International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

Multi-parametric optimization of Universal Cylindrical grinding using Grey Relational Analysis

Sandeep Kumar, Dr. S. Dhanabalan
Dept. of Mechanical Engineering
M. Kumarasamy College of Engineering
Karur-639113, Tamil Nadu, India
Waliasandeep.079@gmail.com

Dr. C. Sathiya Narayanan
Dept. of Production Engineering
NIT-Trichy
Trichy-620015, India
csathiyanarayanan@gmail.com

***Abstract* -- Cylindrical grinding process is most versatile surface finishing process and generally used to smooth the external cylindrical surfaces such as shafts, bearings, spindles, pins, gears, etc. by getting rid of a limited amount of material with the action of abrasive grains. In the present experimental work, Grey-rational method has been used to optimize the multi-parametric optimization of Universal Cylindrical grinding machine parameters such as Abrasive wheel speed, feed rate, workpiece spindle rotation and depth of cut. The consequence of input process parameters was optimized for output responses such as surface roughness and MRR of AISI 1040 medium carbon steel. The values of surface roughness were evaluated with the help of Mitutoyo–Surf, test–4, L. C. 0.1µm surface roughness tester and MRR measurements were calculated during the process by using an electronic digital weight balance. For MRR, workpiece spindle speed and table feed are the most influencing parameter and grinding wheel speed has the least significance. For surface roughness, depth of cut and grinding wheel speed are the most influencing parameter and work piece spindle speed has the least significance. The experimental results and optimized parameters showed the considerable improvement in the process.**

Keywords--- Cylindrical Grinding, Surface roughness, MRR, DOE, Grey relational Analysis.

I. INTRODUCTION

Grinding is essentially a surface finishing process in which an individual abrasive grain acts as the cutting tool. The individual grains are spaced indiscriminately along the periphery of the wheel and it has an irregular geometry. The average rake angle of the abrasive grains is highly negative, i.e. -60^{o} or lower, consequently, the shear angles are very low. The grains in the periphery of a Grinding wheel have different radial positions. The cutting speed of grinding wheels is very high i.e. on the order of 30 m/s.

Cylindrical grinding is also called center-type grinding. The workpiece is held between the centers, held in a chuck or headstock of the grinder. For straight cylindrical surfaces, the axis of rotation of the wheel and the workpiece are parallel. Separate motors drive the wheel and work piece at different speeds. For taper cylindrical surfaces, both the wheel and workpiece axis can be swiveled around a horizontal plane in universal grinding machines. Thread cutting is also done with specially dressed wheels.

An abrasive grinding wheel of suitable diameter gets rid of the layer of workpiece material at a depth, generally known as 'depth of cut'. Each abrasive grain on the outer boundary of the grinding wheel strikes at a tangential velocity. This grain removes a chip with un-deformed thickness, i.e. depth of cut and over the length of the work piece. When the grinding wheel introduces against the workpiece, generation of higher temperature takes place due to the friction and higher rotation of the abrasive wheel. Effects of temperature in Grinding are tempering, Metallurgical burning, heat checking and residual stresses. Residual stresses arise due to the temperature generated by the physical interaction between the grinding wheel and workpiece.

Cutting fluids play a vital role to reduce the generated temperature due to interaction between grinding wheel and workpiece and maintains the surface temperature by providing the cooling effect in grinding zone. Previous researchers investigated that pure oil and water soluble oils decrease the friction, specific energy and temperature from grinding zone. Therefore, these cutting fluids are most preferable for industrial applications. [8]

The important process parameters of cylindrical grinding are abrasive grinding wheel rotation, work piece spindle speed, feed rate, machining condition, material hardness, depth of cut and abrasive grain size. Surface roughness is extremely affected by workpiece speed and grinding wheel speed. Hardness of the material affects the Material Removal Rate (MRR). [21-23] Jingzhu Pang et al proposed heat distribution model by using CBN grinding wheel and Ti-6Al-4V material to calculate the heat flux with measured temperature. [24]

Wang Pei Zhuo et al presented the effect of residual stresses on Inconel-718 and concluded that by embedding source of heat with material, tensile residual stress can be transferred into compressive stress. [25] K. Mekala et al demonstrated the consequence of machining speed, feed rate and depth of cut on SR and MRR of AISI 316 steel material. The author resulted that the machining speed has the important significant essence on SR while the depth of cut has a higher impact on MRR.

