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# Parametric Optimization on Multi-Objective Precision Turning Using Grey Relational Analysis

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**Abstract.**

The quality of a machined surface is becoming more and more important to satisfy the increasing demands of sophisticated component performance, longevity, and reliability. The objective of this paper is to analyze the performance of precision turning of using conventional lathe on Ti-6Al-4V under dry working conditions. Various parameters that affect the machining processes were identified and a consensus was reached regarding its values. The proposed work is to perform machining under the selected levels of conditions and parameters and to estimate the, cutting temperature and surface roughness generated as the result of the machining process. Based upon the experimental values, Analysis of Variance (ANOVA) was conducted to understand the influence of various cutting parameters on, surface roughness, cutting force, tool ware and cutting tool temperatures during precision turning of titanium alloy. Optimal levels of parameters were identified using grey relational analysis, and significant parameter was determined by analysis of variance.



**Keywords:** *Precision Turining; Orthogonal Array; Grey Relational Analysis; Grey Relational Grade; Grey Relational Coefficient;ANOVA*

## 1. Introduction

The machinability of titanium and its alloys is generally considered to be poor owing to several inherent properties of the materials. Titanium is chemically reactive and therefore, has a tendency to weld to the cutting tool during machining, thus leading to chipping and premature tool failure[1-5]. Its low thermal conductivity increases the temperature at the tool/ workpiece interface, which affects the tool life adversely. The Taguchi method [13] is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost [6-8]. However, the original Taguchi method has been designed to optimize a single performance characteristic. Handling multiple performance characteristics of the Taguchi method require further research effect [9-10]. Hence, optimization of the multiple performance characteristics is much more complicated than optimization of a single performance characteristic. In this paper, the orthogonal array with the grey relational analysis [11] is used to investigate the multiple performance characteristics in the precision turning process. The grey system theory initiated by Deng [12-13] in 1982 has been proven to be useful for dealing with poor, incomplete, and uncertain information. The grey relational analysis based on the grey system theory can be used to solve the complicated interrelationships among the multiple performance characteristics effectively [14].

The paper is organized in the following manner. An overview of the optimization of the multiple performance characteristics of the orthogonal array with the grey relational analysis is given first. Then, the selection of machining parameters and the evaluation of machining performance in the precision turning process are discussed. Optimization of the precision turning process based on the orthogonal array with the grey relational analysis is described in detailed. Finally, the paper concludes with a summary of this study. [15].

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This paper presents and demonstrates the effectiveness of optimizing multiple quality characteristics of Nd:YAG laser welded titanium alloy plates via Taguchi method-based Grey analysis. The modified algorithm adopted here was successfully used for both


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detraining the optimum settings of machine parameters and for combining multiple quality characteristics into one integrated numerical value called Grey relational grade or rank.[16] Titanium alloy plates were butt welded under controlled machine parameter settings, machined, and above quality characteristics were measured. The optimized machine parameter settings clearly improved the quality characteristics of welded plates compared to quality levels achieved for conventional machine parameter settings. [17-19] the applications of Taguchi method in either machining or manufacturing field have been extremely success full. In contrast, as implied by its name, which implies a shade between the absolutes of black and white, gray analysis can effectively recommend a method of optimizing the complicated interrelationships among multiple performance characteristics.

The revised laser welding setting then was confirmed and verified via ANOVA analysis for each parameter adopted in this study.[25] Further, some correlated discussions on the basis of either the Taguchi method recommendation or Grey analysis were also explored to expand the future applications of this revised methodology. The Grey analysis was first proposed many decades ago but has been extensively applied only in the last decade. Grey analysis has been broadly applied in evaluating or judging the performance of a complex project with meager information. However, data to be used in Grey analysis must be preprocessed into quantitative indices for normalizing raw data for another analysis.

