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Research Paper

OPTIMIZATION OF CUTTING PARAMETERS IN TURNING OF EN 8 STEEL USING RESPONSE SURFACE METHOD AND GENETIC ALGORITHM

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Manufacturing process primarily spotlights its objective as increasing productivity embedded with improved performance. In the scenario of contest between the sectors of industries, it is most important criteria to have an optimized performance in Machining parameters to have a better role of independence in owing to improve from better production to best production. In this task of Turning it is focused to find optimum cutting parameters such as Spindle speed, Feed and Depth of cut in order to have improved performance on Machining time and Surface Roughness. This work focuses on CNC turning of EN 8 steel using Cemented Carbide tool for varying Spindle speed, Feed and Depth of cut. The experiment is designed for Second order linear model using Response surface Method (CCD). Mathematical formulation is carried out by correlating the values of responses Machining time and Surface Roughness with the contribution of Spindle speed, Feed and Depth to develop the Empirical models for the responses. The Optimization of cutting parameters is carried out using Genetic Algorithm (GA).

Keywords: Response Surface Methodology (RSM), Genetic Algorithm (GA), Surface roughness, Central Composite Design (CCD)

INTRODUCTION

In general, manufacturing process is classified as Primary and secondary process. The Casting, Welding, Forging, etc comes under primary manufacturing process and the machining comes under secondary manufacturing process. The selection of objectives of this work includes the following validation. The MRR and the Machining time are the basic critical factors for production time and the Surface Roughness (R_a) is the most important criteria that to be reduced as far as possible because of its effect of leading to failure in the mating parts due to friction. The work material used for the present study is mild steel EN8 of composition Carbon (0.36-0.44)%, Silicon (0.1-0.4)%, Maganese (0.60-1.00)%, Phosphorus (0.05)% Sulphur (0.05)%.

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Its hardness is (201-255) Brinell. This mild steel EN8 is suitable for shafts, Medium torque shafts, Typical applications include shafts, studs, bolts, connecting rods, screws, rollers, Hydraulic rams (chromed). Key steel and machinery parts. It is mostly used in Automobile parts and machine building industry.

Senthil Kumar *et al.* (2010) has conducted an experimental study on turning and facing of Inconel 718 using uncoated carbide insert considering cutting parameters as cutting speed, feed, depth of cut and the responses as are surface roughness and flank wear. In this Flank wear analysis using image processing. It is predicted that for turning, cutting speed and depth of cut are dominant factors and for facing cutting speed, feed are dominant factors. Sidda Reddy *et al.* (2009) has investigated on turning of Aluminium alloy using carbide cutting tool. The cutting parameters focused on this work are cutting speed, feed, depth of cut and the response is surface roughness. Adaptive Neuro Fuzzy Inference System (ANFIS) and Response Surface Methodology (RSM) are applied to predict the surface roughness.

Rodrigues *et al.* (2012) has conducted an experimental study on turning of Mild steel using High speed cutting tool. The cutting parameters considered in this work are cutting speed, feed, depth of cut and the response are surface roughness and cutting force. Experimental design is Response surface method. This work predicted that feed rate and depth of cut has significant influence on both surface roughness and cutting force. Madhu *et al.* (2012) has investigated on turning of Titanium using Cubic Boron Nitride (CBN). The cutting parameters focused in this work are cutting speed, feed, depth of cut and the response are surface roughness. Surface roughness analysis has been carried out using MAT lab and Artificial neural network to find optimal cutting parameters. It is suggested that to increase the number of neurons to improve the performance of the network.

Yahya Isik (2010) has conducted an experimental study on turning of AISA 1050 steel using CVD coated carbide Tic+Al_2O_3 +TiN insert (ISO P25). This work focuses the cutting parameters cutting speed, feed, depth of cut and the responses flank wear, tool life, tool wear and surface roughness. The experiment carried out in both dry and wet cooled conditions, the tool wear is measured in term of flank wear (V_B) It was concluded that the reduction in tool wear increases the tool life and in turn reduces cutting zone temperature with favourable change in chip tool interaction. And also cutting fluid reduces the main cutting force due to the improved and intimate chip tool interaction. Harsimran Singh Sodhi *et al.* (2012) have investigated an experimental study on turning of mild steel using carbide cutting tool. The cutting parameters focused in this work are cutting speed, feed rate, depth of cut and the response is surface roughness. Experiment is designed using Taguchi method. This work predicted that for turning cutting speed, depth of cut and feed rate are dominant factors for best value of surface.

