

# Optimization of Turning on En31 Material By Taguchi Approach

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**ABSTRACT:** Optimization is one of the techniques used in manufacturing sectors to arrive for the best manufacturing Conditions, which is an essential need for industries towards manufacturing of quality products at lower cost. This Paper aims to investigate the optimal set of process parameters such as speed, feed and depth of cut in turning process to identify the variations in two performance characteristics such as rate of material removal, and surface roughness value on the work material for machining EN31 using TNMG carbide insert. Based on the experiments conducted on L9 orthogonal array, analysis has been carried out using Grey Relational Analysis, a Taguchi method. Response tables and graphs were used to find the optimal levels of parameters in turning process. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for turning were optimized for achieving the combined objectives of higher rate of material removal, and lower surface roughness value on the work material considered in this work. The obtained results show that the Taguchi Grey relational Analysis is being effective technique to optimize the machining parameters for turning process.

**KEYWORDS:** Turning, Surface roughness, Material removal rate, Grey relational analysis, Taguchi method,

## I. INTRODUCTION

Steel is an alloy of iron and carbon or other alloying elements. When the alloying element is carbon, the steel is referred to as carbon steel. Carbon steels are classified by the percentage of carbon in “points” or hundredths of 1 percent they contain. The term hardened steel is often used for medium or high carbon steel that has been given the heat treatments of quenching followed by tempering. The quenching results in the formation of metastable martensite, different medias are selected for getting different structures, the fraction of which is reduced the desired amount during tempering. This is the most common state for finished articles such as machine tools and machine parts. In contrast, the same steel composition in annealed state will be softer as required for forming and machining. Depending on the temperature and composition of the steel, it can be hardened or softened. In order to make steel harder, it must be heated to very high temperatures. The final result of exactly how hard the steel will be depends on the amount of carbon present in the metal. Only steel that is high in carbon can be hardened and tempered. If a metal does not contain the necessary quantity of carbon, then its crystalline structure cannot be broken, and therefore the physical makeup of the steel cannot be altered. EN 31 is a high carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. Applications: For roller bearing components such as brakes, cylindrical, conical & needle roller.

## II. LITERATURE REVIEW

**Sahoo et al. [1]** have used Grey relational analysis to perform multi-objective optimization of surface roughness and *MRR* in turning of AA 1040 steel and determined that cutting speed is the most influencing parameter affecting combined Grey relational grade followed by depth of cut and feed rate

**Tzeng and Chen [2]** used grey relational analysis to optimize the process parameters in turning of tool steels. They performed Taguchi experiments with eight independent variables, the optimum turning parameters were determined

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

based on grey relational grade which maximizes the accuracy and minimizes the surface roughness and dimensional precision

**J Nithyanandam et al., [3]**, performed an experiment on titanium alloy (Ti-6Al-4V) with nano coated carbide insert tool. The three input parameters such as cutting speed, feed rate, nose radius and depth of cut are taken and taguchi method of approach has been implemented for parametric optimization. The analysis of variance (ANOVA) was employed to determine the most factor that affects the output responses. They concluded that feed rate is the most significant factor affect the surface roughness followed by cutting speed when compared to other parameters the nose radius and depth of cut.

**Sudhansu Ranjan Das et al., [4]** developed the prediction model for surface roughness in turning operation. The regression model was developed based on the cutting parameter. By using multiple regression and Analysis of Variance (ANOVA) a strong linear relationship among the parameters (velocity, feed rate and depth of cut) and the response (surface roughness) was found.

**Nambi Muthukrishnan and Paulo Davim, [5]**, conducted a study of TTI 15 ceramic insert (80% Aluminum oxide and 20% Titanium carbide) on machining Ti-6Al-4V at moderate speed with and without the application of water soluble servo cut S coolant. Based on the analysis they found that in wet turning of Ti -6Al-4V, tool wear reduces ,tool life improved by 30% and gives good surface finish.