International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

M. Kiyak et al concluded that the higher workpiece spindle rotation and low feed had most substantial parameters for surface roughness. The author investigated the effect of workpiece spindle rotation and feed rate by using AISI 1050 steel under dry conditions. [3] Rodrigo Daun Monicia et al concluded that the combined use of neat oil and CBN wheel increased the efficiency. [8] H. Saglam et al presented the effect of depth of cut, work piece speed and feed rate on AISI 1050 steel to measure the roundness error and SR. Author concluded that the value of surface roughness improved by the higher value of wheel speed and lower value of feed rate and depth of cut. [5] Arshad Noor Siddiquee et al optimized the seven process parameters of in-feed grinding by using the Grey relational analysis method on EN 52 austenite valve steel. [10]

II. EXPERIMENTAL PLAN

1. Preliminary Experimentation

In the present research work, G. G. -600 Universal Cylindrical grinding machine was used for experimentation. AISI 1040 medium carbon steel bar having diameter 30 mm and a length of 360 mm was used. Standard cutting fluid was used for grinding the specimen. AISI 1040 steel has several applications in Automotive and Manufacturing industries such as shafts, gears, general purpose, axles, bolts and studs, spindles etc. Turning operation had been performed on the test specimen to reduce its diameter up to 28.5 mm. After turning operation the test specimen was divided into 3 equal parts to perform the grinding operation as per DOE. The chemical composition of AISI 1040 material is indicated in the table 1.

Table 1: Chemical Composition (in weight %)

Carbon (c)	Manganese (Mn)	Silicon (Si)	Sulphur (S)	Phosphorous (P)
0.35-0.45	0.6-1.0	0.05-0.35	0.005-0.06	0.015-0.06

Before selection of final parameters for cylindrical grinding process, preliminary experiments were performed on AISI 1040 steel work piece. The set of parameters was selected randomly from Universal cylindrical grinding machine specification as shown in Table 2.

After completion of experimental work by adjusting the machine parameters, surface roughness (SR) values were evaluated by using the Mitutoyo surface roughness tester. From results, it has been observed that the values for SR were minimum in experiment No. 3, 5 and 9. If the value of surface roughness is minimum it means that the value of surface finish is higher. Since the parameters have to be selected for surface roughness (SR) and material removal rate (MRR), therefore the final selected parameters for optimization of cylindrical grinding process were:

Grinding wheel speed: 1800, 2000 (For the higher surface finish of the component, speed of grinding wheel should be higher.)

Range of table feed: 100-175-275

Work head spindle speed range: 80-155-324 (the value of surface roughness was minimum of these parameters)

Table 2: Selection of parameters for Preliminary experimentation

Sr. No.	Grinding wheel Speed (RPM)	Work piece speed (RPM)	Feed Rate (Mm/min)	Depth of Cut (mm)	SR (µm)
1.	1800	324	100	0.02	2.65
2.	1800	155	275	0.02	2.76
3.	1800	80	175	0.04	2.35
4.	1800	165	275	0.06	2.99
5.	1800	324	275	0.02	2.23
6.	2000	80	175	0.04	2.57
7.	2000	165	100	0.02	2.78
8.	2000	80	175	0.04	2.65
9.	2000	155	100	0.06	2.39

Depth of cut: 0.02, 0.04, 0.06 (on observations)

Lower the value of depth of cut, higher the value of surface finish, and higher the value of depth of cut, higher the material removal rate value.

III. DESIGN OF EXPERIMENTS

DOE is the first step of experimental work and a statistical technique introduced by R.A. Fisher (1920). In DOE the change in corresponding output variables is measured by changing the values of Input variables and used to find the most efficient and effective conclusions by designing, planning and organizing.