## 2. Experimental procedure

The target material used for the experimentation is Ti-6Al-4V. Gedee Weiler MLZ 250V variable speed adjusting capstan lathe is used for the experiment. And the experimental setup is shows in Fig 1. PVD coated carbide tool with 98 HRC hardness, nose radius of 0.1 0.2 and 0.4 were used for the turning operation. Surface roughness was measured using mitutotyo surftest SJ-301 portable surface roughness tester with a sampling length of 4 mm. The cutting temperature was measured using a thermocouple. The cutting parameters were so selected after comparison with different literature surveyed. The design of experiments and analysis of variance was done using Minitab 15 software.

Fig 1 Experimental setup

## 3. Design of Experiments and Observations

Design of Experiments is a highly efficient and effective method of optimizing process parameters, where multiple parameters are involved. The design of experiments using the Taguchi approach was adopted to reduce the number of trials. The time and cost for doing an experiment is very high, therefore it is necessary to select an orthogonal array with minimum number of trials. In this research work L27 orthogonal array is chosen which a multilevel experiment is where feed rate, depth of cut, cutting speed and nose radius are the four factors considered in the experiment. Table 1 shows the machining parameters and their levels considered for experimentation.

| Cutting parameter | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Feed (mm/rev) | 0.02 | 0.04 | 0.06 |
| Depth of cut (mm) | 0.05 | 0.10 | 0.15 |
| Cutting speed (m/min) | 30 | 60 | 90 |
| Nose radius (mm) | 0.1 | 0.2 | 0.4 |

**Table 1** Machining parameters and their level

The proposed work is to perform machining under the selected levels of conditions and parameters and to estimate the, cutting force, cutting temperature and surface roughness generated as the result of the machining process. Table 2 shows the machining parameters and observation for each trail of experiments.

| S. No. | Feed (mm/rev) | Depth Of Cut (mm) | Cutting Speed (mm/min) | Nose Radius (mm) | Cutting Force(N) | Max. Tool Wear (mm) | Surface roughness | Cutting tool temp |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.02 | 0.05 | 30 | 0.1 | 25 | 0.038 | 0.45 | 47 |
| 2 | 0.02 | 0.05 | 60 | 0.2 | 34 | 0.046 | 0.42 | 49 |
| 3 | 0.02 | 0.05 | 90 | 0.4 | 24 | 0.239 | 0.47 | 54 |
| 4 | 0.02 | 0.10 | 30 | 0.2 | 36 | 0.101 | 0.47 | 59 |
| 5 | 0.02 | 0.10 | 60 | 0.4 | 38 | 0.117 | 0.42 | 64 |
| 6 | 0.02 | 0.10 | 90 | 0.1 | 26 | 0.129 | 0.65 | 59 |
| 7 | 0.02 | 0.15 | 30 | 0.4 | 33 | 0.222 | 0.58 | 63 |
| 8 | 0.02 | 0.15 | 60 | 0.1 | 32 | 0.142 | 0.64 | 64 |
| 9 | 0.02 | 0.15 | 90 | 0.2 | 37 | 0.142 | 0.43 | 49 |
| 10 | 0.04 | 0.05 | 30 | 0.1 | 32 | 0.134 | 0.76 | 51 |
| 11 | 0.04 | 0.05 | 60 | 0.2 | 38 | 0.142 | 0.67 | 53 |
| 12 | 0.04 | 0.05 | 90 | 0.4 | 27 | 0.173 | 0.6 | 52 |
| 13 | 0.04 | 0.10 | 30 | 0.2 | 26 | 0.15 | 0.69 | 62 |
| 14 | 0.04 | 0.10 | 60 | 0.4 | 22 | 0.141 | 0.61 | 59 |
| 15 | 0.04 | 0.10 | 90 | 0.1 | 33 | 0.16 | 0.79 | 69 |
| 16 | 0.04 | 0.15 | 30 | 0.4 | 24 | 0.202 | 0.57 | 76 |
| 17 | 0.04 | 0.15 | 60 | 0.1 | 38 | 0.229 | 0.81 | 72 |
| 18 | 0.04 | 0.15 | 90 | 0.2 | 27 | 0.163 | 0.71 | 52 |
| 19 | 0.06 | 0.05 | 30 | 0.1 | 30 | 0.288 | 0.97 | 57 |
| 20 | 0.06 | 0.05 | 60 | 0.2 | 25 | 0.266 | 0.82 | 63 |
| 21 | 0.06 | 0.05 | 90 | 0.4 | 27 | 0.27 | 0.68 | 68 |
| 22 | 0.06 | 0.10 | 30 | 0.2 | 30 | 0.221 | 0.87 | 69 |
| 23 | 0.06 | 0.10 | 60 | 0.4 | 21 | 0.231 | 0.57 | 77 |
| 24 | 0.06 | 0.10 | 90 | 0.1 | 34 | 0.15 | 1.12 | 76 |
| 25 | 0.06 | 0.15 | 30 | 0.4 | 27 | 0.19 | 0.69 | 83 |
| 26 | 0.06 | 0.15 | 60 | 0.1 | 35 | 0.022 | 1.19 | 82 |
| 27 | 0.06 | 0.15 | 90 | 0.2 | 33 | 0.283 | 0.89 | 48 |