**Reddy Sreenivasulu and Srinivasa Rao, [6]**, carried out a study on Design of experiments based Grey Relational Analysis in various machining processes. Many methods such as statistical technique, fractional factorial experiments and analysis of variance (ANOVA), has been employed to investigate the influence of cutting parameters.

**Ersan Aslan et al [7]**, performed an optimization study of turning experiment on hardened AISI 4140 grade (63HRC) steel using Al<sub>2</sub>O<sub>3</sub> and TiCN coated ceramic inserts at three different Cutting velocity, feed rate and depth of cut. Taguchi analysis was used to determine the optimal parameter combination. Surface roughness and flank wear are taken as performance measures . From the analysis they found that cutting velocity is the most significant factor influencing the tool wear.

**J. Laxman, Dr. K. Guru Raj, [8]**, made an attempt to optimize the EDM process parameters to achieve less tool wear and high material removal rate (MRR) using grey relational analysis. Positive indicators of machining efficiency in machining process are decrease of tool wear and increase of MRR. In this study they concluded that grey relational analysis is the most suitable method for the parametric optimization of EDM process of Titanium super alloys.

**Prakash Kumar Sahu and Sukhomay Pal [9]**, focussed on the Multi-response optimization of process parameters in friction stir welded AM20 magnesium alloy by Taguchi grey relational analysis. ANOVA is also carried out for determining the most significant factors affect the friction stir welded AM20 magnesium alloy.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

### III. WORKPIECE, CUTTING TOOL USED AND EXPERIMENTAL DETAILS

**Table no.1: Experimental Details**

<b>Work Piece Material</b>	<b>En31</b>	C	Mn	Cr	Si		
	Composition %	1.00%	0.50%	1.40%	0.20%		
	Length	700mm					
	Diameter	25mm					
	Purchased from	Kirti Metal, G.I.D.C , Ankleshwer , Gujarat, India					
<b>Tools and Equipments</b>	Machine Tool	Jyoti CNC turning Centre DX 200					
	Manufactured by	Jyoti CNC Automation Ltd , Rajkot, Gujarat, India					
	Cutting tools	TNMG160404-HS (PC5300)					
	Manufactured by	Korloy inc.(made in Korea)					
	Tool holder	VTJNL2525 M16					
<b>Control Variables</b>	Process related	Speed (rpm) 1600,1800,2000	Feed (mm/rev.) 0.06,0.10,0.15	Depth of Cut (mm) 0.4, 0.6, 0.8			
<b>Response Variables</b>	In-process	Surface roughness, Material removal rate.					
<b>Design of Experiments</b>	Taguchi method	L <sub>9</sub> Orthogonal Array					
<b>Assessment of Response Variables</b>	Surface meter: Mahr Marfest PS1 portable surface roughness tester						

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

<b>Method of Effect Analysis</b>	Taguchi based Grey Relation Analysis	
<b>Software Used</b>	MINITAB-14 software	
<b>Criteria for Analysis</b>	Smaller is Better	Surface Roughness
	Larger is Better	Material Removal Rate
<b>Working condition</b>	Dry	
<b>Experiment Perform At</b>	Elimac Engineering G.I.D.C , Udhana , Surat, Gujarat, India	
<b>Surface roughness Measuring At</b>	Dhara Enterprise G.I.D.C , Makarpura , Baroda , Gujarat, India	

## IV. EXPERIMENTATION

### A. Selection of parameter

Table no.2 Selection of parameter

Input Variable	Level 1	Level 2	Level 3
Speed(rpm)	1600	1800	2000
Feed(mm\rev)	0.06	0.10	0.15
Depth of cut(mm)	0.4	0.6	0.8

### B. Selection of Orthogonal Array:

Orthogonal array is used for reduce the experiments. By using full fractional or partial fraction method orthogonal array is selected. By using two factorial design experiment ru can reduce significantly, Here three level and four parameters are selected so instead of  $3^4 = 81$  only  $3^{4-2} = 9$  experiments are run. So L9 orthogonal array is selected. From following table orthogonal array can be selected.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Table no.3: Orthogonal Array ( L9)

Sr no.	Speed	Feed	Doc
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

### C. Experiment Result

The experiments were conducted, with the process parameter levels set as given in Table 7, to study the effect of process parameters over the output parameters. Experiments were conducted according to the test conditions specified by the Taguchi design. Experimental results are given in Table for surface roughness (Ra), material removal rate (MRR) Altogether 9 experiments were conducted using Taguchi method.