To design the experiments, the first step is selection of appropriate Orthogonal Array, Assign each factor to columns, identify each trial circumstance, and decides the order and repetitions of trial circumstances. An OA Design matrix table is generated. The chosen input parameters with their identification and allocated levels of input parameters are listed in table 3 and table 4.

Table 3: Input parameters with their identification

Parameter	Grinding Wheel Speed (RPM)	Work piece speed (RPM)	Table Feed (mm/min)	Depth of Cut (mm)
Identification	A	B	C	D

International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

Table 4: Allocated values for input parameters at various levels

Factor Identification	Parameters (units)	Levels and comparable values of parameter		
		Level-1	Level2	Level3
A	Grinding wheel Speed (RPM)	1800	1800	2000
B	Work piece spindle Speed (RPM)	80	155	324
C	Table Feed (Mm/min.)	100	175	275
D	Depth of cut (mm)	0.02	0.04	0.06

A. Experimentation

In the present experimentation work, L_{27} ($3^{\wedge 4}$) OA was chosen. This OA consists of 4 columns and 27 rows. One Input parameter was delegated to every column. L27 Orthogonal Array has 27 parametric combination therefore the total number of 27 experiments were conducted to measure the interactions between the various factors. The parameter combinations using the L_{27} ($3^{\wedge 4}$) or OA are shown in Table 5.

Mitutoyo–Surf, test–4, having least count L. C. 0.1µm was utilized to evaluate the surface roughness of each part. For accurate measurements minimum three values were taken for each specimen and the mean value was selected. The mean values of the Surface Roughness (SR) are shown in the table 5.

Fig.1 Cylindrical Grinding Process on test specimen

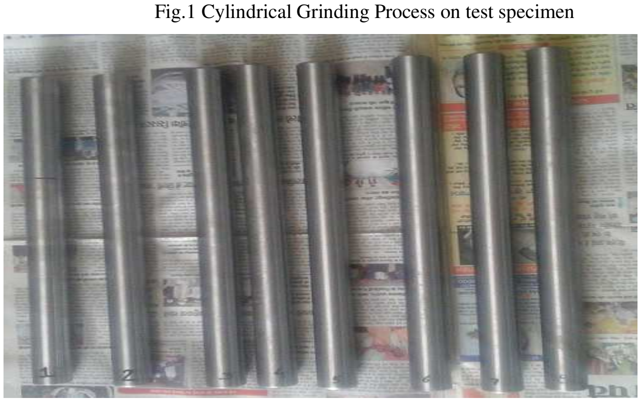

Fig. 2 Work pieces after cylindrical Grinding Process

Table 5: DoE (Design of Experiment) Matrix of L_{27} ($3^{\wedge 4}$) Orthogonal array (OA)

Sr. No.	A	B	C	D	MRR	SR (µm)	Grades
1.	1	1	1	1	0.0504	2.35	0.432571151
2.	1	1	1	1	0.0757	2.57	0.443264316
3.	1	1	1	1	0.125	2.75	0.657151919
4.	1	2	2	2	0.0314	2.23	0.435718193
5.	1	2	2	2	0.0476	1.81	0.669219304
6.	1	2	2	2	0.0793	2.42	0.477896522
7.	1	3	3	3	0.0229	2.5	0.36791148
8.	1	3	3	3	0.0344	2.45	0.390012595
9.	1	3	3	3	0.0574	2.28	0.460716406
10.	2	1	2	3	0.05	2.22	0.464239779
11.	2	1	2	3	0.075	2.36	0.47904034
12.	2	1	2	3	0.125	2.73	0.659474799
13.	2	2	3	1	0.0333	2.74	0.346502911
14.	2	2	3	1	0.0476	2.39	0.419806705
15.	2	2	3	1	0.0793	2.57	0.452537045
16.	2	3	1	2	0.0229	2.44	0.37845706
17.	2	3	1	2	0.0344	2.27	0.428773834
18.	2	3	1	2	0.0574	2.69	0.388358638
19.	3	1	3	2	0.0504	2.22	0.464875493
20.	3	1	3	2	0.0757	2.05	0.574260291
21.	3	1	3	2	0.126	1.78	1.000
22.	3	2	1	3	0.0317	2.6	0.362546415
23.	3	2	1	3	0.0475	2.57	0.388389081
24.	3	2	1	3	0.0793	2.01	0.601501806
25.	3	3	2	1	0.0229	2.22	0.428828829
26.	3	3	2	1	0.0344	2.36	0.407755416
27.	3	3	2	1	0.0574	2.73	0.383513059

