Proceedings in Manufacturing Systems, Volume 11, Issue 1, 2016, 9–14 ISSN 2067-9238

# OPTIMIZATION OF PROCESS PARAMETERS OF SURFACE GRINDING OPERATION USING TAGUCHI BASED GREY RELATION ANALYSIS

**Prashant J. Patil**[1,*], **Chandrakant R. Patil**[2]

[1] Eng, Principal, Abhinav Education Society's COET(P) Pune, India
[2] Prof. in Mech. Dept, Ram Meghe College of Engg. and Management, Amravati, India

***Abstract:*** *Heat produced during the grinding process is always critical in terms of workpiece quality. Effective cooling and lubrication is necessary to control temperature levels. Traditional cooling system has negative impact in terms of cost of recycling and health hazard to machine operator. Most successful fluid reduction method employed in grinding is minimum quantity lubrication (MQL). This study aims for multi objective optimization of MQL grinding process parameters using Grey relational analysis. Water based* $Al_2O_3$ *and CuO nanofluids of various concentrations are used as lubricant for MQL system. Experiments were performed using L27 orthogonal array on instrumented surface grinding machine as per Taguchi's method. The process parameters that considered for optimization are feed rate, depth of cut, type of lubricant, grinding wheel speed, coolant flow rate, and nanoparticle size. Grinding performance is measured in terms of cutting force and temperature of grinding zone. Analysis of variance (ANOVA) has been used to identify most significant factor of the process.*

***Key words:*** *CuO,* $Al_2O_3$ *nanofluids, MQL surface grinding, tangential force, effective thermal conductivity*

## 1. INTRODUCTION

Grinding is a surface finishing process which has ability to obtain close tolerance, good surface finish. Compared to other machining processes the main characteristics of grinding process is high specific energy in material removal due to large contact area between tool and workpiece. This causes extreme high temperature at the interface of grinding wheel and workpiece. High temperature in grinding zone leads to thermal damage to work piece in the form of work piece burn, phase transformation, undesirable residual stress, cracks, and reduced fatigue strength [1]. Effective cooling and lubrication is required to reduce high temperature effects. Grinding coolant plays important role in grinding process. Role of coolant is to lubricate grinding area, transport the chips, and reduce thermal damage of work piece. Many researchers had studied cooling and lubrication of grinding process. Conventional cooling system utilizes large amount of coolant 5400 ml/hr. This system creates unhealthy working environment. Additionally the cost of recycling is very high and constitutes major part of machining cost. Grinding fluid reduction is achieved by two trends one is dry grinding and another is minimum quantity lubrication. Dry grinding process creates thermal damage to the work piece. Therefore MQL system is sound alternative for traditional flood and dry grinding. MQL system integrates advantages of flood and dry grinding [2]. Flow rate of coolant in MQL is in the range of 10–100 ml/hr which is very less compared to wet grinding [3]. In MQL system function of lubrication is provided by high thermal conductive nanofluids and cooling function is achieved by compressed air. In MQL system water based nanoparticles with compressed air was used as a cooling fluid. A nanoparticle is having high surface area to volume ratio so that its heat carrying capacity is increased [4]. Study on MQL performance for grinding application noticed that tangential cutting force and wheel wear rate was reduced in comparison with traditional cooling [5]. Experimental grinding study on cast iron by use of different nanofluids lubricating mixtures gives positive improvement in G ratio, grinding force, surface finish [6]. Cong Mao et al had studied grinding performance for AISI 52100 their team observed that MQL grinding is more environmental friendly and economic [7]. Specific grinding energy for dry, flood and MQL grinding conditions have calculated by Zhang Dongkun et al 2014. They observed Specific grinding energy 84.29 J/mm$^3$ for dry grinding, 45.5 J/mm$^3$ for MQL and 29.8 J/mm$^3$ for flood grinding [8].

Numerous researchers had studied and improved MQL technology for grinding application. But very rare studies are available for optimization of grinding process parameters. For optimization of single performance characteristics problems of manufacturing Taguchi's method is widely accepted. C. C. Tsao et al. had applied Grey relational analysis for the optimization of complicated and uncertain systems [9]. Chang S. H. et al. and Emel Kuram et Alhas concluded that optimization of interrelationship of multiple performance characteristics is effectively achieved by Grey relational analysis [10 and 11]. In Grey relational analysis grade for different performance characteristics is calculated. Grade value decides optimum performance of multiple performance characteristics.

