# TAGUCHI-GREY RELATIONAL BASED MULTI-RESPONSE OPTIMIZATION OF MACHINING PARAMETERS IN TURNING PROCESS OF HCHCR D2

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**Abstract**— Every day scientists are developing new materials and for each new material, we need economical and efficient machining. This work is based on an optimization of turning process by the effects of machining parameters applying Taguchi method and Grey Relational Analysis to improve the quality of manufactured goods, and engineering development of designs for studying variation. HcHCr D-2 steel is used as the work piece material, CNMG120408 insert for carrying out the experimentation to optimize the Surface roughness and Material Removal Rate. Grey relational analyses are applied to determine the suitable selection of machining parameter for turning process. The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete. Besides, it provides an efficient solution to the uncertainty, multi-input and discrete data problem. The main objective of this experimentation is to predict and determine the optimization of surface roughness and metal removal rate under spindle speed, feed and depth of cut.
**Keywords**— Turning, Orthogonal array, Taguchi, Grey relational analysis, Optimization etc.

## I. INTRODUCTION

The engineers manufacturing sector faces a problem of achieving high quality surface finish. It is whiten to achieve high dimensional accuracy, high surface finish with low cost. Surface texture is concerned with the geometric irregularities. The quality of a surface is significantly important factor in estimating the productivity of machine tool and machined parts. The surface roughness of machined parts is a significant effect on some functional attributes of parts, such as, contact causing surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity, coating and resisting fatigue. There are many factors which affect the surface roughness and material removal rate (MRR) i.e. cutting conditions, tool variables and work piece variables [1]. Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behavior of a part [2]. Achieving the desired surface quality is of great importance for the functional behavior of a part. Optimal surface roughness is necessary because of improvement of corrosion resistance, tribology attributes and aesthetic appearance. Selection of optimal cutting parameters is necessary in order to achieve optimal values of surface roughness. Taguchi method is a powerful tool for design of experiments (DOE) which serves as a basis for optimization of various engineering processes. It is an important tool to identify the critical parameters and also predict optimal settings for each process parameter [3]. Grey relational analysis (GRA) utilizes a specific concept of information. It defines situations with no information as black, and those with perfect information as white. In other words, GRA converts a multi-objective optimization problem in to a single objective optimization process [4].

In turning process a cutting tool with a single point cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Turning is the most commonly used as a secondary process to add or refine features on parts that

were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. Parts or components that require turning operation include components that are used in large quantities, such as shafts, axle, piston rod, drill bushes, gear blank, bearings etc. The process is intended to replace or limit traditional grinding operations. Turning can be applied for purely stock removal purpose or finishing purpose [5].

## II. LITERATURE REVIEW

The effects of cutting parameters with coated and uncoated insert on surface roughness are established. The work piece material machined was cold-work tool steel AISI-P20, CNMG 120408 carbide insert employed; insert 1 possesses a coating consisting of a TiCN under layer, an intermediate layer of Al2O3and a TiN outlayer, all deposited by CVD; while insert 2 is PVD coated with a thin TiAlN layer. The result shows that the improvement obtained through the use of higher cutting speeds can be observed clearly when employing CVD coated (TiCN+Al2O3+TiN), lower surface roughness values are achieved when employing PVD coated (TiAlN). Also they concluded that feed rate has the greatest effect on surface roughness. Another factor to consider is cutting speed, increasing cutting speed improves surface quality and cutting depth has no significant effect [6].

An effect of varying machining parameters in turning on surface roughness and material removal rate for +/- 30º filament wound glass fibre reinforced polymers (GFRP) in turning operations using coated tungsten carbide inserts under dry cutting conditions. The result found that the feed rate is the main influencing factor on the surface roughness, followed by depth of cut. Among the interactions, the feed rate and tool nose radius have the effect on Ra. For MRR depth of cut is the main influencing factor, followed by the tool nose radius, while among the interaction effects, the feed rate and depth of cut have the highest effect on MRR [7].