Table 2 Experimental layout using an L27 orthogonal array

## 4. Grey analysis

In the grey relational analysis, data preprocessing is first performed in order to normalize the raw data for analysis. In this study, a linear normalization of the experimental results for cutting force, chip morphology ,surface roughness and the tool wear ratio shown in Table 3 were performed in the range between zero and one, which is also called the grey relational generating.[9] The normalized experimental results Xij can be expressed as:

$$x_{ij} = \frac{y_{ij} - \min\limits_{j} y_{ij}}{\max\limits_{j} y_{ij} - \min\limits_{j} y_{ij}} \qquad \text{……….. (1)}$$

Yij for the ith experimental results in the jth experiment. Basically, the larger the normalized results correspond to the better performance and the best-normalized results should be equal to one.

Table 4 shows the normalized results for chip morphology, surface roughness,cutting force and tool wear ratio. Basically, the larger normalized result corresponds to the better performance and the best-normalized results should be equal to one. Fig. 2. Next, the grey relational coefficient is calculated to express the relationship between the ideal and the actual normalized experimental results.[10]The grey relational coefficient ξij can be expressed as:

$$\xi_{ij} = \frac{\min\limits_{i}\min\limits_{j}\left|x_i^o - x_{ij}\right| + \xi \max\limits_{i}\max\limits_{j}\left|x_i^o - x_{ij}\right|}{\left|x_i^o - x_{ij}\right| + \xi \max\limits_{i}\max\limits_{j}\left|x_i^o - x_{ij}\right|} \qquad \text{……… (2)}$$

Where xi0 is the ideal normalized results for the ith performance characteristics and ξ is the distinguishing coefficient which is defined in the range $0 \le \xi \le 1$. Next, the grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results.

Then, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristics. [11]The overall evaluation of the multiple performance characteristics is based on the grey relational grade, that is:

$$\gamma_j = \frac{1}{m}\sum_{i=1}^{m} \xi_{ij} \qquad \text{……… (3)}$$

Where γj is the grey relational grade for the jth experiment and m is the number of performance characteristics.