---

[*] Corresponding author: Abhinav Education Society's COET(P) Pune, India
Tel.:+919890905025;
Fax: +9102169286105
E-mail addresses: *pjpatil76@rediffmail.com*

In current study Taguchi based Grey relational analysis is used to optimize MQL grinding process. Different concentration of water based nanoparticles of $Al_2O_3$ and CuO were used as a lubricant for MQL system. The selected process parameters for grinding operation are depth of cut, type of lubricant, grinding wheel speed, coolant flow rate, nanoparticle concentration and nanoparticle size. Grinding performance is measured in terms of cutting force and temperature. Here we are optimizing effect of controlled factors on grinding performance.

## 2. EXPERIMENTATION AND MEASUREMENTS

Instrumented grinding machine is used for conduction of grinding experiments. The setup of the grinding machine is shown in Fig. 1 and in Fig. 2. Lubrication for grinding operation is provided by MQL system. A mixture of compressed air and nanofluid is propelled onto the work piece at different flow rates of (5, 10, and 15 ml/min). Average abrasive size grinding wheel is used. Grinding wheel diameter is 150 mm and width is 14 mm. The work material is prepared from EN24 flat plate of 80 mm length and 8 mm width.

Grinding wheel surface speed was set to be (25 m/s, 30 m/s and 35 m/s). Depths of cut setting for grinding operation are 5 $\mu$m, 10 $\mu$m, and 15 $\mu$m. The grinding operation was conducted by traversing the wheel across the workpiece at 2000 mm/min, 2500 mm/min and 3000 mm/min table speed in one direction. The normal and tangential grinding forces were measured using a dynamometer. The grinding temperatures were measured by the embedded thermocouple.

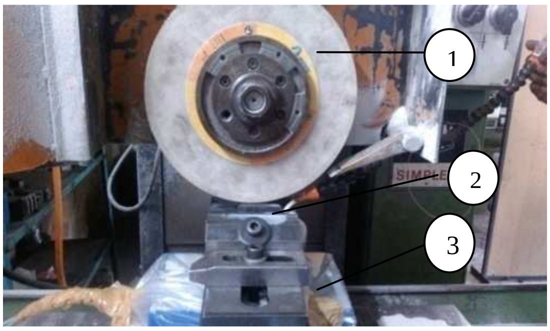

**Fig. 1.** Grinding machine setup: 1 – grinding wheel, 2 – workpiece, 3 – dynamometer.

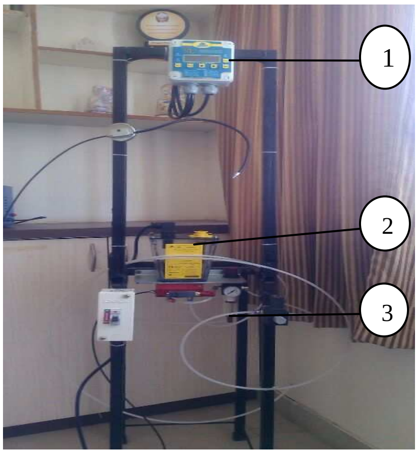

**Fig. 2.** MQL fluid delivery device: 1 – controller, 2 – fluid reservoir, 3 – FRL unit.

*Table 1*

**Grinding controlled variables and their levels**

| Symbol | Control parameters | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | Coolant | | $Al_2O_3$ | CuO | Water |
| B | Concentration | Percentage | 2 | 4 | 6 |
| C | Depth of cut | $\mu$m | 5 | 10 | 15 |
| D | Feed rate | mm/min | 2000 | 2500 | 3000 |
| E | Flow rate | ml/min | 5 | 10 | 15 |
| F | Nanoparticle size | nm | 50 | 100 | 150 |
| G | Grinding wheel speed | m/s | 25 | 30 | 35 |

The profilometer was used to measure the surface roughness of the ground surfaces. Three measurement traces parallel and perpendicular to the grinding direction were measured. The average of the three arithmetic average surface roughness ($Ra$) measurements along and across the grinding direction was used to represent the roughness.

## 3. DESIGN OF EXPERIMENTATION WITH TAGUCHI METHOD

When the process parameters are more, design of experimentation by traditional methods requires larger numbers. Application of Taguchi's high quality experimental design method reduces time, experimental cost and efforts. For the design of experiments a specially constructed orthogonal array is used. Here we are selecting $L_{27}$ orthogonal array for experimentation.