Suleiman Abdulkareem *et al.* (2011) has conducted an experimental study on turning of AISI 1045 medium carbon steel using molybdenum high speed steel turning tool. The cutting parameters considered in this work are depth of cut, feed rate, spindle speed and the response is surface roughness. The experiment is designed using Box Benhenken design. It is suggested that for high cutting speed and spindle speed has positive effect on surface roughness against feed rate. Hardeep Singh *et al.* (2011) have conducted and experimental investigation on turning of EN-8 using carbide cutting tool. The cutting parameters focused in this work are depth of cut, feed rate and the response are surface roughness, MRR. Taguchi methodology has been applied to optimize cutting parameters is applied to analysis surface roughness. The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant factors. It is concluded that spindle speed is the most significant factor, depth of cut is the second most significant factor and the feed rate has less significance than spindle speed and depth of cut on surface roughness.

Tugrul Ozel *et al.* (2007) has conducted an experimental study on turning of AISI D2 steels (60 HRC) using ceramic wiper tool. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the response are tool wear, surface roughness. Tool wear analysis using Neural Network Modeling. He suggested that for high feed rate maintaining good surface finish and best tool life was obtained in lowest feed rate and lowest cutting speed combinations.

Thamizhmanii *et al.* (2008) have investigated an experimental study on turning of hard AISI 440C martensitic stainless steel using cubic boron nitride cutting tool. The cutting parameters focused in this wok are cutting speed, feed rate, depth of cut and the response are flank wear and surface roughness. This work suggested that for turning of martensitic stainless steel it is better to perform the turning with medium level cutting speed, high feed rate and high depth of cut. Diwakar Reddy *et al.* (2011) has conducted an experimental investigation on turning of medium carbon steel using uncoated carbide tool. This work dealt with cutting parameters such as speed, feed and depth of cut and the response as surface roughness. ANN modeling is applied to find optimal cutting parameters. It is concluded that the model has been proved to be successful in terms of agreement with experimental results.

Pragnesh Patel and Patel (2012) has investigated an experimental study on turning of 6063 Al alloy TiC Composites (MMCs) for 5% TiC and 10% TiC composites using PCD tool. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the responses are surface roughness, Power consumption. It is predicted that Power consumption increases with increase in cutting speed, feed rate and depth of cut. Mahajan *et al.* (2010) have conducted a series of face cutting experiments on Oxygen Free High Conductivity Copper (OFHC) using a sharp edge single point uncontrolled waviness diamond tool to analyse the surface roughness. The cutting parameters focused in this work are spindle speed, feed, depth of cut and tool nose radius. It was concluded that with using bigger tool nose radius the surface roughness improves drastically. Upinder Kumar Yadav *et al.* (2012) has conducted an experimental study on turning of Medium Carbon Steel AISI 1045 using STALLION-100 HS CNC lathe. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the response is surface roughness. Experimental Design used in this work is Taguchi design (L27 orthogonal array). In this work it has been predicted that the surface roughness is mainly affected by feed rate and cutting speed. With the increase in feed rate the surface roughness increases and as decrease in cutting speed the surface roughness increases.

Kagade and Deshmukh (2011) has investigated an experimental study on turning of High Carbon High Chromium steel (HCHC) using CNMG 09 03 08-PF carbide insert tool. The cutting parameters focused in this work are cutting speed, depth of cut, feed rate and the outcomes considered are surface roughness, spindle load. This work has revealed a conclusion that speed has maximum effect and depth of cut has minimum effect on surface roughness. Sharma *et al.* (2012) has conducted an experimental study on Hard turning of EN8 steel using High speed steel tool. This work deals with prediction of tool wear with application of Image processing with considering are cutting speed, feed rate and depth of cut as cutting parameters. It was concluded with comparision of deviation of results for tool wear between conventional method and image processing.