Sr no.	Control parameter			Response parameter	
	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	MRR (mm <sup>3</sup> /min.)	(Ra) $\mu$ m
1	1600	0.06	0.4	1389.79	2.0835
2	1600	0.10	0.6	3057.49	1.7502
3	1600	0.15	0.8	5504.06	1.3705
4	1800	0.06	0.6	2183.98	2.088
5	1800	0.10	0.8	4299.63	1.3805
6	1800	0.15	0.4	2866.24	1.6422
7	2000	0.06	0.8	3227.17	1.1372
8	2000	0.10	0.4	2457.12	1.796
9	2000	0.15	0.6	4517.32	1.02675

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

## V. DATA ANALYSIS & RESULTS DISCUSSION

### A. Taguchi Based Grey Relation Analysis

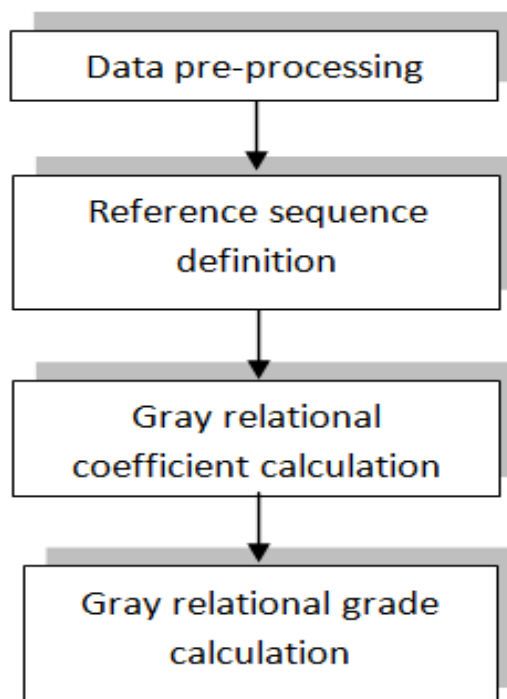
Grey analysis is a new technology, a group of techniques for system analysis and modeling. It is also called grey logic or grey system theory. Grey analysis is useful in situations with incomplete and uncertain information. Grey analysis is particularly applicable in instances with very limited data and in cases with little system knowledge or understanding. Grey analysis was invented by Professor Deng Julong of the Huazhong University of science and Technology in Wuhan, China. Grey analysis has been successfully used in a wide range of fields diverse as agriculture, ecology, economic planning and forecasting, traffic planning, industrial planning and analysis, management and decision making, irrigation strategy, crop yield forecasting, military affairs, target tracking, population control, communication system design, geology, oil exploration, earthquake prediction, material science, manufacturing, biological protection, environmental impact studies, medical management and the judicial system.

According to grey analysis proponents, different grey analysis elements are applicable to all systems. Grey relational analysis is an improved method for identifying and prioritizing key system factors, provides a straightforward mechanism for proposal evaluations and is useful for variable independence analysis

### Steps for Grey Relational Analysis (GRA)

GRA is effective tool for solving the complicated interrelationship among the designated performance characteristics. It also provides an efficient solution to multi-input and discrete data problems. In grey relational analysis the complex multiple response optimization problem can be simplified into optimization of single response grey relational grade. The procedure for determining the grey relational grade is represented graphically in Fig. no.1 and discussed below

