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Optimization of Surface Roughness and Material Removal Rate on Conventional Dry Turning of Aluminium (6061)

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ABSTRACT

The work and study presented in this paper aims to investigate the effect of the cutting speed, feed rate and depth of cut on surface roughness and material removal rate (MRR), in conventional turning of Aluminium (6061) in dry condition. The cutting tool was prepared with positive Rake angle 20. The effect of cutting condition (cutting speed and feed rate) on surface roughness and MRR were studied and analyzed. Design of experiments (DOE) were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness and the maximum MRR. The feed and speed are identified as the most influential process parameters on surface roughness. The optimum MRR was obtained when setting the cutting speed and feed rate at high values, but the optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible. Low surface finish was obtained at high cutting speed.

Keywords: *Aluminium (6061); ANOVA; Surface Roughnes; Taguchi Method;Material Removal Rate (MRR).*

1.0 Introduction

Most of automotive components are manufactured using a conventional machining process, such as turning, drilling, milling, shaping and planning, etc. Aluminium (6061) is widely used for producing automotive components by turning process. This study aims to investigate the effect of the cutting speed, feed rate and depth of cut on surface roughness, and material removal rate (MRR), in conventional turning of Aluminium (6061) in dry condition. Surface roughness is mainly a result of process parameters such as tool geometry (i.e. nose radius, edge geometry, rake angle, etc) and cutting conditions (feed rate, cutting speed, depth of cut, etc).Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed, cutting speed, tool geometry, and tool setup. Other factors, such as tool, work piece and machine vibration, tool wear and degradation, and work piece and tool material variability cannot be controlled as easily. The important cutting parameters discussed here are cutting speed, feed and depth of cut. It is found in most of the cases surface roughness decreases with increase in cutting speed and decrease in feed and depth of cut. Since these cutting parameters will decide about the type of chips which we expect at the time of machining of a single constant material thus we have to analyze them for no such built-up edge chips formation.

The Taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as speed, feed and depth of cut. Many researchers developed many mathematical models to optimize the cutting parameters to get lowest surface roughness by turning process.

The variation in the material hardness, alloying elements present in the work piece material and other factors affecting surface finish. Proper selection of cutting parameters and tool can produce longer tool life and lower surface roughness. Hence, design of experiments by Taguchi method on cutting parameters was adopted to study the surface roughness.

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Taguchi"s parametric design is the effective tool for robust design it offers a simple and systematic Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments (DOE).

In this paper Taguchi"s (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed, and depth of cut on Surface Roughness of Aluminium 6061 work material while machining with The cutting tool which was prepared with positive Rake angle 20 and to obtain an optimal setting of these parameters that may result in good surface finish. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups.

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance.

Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

2.0 Material Removal Rate

The effects of machining parameters on MRR and surface roughness in turning process were widely investigated by previous researchers. According to Qian and Hosan (2007), the cutting force and feed force increased with increasing feed, tool edge radius, negative rake angle, and work piece hardness. Cutting force and feed force also increased linearly with the depth of cut.

According to Jaharah et al. (2009a), the *Ra* produced was significantly affected by the feed rate, followed by the cutting speed and depth of cut where the contribution of feed rate, the cutting speed and depth of cut were 45%, 32%, and 23% respectively. Ghani et al. (2002) investigated that surface finish of the work piece was not influenced by the tool wear; however, increasing cutting speed, feed rate or depth of cut will affect the surface finish.

Tool performance was evaluated with respect to tool wear, surface finish produced and cutting forces generated during turning (Yigit et al., 2008). Jaharah et al. qualitative optimal design to a relatively low cost.

The (2009b) said that the width formation of microstructure changes increases with the increase in wear land and feed rate. Taguchi methods DOE was used to optimize the surface roughness and MRR value. Taguchi methods is a powerful tool for designing a high-quality system that provides smaller, less costly experiments and yet withdraw a valid conclusion. Taguchi"s parameter design also offers a simple, systematic approach and can be used to optimize design for performance, quality and cost. Signal-to-noise (S/N) Ratio and orthogonal array are two major tools used in robust design.

Signal-to- noise (S/N) ratio, which measures quality with emphasis on variation, and orthogonal arrays, which accommodates many design factors simultaneously (Park 1996, Phadke 1998). Taguchi method also offers the quality of product which is measured by quality characteristics such as: nominal is the best, smaller is better and larger is better (Phadke 1998).