MATERIALS AND METHODS

This analysis deals with the finding the optimal cutting conditions in turning of EN 8 mild steel (work piece diameter: 25 mm) using carbide cutting tool in CNC turning centre (JAQUAR-100 HS) for three different values of spindle speed, feed and depth of cut. The details of Levels and Factors are shown in Table 1.

Table 1: Levels and Factors

Levels/Factors	Level 1	Level 2
Spindle Speed (rpm)	800	1000
Feed (mm/rev)	0.2	0.3
Depth of Cut (mm)	0.5	1.5

EXPERIMENTAL DESIGN

Selection of experimental design is a decision making process which decides the degree of validity of the desired model in finding optimal cutting parameters. This work is carried out using Response surface methodology. Methods such as Box Benhenken design and Central Composite Design (CCD) comes under Response surface methodology.

Response Surface Methodology

Response surface methodology is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to find optimized values of cutting parameters for minimization or maximization of response.

The response surface design is a better design, as it generates a second order linear model of regression, which is better predictive model than a first order linear model. In this work, Central Composite Design (CCD) has been applied for the experimental investigation. The values of cutting parameters for CCD are shown in Table 2.

Data Collection

Data collection plays a significant role in statistical analysis of any field, as it decides the progression of the analysis to the best or worst. A proper and suitable data collection leads to better results from analysis. In such

Table 2: Response Surface Design (CCD)

Levels/Factors	–~	–1	0	1	~
Spindle Speed (rpm)	730	800	900	1000	1060
Feed (mm/rev)	0.17	0.2	0.25	0.3	0.33
Depth of Cut (mm)	0.16	0.5	1	1.5	1.84

focus it is very much essential to choose a well suitable data collection technique for the analysis. In this work , Data collection for the turning process is selected for proceeding with Response surface methodology design, i.e., a second order linear model. The values predicted using the model in turning of EN 8 steel using carbide cutting tool has been shown in Table 3.

EFFECTS OF CUTTING PARAMETERS

Analysis of Variance

Any Data collected for responses against set of chosen parameters must be validated for the significant influence of parameters. In this manner the data collected (responses) machining time, Material Removal Rate (MRR) and surface roughness are validated

Table 3: Data Collection Using RSM

W/P No.	Spindle Speed (Rpm)	Feed (mm/rev)	Depth of Cut (Mm)	M/C Time (Secs)	Surface Roughness («)
1	900	0.33	1	20	3.69
2	900	0.25	1	25	3.52
3	800	0.3	0.5	23	2.58
4	800	0.3	1.5	23	4.85
5	730	0.25	1	30	3.48
6	1000	0.2	0.5	27	2.69
7	800	0.2	0.5	33	2.68
8	900	0.25	1	25	3.52
9	1000	0.3	0.5	20	2.59
10	900	0.25	1	25	3.49
11	900	0.17	1	35	3.5
12	900	0.25	1	25	3.33
13	800	0.2	1.5	33	4.46
14	900	0.25	1	25	3.46
15	1000	0.2	1.5	27	4.13
16	900	0.25	1.84	25	4.85
17	900	0.25	1	25	3.47
18	900	0.25	0.16	24	2.51
19	1000	0.3	1.5	19	4.64
20	1060	0.25	1	21	3.71

for the significant effects of cutting parameters spindle speed, feed and depth of cut. This is done by test of hypothesis at 95% significance level using F-test. The results of the test of hypothesis for machining time, MRR and surface roughness are shown in Tables 4 and 5.