Figure no.1: Graphical Representations of Steps to Determine GRG



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

**Step 1 Data pre-processing:**

If the number of experiments is “m” and the number of response is “n” then the  $i^{th}$  experiment can be expressed as  $Y_i = (y_{i1}, y_{i2}, \dots, y_{ij}, \dots, y_{in})$  in decision matrix form, where  $y_{ij}$  is the performance value (or measure of performance) of response  $j$  ( $j = 1, 2, \dots, n$ ) for experiment  $i$  ( $i = 1, 2, \dots, m$ ). The general form of decision matrix D is given as,

$$D = \begin{bmatrix} y_{11} & \dots & y_{1j} & \dots & y_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ y_{i1} & \dots & y_{ij} & \dots & y_{in} \\ \dots & \dots & \dots & \dots & \dots \\ y_{m1} & \dots & y_{mj} & \dots & y_{mn} \end{bmatrix}$$

The term  $Y_i$  can be translated into the comparability sequence  $X_i = (x_{i1}, x_{i2}, \dots, x_{ij}, \dots, x_{in})$  where  $x_{ij}$  is the normalized value of  $y_{ij}$  for the response  $j$  ( $j = 1, 2, \dots, n$ ) of experiment  $i$  ( $i = 1, 2, \dots, m$ ). After normalization, decision matrix D becomes normalization matrix  $D'$  is given as follows.

$$D' = \begin{bmatrix} x_{11} & \dots & x_{1j} & \dots & x_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ x_{i1} & \dots & x_{ij} & \dots & x_{in} \\ \dots & \dots & \dots & \dots & \dots \\ x_{m1} & \dots & x_{mj} & \dots & x_{mn} \end{bmatrix}$$

The normalized values  $x_{ij}$  are determined by use of following equation. There are for beneficial type, non-beneficial type and target value type responses.

1. If the expectancy of the response is larger-the-better (i.e. beneficial response), then it can be expressed by

$$X_{ij} = \frac{(Y_{ij} - \min Y_j)}{(\max Y_j - \min Y_j)} \tag{1}$$

2. If the expectancy of the response is smaller-the-better (i.e. non-beneficial response), then it can be expressed by

$$X_{ij} = \frac{(\max Y_j - Y_{ij})}{(\max Y_j - \min Y_j)} \tag{2}$$

3. If the expectancy of the response is nominal-the-best (i.e. closer to the desired value or target value), then it can be expressed by

$$X_{ij} = 1 - \left[ \frac{(Y_j^* - Y_{ij})}{(\max Y_{ij} - \min Y_{ij})} \right] \tag{3}$$

where  $Y_j^*$  is closer to the desired value of  $j^{th}$  response.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Table no. 5: Signal to Noise Ratio

Sr. no	MRR (mm <sup>3</sup> /min.)	Surface roughness(Ra) $\mu$ m	S\N Ratio(MRR)	S\N Ratio(Ra)
1	1389.79	2.0835	62.8589	-6.3758
2	3057.49	1.7502	69.7059	-4.8617
3	5504.06	1.3705	74.8136	-2.7375
4	2183.98	2.088	66.784	-6.3946
5	4299.63	1.3805	72.66	-2.8007
6	2866.24	1.6422	69.146	-4.3085
7	3227.17	1.1372	70.176	-1.1167
8	2457.12	1.796	67.808	-5.0861
9	4517.32	1.02675	73.0976	-0.2292

### Step 1: Normalised Data

Table no 6: Normalised Data

Sr. no	Speed (rpm)	Feed (mm/rev)	Doc (mm)	Normalised data(MRR)	Normalised data(Ra)
1	1600	0.06	0.4	0	0.00424
2	1600	0.10	0.6	0.405345	0.318289
3	1600	0.15	0.8	1	0.676058
4	1800	0.06	0.6	0.193033	0
5	1800	0.10	0.8	0.707255	0.666635
6	1800	0.15	0.4	0.358861	0.420051
7	2000	0.06	0.8	0.446587	0.895882
8	2000	0.10	0.4	0.259421	0.275134
9	2000	0.15	0.6	0.760166	1