Table 5 shows the grey relational grade for each experiment using the L27orthogonal array. The higher grey relational grade represents that the corresponding experimental result is closer to the ideals normalized value. Experiment 1 has the best multiple performance characteristics among 27 experiments because it has the highest grey relational grade. In other words, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade. Fig. 3. Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels.[12-14] For example, the mean of the grey relational grade for the workpiece polarity at levels 1 and 2 can be calculated by averaging the grey relational grade for the experiments 1 to 9 and 10 to 27, respectively. Grey relational analysis for the experimental results chip morphology, cutting forces cutting temperature, surface roughness, and tool waer.[15]

The mean of the grey relational grade for each level of the other machining parameters can be computed in the similar manner. Fig. 4 shows the grey relational grade graph and the dash line indicated in is the value of the total mean of grey relational grade. Basically, the larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known so that the optimal combinations of the machining parameter levels can be determined more accurately. [16] Table 4 shows Grey relational analysis of the experimental results for cutting forces cutting temperature, surface roughness, and tool wear.

Where :Grey Relational Coefficient GC;SR Surface Roughness; CT Cutting Temperature; CF Cutting Forces; TW Tool Wear;

| Exp. Run | Feed rate | Depth of cut | Cutting speed | Nose radius | GC CF | GC TW | GC SR | GC CT |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.02 | 0.05 | 30 | 0.1 | 0.685 | 0.892 | 0.927 | 1 |
| 2 | 0.02 | 0.05 | 60 | 0.2 | 0.395 | 0.847 | 1 | 0.9 |
| 3 | 0.02 | 0.05 | 90 | 0.4 | 0.739 | 0.38 | 0.885 | 0.72 |
| 4 | 0.02 | 0.1 | 30 | 0.2 | 0.361 | 0.627 | 0.885 | 0.6 |
| 5 | 0.02 | 0.1 | 60 | 0.4 | 0.333 | 0.583 | 1 | 0.514 |
| 6 | 0.02 | 0.1 | 90 | 0.1 | 0.629 | 0.554 | 0.626 | 0.6 |
| 7 | 0.02 | 0.15 | 30 | 0.4 | 0.414 | 0.399 | 0.706 | 0.529 |
| 8 | 0.02 | 0.15 | 60 | 0.1 | 0.435 | 0.525 | 0.636 | 0.514 |
| 9 | 0.02 | 0.15 | 90 | 0.2 | 0.346 | 0.525 | 0.974 | 0.9 |
| 10 | 0.04 | 0.05 | 30 | 0.1 | 0.435 | 0.542 | 0.531 | 0.818 |
| 11 | 0.04 | 0.05 | 60 | 0.2 | 0.333 | 0.525 | 0.606 | 0.75 |
| 12 | 0.04 | 0.05 | 90 | 0.4 | 0.586 | 0.468 | 0.681 | 0.782 |
| 13 | 0.04 | 0.1 | 30 | 0.2 | 0.629 | 0.509 | 0.587 | 0.545 |
| 14 | 0.04 | 0.1 | 60 | 0.4 | 0.894 | 0.527 | 0.669 | 0.6 |
| 15 | 0.04 | 0.1 | 90 | 0.1 | 0.414 | 0.490 | 0.509 | 0.45 |
| 16 | 0.04 | 0.15 | 30 | 0.4 | 0.739 | 0.424 | 0.719 | 0.382 |
| 17 | 0.04 | 0.15 | 60 | 0.1 | 0.333 | 0.391 | 0.496 | 0.418 |
| 18 | 0.04 | 0.15 | 90 | 0.2 | 0.586 | 0.485 | 0.570 | 0.782 |
| 19 | 0.06 | 0.05 | 30 | 0.1 | 0.485 | 0.333 | 0.411 | 0.642 |
| 20 | 0.06 | 0.05 | 60 | 0.2 | 0.684 | 0.352 | 0.490 | 0.529 |
| 21 | 0.06 | 0.05 | 90 | 0.4 | 0.586 | 0.349 | 0.596 | 0.461 |
| 22 | 0.06 | 0.1 | 30 | 0.2 | 0.485 | 0.400 | 0.461 | 0.45 |
| 23 | 0.06 | 0.1 | 60 | 0.4 | 1 | 0.388 | 0.719 | 0.375 |
| 24 | 0.06 | 0.1 | 90 | 0.1 | 0.395 | 0.509 | 0.354 | 0.382 |
| 25 | 0.06 | 0.15 | 30 | 0.4 | 0.586 | 0.434 | 0.587 | 0.333 |
| 26 | 0.06 | 0.15 | 60 | 0.1 | 0.377 | 1 | 0.333 | 0.339 |
| 27 | 0.06 | 0.15 | 90 | 0.2 | 0.414 | 0.337 | 0.450 | 0.947 |