Optimization of machining parameters in turning of EN-31 steel alloy by using tungsten carbide inserts by Taguchi Method. Graph 2.10 shows the S/N response graph for surface roughness. Thus it can be clearly observed that A1B2C1 are the optimal levels of the design parameters for improved surface finish which implies feed rate at low level, depth of cut at medium level and lubricant temperature at low level combination gives the best surface finish within the specified range. In turning for minimum Ra, use of lower feed rate (0.05mm/rev), medium depth of cut (0.4mm) and low lubricant temperature (10°C) i,e, A1B2C1 are recommended to obtain better surface roughness for specific test range. Thus the surface finish is better if cooled lubricant is applied [8].

Investigate the influence of different machining parameters such as cutting speed (  ), feed (f) and depth of cut (t) on different performance measures during dry turning of AISI 304 austenitic stainless steel. ISO P30 grade uncoated cemented carbide inserts was used a cutting tool. L27 orthogonal array design of experiments was adopted with the following machining parameters:   = 25, 35, 45m/min, f=0.1, 0.15, 0.2 mm/rev, t= 1, 1.25, 1.5mm. Three important characteristics of machinability such as material removal rate (MRR), cutting force ($F_c$) and surface roughness ($R_a$) were measured. Attempt was further made to simultaneously optimize the machining parameters using grey relational analysis. The optimal machining parameters are $V_c$ =45 m/min, f =0.1 mm/rev, t =1.25 mm. Result of ANOVA indicates that only speed and feed rate are the significant factors and other factors are not significant. A confirmatory test was done to support the findings and an improvement of 88.78% in GRG was observed [9].

The effect of cutting parameters on turning of AA 6063 T6 aluminium alloy with multiple responses based on orthogonal array with grey relational analysis. Turning test are carried out using uncoated carbide insert under dry cutting condition. The researchers taken turning parameters such as cutting speed, feed rate and depth of cut are optimized considering the multiple responses such as surface roughness, roundness and material removal rate. A grey relational grade (GRG) is determined from the grey analysis. Optimum levels of parameters have been identified based on the values of grey relational grade and then the significant contribution of parameters is determined by ANOVA.

They concluded feed rate is most influencing factor followed by depth of cut. The optimal machining parameters are $V_c$ =119.22 m/min, f= 0.05 mm/rev and t=0.15 mm [10].

Optimization method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieve minimum tool wear, low workpiece surface temperature and maximum MRR. The experimental layout was designed based on the Taguchi's $L_9$ $(3^4)$ orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of cutting parameters on the response variables. The percent contributions of depth of cut (60.85%) and cutting speed (33.24%) in affecting the variation of tool wear are significantly larger as compared to the contribution of the feed (5.70%). The significant parameters for w/p surface temperature were cutting speed and depth of cut with contribution of 41.17% and 34.45% respectively. Although not statistically significant, the feed has a physical influence explaining 21.58% of the total variation. Depth of cut (51.1%) was only found the significant parameter followed by feed (25.5%) on material removal rate (MRR). So the optimal at 250 m/min cutting speed, 1 mm depth of cut and 0.25 mm/rev feed [11].

The study of optimum performance in a turning operation of OHNS using carbide insert CNMG120404 is governed by selecting desired machining parameters. The effect of machining parameters is reflected on temperatures developed in machining. These temperatures developed in machining play an important role in tool wear which results in poor surface finish and can also result in modifications to the properties of workpieces and tool materials. The minimum temperature obtained in this case with the help of optimized cutting parameters (1200 rpm spindle speed, 0.1 mm/rev feed, 0.2 mm depth of cut) is 405.64°C. In case of tool tip temperature, it has been observed that the depth of cut was the most influencing parameter followed by spindle speed and feed. In order to obtain minimum temperature in case of OHNS within work interval considered in this study, one should use low values of depth of cut and spindle speed [12].

An experimental investigation of effects of speed, feed, depth of cut, and nose radius on multiple performance characteristics, namely, surface roughness (Ra) and material removal rate (MRR) during turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool. Taguchi's L8 orthogonal array (OA) is selected for experimental planning. They found that the most significant parameter for surface roughness is feed and followed by nose radius. They also analyzed that the most significant parameter for MRR is DOC and followed by cutting speed [13].