International Journal of Ethics in Engineering & Management Education

Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

The values of MRR were calculated manually by using the formula and it is defined as the rate of volume of material removed at the machining time.

$$MRR = (W_b - W_a)/T_m \quad (1)$$

Where,
W_b = specimen weight before grinding
W_a = specimen weight after grinding
T_m = machining time (Min/Sec).

After completion of grinding at each section, the work piece is removed and the weight of work piece was measured. The experimental values obtained for material removal rate are shown in the table.

B. Multi-parametric Optimization using Grey relational method

The steps used for multi-parametric optimization using the Grey relational analysis are discussed below;

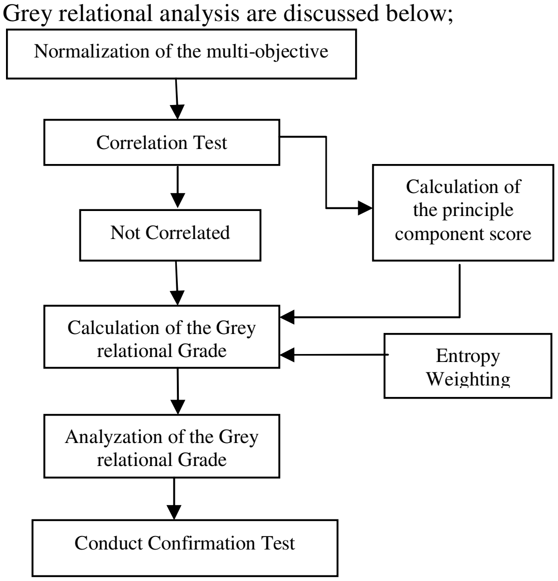

Fig. 3 Optimization procedure of Process parameters with multi-objective characteristics

(a) Normalization of the experimental results of Surface roughness & MRR for all values: Linear normalization of experimental values is performed in the range of 0 and 1. The normalized values for response of surface roughness and MRR were calculated by using the standard formula:

$$Normalized\ Results\ (X_{ij}) = \frac{(y_{ij}) - (\min_j y_{ij})}{(\max_j y_{ij}) - (\min_j y_{ij})} \quad (2)$$

Where,
y_{ij} = i^{th} experiment results in j^{th} experiment.

(b) Calculation for the Grey relational coefficients:
Grey relational coefficients are calculated to show the relation between ideal and actual experimental results. The standard formula used for the computation of Grey relational coefficients is given below:

$$\delta_{ij} = \frac{\min_i \min_j |x^o_i - x_{ij}| + \xi \max_i \max_j |x^o_i - x_{ij}|}{|x^o_i - x_{ij}| + \xi \max_i \max_i |x^o_i - x_j|},\ 0 < \xi \quad (3)$$

Where,
x^o_i = ideal normalized result

(c) Calculation for the Grey relational grade:
Grey relational grades are calculated by the average of Grey relational coefficient using the formula given below:

$$\alpha_j = \frac{1}{m}\sum_{i=1}^{m} \delta_{ij} \quad (4)$$

Where,
α_j = Grey relational grade
m = No. of performance grade characteristics

(d) Calculation of the optimum levels: optimum levels are calculated to find the significant parameter.