Taguchi techniques were widely used in engineering analysis in the system, parameter and tolerance design (Pease, 1993). Other researchers (Hascalik and Caidas, 2008; Pawade et al., 2008; Kurt et al., 2009) also utilized Taguchi methods in their various research activities.

Understanding of material removal concept (MRR) in metal cutting is very important in designing process and cutting tool selection to ensure the quality of the product. The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm3/min. For each revolution of the work piece, a ring shaped layer of material is removed.

Therefore, MRR in mm3/min is: 1000 Vfa Where V is: πdn /1000, is cutting speed in mm/min, d is diameter of the work piece in mm, n is spindle speed in rpm, f is machine feed rate mm/revolution. a is depth of cut.

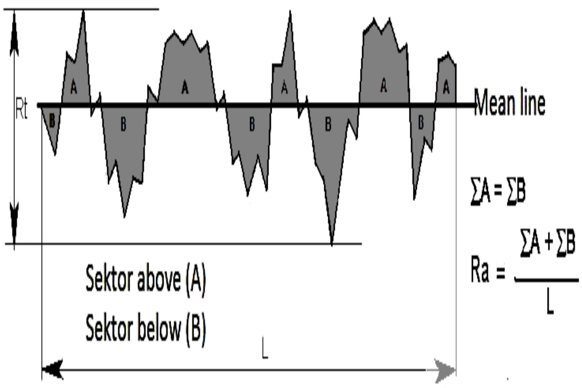
3.0 Surface Roughness

Out of all the surface condition criteria, *Ra* and *Rt* (expressed in µm) are often used to characterize the roughness of machined surfaces.

Rt is total roughness (maximum depth or amplitude of the roughness), and *Ra* is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness) as Ra = (ΣA + ΣB) / L. (*H. Yanda et.al.* 2010).Definition of the mean line is Σ*A* = Σ*B* as shown in Figure 1. Surface condition is being determined by several factors:

- Cutting parameters (cutting speed, feed)
- Tool geometry (angle and sharpness of the cutting edge, corner radius, etc)
- The material the cutting tool is made from the rigidity of the assembly and of the machine
- The forming of chips, cutting forces, etc.

Fig 1: Schematic of parameter definition used to compute the mean arithmetic deviation (*Ra*) and total roughness (*Rt*) (*H. Yanda et.al,* 2010)



4 .0 Experiment Set Up

The machining trials were carried out in dry condition without coolant on conventional Lathe Machine model Kirloskar Turnmaster-35. The work piece material used was 6061 Aluminum HINDALCO made. The cylindrical work piece was prepared in the form of round bar 50 mm in diameter and 150 mm in length. The machining condition parameters were the cutting speed of 180, 450 and 710 rpm, feed rate of 0.2, 0.315 and 0.4 mm/rev, while the depth of cut (DOC) was 0.2,0.4,0.6 mm. The effect of cutting condition (cutting speed and feed rate) on surface roughness and material removal rate (MRR) were studied and analyzed.

Experiments were conducted based on the Taguchi design of experiments (DOE) with orthogonal L27 array, and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness and the maximum MRR.

4.1 Work piece material

Standardized material were selected to ensure consistency of the alloy, which was a common wrought alloy used in industry 6061 Aluminum HINDALCO made in the form of bars with the size of diameter 50 mm 150 mm length so as to fit under the chuck.

Table: 1. Chemical Composition of Aluminum Alloy

Element	Cu	Mg	Si	Fe	Mn	Other
Weight %	0.15-0.4	0.7-1.2	0.4-0.8	0.7 max	0.2-0.8	0.4

The aluminum we have chosen for turning is actually a Heat Treatable Alloy manufactured in the form of bars by HINDALCO. The inputs which were fed in the form of part program include dimensions of the work piece, cutting parameters depth of cut in mm, Speed available was 50-3500 rpm and feed in mm/min. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables.

Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Alloy 6061 is easily welded and joined by various commercial methods. (Caution: direct contact by dissimilar metals can cause galvanic corrosion). For screw machine applications, alloy 6061 has adequate mach inability characteristics in the heat-treated condition.

The different alloying elements present in a work piece are shown in the Table 1.The control factors and their levels are illustrated in Table 1. The cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tools

Table: 2. Cutting Parameters and Levels

Code	Cutting Parameter	Level 1	Level 2	Level 3
	Speed „s" (rpm)	180	450	710
	Feed „f " (mm/rev)	0.2	0.315	0.4
	Depth of cut „d" (mm)	0.2	0.4	0.6

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument, the Surtronic 3+, is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory.

Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm.The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

The dependent variable is surface roughness. Table 3 shows standard L27 (33) orthogonal array designed by Taguchi with experimental results. the Table 3 includes coding values of control factors ,real values of cutting parameters and the results of the measured values of the surface roughness and calculated values. The different units used here are: speed- rpm, feed - mm/ rev, depth of cut -mm and surface roughness Ra - µm. Design – MINTAB software was used for Taguchi"s method and for analysis of variance (ANOVA).

4.2 Surface roughness

Surface properties such as roughness are critical to the function ability of machine components. Increased understanding of the surface generation mechanisms can be used to optimize machining process and to improve component function ability.

The present study has shown two purposes. The first was to demonstrate the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters and a systematic procedure using Taguchi design in process design of turning operations. The second was to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters using ANOVA. The obtained results are analyzed using Minitab software and all the values are shown in the Table 4.

Table: 3. Machine Readings and Calculations of Roughness

Experiment.No	Control Factors			Speeds (s)	Feed (f)	Depth of cut (d)	Measured Ra	MRR mm^3/min	MRR mm^3/sec
	A (s)	B (f)	C (d)	(Rev/min.)	(mm per rev.)	(mm)	(µm)	(mm^3/min)	(mm^3/sec)
1	1	1	1	180	0.2	0.2	1.04	113.927	8.56545
2	1	1	2	180	0.2	0.4	0.98	212.018	6.86697
3	1	1	3	180	0.2	0.6	2.2	261.698	4.36163
4	1	2	1	180	0.315	0.2	2.44	672.129	7.86882
5	1	2	2	180	0.315	0.4	3.84	333.569	5.55948
6	1	2	3	180	0.315	0.6	2.4	897.738	1.62897
7	1	3	1	180	0.4	0.2	2.06	022.443	3.70738
8	1	3	2	180	0.4	0.4	2.3	953.491	5.89151
9	1	3	3	180	0.4	0.6	3.66	901.732	8.3622
10	2	1	1	450	0.2	0.2	0.9	780.859	6.34764
11	2	1	2	450	0.2	0.4	0.94	528.915	2.14858
12	2	1	3	450	0.2	0.6	2.9	145.761	35.7627
13	2	2	1	450	0.315	0.2	1.42	176.76	9.61266
14	2	2	2	450	0.315	0.4	3.38	303.637	38.3939
15	2	2	3	450	0.315	0.6	1.34	2263.05	04.3842
16	2	3	1	450	0.4	0.2	1.74	040.271	4.00451
17	2	3	2	450	0.4	0.4	1.94	890.513	64.8419
18	2	3	3	450	0.4	0.6	2.88	4822.2	47.0366
19	3	1	1	710	0.2	0.2	0.86	130.586	8.84311
20	3	1	2	710	0.2	0.4	0.92	744.814	45.7469
21	3	1	3	710	0.2	0.6	1.98	2862.91	14.3818
22	3	2	1	710	0.315	0.2	1.14	592.809	09.8802
23	3	2	2	710	0.315	0.4	1.22	3098.48	18.308
24	3	2	3	710	0.315	0.6	1.16	9365.24	22.7539
25	3	3	1	710	0.4	0.2	1.2	948.858	32.481
26	3	3	2	710	0.4	0.4	1.38	5658.57	60.9762
27	3	3	3	710	0.4	0.6	2.68	3305.82	88.4304

Table: 4. ANOVA: Analysis of Variance for Raversus s, f, d

Source	DF	SS	MS	F	P
ss	22	3.9387	1.9693	33.97	0.035
ff	22	3.1307	1.5653	33.16	0.064
dd	22	3.9207	1.9604	33.95	0.036
Error	220	9.9167	0.4958		
Total	226	20.9069			

Table: 5. ANOVA: Analysis of Variance for MRR versus s, f, d

Source	DF	SS	MS	F	P
s	2	107200	53600	7.86	0.000
f	2	24922	12461	8.80	0.002
d	2	74221	37110	6.21	0.000
Error	20	28317	1416		

Table: 6. Ranking of Cutting Parameters

Level	1	2	3	Rank
Speed	180	450	710	1
Feed	0.2	0.315	0.4	2
Depth of cut	0.2	0.4	0.6	3

It can be seen from ANOVA table 4 that feed is the maximum contributing factor and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares and Error are mentioned. Hence as a result the individual ranking of cutting parameters on the average value of mean on surface roughness are shown in Table 5.