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

**Step 2 Deviation sequence:**

In comparability sequence all performance values are scaled to [0, 1]. For a response  $j$  of experiment  $i$ , if the value  $x_{ij}$  which has been processed by data pre-processing procedure is equal to 1 or nearer to 1 then the value for any experiment, then the performance of experiment  $i$  is considered as best for the response  $j$ . The reference sequence  $X$  is defined as  $(x_1, x_2, \dots, x_j, \dots, x_n) = (1, 1, \dots, 1, \dots, 1)$ , where  $x_j$  is the reference value for  $j^{th}$  response and it aims to find the experiment whose comparability sequence is closest to the reference sequence.

**Step 2: Deviation Sequences**

Table no 7: Deviation Sequences

Sr. no	Speed (rpm)	Feed (mm/rev)	Doc (mm)	Del MRR	Del Ra
1	1600	0.06	0.4	1	0.99576
2	1600	0.10	0.6	0.594655	0.681711
3	1600	0.15	0.8	0	0.323942
4	1800	0.06	0.6	0.806967	1
5	1800	0.10	0.8	0.292745	0.333365
6	1800	0.15	0.4	0.641139	0.579949
7	2000	0.06	0.8	0.553413	0.104118
8	2000	0.10	0.4	0.740579	0.724866
9	2000	0.15	0.6	0.239834	0

**Step 3 Grey relational coefficients:**

Grey relational coefficient is used for determining how close  $x_{ij}$  is to  $x_j$ . The larger the grey relational coefficient, the closer  $x_{ij}$  and  $x_j$  are. The grey relational coefficient can be calculated by using following equation.

$$\gamma_{ij} = \frac{(\Delta_{min} + (\xi * \Delta_{max}))}{(\Delta_{ij} + (\xi * \Delta_{max}))}$$

For  $i = 1, 2 \dots m$  and  $j = 1, 2 \dots n$

Where,  $\gamma$  = the grey relational coefficient between  $x_{ij}$  and  $x_{0j}$

$$\Delta_{min} = \min_{ij} |X_j - X_{ij}|$$

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

$$\Delta_{max} = \max_{ij} |X_j - X_{ij}|$$

$$\Delta_{ij} = |X_j - X_{ij}|$$

$$D_{min} = \min \{D_{ij}, i=1, 2, \dots, m; j=1, 2, \dots, n\}$$

$$D_{max} = \max \{D_{ij}, i=1, 2, \dots, m; j=1, 2, \dots, n\}$$

$$\zeta = \text{Distinguishing coefficient } \zeta \in (0,1)$$

Distinguishing coefficient ( $\zeta$ ) is also known as the index for distinguish ability. The smaller distinguishing coefficient is, the higher is its distinguishing ability. It represents the equation's "Contrast Control". The purpose of distinguishing coefficient is to expand or compressed the range of the grey relational coefficient. Different distinguishing coefficient may lead to different solution results. Decision makers should try several different distinguishing coefficients and analyze the impact on GRA results. Considering value of distinguishing coefficient is 1

### Step 3: : Grey Relation co-efficient

Table no. 8: Grey Relation co-efficient

Sr. no	Speed (rpm)	Feed (mm/rev)	Doc (mm)	GRC(MRR)	GRC(Ra)
1	1600	0.06	0.4	0.333333	0.334278
2	1600	0.10	0.6	0.456765	0.423115
3	1600	0.15	0.8	1	0.606839
4	1800	0.06	0.6	0.382565	0.333333
5	1800	0.10	0.8	0.63072	0.599977
6	1800	0.15	0.4	0.438159	0.462985
7	2000	0.06	0.8	0.474648	0.827653
8	2000	0.10	0.4	0.403038	0.408208
9	2000	0.15	0.6	0.675828	1

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

**Step 4 Grey relational grades:**

The measurement formula for quantification in grey relational space is called grey relational grade. A grey relational grade (grey relational degree) is a weighted sum of grey relational coefficients and it can be calculated using following equation.

$$\gamma_i = \sum_{j=1}^n w_j \cdot \gamma_{ij} \quad i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n \dots\dots\dots (5)$$

In above equation  $\gamma_i$  is the grey relational grade between comparability sequence  $X_i$  and reference sequence  $X_n$ . It represents correlation between the reference sequence and the comparability sequence.  $w_j$  is the weight of response surface  $j$  and depends on decision maker's judgment.