Table 6: Grey relational grade response table

Parameters	Level 1	Level 2	Level 3
A	0.481606876	0.446354568	0.512407821
B	0.574986454	0.461568665	0.403814146
C	0.453446024	0.489520693	0.497402547
D	0.50815924	0.53528437	0.463759189
Average Grey relational Grade= 0.48767			

(e) Selection of the optimal levels of process parameters by taking the highest values of levels for each parameter from the optimum level table.
The Response table is clearly indicating the level values for process parameters. The highest value of process parameters for each parameter showed the best optimized value. The optimized value of the response for minimum surface roughness and for higher MRR of parameter A is at Level 3, parameter B at Level 1, parameter C at Level 3 and Parameter D at level 2 among all the 27 experiments.

(f) Confirmation of experiment and verification of the optimized process parameters.

C. Confirmation of Experiment

After obtaining the optimized values of process parameters the final step is to confirm the experimentation. The estimated Grey relational grade can be calculated from the following given relation:

$$\hat{\alpha} = \alpha_m + \sum_{i=1}^{q} (\bar{\alpha}_i - \alpha_m) \quad (5)$$

Where,
α_m = Total mean of the Grey relational grade at optimal level
q = No. of machining parameters.

International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

Table 7: Confirmation of Experiment

	Predicted Value	Experimentation
Level	$A_1B_2C_2D_2$	$A_3B_2C_3D_2$
MRR (g/min.)	0.0476	0.126
SR (μm)	1.81	1.78
Grade	0.669	1
Improvement in Grey relational grade: 0.330		

IV. TAGUCHI ANALYSIS (ANOVA)

Taguchi analysis is used for the selection of best-optimized parameter value of the response of individual process parameter and to measure the influence of each parameter at different levels.

I. Influence of input parameters on MRR

The main effect plot for data means is showing the effect of an individual parameter at the different level of MRR. For the measurement of MRR, larger is better (S/N) was utilized because the maximum value of MRR means the higher rate of production. Therefore, for the measurement of MRR, 'Larger is better' ratio is used.

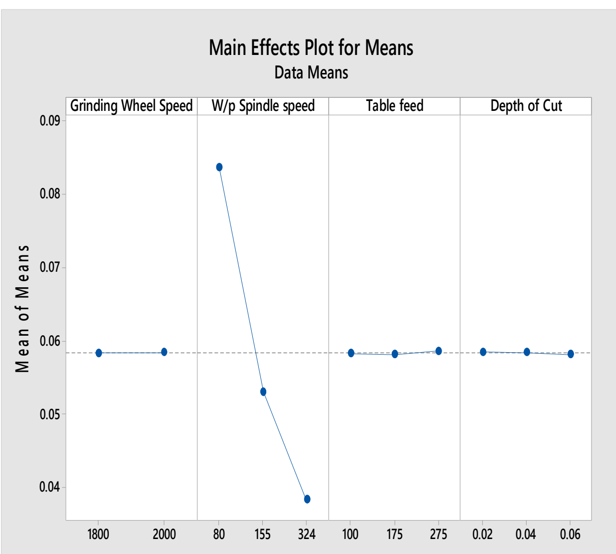

Fig. 3 Main effect plot for data means-MRR-(Larger is better)

As per figure no. 3, the main effect for data means the MRR is maximum at the level-3 of grinding wheel speed, level-1of workpiece spindle speed, level-3 of table feed and level-3 of depth of cut. Therefore, these are the best-optimized values of parameters for MRR. The rank given as 1, 2, 3 and 4 in Table 8 shows the most influencing parameters for MRR. For MRR, workpiece spindle speed and table feed are the most influencing parameter and grinding wheel speed has the least significance, as shown in Table 9.

