Simultaneous Optimization of Material Removal Rate and Surface Roughness in Turning of EN24

A Project report submitted in partial fulfillment of the requirement for the award of the degree of

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IN

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Abstract

The present work is to investigate the effect of cutting parameters on the multiple performance characteristics while turning of a medium carbon steel EN24. The work material has a wide range of applications in the field of aircraft and automotive and used in components such as gears, shafts, studs and bolts, connecting rods, propeller or gear shafts and aircraft landing gear components etc. A series of experiments were carried out using coated carbide tools on CNC turret lathe. Taguchi's mixed L16 orthogonal array has been followed by taking speed, feed, depth of cut and nose radius as the controllable parameters. The multiple responses of material removal rate (MRR) and surface roughness (R_a) are analyzed using grey relational analysis (GRA). From GRA results, the optimal combination for achieving the high material removal rate and low surface roughness simultaneously is obtained at the speed of 2000 rpm, feed of 0.2 mm/rev, depth of cut of 1.2 mm and nose radius of 0.4 mm. Finally, the analysis of variance (ANOVA) is employed to find the influence of cutting parameters on the multi response value. From ANOVA it is concluded that nose radius is the most influencing parameter on the multi response and followed by depth of cut, speed and feed respectively.

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NOMENCLATURE

v	Cutting Speed, m/min
f	Feed, mm/rev
d	Depth of Cut, mm
MRR	Material Removal Rate, cm^3/min
R_a	Arithmetic Surface Roughness Average, µm
CNC	Computerized Numerical Control
DOE	Design of Experiments
OA	Orthogonal Array
S/N	Signal-to-Noise Ratio
ANOVA	Analysis of Variance
DF	Degree of Freedom
SS	Sum of Squares
MS	Mean Square
F	Variance Ratio
P	Probability of Significance
S	Variance
R^2	Coefficient of Determination
R^2 (Adj)	Adjusted R^2
GRC	Grey Relational Coefficient
GRG	Grey Relational Grade
Δ	Quality Loss

δ	Distinguishing Coefficient (o≤δ≤1)
γ_m	Total Mean S/N Ratio
r	Tool Nose Radius

CHAPTER 1

INTRODUCTION

The manufacturing industries are continuously challenged for achieving a high material removal rate and good surface quality in order to remain competitive in the market. Higher material removal rate is desired by the industry to cope up with mass production and it can be achieved through increasing the cutting parameters like speed, feed and depth of cut. But, with an increase in cutting parameters cutting temperature will increase. This increase in temperature causes dimensional inaccuracies by thermal deformation and damages the tool. So, selection of appropriate cutting parameters and cutting tool play important roles in the effectiveness, efficiency and overall economy of manufacturing by machining to achieve a higher material removal rate and low surface roughness. Carbide tools have been developed to meet high speeds for achieving maximum productivity and good surface quality. They have properties like high hardness, high elastic modulus, thermal conductivity and low thermal expansion, etc. In case of machining, productivity and surface quality are the most important requirements of the customer. Surface roughness influences the properties such as appearance, corrosion resistance, wear resistance, fatigue resistance, lubrication, initial tolerance, ability to hold pressure, load carrying capacity, noise reduction in case of gears, etc. Roughness mainly depends on the factors like material of the work piece, type of machining, rigidity of the system consisting of machine tool, fixture cutting tool and work, type and material of cutting tool, cutting conditions i.e., speed, feed and depth of cut and type of coolant used etc.

In real practice the number of experiments to be conducted will increases with an increase in the process parameters and it leads to increase in time and cost. To solve this problem, Denichi Taguchi has proposed a design called an orthogonal array. OA covers the entire parametric space with the least number of experiments. Taguchi method can be used for single objective problems only, for the multi objective optimization Taguchi based grey method was invented by deng. It is useful for dealing the problems with poor, insufficient and uncertain information. Grey theory is a powerful optimization tool to analyze the process with multiple output characteristics. The theory does not attempt to find the best solution, but provides techniques for determining a good solution. From grey analysis, we will obtain a single parametric combination that optimizes the overall process. It can also be used to identify the most influencing factors affecting the output characteristics. In grey analysis a multi objective optimization problem can be converted into a single objective problem in terms of grey relational grade. In case of production to maximize the gain of manufacturer, process parameters such as speed, feed and depth of cut needs to be optimized for individual and multi performance characteristics. The present work concentrated on simultaneous optimization of material removal rate and surface roughness using the grey relational grade method. ANOVA has been done to find the significance of the factors on the multi response.