Fig: 2. Residual Histogram for Ra

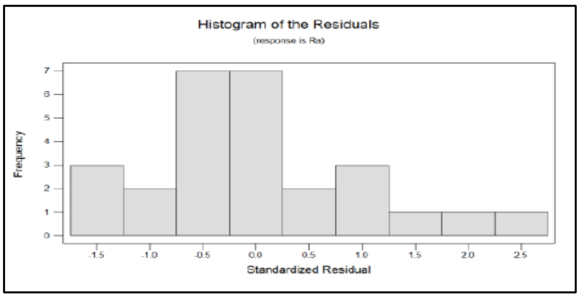


Fig: 3. Normplot of Residuals for Ra

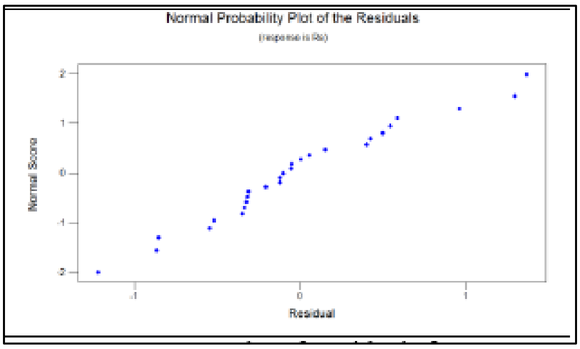


Fig: 4. Normplot of Residuals for MRR

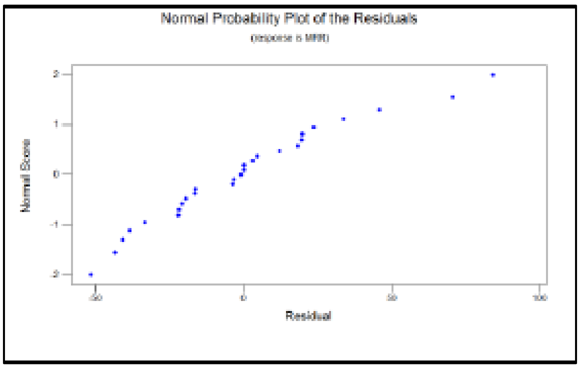


Fig: 5. Residuals vs Order for Ra

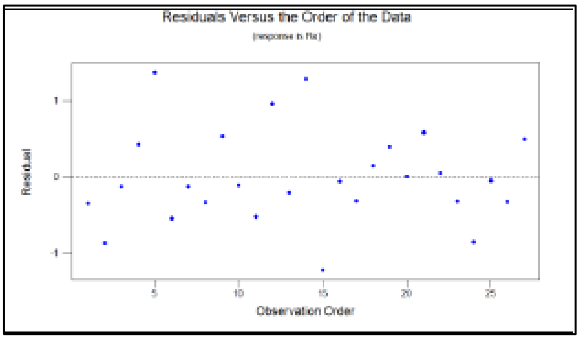
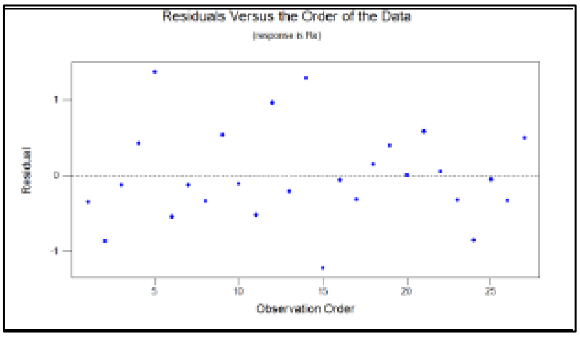


Fig: 6. Residuals vs Order for MRR



5.0 Main effect plots analysis for Ra and MRR

The analysis is made with the help of software package MINITAB. The main effect plot for Ra and MRR are shown in following figures .They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish.

According to this main effect plot, the optimal conditions for minimum surface roughness are speed at level 3 (710 RPM), feed rate at level 1 (0.2 mm/rev) and depth of cut at level 1 (0.2mm). The main effect plot for S/N ratios of the Surface roughness for data means is shown in Fig 7, 8, 9,10,11,12. Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for surface roughness are shown in Fig. These are generally fall on a straight line implying that errors are distributed normally. From Fig .4, 5, 6, 7, it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

Hence these values yield better results in future predictions.