The grinding experimental controlled variables and their levels are shown in Table 1. According to capability of grinding machine the range of controlled grinding parameters was selected. Twenty seven trails were conducted as per the design of the $L_{27}$ orthogonal array. In this study temperature and grinding forces were selected as quality characteristics. Smaller the value better is the performance.

## 4. RESULTS AND DISCUSSION

### 4.1. Signal to noise (S/N) analysis

S/N ratio calculates the deviation of quality characteristics from the desired value. Here signal represents desirable effect and noise is for undesirable effect of output characteristics. Higher S/N ratios were required for optimal level of process parameters.

The S/N ratio for smaller the better characteristics is given by:

$$S/_N = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} yi^2. \tag{1}$$

Where $n$ is the number of repetitions of the experiment and $y_i$ is the average measured value of experimental data $i$. S/N ratio values for experimental result are calculated from Eq. (1).

Optimal parameter value is for highest S/N ratio. Figures 3 to 5 show S/N values of controlled variables for various output parameters. Figure 3 gives the analysis results of optimal process parameters for minimum temperature. They are as coolant – CuO, concentration – 2%, depth of cut – 15 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/minute, nanoparticle size 50 nm, grinding wheel speed 25 m/s.

Figure 4 gives the analysis results of optimal process parameters for normal force. They are as coolant – CuO, concentration – 4%, depth of cut – 5 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/minute, nanoparticle size 50 nm, grinding wheel speed 25 m/s. Parameter value is for highest S/N ratio.

Figure 5 gives the analysis results of optimal process parameters for tangential force. They are as coolant type CuO, concentration – 4%, depth of cut – 5 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/min, nanoparticle size 50 nm, grinding wheel speed 25 m/s.

Parameter value is for highest S/N ratio.

From the entire main effect plot we analyzed that type of coolant that was more significant factor for all the responses. This is because slope gradient was bigger for all figures.

### 4.2. Effect of grinding process parameters on responses

3D surface plots were drawn for the graphical analysis of the effect of grinding process parameters on normal force, tangential force and temperature. 3D surface plots where drawn by varying two parameters while third parameter kept constant. 3D surface plots for normal force, tangential force and temperature were shown in Figs. 6–11.

Figure 6 shows normal force on workpiece increases with increase in feed rate and depth of cut.

Figure 7 shows normal force on workpiece decreases with increase in coolant flow rate and normal force increases with increase in feed rate. Figure 8 shows tangential force on workpiece increases with increase in feed rate and depth of cut.

