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# Grey Relational Analysis and Response Surface Methodology for Modeling, Analyzing and Optimization of machining parameters for turning 'Niobium C-103'

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*Abstract:* **The primarily application of Niobium based Super-alloys is in the manufacturing of Space propulsion system due to it's light weight , ability to withstand high stress levels at elevated temperatures and also have a low ductile-to-brittle transition temperature for withstanding high frequency vibrations at cryogenic temperatures. Niobium C-103 is selected due to its excellent fabric ability, high melting point and Corrosion resistance at elevated temperatures. It is important to choose the best machining parameters for achieving optimum performance characteristics. In the present study, an attempt has been made to investigate the effect of cutting parameters (cutting speed, feed rate and depth of cut) on surface roughness and cutting force in finish hard turning experiments of niobium C-103 on Retrofitted VDF lathe using PVD coated Tungsten Carbide insert in Dry conditions. The methodologies used for optimizing the machining parameters are based on the integrated approach of Response Surface Methodology (RSM) and Grey relational Analysis (GRA). RSM is very effective when several inputs affect output response and take lesser time for optimization. In RSM Central composite Design for experiment is used, since it gives a comparatively accurate prediction of all response variables averages. GRA is a technique which converts a multiple response process optimization problem into a single response optimization problem. In GRA Taguchi's L'9 orthogonal array design is used and the relatively significant parameters is determined by Analysis of Variance (ANOVA). The result and conclusion are drawn on the basis of comparison between the two methodologies.*(Abstract)***

***Keywords*:GRA,RSM,ANOVA, Cutting force, Surface roughness, Taguchi's L'9, Optimization.( *Keywords)***

## I. Introduction

In today's rapidly changing era quality of product plays an important role. The term quality in manufacturing relates with surface finish. Surface roughness gives an indication of how finish the component is and influential factor for product performance and cost.It measures the finer irregularities of the surface texture. In turning operation the surface roughness depends on cutting speed, feed rate, depth of cut, tool nose radius, lubrication of the cutting tool, machine vibrations, tool wear and on the mechanical and other properties of the material being machined .Even small changes in any of the mentioned factors may have a significant effect on the produced surface.[**1**]

Cutting force is an indication of the resistance offered by the material during machining which in turn gives a limit of depth up to which tool can be inserted in one pass. The measurement of cutting force helps us in determining the amount of power actually used for cutting. Therefore, it is important to model and quantify the relationship between roughness, Cutting Force and the parameters affecting its value. Statistical design of experiments refers to the process of planning the experiments so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions.In the present approach both the Response Surface Methodology and Grey relational Analysis methodologies are. Ashvin J. Makadia and J.I. Nanavati **[1]** had used Response Surface Methodology for Optimisation of machining parameters for turning operations and generated a model for surface roughness which can predict value with a error of 6% . M. Aruna and V. Dhanalaksmi **[2]** had done Optimization of Cutting Parameters when Turning Inconel 718 with Cermet Inserts with a error range of 4.356-9.032 % for surface roughness.

Grey theory is short for grey system theory; it was proposed in 1982 by Prof. Ju-Long Deng.Grey relational analysis of grey theory is a method to analyze degrees of relationships among discrete sequence data. Upinder kumar and Deepak Narang **[3]**uses Grey Relational Analysis for Optimization of Cutting Parameters in High Speed Turning with error of 4.3% in case of MRR and 4% for surface roughness and it was observed in that study Depth of cut has a major effect on the combined affect of MRR and surface roughness. Bala Murugan Gopalsamy Biswanath Mondal & Sukamal Ghosh **[4]** applied Grey Relational Theory approach and ANOVA for Optimisation of machining parameters for hard machining in which he have taken multiple responses i.e, volume of material removed, surface finish, tool wear and tool life and observed that for rough machining depth of cut and width of cut has main effect while for finish machining cutting speed dominates.

In present study optimization of machining parameters (speed, feed and depth of cut) for Niobium C-103 is done by two methodologies by generating the model through Response Surface Methodology and comparing the result obtained with Grey relational Analysis.

## II. Experimentation

In order to perform experiment 3 level have been taken for input parameters: speed, feed and depth of cut (Table 1) and using Central Composite Design 20 set of experiments are performed which is shown in Table 2. The experiment was performed on retrofitted VDF lathe and measurement of surface roughness and cutting force is done with the help of handy surf and 3-axis dynamometer respectively.