Optimization of machining parameters for surface roughness in CNC Turning by Taguchi method. Medium Carbon Steel (AISI 1045) of Ø: 28 mm, length: 17 mm were used for the turning experiments in the present study. AISI 1045 has a variety of applications in vehicle component parts & machine building industry. Surface roughness is the main quality function in high speed turning of medium carbon steel in dry conditions. An L27 orthogonal array, analysis of variance (ANOVA) and the signal-to-noise (S/N) ratio are used in this study. They concluded that feed rate is the most significant factor affecting surface roughness followed by depth of cut. Cutting speed is the least significant factor affecting surface roughness [14].

### III. EXPERIMENTAL DETAILS

Taguchi method is used to get more accurate results and the dependency of the process outputs not only on the individual parameters but also on their all possible combinations; we followed $L_9$ orthogonal array design. In this paper the considered process parameters are speed, feed rate and depth of cut. And we are optimizing the values of MRR and surface roughness. As we need the MRR to be high and surface roughness to be low, so this problem falls under multiple objective optimizations. As mentioned above we have used grey relational analysis to convert this multi objective optimization problem to a single objective optimization.

## A. Workpiece and Cutting Tool

The workpiece used for this experimentation is HcHCr D-2 (High Carbon High Chromium). The chemical composition of this material is shown in Table 1 given below.

Table1: Chemical Composition of HcHCr

| C | Mn | Cr | Ni | Mo | S | P | Si | V | W |
|---|----|----|----|----|----|----|----|----|----|
| 1.67% | 0.52% | 11.41% | 0.29% | 0.03% | 0.03% | 0.023% | 0.39% | 0.04% | 0.02% |

The hardness of HcHCr is 179 BHN. The insert used for this study is manufactured by WIDIA. The insert used was CNMG120404. It is carbide based cutting tool. It is excellent for machining most steels, stainless steels, non ferrous materials and super alloys under suitable conditions. The code CNMG120408 indicates that, it is having a cutting edge length of 12 mm with a thickness of 4 mm and cutting point radius of 0.8 mm. The insert was placed on a right-hand tool holder with a designation of PCLNL2020K1219A.

## B. Machining Parameters and Their Levels

The machining parameters used for this study are spindle speed, feed rate and depth of cut. Taguchi's L9 Orthogonal Array is used for experimentation. The levels selected are as shown in Table 2.

Table 2: Levels and values of Input parameters

| Parameters | Levels | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Spindle Speed (rpm) | 600 | 1200 | 1800 |
| Feed (mm/rev) | 0.1 | 0.15 | 0.2 |
| Depth of Cut (mm) | 0.4 | 0.6 | 0.8 |

## C. Experimental Planning

Table 3: Experimental Results for $L_9$ Orthogonal Array

| Trial No | Speed (RPM) | Feed (mm/rev) | DOC (mm) | $R_a$ (µm) | MRR (gm) |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0.29 | 0.151 |
| 2 | 1 | 2 | 2 | 0.57 | 0.304 |
| 3 | 1 | 3 | 3 | 0.64 | 0.608 |
| 4 | 2 | 1 | 2 | 0.32 | 0.469 |
| 5 | 2 | 2 | 3 | 0.43 | 0.772 |
| 6 | 2 | 3 | 1 | 0.57 | 0.386 |
| 7 | 3 | 1 | 3 | 0.28 | 0.807 |
| 8 | 3 | 2 | 1 | 0.24 | 0.432 |
| 9 | 3 | 3 | 2 | 0.53 | 0.553 |

## D. Anova

To determine the best suited equation connecting response with input variables, regression technique has been used. Regression coefficient is the measure to indicate how far the established relationship is valid to ensure the values of dependent variables, using the values of independent variables for which readings are not available in the range of minimum and maximum value of independent variables. ANOVA table is used to check the significance of the regression model. The value of R is termed as regression coefficient. The error in the prediction is estimated by the coefficient of determination ($R^2$). The value of $R^2$ is the important criteria to decide validity of

regression model. If this value is 0.80 or more than that, the relationship established by regression model is acceptable. There is difference between predicted and actual value of the response for the same set of independent variables.