Tables 4 and 5 determines that all the factors Spindle speed, Feed and Depth of cut are having significant influence on Machining time,

Table 4: ANOVA for Machining Time

Source	Sum of Squares	DOF	Mean Square	F-Value	p-value Prob > F	
Model	332.9889	9	36.99877	26.03517	< 0.0001	Significant
A-speed	41.09262	1	41.09262	28.91592	0.0003	
B-feed	265.6013	1	265.6013	186.8974	< 0.0001	
C-depth	0.034037	1	0.034037	0.023951	0.8801	
AB	3.125	1	3.125	2.19899	0.1689	
AC	0.125	1	0.125	0.08796	0.7729	
BC	0.125	1	0.125	0.08796	0.7729	
A^2	11.35976	1	11.35976	7.993596	0.0179	
B^2	5.199752	1	5.199752	3.658944	0.0848	
C^2	3.060151	1	3.060151	2.153357	0.1730	
Residual	14.21107	10	1.421107			
Lack of Fit	14.21107	5	2.842215			
Pure Error	0	5	0			
Cor Total	**347.2**	**19**				
R^2 = 0.9591						

Table 5: ANOVA for Surface Roughness

Source	Sum of Squares	DOF	Mean Square	F-Value	p-value Prob > F	
Model	9.91	6	1.65	65.99	<0.0001	Significant
A-SPEED	$1.53*10^{-03}$	1	$1.53*10^{-03}$	0.061	0.809	
B-FEED	0.077	1	0.077	3.07	0.103	
C-DOC	9.64	1	9.64	385.14	<0.0001	
AB	$1.80*10^{-03}$	1	$1.80*10^{-03}$	0.072	0.793	
AC	0.039	1	0.039	1.57	0.233	
BC	0.15	1	0.15	6.04	0.029	
Residual	0.33	13	0.025			
Lack of Fit	0.32	8	0.04	46.87	$3*10^{-04}$	Significant
pure Error	$4.28*10^{-03}$	5	$8.57*10^{-04}$			
Cor Total	**10.24**	**19**				
R^2 = 0.9443						

Metal removal rate and Surface roughness. As the R^2 values of Machining time, Surface roughness and Metal removal rate respectively 0.9591, 0.9997 and 0.9443 are greater than 0.8 The model is suitable to navigate the design space.

Surface Plot and Inference for Machining Time

Figure 1, 2 and 3 determines that Machining time decreases considerably with increase in

