, it is clear that ANOVA analysis is significant for the surface roughness (SR) while p-value comes to be 0.002 which is far less than 0.05. The speed has least effect on surface roughness (SR) while depth of cut (DOC) has the most significant effect followed by the feed rate. The interaction between speed, feed and depth of cut also affects surface roughness.

Table 5: Analysis of variance for surface roughness (SR)

Source	df	Seq SS	Adj SS	Adj MS	F-Value	P-value	PCR (%)
Speed	3	1.6	1.6	0.5	446.9	0.000	58.6
Feed	3	1.1	1.1	0.3	295.7	0.000	38.8
DOC	3	0.0	0.0	0.0	17.1	0.002	2.2
Residual Error	6	.007	.007	0.001	-	-	0.2
Total	15	2.80	-	-	-	-	-

From Table 6, it is clear that the ANOVA analysis is significant for material removal rate (MRR) having p-value 0.05. The feed rate has the least effect on material removal rate (MRR) while the depth of cut has the most significant effect followed by cutting speed. The interaction between cutting speed, feed and depth of cut (DOC) also affects tool wear (TW). From Table 7, it is clear that the ANOVA is significant for tool wear (TW) having p-value less than 0.05. The feed rate has the least significant effect on material removal rate, depth of cut has the most significant effect followed by cutting speed.

4.4 Regression Analysis

For the displaying and examining of factors where there is relationship between a dependent variable and independent variables, regression analysis was used. The dependent variables are surface roughness (SR), material removal rate (MRR) and tool wear (TW), whereas the independent variables are cutting speed, feed and depth of cut. The regression equations are used for the surface roughness (SR), material removal rate (MRR) and tool wear (TW) as shown in equations (1), (2) and (3). These predictive equations are generated for both linear and quadratic regression equations for plane carbide tool. The regression analysis generates equations for output parameter as a function of input variables.

Table 6: Analysis of variance for material removal rate (MRR).

Source	df	Seq SS	Adj SS	Adj MS	F-Value	P-value	PCR (%)
Speed	3	207.7	207.7	69.2	75.8	0.000	38.4
Feed	3	290.5	290.5	96.8	106.1	0.000	53.7
DOC	3	37.8	37.8	12.6	13.8	0.004	6.9
Residual Error	6	5.4	5.4	0.9	-	-	1.0
Total	15	541.5	-	-	-	-	-

Table 7: Analysis of variance for tool wear (TW)

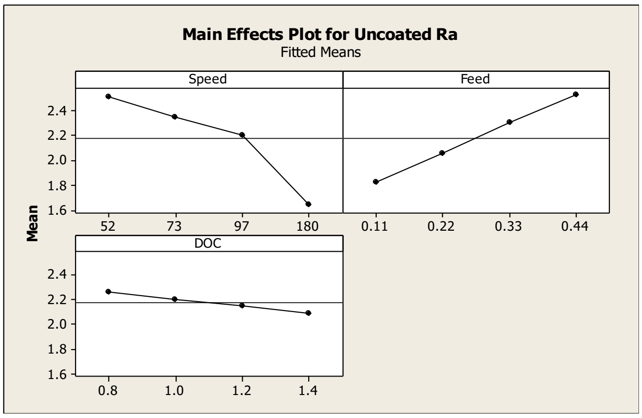
Source	df	Seq SS	Adj SS	Adj MS	F-Value	P-value	PCR (%)
Speed	3	149.1	149.1	49.7	38.5	0.000	41.0
Feed	3	163.6	163.6	54.5	42.3	0.000	44.9
DOC	3	43.1	43.1	14.3	11.1	0.007	11.8
Residual Error	6	7.7	7.7	1.2	-	-	2.12
Total	15	363.7	-	-	-	-	-

The linear regression model as obtained for surface roughness (SR), material removal rate (MRR) and tool wear (TW) is given below:

S.R = 2.57 - 0.00670 (speed) + 2.15 (feed) - 0.285 (Depth of cut) (1)

MRR = - 969 + 4.11 (speed) + 1535 (feed) + 520 (Depth of cut) (2)

TW = 76.5 - 0.0618 (speed) - 25.9 (feed) + 7.32 (Depth of cut) (3)