## 1. Anova for $R_a$

Analysis of variance technique (ANOVA) is carried with Minitab 16. Table 4 shows the result of Anova for $R_a$. It was observed that, the feed is the most significant parameter followed by the spindle speed. However, the insignificant parameter (DOC) has the least effect in controlling the surface roughness. The regression equation for $R_a$ is

$$Ra = 0.0472 - 0.000103 \ N + 2.80 \ F + 0.158 \ DOC$$

Table 4: ANOVA for Ra

| PREDICTOR | COEFFICIENT | SE COEFFICIENT | T | P |
|---|---|---|---|---|
| CONSTANT | 0.04722 | 0.09464 | 0.50 | 0.639 |
| SPEED | -0.00010278 | 0.00003313 | -3.10 | 0.027 |
| FEED | 2.8000 | 0.3976 | 7.04 | 0.001 |
| DOC | 0.15833 | 0.09940 | 1.59 | 0.172 |
| S = 0.0486941 | | $R^2 = 92.5\%$ | $R^2$ (ADJ.) = 88.0% | |
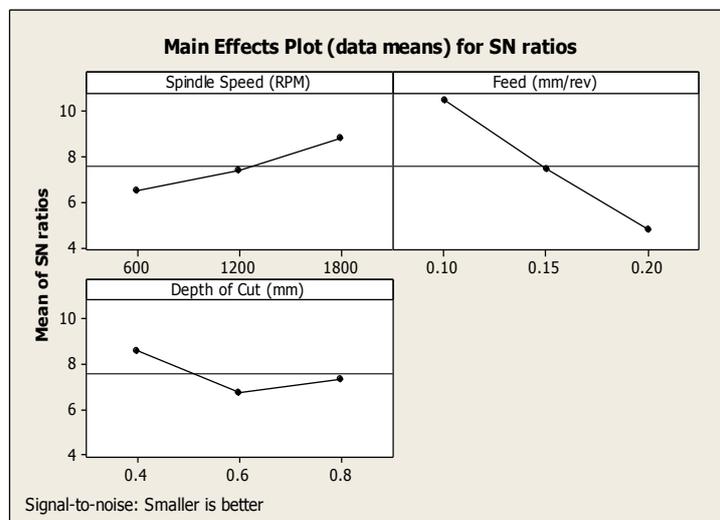


Graph 1: Main effect plot for S/N Ratio (Ra)

As shown in Graph 1 decreasing in surface roughness with increasing feed rate. The surface roughness appears to be an almost linear increasing function of feed. Feed is the dominant factor affecting surface roughness. According to this main effect plot, the conditions for good surface finish are: cutting speed at (600 rpm), feed at (0.20 mm/rev) and depth of cut at (0.6 mm).

## 2. Anova for MRR

Table 5 shows that the significant parameter for the MRR is depth of cut followed by the next largest contribution comes from spindle speed and then feed rate which is not statistically significant. The regression equation for MRR is
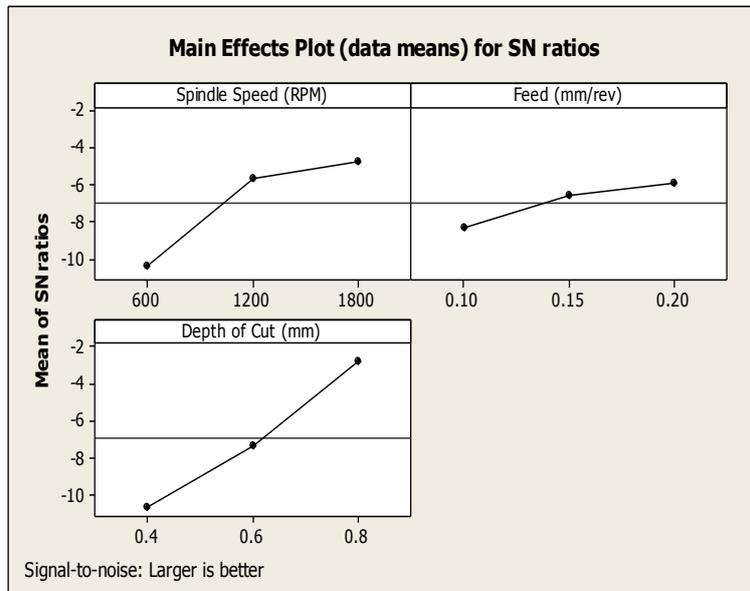
$$MRR = - 0.414 + 0.000202 \ N + 0.400 \ F + 1.02 \ D$$