CHAPTER 2

LITERATURE REVIEW

Numerous investigations have been carried out in the fields of optimization of working parameters of CNC lathe by considering different input parameters like cutting speed, feed and depth of cut to optimize and getting better output characteristics like Material Removal Rate (MRR), Surface Roughness (R_a), Tool Wear and Dimensional Accuracy etc.

Vinod Kumar Vankanti, et al. [1] in 2014 investigated the effect of process parameters in drilling of glass fiber reinforced polymer (GFRP) composites by using Taguchi L9 orthogonal array and ANOVA. The results indicated that the feed rate is most significant factor for thrust force followed by speed, chisel edge width and point angle. The cutting speed is the most significant factor affecting the torque and the circularity of the hole followed by feed, chisel edge width and point angle.

Reddy Sreenivasulu [2] in 2013 investigated the influence of speed, feed and depth of cut on Delamination damage and Surface Roughness of glass fiber reinforces polymeric composite material (GFRP) during end milling by using Taguchi method. From the results of ANOVA, it is concluded that cutting speed and depth of cut are the most significant factors affecting the responses.

C.J.Rao, et al. [3] in 2013 investigated the significance of influence of speed, feed, and depth of cut on Surface Roughness and Cutting forces on AISI 1050 steels (hardness of 484HV) on CNC lathe with ceramic (Al2O3+TiC matrix) tool by using Taguchi method (L27 design with 3 levels and 3 factors). The results indicated that feed rate has most influence on both Cutting forces as well as Surface Roughness. Depth of cut has a significant influence on Cutting force, but has an insignificant influence on Surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters have significant influence on cutting forces, whereas none of the interaction effects are having significant influence on the Surface Roughness produced.

Harish Kumar, et al. [4] in 2013 were conducted experiments on MS 1010 by HSS tool using CNC lathe under dry condition. They have taken speed, feed and depth of cut taken as input parameters and Surface Roughness as output parameter for analysis. They analyzed the data using Taguchi methodology and ANOVA. They found that for MS1010 speed is the most significant parameter for Surface Roughness and least significant parameter is DOC.

M. Kaladhar, et al. [5] in 2013 were conducted experiments on turning of AISI 304 austenitic stainless steel with Physical Vapour Deposition (PVD) coated insert for optimizing Material Removal Rate and Surface Roughness by using Taguchi L16 orthogonal array and ANOVA. They found that feed is the most significant parameter and followed by nose radius for Surface Roughness and for Material Removal Rate depth of cut is most significant parameter followed by feed.

N.E. Edwin Paul, et al. [6] in 2013 were conducted experiments on EN8 material using CNC lathe on Taguchi L9 Orthogonal array. Signal to Noise ratio and ANOVA used for analyzing the data. The results concluded that the feed has greater influence on the Surface Roughness followed by the cutting speed and the depth of cut has least influence.

Upinder Kumar Yadav, et al. [7] in 2012 investigated the significance of machining parameters on Surface Roughness in CNC turning of medium carbon steel AISI 1045 by using Taguchi L27 orthogonal array and Analysis of variance (ANOVA). The results concluded that feed rate is the most significant factor for Surface Roughness next to depth of cut. Cutting speed is the least significant factor affecting Surface Roughness.

M. Kaladhar, et al. [8] in 2011 conducted experiments on AISI 202 austenitic stainless steel by using 2^4 full factorial designs. The experiments have been employed to determine the best combination of the machining parameters such as cutting speed, feed, depth of cut and nose radius to attain the minimum Surface Roughness and also predictive models obtained for Surface Roughness. From results, it is concluded that feed is the most significant factor for Surface Roughness followed by nose radius.

Sunil J Raykar, et al. [9] in 2014 investigated on the effect of process parameters on R_a, R_z, R_q parameters of surface topology in dry machining of EN8 steel by using Taguchi L27 orthogonal array and Regression analysis. Results concluded that feed has greatest influence on surface finish of all three surface topology parameters R_a, R_q and R_z next is to cutting speed and depth of cut has least significance. Regression models were prepared and a good correlation is found between Surface Roughness and cutting parameters and hence the models were used for predict the Surface Roughness within the range of cutting parameters under investigation.

A Mahamani [10] in 2014 studied the influence of machining parameters on cutting force and surface roughness in hard turning of AA2219-TiB2/ZrB2 in-situ metal composites with uncoated tungsten carbide tool by using Taguchi L27 orthogonal array and Regression analysis. The results concluded that the feed rate has strongest effect on both Cutting force and Surface Roughness. Regression models also developed between the machining parameters and responses.

Mohamad Syahmi Shahrom, et al. [11] in 2013 investigated the effect of lubrication condition on milling processes of AISI 1060 aluminium work material by using Taguchi method. From the results it is observed that Minimum quantity lubricant (MQL) produced better surface finish as compared to wet machining. The results significantly reduced the cost and Environmental pollution.