Table 8: Levels of selected input parameters at maximum MRR

Factor	Grinding Wheel Speed (RPM)	Work piece speed (RPM)	Table feed (mm/min)	Depth of Cut (mm)
Level	3	1	3	3
Rank	4	1	2	3

Table 9: Response table for means (MRR)

Level	Grinding Wheel Speed (RPM)	Work piece speed (RPM)	Table feed (mm/min)	Depth of Cut (mm)
1	0.0583	0.0837	0.0583	0.0584
2	0.0584	0.0530	0.0581	0.0583
3	---	0.0382	0.0586	0.0581
Delta	0.00009	0.0455	0.0004	0.0003
Rank	4	1	2	3

II. Influence of input parameters on Surface roughness (SR)

The main effect plot for data means is showing the effect of the individual parameter at the different level of SR (Ra). For the measurement of SR, smaller is better (S/N) was utilized because the minimum value of SR means the higher value of surface finish. Therefore, for the measurement of surface roughness, 'Smaller is better' ratio is used.

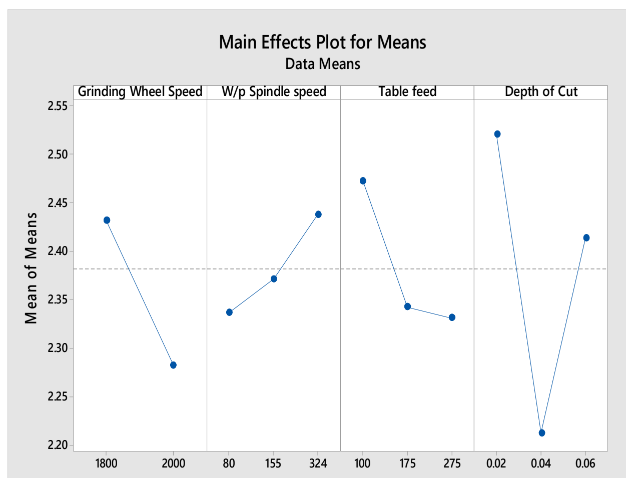

Fig. 4 Main effect plot for data means-SR-(Smaller is better)

As per Fig. 4, the main effect for data means the surface roughness is minimum at the level-3 of grinding wheel speed, level-1of workpiece spindle speed, level-3 of table feed and level-2 of the depth of cut. Therefore, these are the best-optimized values of parameters for the minimum surface roughness. The rank given at 1, 2, 3 and 4 in Table 10 shows the most influencing parameters for surface roughness. For surface roughness, depth of cut and grinding wheel speed are

IJEEE

International Journal of Ethics in Engineering & Management Education

Website: www.ijeee.in (ISSN: 2348-4748, Volume 5, Issue 3, March 2018)

the most influencing parameter and work piece spindle speed has the least significance, as shown in table 11

Table 10: Response table for means (SR)

Level	Grinding Wheel Speed (RPM)	Work piece speed (RPM)	Table Feed (mm/min)	Depth of Cut (mm)
1	2.432	2.337	2.472	2.520
2	2.282	2.371	2.342	2.212
3	---	2.438	2.331	2.413
Delta	0.149	0.101	0.141	0.308
Rank	2	4	3	1

Table 11: Levels of selected input parameters at minimum SR

Factor	Grinding Wheel Speed (RPM)	Work piece speed (RPM)	Table feed (mm/min)	Depth of Cut (mm)
Level	3	1	3	2
Rank	2	4	3	1

V. REGRESSION ANALYSIS AND EMPIRICAL MODEL

In regression equations, the coefficient of determination, R2 is used to decide whether regression model is appropriate or not. The value of R^2 provides an exact model if the value is 1. The calculated regression empirical models for MRR and surface roughness are given in following equations;

MRR = 0.074 + 0.00 Grinding wheel speed – 0.000108 spindle speed + 0.000002 Table feed – 0.008 depth of cut (6)

Surface Roughness = 3.98 – 0.000747 Grinding wheel speed + 0.000315 spindle speed – 0.000769 Table feed – 2.67 depth of cut (7)

If the value of residual increases, the value of R^2 decreases in the range from 0 to 1. In this experimental study, the value of R^2 for MRR and SR is very close to unity. Therefore, this model is reliable. Adj R^2 is used for comparing the residual per unit degree of freedom.