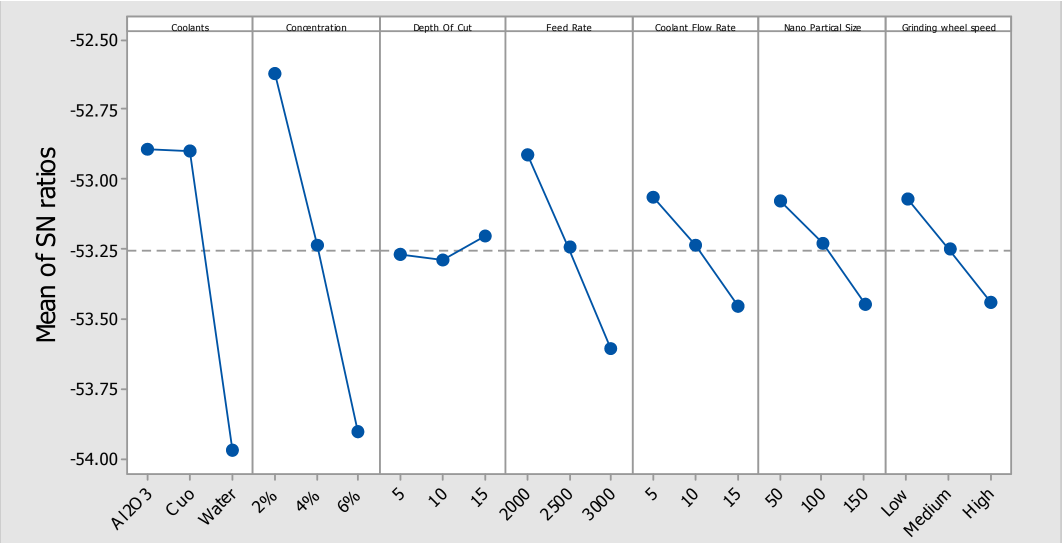

**Fig. 3.** Main effect plot of S/N ratios for temperature.

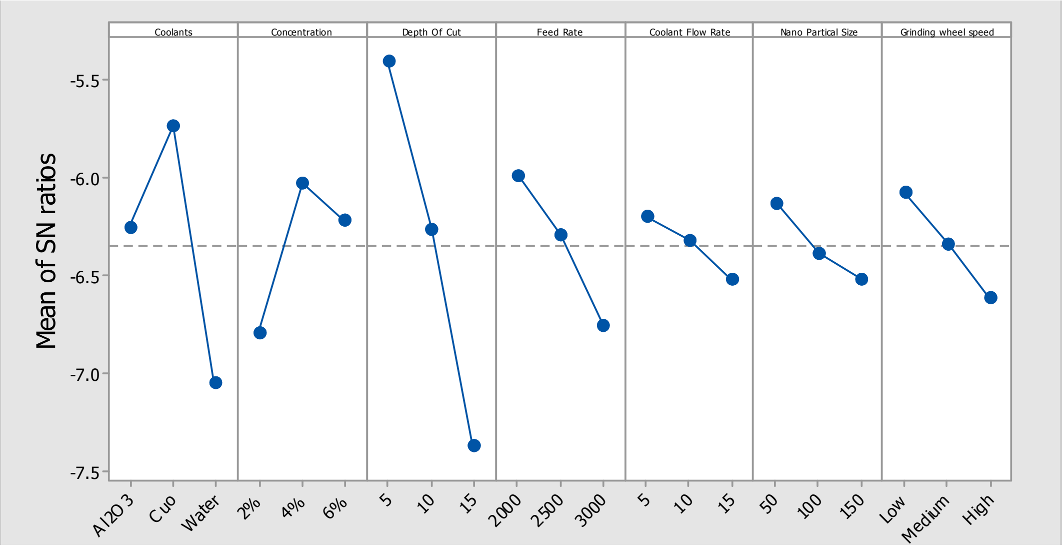

**Fig. 4.** Main effect plot of S/N ratios for normal force.

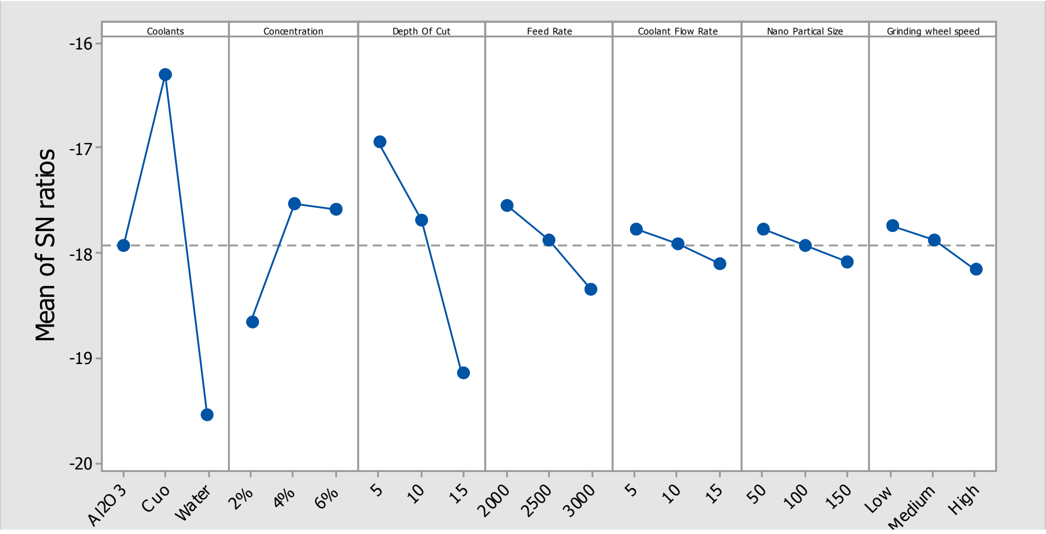

**Fig. 5.** Main effect plot of S/N ratios for tangential force.

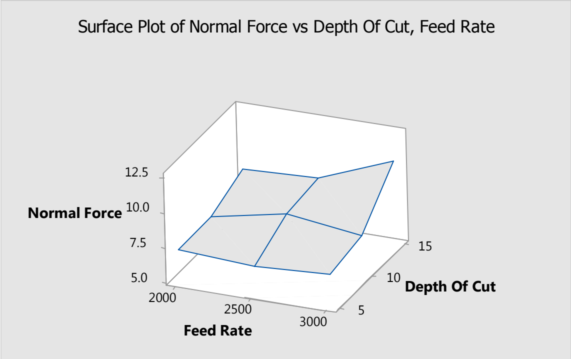

**Fig. 6.** 3D surface plot for effect of depth of cut and feed rate on normal force.

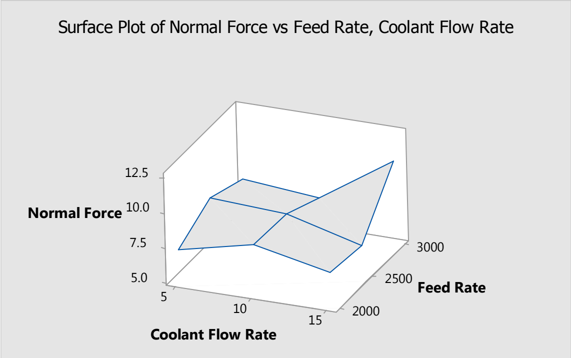

**Fig. 7.** 3D surface plot for effect of coolant flow rate and feed rate on normal force.

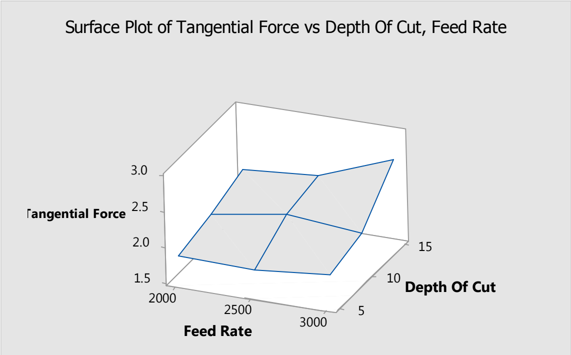

**Fig. 8.** 3D surface plot for effect of feed rate and depth of cut on tangential force.

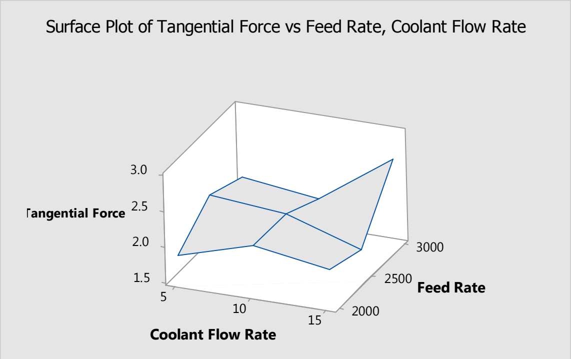