5.1 Main effect plots analysis for Ra

Fig: 7. Main Effects for S/N Ratios: Ra

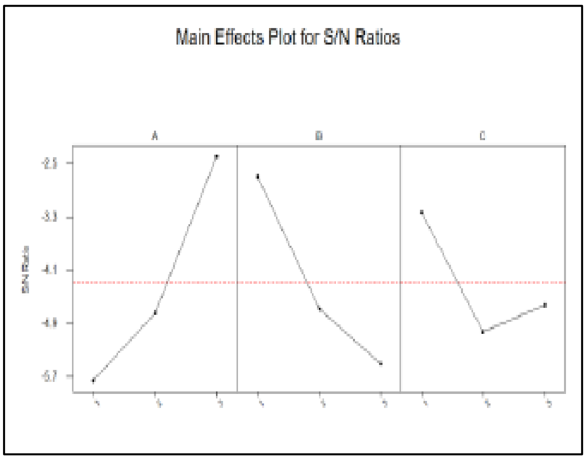


Fig: 8. Main Effects for Means: Ra

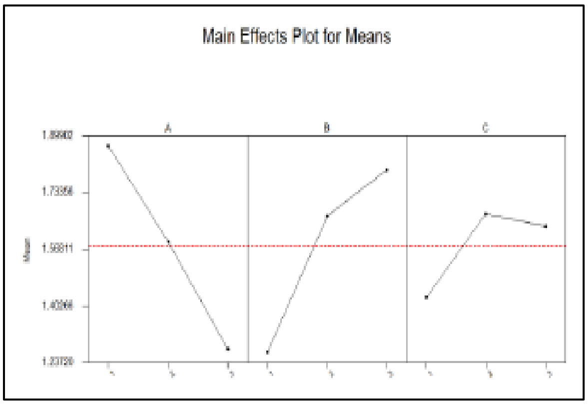
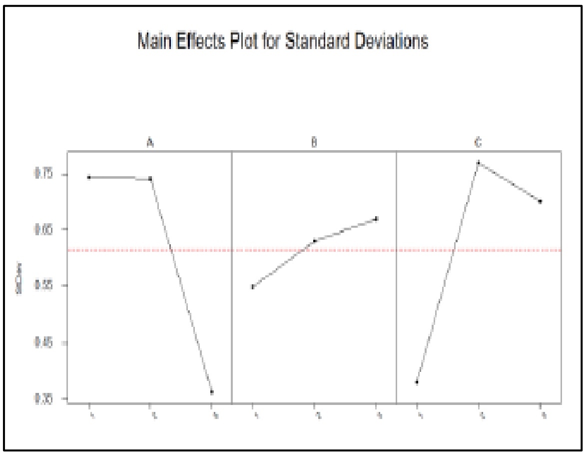