Table 3 Data preprocessing of the experimental result for each performance characteristic Grey Coefficient

| Exp. Run | Feed rate | Depth of cut | Cutting speed | Nose radius | Normalized CF | Normalized TW | Normalized SR | Normalized CT |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.02 | 0.05 | 30 | 0.1 | 0.764 | 0.939 | 0.96 | 1 |
| 2 | 0.02 | 0.05 | 60 | 0.2 | 0.235 | 0.909 | 1 | 0.944 |
| 3 | 0.02 | 0.05 | 90 | 0.4 | 0.823 | 0.184 | 0.935 | 0.805 |
| 4 | 0.02 | 0.1 | 30 | 0.2 | 0.117 | 0.703 | 0.935 | 0.666 |
| 5 | 0.02 | 0.1 | 60 | 0.4 | 0 | 0.642 | 1 | 0.527 |
| 6 | 0.02 | 0.1 | 90 | 0.1 | 0.705 | 0.597 | 0.701 | 0.666 |
| 7 | 0.02 | 0.15 | 30 | 0.4 | 0.294 | 0.248 | 0.792 | 0.555 |
| 8 | 0.02 | 0.15 | 60 | 0.1 | 0.352 | 0.548 | 0.714 | 0.527 |
| 9 | 0.02 | 0.15 | 90 | 0.2 | 0.058 | 0.548 | 0.987 | 0.944 |
| 10 | 0.04 | 0.05 | 30 | 0.1 | 0.352 | 0.578 | 0.558 | 0.888 |
| 11 | 0.04 | 0.05 | 60 | 0.2 | 0 | 0.548 | 0.675 | 0.833 |
| 12 | 0.04 | 0.05 | 90 | 0.4 | 0.647 | 0.432 | 0.766 | 0.861 |
| 13 | 0.04 | 0.1 | 30 | 0.2 | 0.705 | 0.518 | 0.649 | 0.583 |
| 14 | 0.04 | 0.1 | 60 | 0.4 | 0.941 | 0.552 | 0.753 | 0.666 |
| 15 | 0.04 | 0.1 | 90 | 0.1 | 0.294 | 0.481 | 0.519 | 0.388 |
| 16 | 0.04 | 0.15 | 30 | 0.4 | 0.823 | 0.323 | 0.805 | 0.194 |
| 17 | 0.04 | 0.15 | 60 | 0.1 | 0 | 0.221 | 0.493 | 0.305 |
| 18 | 0.04 | 0.15 | 90 | 0.2 | 0.647 | 0.469 | 0.623 | 0.861 |
| 19 | 0.06 | 0.05 | 30 | 0.1 | 0.470 | 0 | 0.285 | 0.722 |
| 20 | 0.06 | 0.05 | 60 | 0.2 | 0.764 | 0.082 | 0.480 | 0.555 |
| 21 | 0.06 | 0.05 | 90 | 0.4 | 0.647 | 0.067 | 0.662 | 0.416 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **22** | **0.06** | **0.1** | **30** | **0.2** | **0.470** | **0.251** | **0.415** | **0.388** |
| **23** | **0.06** | **0.1** | **60** | **0.4** | **1** | **0.214** | **0.805** | **0.166** |
| **24** | **0.06** | **0.1** | **90** | **0.1** | **0.235** | **0.518** | **0.090** | **0.194** |
| **25** | **0.06** | **0.15** | **30** | **0.4** | **0.647** | **0.349** | **0.649** | **0** |
| **26** | **0.06** | **0.15** | **60** | **0.1** | **0.176** | **1** | **0** | **0.027** |
| **27** | **0.06** | **0.15** | **90** | **0.2** | **0.294** | **0.018** | **0.389** | **0.972** |