**Fig. 9.** 3D surface plot for effect of coolant flow rate and feed rate on tangential force.

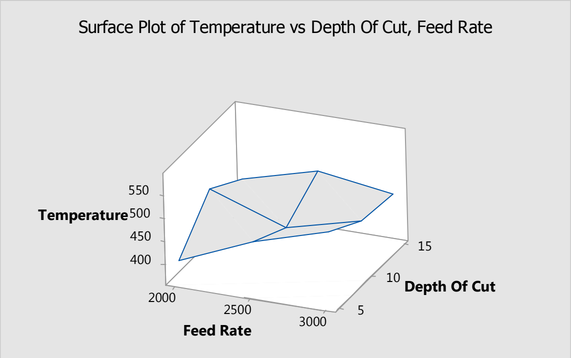

**Fig. 10.** 3D surface plot for effect of depth of cut and feed rate on temperature.

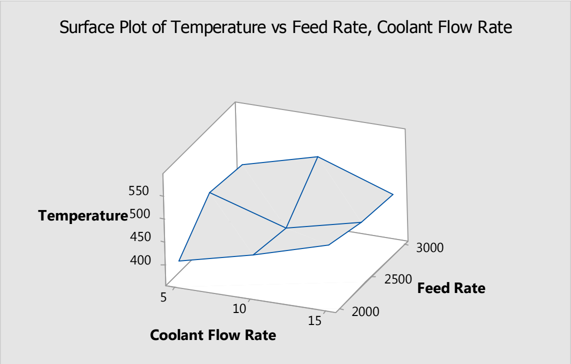

**Fig. 11.** 3D surface plot for effect of coolant flow rate and feed rate on temperature.

Figure 9 shows tangential force on workpiece decreases with increase in coolant flow rate and tangential force on work piece increases with increase in feed rate. Surface temperature of workpiece increases with increase in feed rate and depth of cut is reflected in Fig. 10. Figure 11 shows surface temperature of work piece decreases with increase in coolant flow rate and work piece surface temperature increases with increase in feed rate.