VI. RESULTS AND CONCLUSION

In this experimental study, DOE (Taguchi) and Grey relational analysis was applied to optimize the multi-parametric response features of the Cylindrical grinding process of EN8 steel. This paper represents the optimum process parameters for Surface roughness (SR) and Material Removal Rate (MRR). The optimized parameters for the response of Surface roughness and MRR in Universal cylindrical grinding process are: 2000 RPM of grinding wheel speed, 80 RPM work piece speed, 275 feed rate & 0.04 mm depth of cut. For MRR, workpiece spindle speed and table feed are the most influencing parameter and grinding wheel speed has the least significance. For surface roughness, depth of cut and grinding wheel speed are the most influencing parameter and work piece spindle speed has the least significance. The experimental results showed the considerable advancement in the process. Therefore, The Grey relational technique simplifies the optimization method by convert of the multi response variable to a single response grade by normalizing.

REFERENCES

[1] Guoxian Xiao, Stephen Malkin, Kourosh Danai (1993), “ Automonous system for Multistage Cylindrical grinding”, Journal of Dynamic Systems, Measurement & control, Vol. 115, p.p. 667-672.

[2] G. S. Li, L.S. Wand, L.B. Yang (2002), “ Multi- parameter optimization and control of Cylindrical grinding process”, Journal of Materials Processing Technology 129, p.p. 232-236.

[3] M. Kiyak, O. Cakir, E. Altan (2003), “ A study on surface roughness in external cylindrical grinding”, 12th Int. Scientific conference Achievements in Mechanical & Materials engineering, p.p. 459-462.

[4] Rogelio L. Hecker, Steven Y. Liang (2003), “Predictive modeling of surface roughness in grinding”, Int. J. of Machine tools and Manufacture 43, p.p. 755-761.

[5] H. Saglam, F. Unsacar And S. Yaldiz (2005), “An experimental investigation as to the effect of cutting parameters on roundness error and surface roughness in cylindrical grinding” International Journal of Production Research, Vol. 43, No. 11, 2309–2322.

[6] Jeremiah A. Couey, Eric R. Marsh, Byron R. Knapp, R. Ryan Vallance, (2005), “Monitoring force in precision cylindrical grinding”, Precision Engineering 29, p.p. 307–314.

[7] Oscar Gonza lez-Brambila, Eduardo Rubio, Juan C. Ja uregui, Gilberto Herrera-Ruiz, (2006), “Chattering detection in cylindrical grinding processes using the wavelet transform”, International Journal of Machine Tools & Manufacture 46, 1934–1938.

[8] Rodrigo Daun Monici, Eduardo Carlos Bianchi, Rodrigo Eduardo Catai, Paulo Roberto de Aguiar (2006), “Analysis of the different forms of application and types of cutting fluid used in plunge cylindrical grinding using conventional and superabrasive CBN grinding wheels”, International Journal of Machine Tools & Manufacture 46, p.p. 122–131.

[9] Paulo R. Aguiar, Carlos E. D. Cruz, Wallace C. F. Paula and Eduardo C. Bianchi (2008), “Predicting Surface Roughness in grinding using Neural Networks”, Advances in Robotics, Automation and Control, ISBN 78-953-7619-16-9, pp. 472.

[10] Arshad Noor Siddiquee, Zahid A. Khan, Zulquernain Mallick (2009), “Grey relational analysis coupled with principal component analysis for optimization design of the process parameters in in-feed centre less cylindrical grinding” Int. J. Adv. Manuf. Technology DOI 10.1007/s00170-009-2159-8.

[11] Halil Demir, Abdulkadir Gullu, Ibrahim Ciftci, Ulvi Seker (2010), “An Investigation into the Influences of Grain Size and Grinding Parameters on Surface Roughness and Grinding Forces when Grinding” Journal of Mechanical Engineering 56, 7-8, 447-454, UDC 621.795:621.922.025.

[12] V. Suresh Babu, S. Sriram Kumar, R. V. Murali, M. Madhava Rao (2011), “Investigation and validation of optimal cutting parameters for least surface roughness in EN24 with response surface method”, International Journal of Engineering, Science and Technology Vol. 3, No. 6, 2011, pp. 146-160.