**Step 4: Grey Relation Grade**

**Table no.9: Grey Relation Grade**

Sr. no	Speed (rpm)	Feed (mm/rev)	Doc (mm)	GRG	RANK
1	1600	0.06	0.4	0.333806	9
2	1600	0.10	0.6	0.43994	6
3	1600	0.15	0.8	0.803419	2
4	1800	0.06	0.6	0.357949	8
5	1800	0.10	0.8	0.615349	4
6	1800	0.15	0.4	0.450572	5
7	2000	0.06	0.8	0.651151	3
8	2000	0.10	0.4	0.405623	7
9	2000	0.15	0.6	0.837914	1

**B. Result**

From table 9 it is observe that the maximum material removal rate is 4517.32 mm<sup>3</sup>/min and minimum surface roughness is 1.0267μm which is at Sr no 9 with the best combination of parameter Speed 2000 rpm, Feed 0.15 mm/rev, Depth of Cut 0.6 mm., and So its rank is 1st. Minimum material rate is 1389.79 mm<sup>3</sup>/min and maximum surface roughness 2.088μm and its parameters are Speed 1600 rpm, Feed 0.06 mm/rev, Depth of cut 0.4 mm.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Fig no.2: Graph of Grey Relation Grade

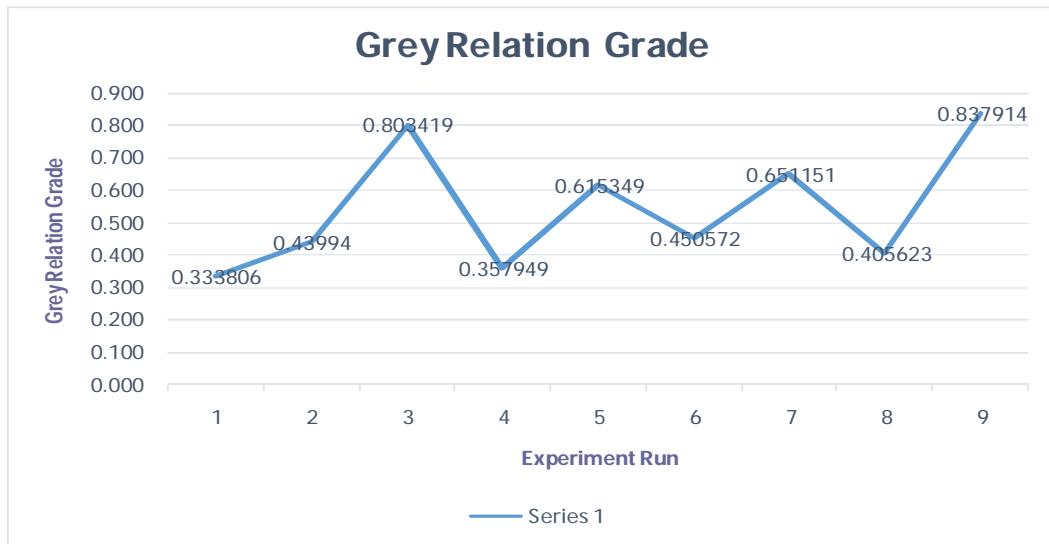
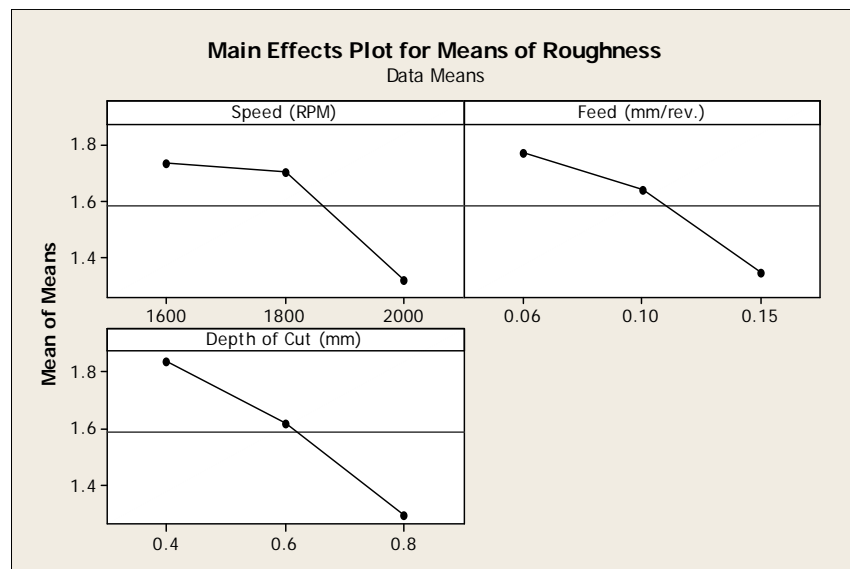