### 4.3. Multi-objective optimization by use of Grey relational analysis

Grey relational analysis is used for conversion of problem from multi-objective to a single objective. Optimal combination of MQL grinding process parameters will be determined by Grey relational analysis. Optimal combination of MQL grinding process parameters that simultaneously minimizes grinding forces and temperature of grinding zone.

**4.3.1. Evaluation of Grey relational coefficient.** Grey relational coefficient expresses the relationship between ideal and actual experimental results. Grey relational coefficient is calculated from Eq. (2):

$$\xi_i(k) = \frac{\Delta\min + \zeta\Delta\max}{\Delta_{0i}(k) + \zeta\Delta\max}, \tag{2}$$

where $\Delta\min$ is the smallest value of $\Delta_{0i}(k)$ and $\Delta\min = min_i min_k |x_0(k) - x_i(k)|$;
$\Delta\max$ is the largest value of $\Delta_{0i}(k)$ and $\Delta\max = \max_i \max_k |x_0(k) - x_i(k)|$;
where $\Delta_{0i}$ is the deviation sequence of the reference sequence ($x_0$) and the comparability sequence ($x_i$)

$$\Delta_{0i} = \| x_0(k) - x_i(k) \| \tag{3}$$

and ζ is the distinguishing coefficient set between zero and one. In this study, it is considered as 0.5. Grey relational coefficients calculated from Eq. 3 are given in Table 2.

*Table 2*

**Grey relational coefficients, grade and order**

| Expt. No. | Normal Force Coefficient | Tangential Force Coefficient | Temp Coefficient | Grade | Order |
|---|---|---|---|---|---|
| 1 | 0.663 | 0.796 | 0.754 | 0.738 | 4 |
| 2 | 0.549 | 0.547 | 1 | 0.699 | 8 |
| 3 | 0.397 | 0.370 | 0.686 | 0.484 | 22 |
| 4 | 0.722 | 0.772 | 0.414 | 0.636 | 11 |
| 5 | 0.726 | 0.834 | 0.813 | 0.791 | 3 |
| 6 | 0.597 | 0.595 | 0.720 | 0.637 | 10 |
| 7 | 0.654 | 0.640 | 0.361 | 0.551 | 19 |
| 8 | 0.573 | 0.515 | 0.487 | 0.525 | 21 |
| 9 | 0.548 | 0.519 | 0.577 | 0.548 | 20 |
| 10 | 0.844 | 0.950 | 0.893 | 0.896 | 1 |
| 11 | 0.691 | 0.666 | 0.662 | 0.673 | 9 |
| 12 | 0.511 | 0.445 | 0.901 | 0.619 | 12 |
| 13 | 1 | 1 | 0.582 | 0.860 | 2 |
| 14 | 0.750 | 0.579 | 0.451 | 0.594 | 14 |
| 15 | 0.718 | 0.626 | 0.856 | 0.733 | 5 |
| 16 | 0.953 | 0.807 | 0.409 | 0.723 | 6 |
| 17 | 0.949 | 0.776 | 0.431 | 0.719 | 7 |
| 18 | 0.704 | 0.519 | 0.577 | 0.600 | 13 |
| 19 | 0.548 | 0.565 | 0.659 | 0.591 | 15 |
| 20 | 0.458 | 0.450 | 0.447 | 0.452 | 23 |
| 21 | 0.333 | 0.333 | 0.333 | 0.333 | 27 |
| 22 | 0.542 | 0.617 | 0.580 | 0.579 | 16 |
| 23 | 0.460 | 0.468 | 0.405 | 0.445 | 24 |
| 24 | 0.405 | 0.430 | 0.402 | 0.412 | 25 |
| 25 | 0.531 | 0.631 | 0.518 | 0.560 | 18 |
| 26 | 0.568 | 0.664 | 0.499 | 0.577 | 17 |
| 27 | 0.406 | 0.460 | 0.364 | 0.410 | 26 |