Table 4 Grey relational analysis for the experimental results, for cutting forces cutting temperature, surface roughness, and tool wear

### 4.1. Analysis of variance

Analysis of Variance (ANOVA) is a method of apportioning variability of an output to various inputs. Table - 5 shows the results of ANOVA analysis. The purpose of the analysis of variance is to investigate which machining parameters significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, in contributions by each machining parameter and the error. [17] First, the total sum of the squared deviations SST from the total mean of the grey relational grade γm can be calculated as:

$$SS_T = \sum_{j=1}^{p} (\gamma_j - \gamma_m)^2 \qquad \text{.........} \ (4)\text{S}$$

Where p is the number of experiments in the orthogonal array and γj is the mean grey relational grade for the j th experiment.

The total sum of the squared deviations SST is decomposed into two sources: the sum of the squared deviations ceased due to each machining parameter and its interaction effects and the sum of the squared error SSe . The percentage contribution of each of the machining parameters in the total sum of the squared deviations SST can be used to evaluate the importance of the machining parameter change on the performance characteristic. In addition, the Fisher's F- test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, the change of the machining parameters has a significant effect on performance characteristic when F is large. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error. First, the total sum of the squared deviations SST from the total mean of the grey relational grade gm can be calculated as: [18]

### 4.4 Response Table for Means

| Level | Feed rate | D OC | Cutting Speed | Nose radius |
|---|---|---|---|---|
| 1 | 0.6135 | 0.6034 | 0.5549 | 0.5457 |
| 2 | 0.5511 | 0.5380 | 0.5461 | 0.5765 |
| 3 | 0.5066 | 0.5298 | 0.5701 | 0.5491 |
| Delta | 0.1069 | 0.0736 | 0.0240 | 0.0308 |
| Rank | 1 | 2 | 4 | 3 |

Main Effects Plot (data means) for Means

Analysis of Variance for grey grade, using Adjusted SS for Tests

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Feed rate | 2 | 0.051912 | 0.051912 | 0.025956 | 4.24 | 0.031 |
| Depth of cut | 2 | 0.029298 | 0.029298 | 0.014649 | 2.39 | 0.120 |
| Cutting speed | 2 | 0.002655 | 0.002655 | 0.001327 | 0.22 | 0.807 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Nose radius | 2 | 0.005140 | 0.005140 | 0.002570 | 0.42 | 0.663 |
| Error | 18 | 0.110177 | 0.110177 | 0.006121 | | |
| Total | 26 | 0.199182 | | | | |