**Table 1** Input parameters and levels

| Parameters | | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| V) | Speed (m/min) | 80 | 85 | 90 |
| F) | Feed (mm/rev) | 0.08 | 0.14 | 0.2 |
| D) | Depth of cut (mm) | 0.1 | 0.2 | 0.3 |

## A. *Response Surface Methodology*

It is a collection of mathematical and statistical techniques for empirical model building.The objective is to optimize a response which is influenced by several independent variables..In order to select a particular model various statistical calculation were done and the analysis of fit summary suggested quadratic model for both surface roughness and cutting force and for model generation multiple regression method is used which is assisted by Design Expert Software.The equation corresponding to quadratic model for surface roughness is 1 and Cutting force is 2 having $R^2$ value of 93.75 % and 88.72 % respectively

$$Ra=-63.8255+(1.6676*V)-(35.6339*+F)-(35.8510*D)+(0.1458*V*F)+(0.3125*V*D)+(25.6250*F*D)-(0.0103*V^2+(78.8262*F^2)+(16.6274*D^2) \quad \ldots\ldots\ldots(1)$$

$$Fz=3815.640-97.265*V+2390.028*F+4109.18*D+8.292*V*F-56.975*V*D-7802.083*F*D+0.594*V^2-12038.344*F^2+6621.196*D^2 \quad \ldots\ldots(2)$$

**Table2** Input parameters and output response

| Run | V (m/min) | F (mm/rev) | D (mm) | Ra (µm) | Fz (N) |
|---|---|---|---|---|---|
| 1 | 80 | 0.08 | 0.1 | 1.3 | 104.2 |
| 2 | 90 | 0.2 | 0.1 | 1.01 | 205.4 |
| 3 | 85 | 0.14 | 0.2 | 1.06 | 195.4 |
| 4 | 90 | 0.08 | 0.3 | 1.01 | 307.2 |
| 5 | 90 | 0.08 | 0.1 | 0.8 | 90.4 |
| 6 | 85 | 0.14 | 0.2 | 1 | 168.7 |
| 7 | 80 | 0.2 | 0.1 | 1.3 | 146.8 |
| 8 | 85 | 0.14 | 0.2 | 1.1 | 171.4 |
| 9 | 80 | 0.2 | 0.3 | 1.5 | 290.3 |
| 10 | 85 | 0.14 | 0.2 | 0.96 | 173.2 |
| 11 | 80 | 0.08 | 0.3 | 0.85 | 396.5 |
| 12 | 90 | 0.2 | 0.3 | 1.8 | 196.5 |
| 13 | 85 | 0.14 | 0.2 | 0.72 | 175.4 |
| 14 | 85 | 0.2 | 0.2 | 1.6 | 114.3 |
| 15 | 80 | 0.14 | 0.2 | 0.75 | 207.24 |
| 16 | 85 | 0.08 | 0.2 | 0.875 | 136.8 |
| 17 | 85 | 0.14 | 0.1 | 1.02 | 145.7 |
| 18 | 90 | 0.14 | 0.2 | 0.64 | 160.24 |
| 19 | 85 | 0.14 | 0.2 | 0.92 | 186.5 |
| 20 | 85 | 0.14 | 0.3 | 1.22 | 324.5 |

# 1. Result

Anova is used to investigate and model the relationship between a response variable and input parameters. The Anova table for surface roughness and cutting force is shown in table 3 and 4 it can be observed that in case of surface roughness feed has major effect while it is Depth of cut in the case of Cutting Force

## a) *Confirmation Runs*

To verify the robustness of the model developed three confirmation runs are carried out. The values taken for the experiments are within the range of previously defined levels and output response is measured and compared with the predicted value of output response which is shown in Table 5 and it can be noted that error obtain is within permissible limits so RSM model obtain for surface roughness and cutting force is significant and can be useful for predicting the values