Figure 1: Speed vs Feed

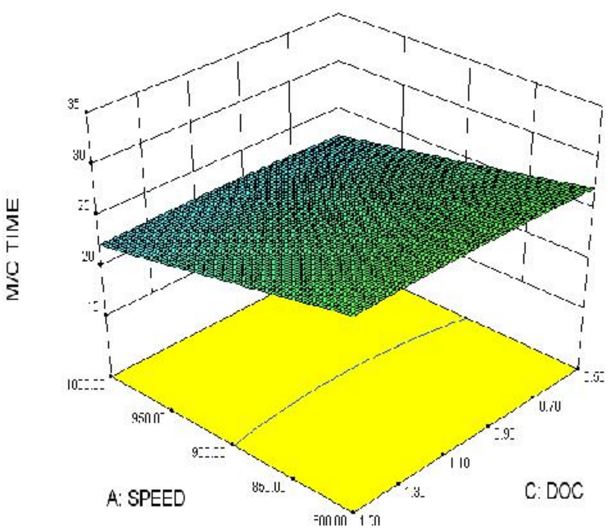


Figure 2: Feed vs Depth

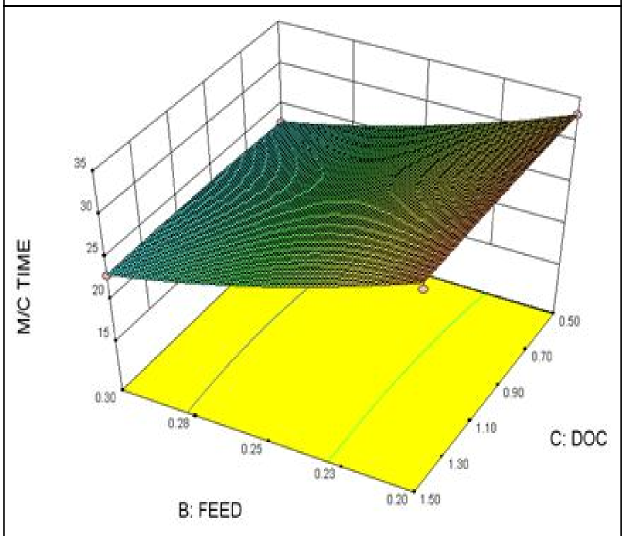
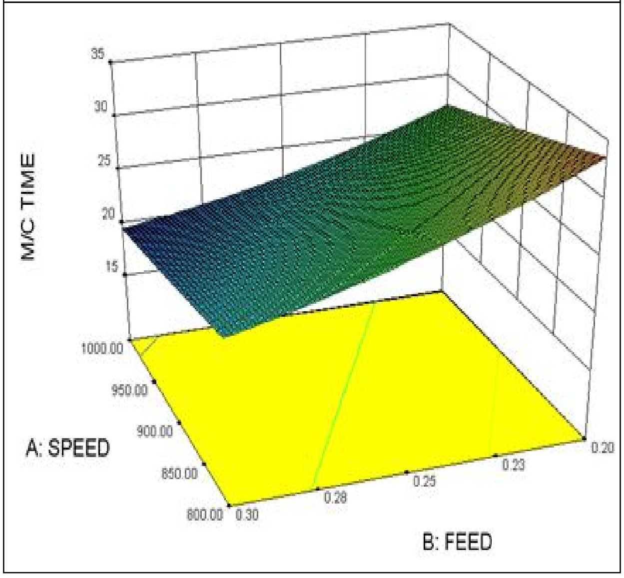


Figure 3: Speed vs Feed



spindle speed and also with increase in Feed. Machining time has negligible influence of depth of cut.

Surface Plot and Inference for Surface Roughness

Figure 4, 5 and 6 determines that Surface roughness is minimum for balance values of Spindle speed, feed and depth of cut.