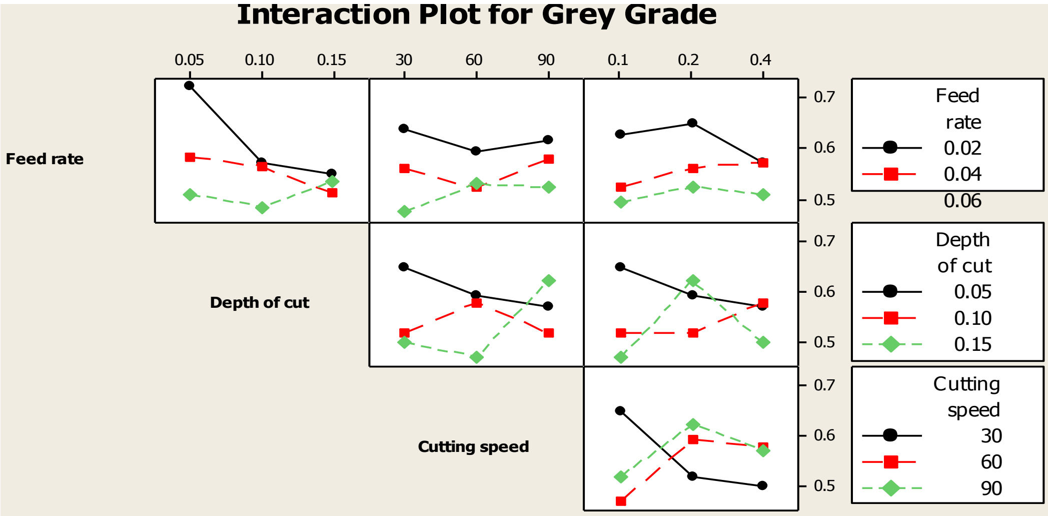


Fig.2. Interaction plot for gray grade

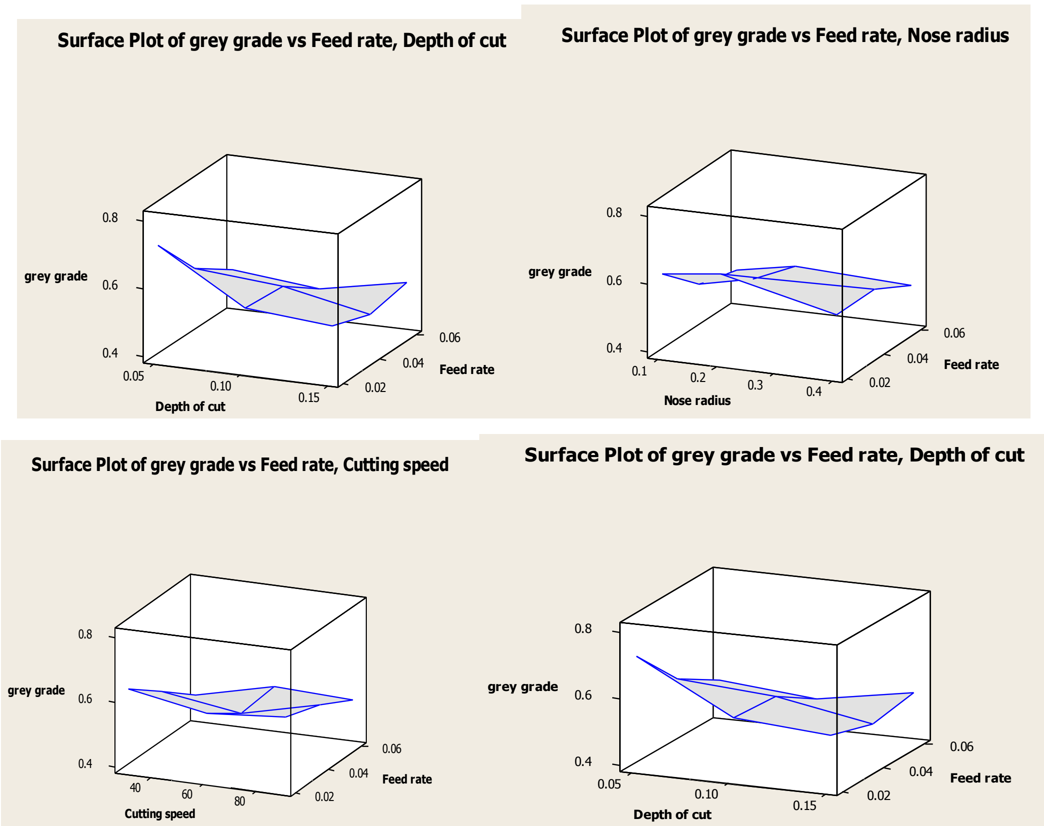


Fig. 3. Surface Plot of grade vs Feed rate, cutting speed, Depth of cut, and Nose radius