**Fig. 1** Experimental Set-up

**Table 3** Anova table for surface roughness

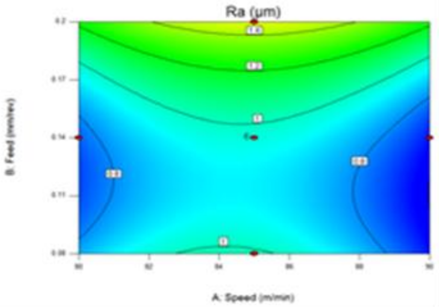



**Fig. 2**Surface Roughness Contour

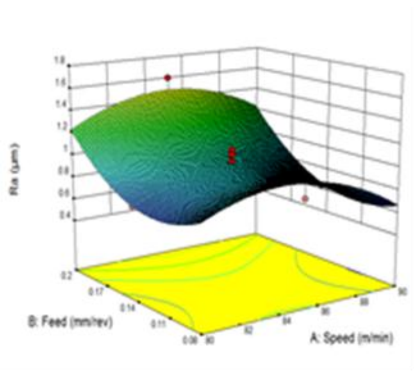



**Fig. 3** Surface Roughness 3D Surface

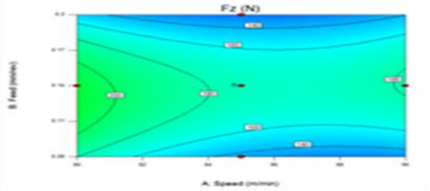


**Fig4** Cutting Force Contour

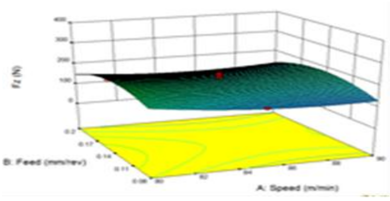


**Fig5** Cutting Force 3D Surface

**Table3** Confirmation runs

| Sr. | V (m m/m in) | Feed (mm/ rev) | Doc (m m) | Predicted RSM | Experimen tal | Error % |
|---|---|---|---|---|---|---|
| 1 | 80 | .1 | .3 | Ra =0.754 Fz = 404.284 | Ra = 0.788 Fz =426.52 | Ra – 4.6 Fz – 5.5 |
| 2 | 84 | .2 | .2 | Ra = 1.47 Fz =124.89 | Ra = 1.56 Fz = 131.63 | Ra – 6.1 Fz – 5.4 |
| 3 | 88 | .08 | .1 | Ra =0.99 Fz =81.450 | Ra = 0.953 Fz = 84.22 | Ra – 5.8 Fz – 3.4 |

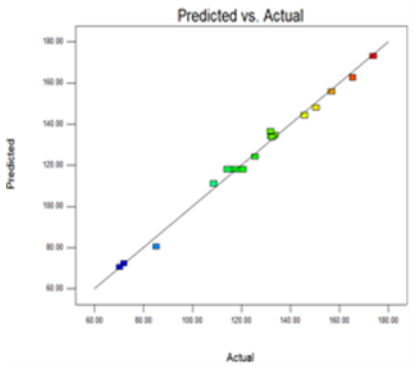



**Fig.6** plot for predicted vs actual value for Surface

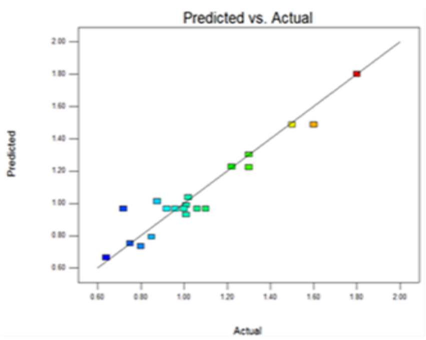



**Fig.7** plot for predicted vs actual value for Cutting Force

### B. *Grey Relational Analysis*

GRA is a stepwise procedure that lead to optimization. The first step is Grey Relational Generation in which the output response are first normalized, ranging from zero to one. Based on this above obtained value grey relational coefficient is calculated in next step in order to find out interaction between actual and desired experiment value. Third step is the averaging of grey relational coefficient which is designated as Grey relational Grade (GRG).

The GRG calculation is the ultimate step of GRA which signifies it's approach of converting a multiple response process optimization problem into a single response optimization problem and is used in determining the optimal combination of parameters which is generally the one with higher GRG value. Taguchi method is used for maximizing Grey Relational grade.In Grey relational generation, the normalized Ra and Cutting Force should follow the smaller-the-better (SB) criterion which can be expressed as:

$$x_i(k) = \frac{max y_i(k) - y_i(k)}{max y_i(k) - min y_i(k)}$$

where, $x_i(k)$ are the value after Grey Relational Generation SB criteria. Max $y_i(k)$ is the largest value of $y_i(k)$ for kth response and min $y_i(k)$ is the minimum value of $y_i(k)$ for the kth response.