**4.3.2. Normalization of experimental data.** First step of Grey relational analysis is to linearly normalize the experimental data in between zero and one. This process is also called as Grey relational generation. For minimization of grinding forces and temperature of grinding zone smaller the better characteristics is applied. Normalization is done by Eq. (4):

$$xi^*(k) = \frac{\max(xi^0(k)) - xi^0(k)}{\max(xi^0(k)) - \min(xi^0(k))}, \tag{4}$$

where $xi^*(k)$ is the value after normalization, $\min(xi^0(k))$ and $\max(xi^0(k))$ are the smallest and largest d values of $(xi^0(k))$ for the $k^{th}$ experimental results respectively.

**4.3.3. Evaluation of Grey relational grade.** Multiple performance characteristics are evaluated on the basis of Grey relational grade. Grey relational grade is evaluated by averaging Grey relational coefficient and is given by Eq. (5):

$$\varepsilon = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k), \tag{5}$$

where $n = 2$ performance characteristics number. Higher Grey relational grade indicates that the corresponding controlled parameter combination is closer to the optimum value.

*Table 3*

**ANNOVA for Grey relational grade (Multiple performance characteristics)**

| Source | DF | SS | MS | F-Value | P-Value | Contribution |
|---|---|---|---|---|---|---|
| Coolants | 2 | 0.328 | 0.164 | 16.86 | 0.00 | 66.37 |
| Concentration | 2 | 0.013 | 0.006 | 0.69 | 0.521 | 2.71 |
| Depth of cut | 2 | 0.008 | 0.004 | 0.46 | 0.644 | 1.80 |
| Feed rate | 2 | 0.017 | 0.008 | 0.9 | 0.431 | 3.55 |
| Coolant flow rate | 2 | 0.0004 | 0.0002 | 0.02 | 0.979 | 0.089 |
| Nanoparticle size | 2 | 0.002 | 0.001 | 0.14 | 0.867 | 0.57 |
| Grinding wheel speed | 2 | 0.006 | 0.003 | 0.33 | 0.728 | 1.28 |
| Error | 12 | 0.117 | 0.009 | | | |
| Total | 26 | 0.495 | | | | |

**4.3.4. Evaluation of Grey relational order.** Grey relational grade determines order of experiment. Table 2 gives Grey relational grade and order for different experiments. As per the table data 3 the controlled parameters for experiment 10 had highest Grey relational order. This shows that experiment 10 has optimal grinding factors setting for minimum force, and temperature of grinding zone and they are as coolant – CuO, concentration – 2%, depth of cut – 5 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/min, nanoparticle size 100 nm, grinding wheel speed 35 m/s.

### 4.4. Analysis of variance (ANOVA)

Table 4 illustrates the results of ANOVA for Grey relational grade of grinding operation. Percentage contribution of variables gives impact of that individual variable on total process. From Table 3 the most important controlled parameters variables affecting the Grey relational grade are coolants (66.37 %) followed by feed rate (3.55 %), concentration (2.71%). Coolant flow rate, nano particle size and grinding wheel speed had lesser effect on Grey relational grade.

## 5. CONCLUSIONS

In this experimental work Grey relational analysis is used for optimization of grinding process parameters for EN 24 material for multi performance characteristics. Process parameters selected for surface grinding operation are depth of cut, feed rate, type of lubricant, grinding wheel speed, coolant flow rate, and nano particle size. Grinding performance is measured in terms of cutting force and Temperature. From experimental work and Grey relational analysis following conclusions are made:

- Analysis results based on mono objective Taguchi's optimization method, the optimal process parameters for minimum Temperature are as coolant CuO, concentration 2%, depth of cut 15 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/minute, nanoparticle size 50nm, grinding wheel speed 25m/s.
- The best optimized combination process parameters for minimum tangential force, normal force and temperature on the basis of multi-objective Grey relational analysis, are coolant CuO, concentration 2%, depth of cut 5 $\mu$m, feed rate 2000 mm/min, coolant flow rate 5 ml/minute, nanoparticle size 100 nm, grinding wheel speed 35m/s.
- Work efficiency and production quality can be increased by properly adjusting process parameters.