J Gokula chandran, et al. [12] in 2012 has done his study on prediction of tool life using regression and fuzzy logic method on end milling of IS2062 steel using P30 uncoated carbide tipped tool by using Taguchi and ANOVA. The results obtained by two methods were compared and it is observed that good agreement between the experimental and predicted values. %error for predicted and experimental values are found in the limit of 0.15.

Gaurav Bartarya, et al. [13] in 2012 were studied the effect of cutting parameters on cutting force and surface roughness during hard turning of AISI 52100 steel with CBN tool by using full factorial design of experiments, regression analysis and ANOVA. The Regression models developed show that the dependence of Cutting forces and Surface roughness on machining parameters are significant, hence they could be used for making predictions for the forces and Surface roughness. The predicted values were compared with the experimental values, good agreement between the two is observed.

V.Bushlya, et al. [14] in 2012 have done a research on effect of cutting conditions on machinability of super alloy inconel 718 during high speed turning with coated and uncoated PCBN tools. In the research the author differentiates the machinability with uncoated and coated PCBN tools aiming at increasing speeds and efficiency and the aspects of tool life, tool wear and surface integrity were studied. It was found that protective function of coating increases the tool life to 20% than with the uncoated case.

IIhan Asilturk, et al. [15] in 2011 conducted experiments in turning of AISI 4140 with coated carbide cutting tool by using Taguchi L9 orthogonal array. They investigate the effects of process parameters on Surface Roughness (R_a and R_z). Results indicated that feed rate is the most significant parameter for Surface Roughness parameters R_a and R_z. They developed mathematical models and they can be used in the metal machining industries in order to determine the optimum cutting parameters for minimum Surface Roughness.

Mohit Tiwari, et al. [16] in 2014 were investigated the optimal combination of process parameters in machining of carbon fiber epoxy composite by EDM using Taguchi's L9 orthogonal array and Grey relational analysis for maximum Material Removal Rate (MRR) and minimum Tool wear rate (TWR). From the mean of the overall Grey relational grade it is concluded that the peak current (Ip) is most significant factor towards both MRR and TWR together followed by pulse on time, duty cycle and gap voltage.

Shreemoy Kumar Nayak, et al. [17] in 2014 Conducted experiments by using multi objective Grey relational analysis for optimization of cutting process parameters in dry turning of AISI 304 austenitic stainless steel, and machinability characteristics of material removal rate, cutting force and surface roughness were studied. Experiments were conducted as per Taguchi L27 orthogonal array. From the mean of the overall Grey relational grade it is concluded that feed has high significance on Material Removal Rate (MRR), cutting forces and Surface roughness together followed by speed and depth of cut has least significance.

Dipti Kanta Das, et al. [18] in 2014 Investigated for finding the optimal combination of cutting process parameters during hard machining of EN 24 steel with coated carbide insert by using Grey based Taguchi(L9 orthogonal array) and Regression methodology for minimum Surface quality characteristics R_a and R_z. The results concluded that the feed is considered to be the most dominant parameter for both Surface Roughness parameters R_a and R_z. The prediction models have been developed using regression analysis for surface Roughness and they are adequate and significant.

Reddy Sreenivasulu, et al. [19] in 2012 have studied; the effects of drilling parameters on surface roughness and roundness error were investigated in drilling of AI6061 alloy with HSS twist drills. The obtained experimental results were analyzed by Taguchi Grey relation analysis. They had taken Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio as control factors. They found that minimum surface roughness and roundness error were obtained with treated drills at 25.13 m/min cutting speed and 0.3 mm/rev feed rate,10mm drill diameter, 110 degrees point angle and 12% cutting fluid mixture ratio.

S V Subrahmanyam, et al. [20] in 2013 had tried to demonstrate the optimization of Wire Electrical Discharge Machining process parameters for the machining of H13 Hot Die Steel, with multiple responses material removal rate, surface roughness based on the Grey–Taguchi Method. They used Taguchi L27 (2^1x3^8) orthogonal to conduct experiments. They had taken eight process parameters T_{ON}, T_{OFF}, IP, SV WF, WT, SF, WP each to be varied in three different levels. They used grey relation analysis to obtained optimal sequence for multi quality parameters. They found that the material removal rate was increased from 304.46 mm3/min to 322.66 mm3/min and the Surface Roughness was reduced from 2.11µm to 2.01µm respectively. They have also presented the mathematical model for individual quality parameter.