Table 5: Anova for MRR

| PREDICTOR | COEFFICIENT | SE COEFFICIENT | T | P |
|---|---|---|---|---|
| CONSTANT | -0.4140 | 0.1325 | -3.12 | 0.026 |

| | | | | |
|---|---|---|---|---|
| SPEED | 0.00020250 | 0.00004639 | 4.37 | 0.007 |
| FEED | 0.4000 | 0.5567 | 0.72 | 0.505 |
| DOC | 1.050 | 0.1392 | 7.29 | 0.001 |
| | S=0.0681770 | $R^2 = 93.6\%$ | $R^2$(ADJ.) $= 89.7\%$ | |



Graph 2: Main effect plot for S/N Ratio (MRR)

Main effect plot for S/N Ratio MRR is shown in Graph 2. Based on the analysis using Graph 4.1, high MRR obtained at cutting speed (1800 rpm), depth of cut (0.8 mm) and feed (0.20 mm/rev). So it is concluded that the depth of cut factor has greater influence on metal removal rate of D2 material.

**E. Grey Relational Analysis**

Grey relational analysis (GRA) has been proposed to solve the problem. GRA is a kind of effective tool to make system analysis. GRA analysis is already proved to be simple and accurate method for selecting factors especially for those problems with unique characteristic. Grey relational grade (GRG) can be used to describe the relationships among the factors and to determine the important factors that significantly influence some defined objectives. In Grey relational analysis, experimental data i.e., measured features of quality characteristics are first normalized ranging from zero to one. This 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 higher Grey relational grade. The optimal parametric combination is then evaluated which would result highest Grey relational grade. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal [9]. Table 6 shows the normalization of the S/N ratio, GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio and Grey Relational Grade.

Table 6: Experimental results and GRG

| Exp No | Normalized | | GRC | | GRG |
|---|---|---|---|---|---|
| | MRR | Ra | MRR | Ra | |

| 1 | 0 | 1.0285 | 0.3333 | 1.0606 | 0.6969 |
|---|---|--------|--------|--------|--------|
| 2 | 0.2332 | 0.2 | 0.3947 | 0.3846 | 0.3896 |
| 3 | 0.6966 | 0 | 0.6223 | 0.3333 | 0.4778 |
| 4 | 0.4847 | 0.9142 | 0.4924 | 0.8536 | 0.6730 |
| 5 | 0.9466 | 0.6 | 0.9035 | 0.5555 | 0.7295 |
| 6 | 0.3582 | 0.2 | 0.4379 | 0.3846 | 0.4112 |
| 7 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0.4283 | 0.9428 | 0.4665 | 0.8974 | 0.6820 |
| 9 | 0.6128 | 0.3142 | 0.5635 | 0.4216 | 0.4926 |