The Grey relational coefficient $\xi_i(k)$ can be calculated as:

$$\xi_i = \frac{\Delta_{\min} + \varsigma\ \Delta_{\max}}{\Delta_{oi}(k) + \varsigma\, \Delta_{\max}}$$

and $\Delta o_i(k) = \| x_o(k) - x_i(k) \|$

where $\Delta o_i$ is the difference between absolute value $x_o(k) = 1$ and $x_i(k)$. $\varsigma$ is the distinguishing coefficient $0 \le \varsigma \ge 1$. $\Delta_{min}$ and $\Delta_{max}$ are the minimum and maximum value among the $\Delta o_i$ for corresponding kth response. Now the Grey Relational Grade (GRG) $\gamma_i$ can be calculated as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

where n = number of process responses. The extent of relation between the Reference Sequence $x_o(k)$ and the given sequence $x_i(k)$ is determined by the high value of GRG and the Reference Sequence $x_o(k)$ represents the best process sequence. Therefore the parameter combination having higher GRG value is closer to optimal.

**Table4** GRA calculation

| Sr No. | GRGC (Ra) | GRGC (Fz) | GRCC (Ra) | GRCC (Fz) |
|---|---|---|---|---|
| 1 | 0.250 | 1.000 | 0.400 | 1.000 |
| 2 | 0.938 | 0.532 | 0.889 | 0.517 |
| 3 | 0.000 | 0.155 | 0.333 | 0.372 |
| 4 | 0.781 | 0.852 | 0.696 | 0.772 |
| 5 | 0.350 | 0.000 | 0.435 | 0.333 |
| 6 | 0.475 | 0.876 | 0.488 | 0.801 |
| 7 | 0.613 | 0.079 | 0.563 | 0.352 |
| 8 | 1.000 | 0.948 | 1.000 | 0.905 |
| 9 | .125 | 0.836 | 0.364 | 0.753 |

Where,
GRGC – Grey Relational Generation Calculation
GRCC – Grey Relational Co-efficient Calculation

**Table5** Grey relational Grade Calculation

| Sr no. | GRG | S/N Ratio | Rank |
|---|---|---|---|
| 1 | 0.700 | -4.292 | 4 |
| 2 | 0.703 | -2.918 | 3 |
| 3 | 0.353 | -8.681 | 9 |
| 4 | 0.734 | -2.754 | 2 |
| 5 | 0.384 | -8.312 | 8 |
| 6 | 0.645 | -3.926 | 5 |
| 7 | 0.458 | -6.499 | 7 |
| 8 | 0.953 | 0.000 | 1 |
| 9 | 0.558 | -3.985 | 6 |

**Table6** Response Table for GRG

| Level | Cutting Speed | Feed | Doc |
|---|---|---|---|
| 1 | 0.585 | 0.630 | **0.766** |
| 2 | 0.587 | **0.680** | 0.665 |
| 3 | **0.656** | 0.518 | 0.398 |
| Delta | 0.071 * | 0.162 ** | 0.368 *** |

**Fig.8** Plot for main effect of means of GRG

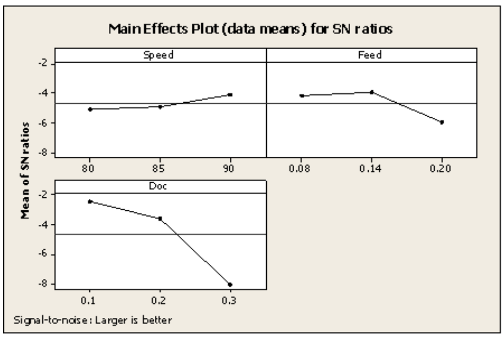
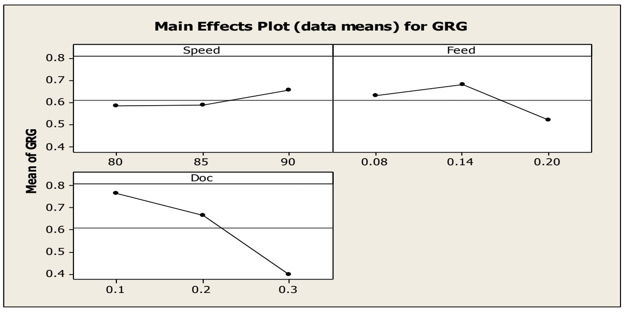



**Fig. 9** Main effect plot for S/N ratio of GRG




## 1. *Result*

From Table 15 and surface plot of GRG means and S/N ratio (Fig. 7 and 8) it can be observed that optimal process combination is V3-F2-D1 which is the one with highest GRG value among experiments.