T V K Gupta, et al. [21] in 2013 had tried to demonstrate the optimization of abrasive water jet machining process parameters for the machining of SS 304 material, with multiple responses surface roughness, taper, impact force, vibration & depth and width of cut based on the Grey–Taguchi Method. They have taken reverse speed, abrasive flow rate, abrasive size and standoff distance as process parameters. Based on the grey coefficients and grades of the experimental data, a traverse speed of 3000 mm/min, a diameter of 0.125 mm of abrasive particle at 0.49 kg/min abrasive flow rate and a standoff distance of 4 mm given an optimum machining conditions for the required output.

M. Durairaj, et al. [22] in 2013 done a study on machining of SS304 in wire EDM by using Taguchi's (L16 orthogonal array) method and multi objective grey relational theory in order to optimize kerf width and surface quality separately and simultaneously. The input parameters selected are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. In both the optimization methods the results concluded that pulse on time has highest significance and gap voltage has least significance.

From the above literature review, it has been observed that no much work is reported on Multi objective optimization of Material Removal Rate (MRR) and Surface Roughness

(R_a) characteristics in turning of EN24 medium carbon steel with a coated carbide tools. Also very less works are there by considering the nose radius as one of the controlling parameter. In the present investigation, Multi objective optimization of responses was done using Grey Analysis. The optimal combination of machining parameters (cutting speed, feed, depth of cut and nose radius) in order to attain the maximum Material Removal Rate and minimum Surface Roughness simultaneously has been obtained.

CHAPTER 3

METHODOLOGY

In the present chapter the methodology used for obtaining better response parameters is briefly discussed. In modern industrial environment a numerous kinds of Investigations have been done for the improvement of product quality in the field of manufacturing. Some have few factors to be considered, some have many. While there are others, that demand factors to have mixed levels. A vast majority of experiments however fall in the category where all factors possess the same number of levels. In the conventional technique of varying one factor at a time, lot of experimental data can be obtained. This way of experimentation not only consumes lot of time but also poses a challenge to the investigator for deriving appropriate conclusion from the huge experimental data. Design of Experiments (DOE) is at ever rescue for planning systematic experimentation and arriving at meaningful conclusion without being inundated in huge set of experimental data. DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of factors. There are number of statistical techniques available for engineering and scientific studies. In the present investigation a multi objective optimization method Grey Relational Analysis is employed for optimizing the control parameters.

3.1 Methodology

- Selection of process parameters and their levels
- Selection of quality characteristics for each response characteristic
- Taguchi Design of Experiments
- Conducting experimentation as per the Taguchi Design of Experiments
- Analyzing the results using Grey relational analysis after converting multi objective into a single objective function.
- Determining the optimal conditions of cutting parameters and their contributions towards the response.

3.2 Selection of the Process Parameters and Their Levels

Selection of right combination of process parameters and setting the range of the process parameters is very important step in unconventional process. Small variation in process parameters will effect adversely on the Surface Roughness and accuracy of the machined components. In general the process parameters are of two types.

- Fixed parameters
- Controlled parameters

In this present work the tool geometry, work piece hardness and its mechanical properties and environmental conditions are taken as fixed parameters which will not be changed throughout the investigation, whereas cutting speed, feed depth of cut and nose radius are considered as the controlled parameters are used to change for each experiment by Taguchi approach. The selected process parameters for the experiment with their limits, notations and units are given in table 3.1.

Table 3.1 Process Parameters and Their Levels

Parameter	Levels			
	1	2	3	4
s, rpm	1500	2000	2500	3000
f, mm/rev	0.05	0.1	0.15	0.2
d, mm	0.3	0.6	0.9	1.2
r, mm	0.4	0.8	-	-

3.3. Selection of Orthogonal Array (OA)

Taguchi has developed a design called orthogonal array it is used to study the entire design space with a very less number of experiments. For the four parameters with mixed levels taguchi's standard L16 has been chosen and it is given in the table 3.2.

Table 3.2 Taguchi L16 Orthogonal Array

S.No	s (rpm)	f (mm/rev)	d (mm)	r (mm)
1	1500	0.05	0.3	0.4
2	1500	0.1	0.6	0.4
3	1500	0.15	0.9	0.8
4	1500	0.2	1.2	0.8
5	2000	0.05	0.6	0.8
6	2000	0.1	0.3	0.8
7	2000	0.15	1.2	0.4
8	2000	0.2	0.9	0.4
9	2500	0.05	0.9	0.4
10	2500	0.1	1.2	0.4
11	2500	0.15	0.3	0.8

12	2500	0.2	0.6	0.8
13	3000	0.05	1.2	0.8
14	3000	0.1	0.9	0.8
15	3000	0.15	0.6	0.4
16	3000	0.2	0.3	0.4

3.4. Performance Quality Characteristics

3.4.1. Material Removal Rate (MRR)

The Material Removal Rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in cm^3/min. For each revolution of the work piece, a ring-shaped layer of material is removed.