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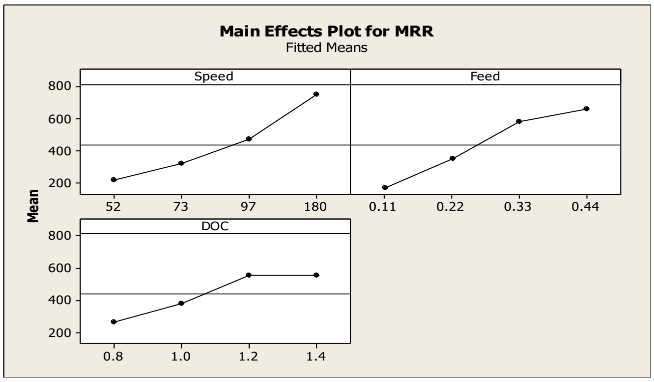

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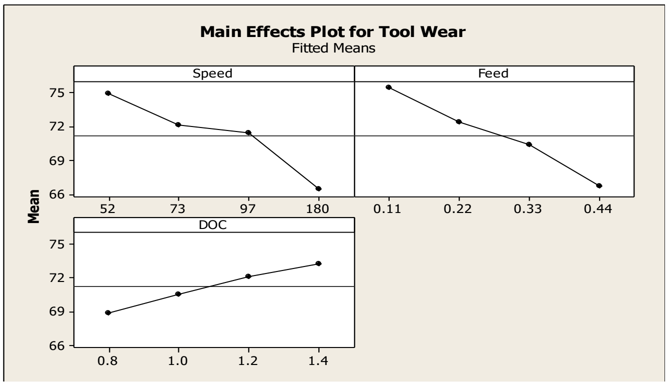

(c)

Figure 4 **(a)** Main effect plot for SR **(b)** Main effect plot for MRR **(c)** Main effect plot for TW

4.5 Result and Discussions

The main effect of cutting parameters on MRR are shown in the graph shown in Fig.4 (a-c), it was concluded that with an increase in cutting speed (V), surface roughness (SR) decreases slowly and with further increase, it starts decreasing sharply. The slope of the cutting speed is neutral, which shows that by increasing speed surface roughness decreases. In the case of feed rate (F), slope is very steep which shows that with increase in feed rate, surface roughness increases gradually and feed rate has the most significant effect on the surface roughness. As far as depth of cut is concerned, surface roughness increases gradually with the decrease in the depth of cut up to a certain extent and with further increase the depth of cut the decreases slowly. The feed is obtained as most dominant factor for surface roughness. In case of tool wear (TW), with increase in the depth of cut ,tool wear increases.

4.6 Confirmation tests

The experimental confirmation tests are the steps which validate the optimal values obtained for the Taguchi method and regression equations through optimization method. Table 8, shows comparison of results between optimized and experimental values obtained at optimized input parameters. For reliable statistical analyses, error values must be less than 0.05%. Although the error percentages calculated in the tool wear are higher than the ones in surface roughness (SR), they are within acceptable limits. Consequently, the outcomes obtained from the confirmation tests reflect successful optimization.

Table 8 : Optimized Parameters for Validation of Machining

Parameters		Experi-mental Values (A1)	Taguchi Values (A2)	% Error = ((A1-A2)/A1)*100
Input parameters	V	52	180	
	F	0.11	0.11	
	DOC	0.8	1.4	
Output parameters	SR	1.40	1.34	4.28
	MRR	76.01	73.23	3.65
	TW	64.32	61.16	4.91

IV. CONCLUSIONS

The turning of EN 45 was done with carbide inserts to optimize the process parameters for better surface finish, i.e., surface roughness (SR), material removal rate (MRR) and tool wear (TW). Taguchi method was used for generating the experiment runs. The predicted value of the model was compared with the observed values. The optimum values for dry turning for the criteria of surface finish, obtained were speed (V) = 180 m/min, feed (F) = 0.11 mm/rev and depth of cut (DOC) = 1.4 mm for achieving the Surface roughness (SR) = 1.34 µm. The optimum values for the criteria of maximum material removal rate (MRR), obtained are speed (V) = 52 m/min, feed (F) = 0.11 mm/rev and depth of cut (DOC) = 0.8 mm for achieving the material removal rate (MRR) =73.23 mm3/sec. The optimum values for the criteria of tool wear, obtained are speed (V) = 52 m/min, feed (F) = 0.11 mm/rev and depth of cut (DOC) = 1.4 mm for achieving the tool wear (TW) = 61.16µm.

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