Fig: 9. Main Effects for St Devs: Ra



5.2 Main effect plots analysis for MRR

Fig: 10. Main Effects for S/N Ratios: MRR

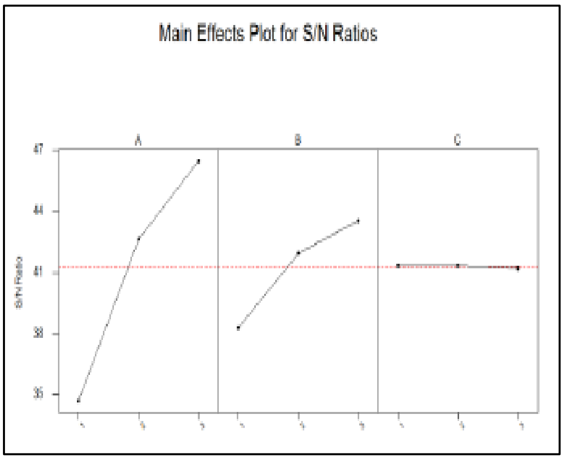


Table: 7. Response Table for Signal to Noise Ratios for Ra and MRR

Response Table for Signal to Noise Ratios for Ra	Response Table for Signal to Noise Ratios for MRR
Smaller is better Level A B C 1 -5.74857 -2.68229 -3.22270 2 -4.73456 -4.68106 -5.02022 3 -2.37977 -5.49955 -4.61998 Delta 3.36880 2.81726 1.79752 Rank 1 2 3	**Larger is better** Level A B C 1 34.6822 38.2777 41.3009 2 42.6291 41.9417 41.3000 3 46.4629 43.5548 41.1734 Delta 11.7807 5.2772 0.1275 Rank 1 2 3
Response Table for Means Level A B C 1 1.86893 1.26729 1.42604 2 1.58814 1.66609 1.67230 3 1.27651 1.80020 1.63525 Delta 0.59243 0.53292 0.24626 Rank 1 2 3	Response Table for Means Level A B C 1 1602.31 2755.25 4258.54 2 4007.47 4162.88 4138.52 3 6309.44 5001.09 3522.15 Delta 4707.13 2245.84 736.39 Rank 1 2 3
Response Table for Standard Deviations Level A B C 1 0.744674 0.549658 0.378507 2 0.742362 0.630062 0.769872 3 0.362392 0.669709 0.701050 Delta 0.382283 0.120051 0.391365 Rank 2 3 1	Response Table for Standard Deviations Level A B C 1 1958.01 3384.97 5209.71 2 4901.91 5089.40 5059.80 3 7732.96 6118.51 4323.37 Delta 5774.95 2733.55 886.33 Rank 1 2 3

Fig: 12. Main Effects for St Devs: MRR

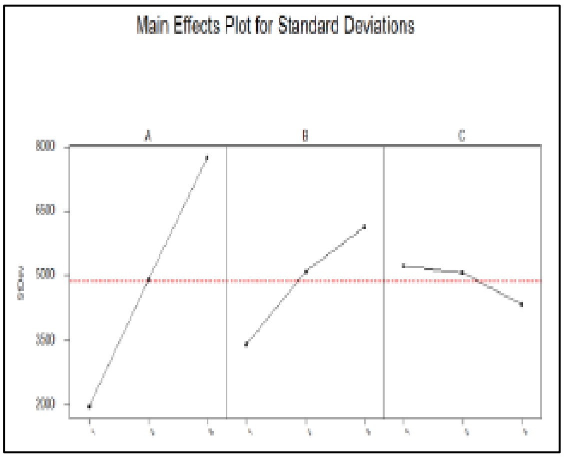
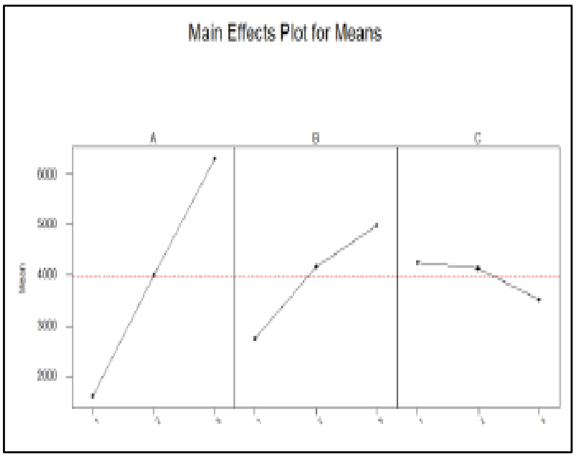


Fig: 11. Main Effects for Means: MRR



6.0 Conclusions

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. Strong interactions were observed among the turning parameters. Most significant interactions were found between work materials, feed and cutting speeds. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend. The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- From the data collection it has been observed that the increase in cutting speed tends to improve the finish, thus the average surface roughness value decreases.
- The increase in depth of cut influences the finish slightly, but greater depth of cut marks the finish poor.
- Speed is the most critical parameter when finish is the criterion.
- Finish gets poor as the feed increases, thus the average surface roughness value increases with increase in feed.
- The ANOVA and F-test revealed that the speed and depth of cut are dominant parameters followed by feed for surface roughness.
- The optimal combination process parameters for minimum surface roughness are obtained at 710 rpm, 0.2 mm/rev and 0.2mm.
- Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

References

[1] A. V. N. L. Sharma, K.Venkatasubbaiah, P. S. N. Raju, "Parametric Analysis And Multi Objective Optimization Of Cutting Parameters In Turning Operation Of EN353 – With CVD Cutting Tool Using Taguchi Method" Journal Of Engineering And Innovative Technology (IJEIT), 2, ISSN: 2277-3754 ISO 9001:2008, 2013

[2] Alexandru Stanimir, Marius Zamfirache, Nicolae Cătălin EFTENIE Universityof Craiova "Regressions Modeling Of Surface Roughness In FinishTurning Of Hardened 205cr115 Steel Using Factorial Design Methodology" Fiabilitate Si Durabilitate - Fiability & Durability No 1(7)/ 2011, Editura "Academica Brâncuşi" , Târgu Jiu, ISSN 1844 – 640X, 2011