Material Removal Rate (MRR) = (v. f. d) in cm^3/min.
Where, v is cutting speed in m/min
f is feed in mm/rev
d is depth of cut in mm.

3.4.2 Surface Roughness

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as cutting conditions, tool variables and work piece variables.

Cutting conditions includes

- Cutting speed
- Feed
- Depth of cut.

Tool variables includes

- Nose radius
- Rake angle
- Cutting edge geometry

- Auxiliary tooling, and lubricant used, and
- Vibrations between the work piece and cutting tool.

Work piece variables includes

- Hardness of material
- Mechanical properties of materials

3.5. Grey Relational Grade Method

3.5.1 Introduction

In the year of 1980, Grey systems theory was brought forward by Professor Deng Ju-long from China Grey analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown. With this definition, information quantity and quality form a continuum from a total lack of information to complete information from black through grey to white. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, somewhere in the grey area. Grey analysis then comes to a clear set of statements about system solutions. At one extreme, no solution can be defined for a system without any information. At the other extreme, a system with perfect information has a unique solution. In the middle, grey systems will give a variety of available solutions. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problems.

The proposition of Grey theory occurring in the 1990 to 1999 time period resulted in the uses of Grey theory to each field, and the development is still going on. The major advantage of Grey theory is that it can handle both incomplete information and unclear problems very precisely. It serves as an analysis tool especially in cases when there is no enough data. It was recognized that the Grey relational analysis in Grey theory had been largely applied to project selection, prediction analysis, performance evaluation and factor effect evaluation due to the Grey relational analysis software development. Recently, this technique has also applied to the field of sport and physical education.

3.5.2. Steps involved in Grey relational analysis

- Identification of the process parameters with their levels and the performance characteristics to be evaluated.
- Selection of orthogonal array (OA) and assign the process parameters to the array.
- Experimentation as per the orthogonal array.
- Normalization of the experimental results.
- Determination of deviation sequences.
- Determination of Grey relational coefficient (GRC).
- Determination of Grey relational grade (GRG).
- Determination of optimal combination of the process parameters.

In Grey relational analysis, experimental data i.e. measured features of quality characteristics are first normalized ranging from zero to one. The process is known as Grey relational generation. Next, based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is overall Grey relational grade. The optimal parametric combination is then evaluated which would result into highest Grey relational grade. The optimal factor setting for maximizing overall Grey relational grade can be performed by Taguchi method. The steps in grey relational analysis are as follows:

3.5.3. Calculation Procedure of Grey Relational Grade Method

Step1: Normalize the experimental values y_{ij} as Z_{ij} ($0 \leq Z_{ij} \leq 1$) by following formulae to avoid the effect of using different units and to reduce variability.

$$Z_{ij} = \frac{Y_{ij} - \min(Y_{ij}, i=1,2,....,n)}{\max(Y_{ij}, i=1,2,....,n) - \min(Y_{ij}, i=1,2,......,n)};$$ for Higher-the-Better case.

$$Z_{ij} = \frac{\max(Y_{ij}, i=1,2,....,n) - Y_{ij}}{\max(Y_{ij}, i=1,2,......,n) - \min(Y_{ij}, i=1,2,.....,n)};$$ for Smaller-the-Better case.

$$Z_{ij} = \frac{|Y_{ij} - \text{Target}| - \min(|Y_{ij} - \text{Targ}\quad|, i=1,2,...n)}{\max(|Y_{ij} - \text{Target}|, i=1,2,...n) - \min(|Y_{ij} - \text{Target}|, i=1,2,...,n)};$$ for Nominal-the-Better case.

Step2: Determine quality loss functions by using

Delta (Δ) = (Quality loss) = $|y_o - y_{ij}|$

Step3 Compute Grey relational coefficient for normalized experimental values,

$$GC_{ij} = \frac{\Delta_{min} + \delta\Delta_{max}}{\Delta_{ij} + \delta\Delta_{max}} \begin{cases} i = 12, \dots . n \\ j = 1,2, \dots k \end{cases}$$

Where, GC_{ij}= Grey relational coefficient for the i^{th} replicate of j^{th} response.