Figure 4: Speed vs Feed

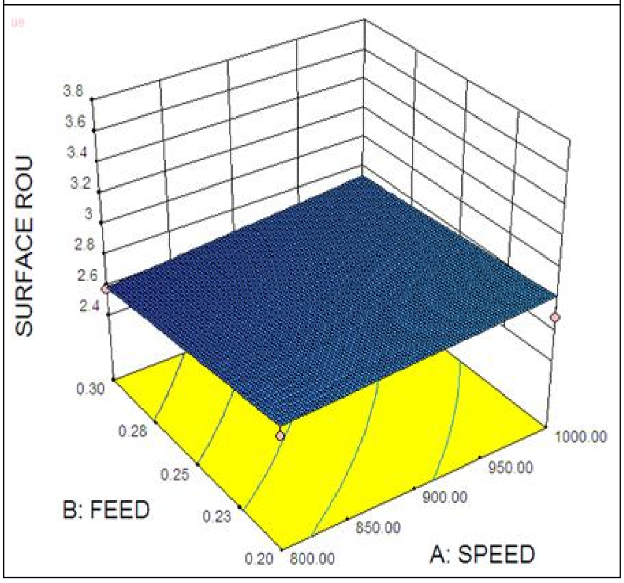


Figure 5: Speed vs Depth

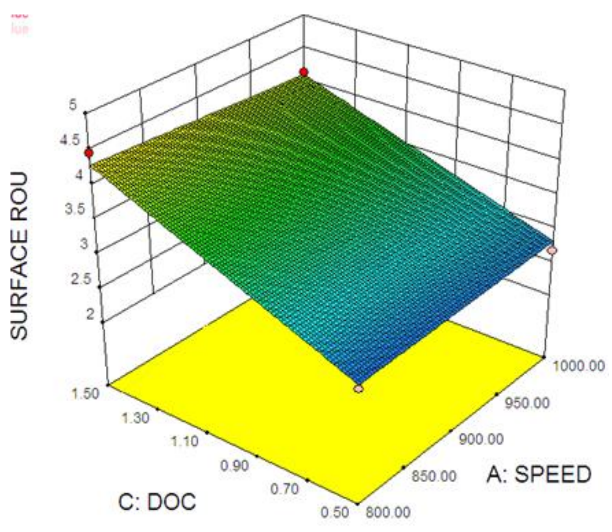
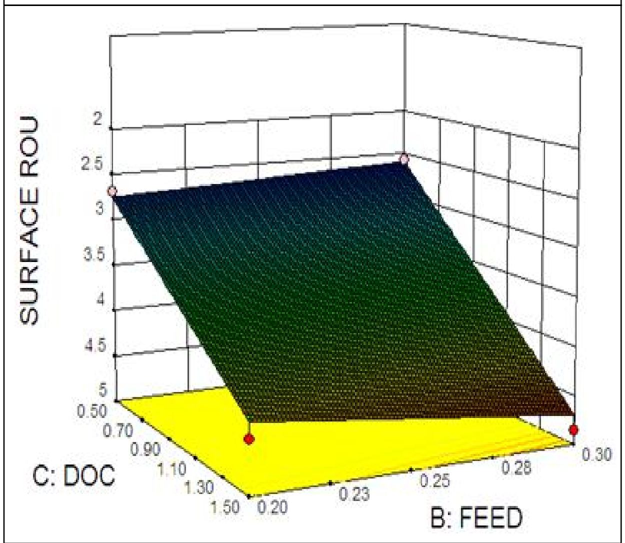


Figure 6: Feed vs Depth



MATHEMATICAL MODELING:

The mathematical modeling is a better statistical tool used to evaluate the values of response outcomes for various combinations of input parameters. This method of data evaluation helps in theoretical decision making for finding optimal cutting conditions. Mathematical model can be derived by using Regression Analysis. In this work, a second order linear model has been deduced for the readings obtained from Response Surface method (Central composite design). The Central composite design enables the model to generate a second order correlation between the cutting parameters and the responses. A typical model of second order mathematical model has shown in equation 1.

$$y = n_0 + {}_1x_1 + {}_2x_2 + {}_3x_1^2 + {}_4x_2^2 + {}_5x_1x_2 + \ldots + {}_{nxn} \quad \ldots(1)$$

where

y – Response

n – Regression constant

B – Correlation coefficient

$x_1, x_2, \ldots, x_n$ – are cutting parameters

The mathematical models of Machining time and Surface roughness deduced for this work are shown in Equations (2 and 3).

$$\text{Machining time} = 122.33898 - 0.067609 \text{ x } N - 377.24348 \text{ x } f + 5.53017 \text{ X } d + 0.12500 \text{ x } N \text{ x } f - 2.50000 \text{ x } 10^{-3} \text{ x } N \text{ x } d - 5.00000 \text{ x } f \text{ x } d + 7.61213 \text{ x } 10^{-6} \text{ x } N^2 + 359.60891 \text{ x } f^2 - 0.96525 \text{ x } d^2 \quad \ldots(2)$$

$$\text{Surface Roughness} = 2.38928 + 5.43490 \text{ x } 10^{-4} \text{ x } N - 6.66951 \text{ x } f + 1.56640 \text{ x } d + 3.0 \text{ x } 10^{-3} \text{ x } N \text{ x } f - 1.4 \text{ x } 10^{-3} \text{ x } N \text{ x } d + 5.5 \text{ x } f \text{ x } d \quad \ldots(3)$$

where

N – Speed

f - Feed

d – Depth of cut

OPTIMIZATION

Optimization is the approach of obtaining feasible outcome effectively from available key resources in a process. In such a way in this work in order obtain feasible values of Machining time and Surface Roughness from significant cutting parameters Speed, feed and depth of cut, an approach of optimization Genetic Algorithm is applied.

Genetic Algorithm

Optimization is the technique most needed in the current scenario of competitive growth in productivity, quality and cost of a product in order to obtain a best fit combination of values of cutting parameter that to lead effective improvement in responses.

A genetic algorithm (or short GA) is a search technique used in computing to find true or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

Selection: Select the individuals, called parents, that contribute to the population at the next generation.