[3] P. Ananthakumar, M. Ramesh, Parameshwari, "Optimization of Turning Process Parameters Using Multivariate Statistical Method-PCA Coupled With Taguchi Method",

[4] A. E. Cerenitti, B. P. Fallbohmer, W. Wu, B. T. Altan, "App. of 2D FEM to chip formation in orthogonal cutting", J of Materials Processing Technology, 59, 169-180, 1996

[5] Choudhury, M. A. El-Baradie, "Surface roughness prediction in the turning of high strength steel by factorial design of experiments", Journal of Materials Processing technology, 67 (1997) 55-67

[6] D. Philip Selvaraj, P. Chandramohan, "Optimization Of Surface Roughness Of AISI 304 Austenitic Stainless Steel In Dry Turning Operation Using Taguchi Design Method", Journal Of Engineering Science And Technology 5(3), (2010) 293 – 301

[7] A. K. Ghani, I. A. Choudhury, Husni, "Study of tool life, surface roughness & vibration in machining nodular cast iron with ceramic tool", J of Material Processing Technology, 127, 17–22, 2002

[8] A. Hascalik, U. Caydas, "Optimization of turning parameter for surface roughness and tool life based on the Taguchi method", Int. J. Advanced Manufacturing Technology, 38, 1148- 1156, 2008

[9] H. Yanda, J. A. Ghani, M. N. A. M. Rodzi, K. Othman, C.H.C. Haron, "Optimization of Material Removal Rate, Surface Roughness and Tool Life on Conventional Dry Turning Of FCD700", International Journal of Mechanical and Materials Engineering, 5(2), 182-190, 2010

[10] Ilhan Asiltürk, Harun Akkus, "Determining The Effect Of Cutting Parameters On Surface Roughness In Hard Turning Using The Taguchi Method" Measurement 44 (2011) 1697–1704, Journal Homepage: Www.Elsevier.Com/ Locate/Measurement

[11] A. G. Jaharah, M. N. Azmi, M. Rodzi, A. R Moh. Nizam, Che C. H. Hassan, "Machinability of FCD500 ductile cast iron using coated carbide tool in dry machining

condition", Int. J. of Mechanical and Materials engineering, 4 (3), 279- 284, 2009a

[12] A. G. Jaharah, C. H. Che Hassan, N. Muhamad, "Machined surface of AISI H13 tools steels when end milling using P10 tin ciated carbide tools", European Journal of Scientific Research, 26 (2), 247-254, 2009b

[13] Jitendra Verma, Pankaj Agrawal, Lokesh Bajpai, "Turning Parameter Optimization for Surface Roughness of Astm A242 Type-1 Alloys Steel by Taguchi Method", International Journal of Advances in Engineering & Technology, March, ©IJAET ISSN: 2231-1963, 255 3(1), Pp. 255-261, 2012

[14] K. Mani lavanya, R.K.Suresh, A. Sushil Kumar Priya, V. Diwakar Reddy, "Optimization Of Process Parameters In Turning Operation Of AISI-1016 Alloy Steels With CBN Using Taguchi Method And Anova", IOSR Journal Of Mechanical And Civil Engineering (IOSR-JMCE) E-ISSN: 2278-1684,P-ISSN: 2320-334X, 7(2), PP 24-27 www.Iosrjournals.Org, 2013

[15] M. Kurt, E. Bagci, Y. Kaynal, 2009. App. of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes, Int. Journal Advanced Manufacturing Technology, 40, 458- 469

[16] M. Kaladhar, K. V. Subbaiah, Ch. Srinivasa Rao, K. Narayana Rao, "Application Of Taguchi Approach and Utility Concept In Solving The Multi-Objective Problem When Turning AISI 202 Austenitic Stainless Steel", Journal Of Engineering Science And Technology Review 4 (1) 55-61, 2011

[17] Manish Kumar Yadav, P. K. Sinha, Gopal P. Sinha, "Paper On A Comparative Study Of Surface Roughness In Multi Tool Turning With Single Tool Turning Through Factorial Design Of Experiments", International Journal Of Scientific & Engineering Research, 3(8), August-2012 1 ISSN 2229-5518 IJSER © 2012 http://Www.Ijser.Org, 2009