Figure no 3 : Main Effect Plot for Ra

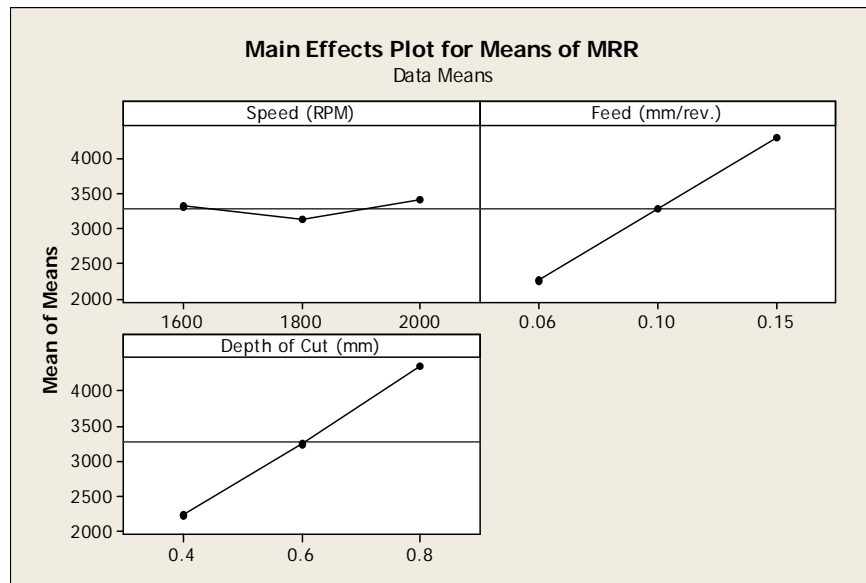


# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Figure no 4 : Main Effect Plot for MRR



## V. CONCLUSION

This paper presents research work of the optimal combination of various cutting parameters affecting the surface roughness, material removal rate in Dry turning of EN31 material by using PVD coated carbide tools. An orthogonal array with grey relational analysis was used to optimize the multi response characteristics of the EN31 turning process. The performance characteristics such as the minimum surface roughness and maximum material removal rate were improved using the method proposed in this study. According to the Taguchi L9 Orthogonal array, 9 experiment need to be conducted to find the optimal parameter conditions at three levels, three control factor en31 turning. Grey relational analysis found that the feed is the most influencing factors for surface roughness and speed and depth of cut are most influencing factors for Material removal rate. The optimal parameter combinations obtained by the analysis is at Speed 2000 rpm, Feed 0.15 mm/rev, Depth of cut 0.6 mm. The experiment value is also very closer to predicted value .The highest grey relation grade is 0.837914.

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