[13] Kiran kumar Ramakantrao Jagtap (2011), “Optimization Of Cylindrical Grinding Process Parameters For Aisi 5120 Steel Using Taguchi Method”, International Journal of Design and Manufacturing Technology (IJDMT), ISSN 0976 – 6995(Print), ISSN 0976 – 7002(Online) Volume 2, Number 1, pp. 47-56.

[14] Rafael de Mello Belentani, Paulo Roberto de Aguiar, Anselmo Eduardo Diniz (2011), "Utilization The Minimum Quantity Of Lubrificant (Mql) With Water For External Cylindrical Grinding Process Of Hardened Steel", 21st Brazilian Congress of Mechanical Engineering, October 24-28, Natal, RN, Brazil.

[15] L B Abhang and M Hameedullah (2011), "Modeling and Analysis for Surface roughness in Machining EN-31 steel using Response Surface Methodology", International Journal of Applied Research in Mechanical Engineering, Volume-1, Issue-1, P.P. 33-38.

[16] Liu Judong, Yuan Wei, Huang Songwei, Xu Zhilong (2012), "Experimental Study on Grinding-hardening of 1060 Steel", International Conference on Future Energy, Environment, and Materials, Energy Procedia 16, 103 – 108.

[17] Mustafa Kemal Külekcý (2013), "Analysis Of Process Parameters For A Surface-Grinding Process Based On The Taguchi Method", Materials and technology 47, 105–109, UDK 621.923:620.179.11:519.233.4 ISSN 1580-2949.

[18] K Mekala1, J Chandradas, K Chandrasekaran, T T M Kannan, E Ramesh And R Narasing Babu (2014), "Optimization Of Cylindrical Grinding Parameters Of Austenitic Stainless Steel Rods (AISI-316) By Taguchi Method", Int. J. Mech. Eng. & Rob. Res. 2014, Vol. 3, No. 2, ISSN 2278 – 0149. P.P. 209-215.

[19] Lianjie, Yadong Gong, Xiaohui Chen, (2014), "Study on surface roughness model and surface forming mechanism of ceramics in quick point grinding", International Journal of Machine Tools & Manufacture 77, 82–92.

[20] Karanvir Singh, Parlad Kumar, Khushdeep Goyal (2014), "To Study the Effect of Input Parameters on Surface Roughness of Cylindrical Grinding of Heat Treated AISI 4140 Steel", American Journal of Mechanical Engineering, 2014, Vol. 2, No. 3, 58-64, DOI:10.12691/ajme-2-3-2.

[21] Jianbin Chen, QihongFang, PingLi (2014), "Effect of grinding wheel spindle vibration on surface roughness and subsurface damage in brittle material grinding", International Journal of Machine Tools & Manufacture 91, 12–23.

[22] Ali Zahedi, TaghiTawakoli, JavadAkbari (2014), "Energy aspects and work piece surface characteristics in ultrasonic- assisted cylindrical grinding of alumina–zirconia ceramics", International Journal of Machine Tools & Manufacture 90, 16–28.

[23] Naresh Kumar, Himanshu Tripathi, Sandeep Gandotra (2015), "Optimization of Cylindrical Grinding Process Parameters on C40E Steel Using Taguchi Technique", Int. Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 5, Issue 1(Part 3), pp.100-104.

[24] Jingzhu Pang, Beizhi Li, Yao Liu, Chongjun Wu, (2016) , "Heat Flux Distribution Model in the Cylindrical Grinding Contact Area", 44th Proceedings of the North American Manufacturing Research Institution of SME, Volume 5, 2016, Pages 158–169, doi: 10.1016/j.promfg.2016.08.015

[25] Wang Pei-Zhuo, He Zhan-Shu, Zhang Yuan-xi, Zhao Shu-Sen, (2017), "Control of Grinding Surface Residual Stress of Inconel, 718", 13th Global Congress on Manufacturing and Management, GCMM 2016, Procedia Engineering 174, 504 – 511, doi: 10.1016/j.proeng.2017.01.174.