[18] Marinković Velibor, Madić Miloš, "Optimization of Surface Roughness in Turning Alloy Steel by Using Taguchi Method", Scientific Research and Essays, 6(16), Pp. 3474-3484, 19 August, 2011, ISSN 1992-2248 ©2011 Academic Journals

[19] Naveen, A. Sait, S, Aravindan, Noorul Haq., A., "Influence of machining parameters on surface roughness of GFRP pipes", Journal of Advances on Production Engineering and Management, 4 (1-2), p. 47-58, 2009

[20] Palanikumar, L. Karunamoorthy, R. Krathikeyan, "Assessment of factors influencing surface roughness on the machining of glass– reinforced polymer composites", Journal of Materials and Design, 27 (2006) 862-871

[21] S. H. Park, "Robust Design and Analysis for Quality Engineering, London, Chapman & Hall, 1996

[22] R. S. Pawade, S. S. Joshi, P. K.Brahmankar, "Effect of machining parameters and cutting edge geometry on surface integrity of high speed machining turned Inconel" 718, Int. J. Machining, Tools Manufacturing, 48, 15-28, 2008

[23] G. S. Pease, "Taguchi Methods: A Hands-on Approach to Quality Engineering", Addison Wesley, New York, 1993

[24] M. S. Phadke, "Quality Engineering Using Design of Experiment, Quality Control, Robust Design and Taguchi Method", California, Warsworth & Books, 1998

[25] Puertas Arbizu, C. J. Luis Perez, "Surface roughness prediction by factorial design of experiments in turning processes", Journal of Materials Processing Technology, 143- 144 (2003) 390-396

[26] L. Qian, Hossan, M. R, "Effect on cutting force in turning hardened tool steels with cubic boron nitride insert", J of Materials Processing Technology, 191, 274-278, 2007

[27] Rahul Davis, Jitendra Singh Madhukar, Vikash Singh Rana, Prince Singh, "Optimization of Cutting Parameters in Dry Turning Operation of EN24 Steel", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com, ISSN 2250-2459, 2(10), October 2012

[28] Ranganath M S, Vipin, "Experimental Investigations on Surface Roughness for Turning of Alumunium (6061) Using Regression Analysis" Journal of Modeling

and Simulation in Design and Manufacturing, 3(1&2), 2013, pp 190-196

[29] Ranganath M S, Vipin, R S Mishra, "Optimization Of Process Parameters In Turning Operation Of Aluminium (6061) With Cemented Carbide Inserts Using Taguchi Method And ANOVA", International Journal of Advance Research and Innovation Website: www.ijari.org ISSN 2347-3258, 1(1), 16-28,2013

[30] Ranganath M S, Vipin, "Optimization of Process Parameters in Turning Using Taguchi Method and ANOVA: A Review" International Journal of Advance Research and Innovation Website: www.ijari.org ISSN 2347-3258, Volume 1(1), 42- 61, 2013, 2013

[31] L. L. R. Rodrigues, A. N. Kantharaj, B. Kantharaj, W. R. C. Freitas, B. R. N. Murthy, "Effect Of Cutting Parameters On Surface Roughness And Cutting Force In Turning Mild Steel" Research Journal Of Recent Sciences International Science Congress Association Vol. 1(10), 19-26, October (2012) Res. J. Recent Sci ISSN 2277-2502, 2012

[32] T. Tamizharasan, T. Selvaraj, A. Noorul Hag, "Analysis of tool wear and surface finish in hard

[33] Vipin, Harish Kumar, "Surface Roughness Prediction Model by Design of Experiments for Turning Leaded Gun Metal", International Journal of Applied Engineering Research ISSN 0973-4562, 4(12) Pp. 2621–2628

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

[35] X. L. Liu, D. H. Wen, Z. J. Li, Xiao, .G. Yan, "Experimental study on hard turning of hardened GCr15 steel with PCBN tool", Journal of Materials Processing Technology, 129 (2002) 217-221

[36] Yigit Kazancoglu, Ugur Esme, Melih Bayramo glu, Onur Guven, Sueda Ozgun", Multi-Objective Optimization Of The Cutting Forces In Turning Operations Using The Grey-Based Taguchi Method", Original Scientific Article/Izvirni Znanstveni ~Lanek MTAEC9, 45(2)105(),ISSN 1580-2949, 2011

[37] R. Yigit, E. Celik, F. Findik, S. Koksal, "Effect of cutting speed on the performance of coated and uncoated cutting tools in turning nodular cast iron", Int. J of Materials Processing Technology, 204, 80-88, 2008