## REFERENCES

[1] C. Guo, Y. Wu, V. Varghese, S. Malkin, *Temperatures and Energy Partition for Grinding With Vitrified CBN Wheels*, CIRP Annals-Manufacturing Technology, Vol. 48, No. 1, 1999, pp. 247–250.

[2] C. Mao, X. Tang, H. Zou, X. Huang, & Z. Zhou, *Investigation of grinding characteristic using nanofluid minimum quantity lubrication*, International Journal of Precision Engineering and Manufacturing, Vol. 13, No. 10, 2012, pp. 1745–1752.

[3] T. Dobrescu, N.E. Pascu, A.F. Arion, *Improving the slicing process characteristic parameters*, Proceedings in Manufacturing Systems, Vol. 8, No. 4, 2013. pp. 233–238.

[4] W.F. Ding, J.H. Xu, Z.Z. Chen, H.H. Su, Y.C. Fu, *Grindability and surface integrity of cast nickel-based superalloy in creep feed grinding with brazed CBN abrasive wheel's*, Chin J Aeronaut Vol. 23, No. 4, 2010, pp. 501–10.

[5] S. Wang, C.H. Li, Q. Zhang, *Evaluation of grinding performance in minimum quantity lubrication with nanoparticles*, Manuf Tech Mach Tool, Vol. 2, 2010, pp. 86–90.

[6] L. R. Silva, E. C. Biianchi, R. E. Catai, R. Y. Fusse, *Study on the Behaviour of the Minimum Quantity Lubricant-MQL Technique under different Lubricating and cooling conditions when grinding ABNT 4340 Steel*, Journal of the Brazilian Society of Mechanical Sciences and Engineering,Vol. 27, No. 2, 2005, pp. 192–199.

[7] B. Shen, A.J. Shih, & S.C. Tung, *Application of nanofluids in minimum quantity lubrication grinding*, Tribology Transactions, Vol. 51, No. 6, 2008, pp. 730–737.

[8] C. Mao, Z.H. Zhou, J. Zhang, X.M. Huang, and D.Y. Gu, *An experimental investigation of affected layers formed in grinding of AISI 52100 steel*, The International Journal of Advanced Manufacturing Technology, Vol. 54, No. 5–8, 2011, pp. 515–523.

[9] D. Zhang, C. Li, D. Jia, Y. Zhang, X. Zhang, *Specific grinding energy and surface roughness of nanoparticle jet minimum quantity lubrication in grinding*, Chinese Journal of Aeronautics, Vol. 28, No. 2, 2015, pp. 570–581.

[10] C.C.Tsao, *Grey–Taguchi method to optimize the milling parameters of aluminum alloy*, The International Journal of Advanced Manufacturing Technology,Vol. 40, No. 1–2, 2009, pp. 41–48.

[11] S.H. Chang, J.R. Hwang, J.L. Doong, *Optimization of the injection molding process of short glass fiber reinforced polycarbonate composites using Grey relational analysis*, Journal of Materials Processing Technology, Vol. 97, No. 1, 2000, pp. 186–193.

[12] E. Kuram, B. Ozcelik, *Multi-objective optimization using Taguchi based Grey relational analysis for micro-milling of Al 7075 material with ball nose end mill*, Measurement Vol. 46, No. 6, 2013, pp. 1849–1864.

[13] U.A. Dabade, *Multi-objective Process Optimization to Improve Surface Integrity on Turned Surface of Al/SiCp Metal Matrix Composites Using Grey Relational Analysis*, Forty Sixth CIRP Conference on Manufacturing Procedia CIRP 7, 2013, pp. 299–304.

[14] U. Esme, *Application of Taguchi Method for the Optimization of Resistance Spot Welding Process*, Arabian Journal for Science and Engineering Vol. 34, No. 2, 2009, p. 519.

[15] P. Sathiya. P, M.Y. Jaleel. M.Y, *Grey Based Taguchi Method for Optimization of Bead Geometry in Laser Bead-on-plate Welding*, Advances in Production Engineering and Management, Vol. 5, No. 4, 2010, pp. 225–234.

[16] J. Steiningerová, J. Majerík, *Surface quality analysis of 102Cr6 bearing steel after CC6050 insert by hard turning and by SG grinding wheel*, Proceedings in Manufacturing Systems, Vol. 5, No. 3, 2010, pp. 137–142.