Y_{oj}= optimum performance value of j^{th} response

Y_{ij}= the i^{th} normalized value of the j^{th} response

Δ= quality loss $|Y_0\text{-}Y_{ij}|$

Δ_{min}= minimum value of Δ

Δ_{max}= maximum value of Δ

δ = distinguishing coefficient which is in range of $0 \leq \delta \leq 1$ (assume δ=0.5)

Step4: Find the Grey relational grade by using,

$$G_i = \frac{1}{m} \sum GC_{ij}$$

Here, m is the number of process responses.

The higher value of Grey relational grade means that the corresponding parameter combination is closure to the optimal. The mean response for the Grey relational grade with its grand mean and the Main effect plot of Grey relational grade are very important because optimal process condition can be evaluated from this plot. For getting the contribution of each parameter ANOVA is performed by using Statistical tool, and Taguchi analysis is done to find out S/N ratio, for each Grey relational grade value. Optimal process parameters and their predicted values are calculated.

CHAPTER 4

EXPERIMENTAL DETAILS

The work material selected for the study is En24 a medium carbon steel. The work specimens are of cylindrical shape having dimensions 32 mm diameter and 65 mm length are taken as shown in figure 4.1. En24 has a wide range of applications in the field of aircraft and automotive and used in components such as gears, shafts, studs and bolts, connecting rods, propeller or gear shafts and aircraft landing gear components etc. The chemical and mechanical properties of En24 are given in the tables 4.1and 4.2.

Figure 4.1 EN24 Material

Table 4.1. Chemical Composition of En24

C	Si	Mn	S	P	Cr	Mo	Ni
0.36-0.44	0.10-0.35	0.45-0.7	0.04 max	0.035 max	1-1.4	0.2-0.35	1.30-1.70

Table 4.2. Mechanical Properties of En24

Density (gm/cm^3)	Tensile strength (N/mm^2)	Yield Strength (N/mm^2)	Elongation (%)	Impact (Izod)	Hardness (BHN)
2.8	850-1000	680	13	54	248

The experiments were conducted on CNC turret lathe (7.5 KW, 6000 rpm Spindle speed) it is shown in the figure 4.2. The work pieces are first trued for 0.5 mm to remove the unevenness and the components after machining were shown in the figure 4.3. After machining the finished components were tested for their roughness with SJ-210 tester shown in the figure 4.4.

Figure 4.2. CNC Machine

Figure 4.3. Machined Components

Figure 4.4. SJ-210 Roughness Tester

CHAPTER 5
RESULTS & DISCUSSIONS

In this chapter the experimental results of material removal rate (MRR) and surface roughness (R_a) are analyzed using grey relational grade method and ANOVA. The focus of the work is to identify the optimal combination of process parameters that concurrently maximize the material removal rate and minimize the surface roughness.

5.1. Experimental Results

The measured results of both material removal rate and surface roughness were tabulated in table 5.1. The results were normalized to zero-one range using higher-the-better and lower-the-better characteristics as given in the methodology chapter3.

Table 5.1 Experimental Results

S.No.	MRR (Cm^3/min)	R_a (μm)
1	2.25	0.2
2	9	0.32
3	20.25	1.2
4	36	1.41
5	6	0.46
6	6	0.39
7	36	0.57
8	36	0.56
9	11.25	0.28
10	30	0.37
11	11.25	0.91
12	30	1.22
13	18	0.5
14	27	1.82
15	27	0.56
16	18	1.02

5.2. Results of Grey Analysis

Table 5.2showing the normalized values of the responses. From the normalized values the quality loss values from the target values are found and are given in the table 5.3.

Table 5.2. Normalized Values of the Responses

S.No.	MRR	R_a
1	0.0000	1.0000
2	0.2000	0.9259
3	0.5333	0.3827
4	1.0000	0.2531
5	0.1111	0.8395
6	0.1111	0.8827
7	1.0000	0.7716
8	1.0000	0.7778
9	0.2667	0.9506
10	0.8222	0.8951
11	0.2667	0.5617
12	0.8222	0.3704
13	0.4667	0.8148
14	0.7333	0.0000
15	0.7333	0.7778
16	0.4667	0.4938

Table 5.3. Loss Function Values (Δ)

S.No.	MRR	R_a
1	1.0000	0.0000
2	0.8000	0.0741
3	0.4667	0.6173
4	0.0000	0.7469
5	0.8889	0.1605
6	0.8889	0.1173

7	0.0000	0.2284
8	0.0000	0.2222
9	0.7333	0.0494
10	0.1778	0.1049
11	0.7333	0.4383
12	0.1778	0.6296
13	0.5333	0.1852
14	0.2667	1.0000
15	0.2667	0.2222
16	0.5333	0.5062

The Grey relational coefficient values for the individual responses were derived from the corresponding quality loss values and are given in table 5.4. Finally, the grey relational grade values were calculated by taking the average of the corresponding responses.