Figure 7: Graphical Simulation of Genetic Algorithm for Machining Time Using MATLAB

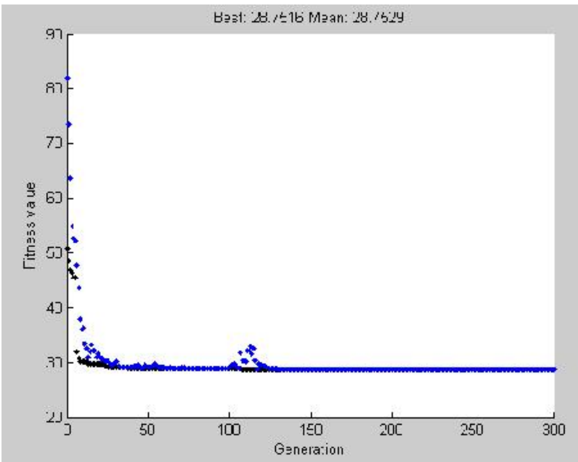
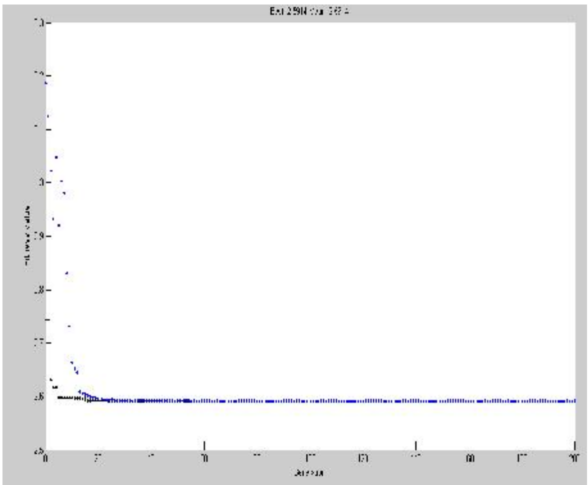


Figure 8: Graphical Simulation of Genetic Algorithm for Machining Time Using MATLAB



Crossover: Combine two parents to form children for the next generation.

Mutation: Apply random changes to individual parents to form children.

The Genetic algorithm is applied in this work in order to find optimal cutting parameters, has been carried out in MATLAB 7.6.0 (R2008a).

The Graphical simulation of finding best individuals of cutting parameters for Machining time and Surface roughness are shown in Figures 7 and 8.

RESULTS AND DISCUSSION

From ANOVA, It is predicted that the considered parameters speed, feed and depth of cut are significant for the objective functions Machining time and Surface Roughness. As the R^2 value of both Machining time and Surface roughness are greater than 0.8 which ensures the navigation of model through the design space.

Machining time decreases considerably with increase in spindle speed and also with increase in Feed. Machining time has negligible influence of depth of cut. Surface roughness is minimum for balance values of Spindle speed, feed and depth of cut.

CONCLUSION

This paper presents the findings of an experimental investigation into the effect of feed, speed and depth of cut on the surface roughness when turning EN8 Mild steel. Genetic Algorithm is best modeling as it learns the best fit of even linear models. It unveils better performance in enhancement of surface finish in Genetic Algorithm. The minimum value of surface roughness (Ra) obtained from GA is 2.51 μ. From these values, it is easily predictable that the Genetic Algorithm search to find optimal cutting parameters. The Optimal cutting conditions obtained from GA are shown in Table 6.

Table 6: Optimal Cutting Conditions

Objective Function – Minimization		Speed (rpm)	Feed (mm/rev)	DOC (mm)
Machining Time (sec)	19.87	996.189	0.3	0.501
Surface Finish (μ)	2.591419	800	0.3	0.5

FUTURE WORK

Although the current approach used Genetic Algorithm as a tool for finding optimal cutting parameters, the results of optimal values are varying for the objectives Machining time and Surface finish. This shall be improved unique optimal values for both Machining time and Surface finish by using Multi objective optimization in GA.

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