## *a) Prediction*

The equation is used to calculate the predictive value of GRG, Ra and Fz at optimum levels

$$P = pm + \sum_{i=1}^{n}(pim - pm)$$

Where, P – predicted value of optimized response.

Pm – Total mean value of concerned response

Pim – Mean value of concerned response at optimum level

n – Total no of input parameters that affect response

Applying the equation, Predicted values are:

P(Ra) = 0.772

P(Fz) = 116.353

This predicted values are verified experimentally . For this confirmation runs are taken at optimum parameter combination and result obtained (Table 16) are as follows

**a)For Surface Roughness**

The experimental value is 0.7 and predicted is 0.772 and so the error is 9.3 %

**b)For Cutting Force**

The experimental value is 115.7 and predicted is 116.653 and so the error obtain 1 % is within permissible limit and result is shown in table

**Table 7** Predicted v/s Experimental value at optimal factor combination

| CP | OL | OPV | POV | EOV | Optimal Range |
|---|---|---|---|---|---|
| V | V3 | 90 | Ra = 0.772 | Ra = 0.7 | Ra 0.7-0.772 |
| F | F2 | .14 | | | |
| D | D1 | .1 | Fz = 116.65 | Fz = 115.7 | Fz 115.7 - 116.65 |

where,
CP – Cutting Parameters
OL – Optimum Level
OPV – Optimum Parameter Value

POV – Predicted Optimum Value
EOV – Experimental Optimal value

**Table8** Optimal set of solutions through RSM

| Sr. No. | V | F | D | Ra | Fz | Desira-bility |
|---|---|---|---|---|---|---|
| 1 | 90.000 | 0.080 | 0.143 | 0.665 | 92.107 | 0.986 |
| 2 | 90.000 | 0.080 | 0.144 | 0.664 | 92.341 | 0.986 |
| 3 | 90.000 | 0.080 | 0.140 | 0.668 | 91.516 | 0.986 |
| 4 | 90.000 | 0.081 | 0.143 | 0.661 | 93.433 | 0.986 |
| 5 | 90.000 | 0.081 | 0.141 | 0.663 | 92.897 | 0.986 |
| 6 | 90.000 | 0.081 | 0.142 | 0.660 | 93.657 | 0.986 |
| 7 | 90.000 | 0.081 | 0.142 | 0.658 | 94.395 | 0.986 |
| 8 | 90.000 | 0.083 | 0.144 | 0.646 | 98.058 | 0.985 |
| 9 | 90.000 | 0.084 | 0.145 | 0.640 | 99.894 | 0.984 |
| 10 | 80.000 | 0.103 | 0.154 | 0.847 | 152.391 | 0.809 |

Table 17 shows the optimal set of solutions suggested by RSM for getting minimum Surface Roughness (Ra), Cutting Force (Fz) and Cutting Temperature (CT).

## *III. Conclusion and Comparison*

In this paper the optimization of machining parameters for turning Niobium C-103 is done through two methodologies. In RSM the quadratic model is suggested and has been developed for all the three output response in order to investigate the influence of machining parameters. The Anova is used for finding the relative effect of input parameters on response. Response surface contours are used in predicting the values in RSM while 3D surface counter plots are useful in determining the optimum condition to obtain particular values of output response and plot for main effect of responses are used for getting the optimal sequence in GRA. In GRA the results are verified using Taguchi S/N ratio which was lower the better for all three responses. The error pertaining to the predicted versus actual value through RSM is slightly lesser with the one with GRA and also RSM can explore the optimal space better. Design Expert 9 and Minitab 16 are used for statistical calculation and for generating plots. The following conclusion can be inferred:

a)It was found that after applying ANOVA in the case of both Central Composite Design as well as Taguchi L'9 design Feed is dominant factor in the case of surface roughness and Depth of cut in case of cutting force

b) The output response at optimal process combination incur through RSM are in resemblance with the one obtained through GRA

c) It can also be conclude that RSM has some edge over GRA in exploring the optimal search space.d) The error obtained with RSM and GRA is within permissible limit which means that the model developed can be effectively used for predicting the values.