| Sl.N0 | GRADE | Rank | 11 | 0.5450 | 14 | 21 | 0.4940 | 22 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.8076 | 1 | 12 | 0.5847 | 9 | 22 | 0.4352 | 26 |
| 2 | 0.7266 | 2 | 13 | 0.5346 | 16 | 23 | 0.5729 | 12 |
| 3 | 0.6316 | 4 | 14 | 0.6076 | 7 | 24 | 0.4371 | 25 |
| 4 | 0.5809 | 10 | 15 | 0.5450 | 15 | 25 | 0.4550 | 24 |
| 5 | 0.5548 | 13 | 16 | 0.5211 | 18 | 26 | 0.5103 | 20 |
| 6 | 0.5738 | 11 | 17 | 0.4047 | 27 | 27 | 0.6299 | 5 |
| 7 | 0.5196 | 19 | 18 | 0.6005 | 8 | | | |
| 8 | 0.4921 | 23 | 19 | 0.5236 | 17 | | | |
| 9 | 0.6343 | 3 | 20 | 0.5010 | 21 | | | |
| 10 | 0.6164 | 6 | | | | | | |

Table 5 Grey relational grade for each experimental

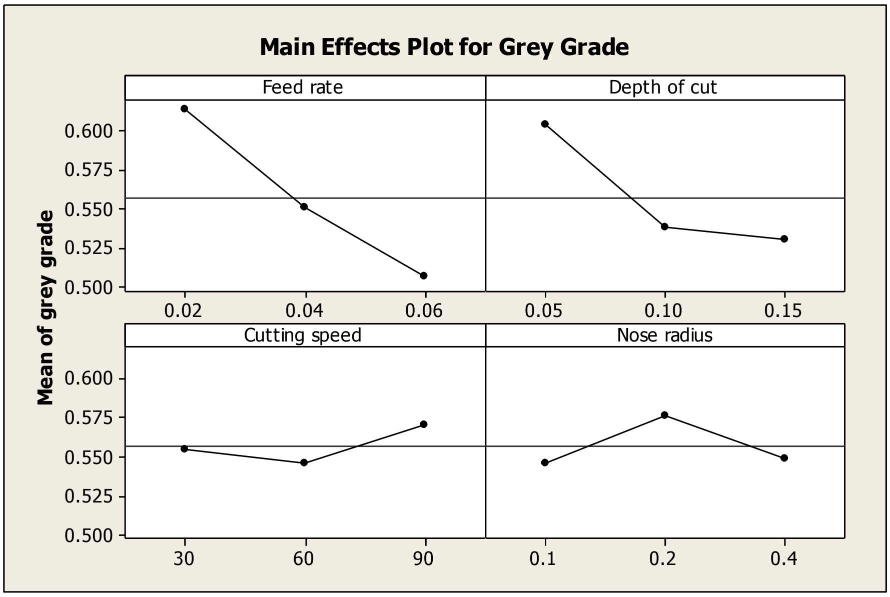


Fig. 4 Main effects plot for Grey grade

The total sum of the squared deviations SST is decomposed into two sources: the sum of the squared deviations SSd due to each machining parameter and the sum of the squared error SSe. The percentage contribution by each of the machining parameters in the total sum of the squared deviations SST can be used to evaluate the importance of the machining parameter change on the performance characteristic.[19]

In addition, the Fisher's F tester can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, the change of the machining parameter has a significant effect on the performance characteristic when $F$ is large. Results of analysis of variance indicate that workpiece polarity is the most significant machining parameter for affecting the multiple performance characteristics.

## 5. Conclusion

The use of the orthogonal array with grey relational analysis to optimize the precision turining process with the multiple performance characteristics has been reported in this paper. A gray relational analysis of the experimental results of cutting forces cutting temperature, surface roughness, and tool wear can convert optimization of the multiple performance characteristics into optimization of a single performance characteristic called the grey relational grade. It has found that the optimization of cutting paprmeter used in the fist and secand experimental trial resulted as a opimuam values.

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