Table 7: The Main Effects of the Factors on the Grey Relational Grade
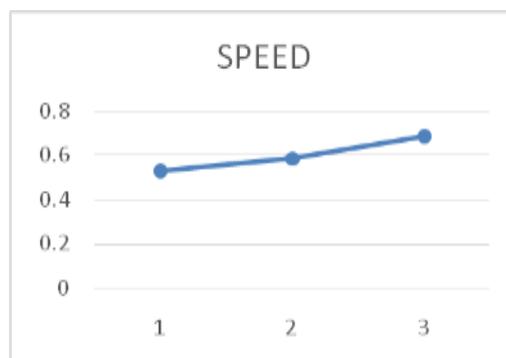
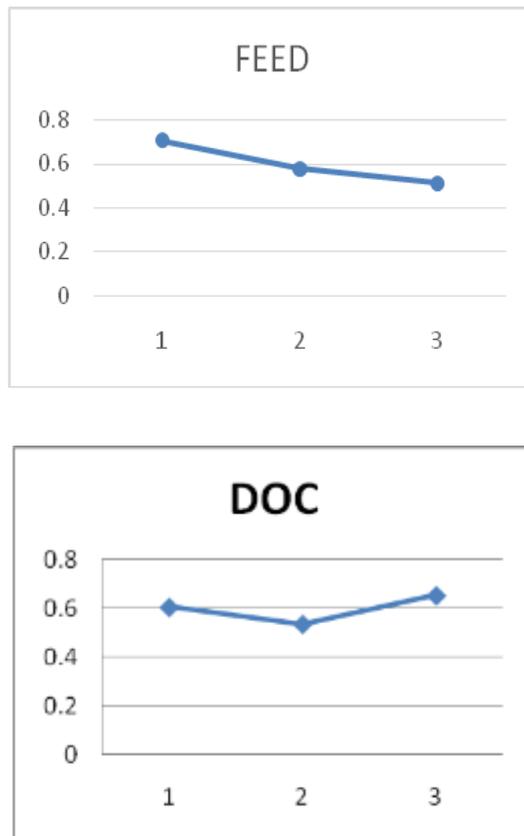| Parameters | Grey Relational Grade | | | Max – Min | Rank |
|------------|---------|---------|---------|-----------|------|
| | Level 1 | Level 2 | Level 3 | | |
| SPEED [A] | 0.5214 | 0.6046 | 0.7248 | 0.2034 | 3 |
| FEED [B] | 0.7900 | 0.6004 | 0.4605 | 0.3294 | 1 |
| DOC [C] | 0.5967 | 0.5184 | 0.7358 | 0.2174 | 2 |

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. From Table 7, the optimal parameter combination can be determined as A3 (Speed, 1800 rpm), B1 (Feed, 0.1 mm/rev) and C3 (DOC, 0.8mm).

From graph 3 (a) it is observed that, surface roughness increases with increasing cutting speed. This can be explained by the reason that, surface roughness continuously increases due to temperature, stress and wear at tool tip temperature. The lubricating characteristics of cutting fluid are helpful in eliminating this.

Graph 3 (b) shows the effect of feed on surface roughness and metal removal rate. Increasing feed rate there may be chances of wear of the tool or in some cases the tool may get break. As increasing feed rate cutting forces increases as it affect on surface roughness. This can be explained by the reason that, surface roughness continuously increases due to temperature, stress and wear at tool tip temperature. At high feed rate the cutting forces, power required for machining is also high.

From graph 3 (c) clearly observed that as depth of cut increases, the surface roughness increases. This can be explained as more area in contact takes place between tool and workpiece, this results in high friction and tool wear leads to high surface roughness.

Graph 3: Grey relational grades for each level of parameters for (a) Speed (b) Feed (c) Depth of cut

## IV. COFIRMATION RESULTS

The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. After determining the optimum level of process parameters, a new experiment is designed and conducted with optimum levels of parameters obtained.

Table 6: Confirmation results

|  | Predicted | Experimental | % Error |
|---|---|---|---|
| MRR (Gram/sec) | 0.805 | 0.824 | 2.30 |
| Ra (µm) | 0.26 | 0.25 | 3.84 |

Confirmatory experiments were performed using the optimum values and it was found that experimental response values were close enough to predicted values. These values and percentage error between actual and predicted values of the responses are given in Table 6. The percentage error between the actual and predicted values of the responses falls below 5%, which shows that the optimized value of process parameters obtained is good enough for achieving the target set during the experiment. The comparison again shows the good agreement between the predicted and the experimental results.

## V. CONCLUSION

The most influencing factor on surface roughness is feed rate. Increasing feed rate causes the chatter marks on surface produced. At higher feed rate there may be chances of wear of the tool or in some cases the tool may get break. As increasing feed rate cutting forces increases as it affect on surface roughness. From the response table of the average grey relational grade, it is found that the largest value of the GRA for the cutting speed of 1800 rpm, the feed rate 0.2 mm/rev and depth of cut 0.8 mm. It is the recommended levels of the controllable parameters for the process of turning as

the minimization of average surface roughness and metal removal rate. The optimal parameters combination was determined as A3B1C3 i.e spindle speed 1800 rpm, feed rate 0.2 mm/rev and depth of cut 0.8 mm. The order of the importance of influencing factors for $R_a$ and MRR based on the Taguchi-GRA response table sequence is feed rate, depth of cut and spindle speed.

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