## *IV.* References

[1] Ashvin J. Makadia and J.I. Nanavati ,Optimisation of machining parameters for turning operations based on response surface methodology, Journal of measurement , Elsevier ,SciVerse Science Direct – Vol. 46(2013), Pp 1521-1529

[2]M. Aruna and V. Dhanalaksmi, Design Optimization of Cutting Parameters when Turning Inconel 718 with Cermet Inserts, World Academy of Science, Engineering and Technology 61 (2012), Pp. 952-955

[3]Upinderkumar and Deepak Narang , Optimization of Cutting Parameters in High Speed Turning by Grey Relational Analysis, International Journal of Engineering Research and Applications (IJERA), Vol. 3( 2013), pp.832-839

[4]Bala Murugan Gopalsamy ,Biswanath Mondal and Sukamal Ghosh , Optimisation of machining parameters for hard machining grey relational theory approach and ANOVA , Int J Adv Manuf Technol (2009) Vol.45 , Pp.1068–1086

[5] Vikas B. Magdum and Vinayak R. Naik ,Evaluation and Optimization of Machining Parameter for turning of EN 8 steel, International Journal of Engineering Trends and Technology (IJETT) – Vol. 4 ( 2013), Pp. 1564-1568

[6]Radhakrishnan Ramanujam, Nambi Muthukrishnan and Ramasamy Raju ,optimization of Cutting Parameters for Turning Al-SiC(10p) MMC Using ANOVA and Grey Relational Analysis , International Journal Of Precision Engineering And Manufacturing Vol. 12 No. 4 (2011) , Pp. 651-656

[7] S.R. Das, R.P. Nayak and D. Dhupal,Optimization of Cutting Parameters on Tool Wear and Work piece Surface Temperature in turning of AISI D2 Steel ,International Journal of Lean Thinking , Vol. 3(2012), Pp. 141-156

[8] Dr. M. K. Pradhan , Optimization of MRR, TWR and surface Roughness of ED Med D2 Steel using an integrated approach of RSM, GRA and Entropy measurement Method , Institute of Electrical and Electronic Engineers,Vol.978-1-4673-6150 , Pp.865-869

[9]Hossein Hasani, Somayeh Akhavan Tabatabaei, Ghafour Amiri, Grey Relational Analysis to determine the optimum process parameters for open-end spinning yarns, Journal of Engineered Fibers and Fabrics, Volume 7, Issue 2 – 2012, Pp. 81-86

[10]Yang, W. H., &Tarng, Y. S. (1998). Design optimization of cutting parameters for turning operations based on the Taguchi method. Journal of Materials Processing Technology, 84, 122-129.

[11]Palanikumar K. and Karunamoorthy L., "Optimization of Machining Parameters in Turning GFRP Composites Using a Carbide (K10) Tool Based on the Taguchi Method with Fuzzy Logics", metals and materials International, Vol. 12, No. 6 (2006), pp. 483-491.

[12]M.Y. Noordin, V.C. Venkatesh, S. Sharif, S. Elting, A. Abdullah, Application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel, J. Mater. Process. Technol. 145 (2004) 46–58.

[13]J.P. Davim, A note on the determination of optimal cutting conditions for surface finish obtained in turning using design of experiments, J. Mater. Process. Technol. 116 (2001) 305–308.

[14]E.D. Kirby, Z. Zhang, J.C. Chen, J. Chen, Optimizing surface finish in a turning operation using the Taguchi parameter design method, Int. J. Adv. Manuf. Technol. 30 (2006) 021–1029. doi 10.1007/s00170-005-0156-0.

[15]N.I. Galanis, D.E. Manolakos, Surface roughness prediction in turning of femoral head, Int. J. Adv. Manuf. Technol. 51 (2010) 79–86.

[16]Lin JL, Tang YS (1998) Optimisation of multi response process by Taguchi method with grey relational analysis. J Grey Syst 10 (4):355–370

[17]Deng J (1989) Introduction grey system. J Grey Syst 1:1–24

[18]D.I. Lalwani, N.K. Mehta, P.K. Jain, Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel, J. Mater. Process. Technol. 206 (2008) 167–17