Table 5.4. GRC and GRG Values

S.No.	GRC		GRG	S/N of GRG
	MRR	R_a		
1	0.3333	1.0000	0.6667	-3.5218
2	0.3846	0.8710	0.6278	-4.0436
3	0.5172	0.4475	0.4824	-6.3322
4	1.0000	0.4010	0.7005	-3.0919
5	0.3600	0.7570	0.5585	-5.0594
6	0.3600	0.8100	0.5850	-4.6568
7	1.0000	0.6864	0.8432	-1.4811
8	1.0000	0.6923	0.8462	-1.4510
9	0.4054	0.9101	0.6578	-3.6386
10	0.7377	0.8265	0.7821	-2.1345
11	0.4054	0.5329	0.4692	-6.5737
12	0.7377	0.4426	0.5902	-4.5805
13	0.4839	0.7297	0.6068	-4.3390
14	0.6522	0.3333	0.4928	-6.1474
15	0.6522	0.6923	0.6722	-3.4495

16	0.4839	0.4969	0.4904	-6.1889

The values of the grey relational grade are analyzed using taguchi's higher-the-better characteristic and the signal to noise (S/N) ratios were calculated. From the S/N ratios the main effect plot has been plotted to identify the optimal combination of process parameters on the multi response. From the main effect plot for signal-to-Noise ratios of Grey relational grade values shown in figure 5.1.the optimal combination of cutting parameters is obtained at 2000 rpm of speed, 0.2 mm/rev of feed, 1.2 mm of depth of cut and 0.4 mm nose radius respectively.

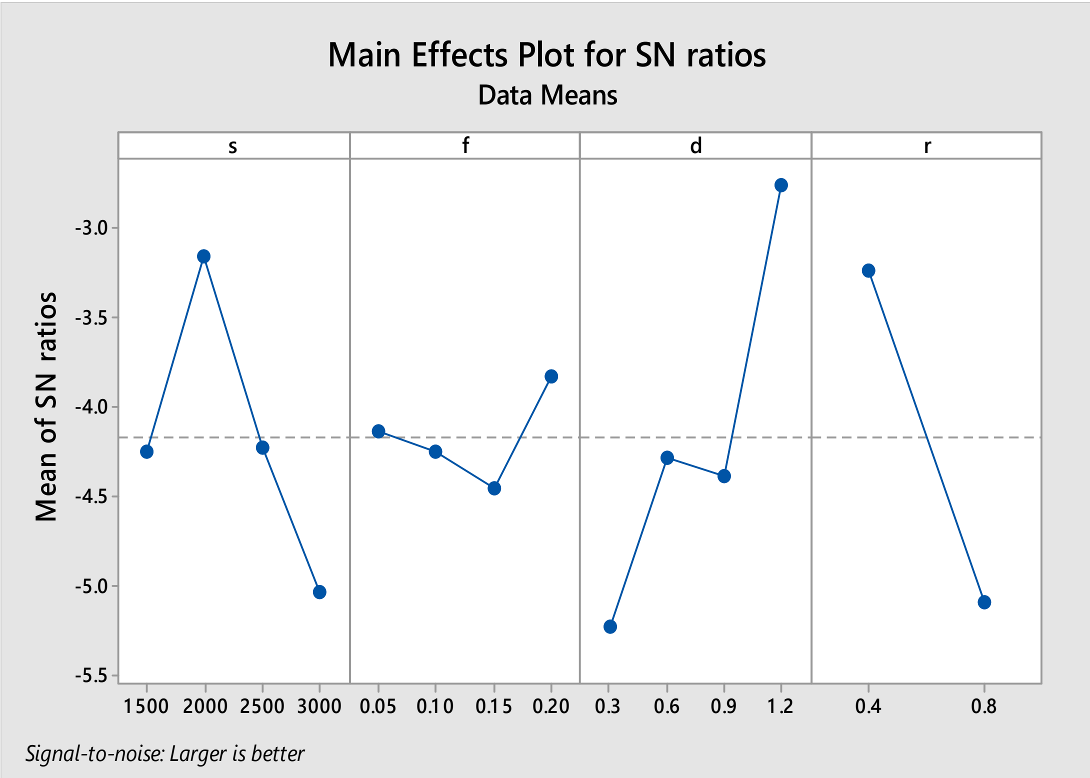

Figure 5.1. Main Effect Plot for GRG

5.3. ANOVA Reaults

The Analysis of variance is used to investigate the significance of cutting parameters on the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of squared deviations from the total mean of the grey relational grade, into contributions by each parameter and the error. The percentage contribution by each factor to the total sum of the squared deviations SST can be used to evaluate the importance of the cutting parameter change on the performance characteristic. In addition, the F-test can also be used to determine which factor has a significant effect on the performance characteristic. Usually, the change of a determined factor has a significant effect on the performance characteristic when the F value is large. From the results of table 5.5 it is clear that the nose radius is the most influencing parameter and followed by the depth of cut, speed and feed.

Table 5.5. Anova Results

Source	DF	Adj SS	Adj MS	F-value	p-value
s	3	0.041648	0.013883	2.32	0.192
f	3	0.004062	0.001354	0.23	0.874
d	3	0.068089	0.022696	3.80	0.092
r	1	0.075777	0.075777	12.68	0.016
error	5	0.029869	0.005974		
total	15	0.219446			

From the residual plots of figure 5.2, it is observed that all the errors are following the normal distribution as all the residuals are laying near to the straight line in the normal probability plot. Versus fits and order plots are implying that the errors are distributed on both the sides of mean line i.e. they are not following any regular pattern hence maintaining the constant variance.

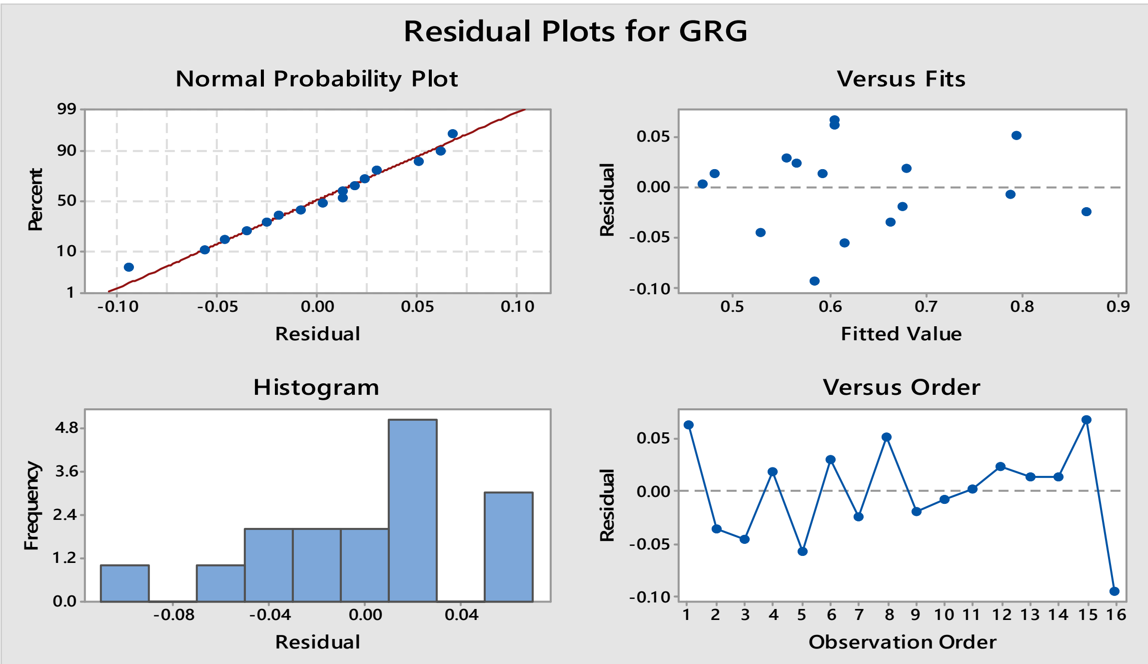

Figure 5.2 Residual Plots for GRG

CHAPTER 6

CONCLUSIONS

The present work discussed an application of taguchi based grey relational grade method for investigating the effects of turning parameters on material removal rate and surface roughness in turning of EN24. From the results of grey analysis and ANOVA the following conclusions can be drawn:

- From the Grey analysis, the optimal combination of cutting parameters is obtained at 2000 rpm of speed, 0.2 mm/rev of feed, 1.2 mm of depth of cut and 0.4 mm nose radius respectively.
- ANOVA results concluded that the nose radius is the most influencing parameter and followed by the depth of cut, speed and feed on the multi-response.
- The errors are distributed normally and they are not following any regular patterns hence following the assumptions normality and constant variance of ANOVA.

SCOPE OF FUTURE WORK

In the present work, optimization of cutting process parameters in dry turning of EN24 with a multi coated carbide tool on CNC lathe has been done by using Taguchi and Grey relational grade methods. For further extension of the work we can conduct the experimentation with different types of tool shapes (C-type, round type etc.) and with multi-layer coated tools or by changing the coating material type of the tool and for different material grades or composites.

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