MULTI OBJECTIVE OPTIMIZATION OF PROCESS PARAMETERS IN TURNING OF ALUMINIUM 7068 USING TAGUCHI BASED GREY RELATIONAL ANALYSIS

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ABSTRACT

The present work focuses on optimizing the process parameter in CNC turning of Aluminium 7068 alloy using the Taguchi method with the use of multi-response criteria for grey relational analysis. Nine experimental trials were performed using L9 orthogonal Taguchi Array. Cutting speed, feed rate & cutting depth is optimized by taking as a response of performance characteristic such as surface roughness & material removal rate. Taguchi signal to noise ratio was used to define optimum levels of parameters. Analysis of grey relationships used to solve the multi-response optimization problem and find the optimum set of parameters. Analysis of variance (ANOVA) has assessed the impact of parameters on the overall quality characteristics of the cutting process. The optimal parameter values obtained during the study have been validated by confirmation experiment.

KEYWORDS: GRA, ANOVA, Surface Roughness, MRR, Cutting Depth & S/N Ratio etc

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ABBREVIATIONS

CNC	Computer numeric control
ANOVA	Analysis of variance
GRA	Grey Relational Analysis
SR	Surface Roughness (μm)
MRR	Material removal rate (mm^3/min)
TS	Tool speed
FR	Feed rate
CD	Cutting depth

1. INTRODUCTION

Turning is the most frequently used in all cutting processes. Surface finish is the product quality measurement tool, and is an important parameter in the process of machining. This is one of the customer's prime demands for machined parts. Productivity is also required to meet demand from customers. For this reason, product quality and productivity should be high. Indeed an important feature in turning phase is the material removal rate (MRR), which is also desirable in addition to surface finish consistency and high MRR. Aluminium alloys are common structural materials used in different engineering components because of their low density and beneficial mechanical characteristics. Al 7068 alloy is one of the 7xxx series' most common aluminium alloys that can provide alloy elements with high

mechanical strength [1]. Due to their combination of weightlessness and high strength property, the application of aluminium alloys in manufacturing companies has increased significantly over the years. With this production, the machining of aluminium alloys has increased enormously in volumetric proportions, allowing it to be widely used in specific sectors such as aerospace [2]. The use of such alloys is also of concern to the automobile industry applications where high-resistance alloys can lead to significant weight savings which is a viable strategy for reducing the effect of automobiles on the environment while preserving crash worth [3]. It is widely applied in the aerospace and aeronautical manufacturing companies due to its higher strength to weight ratio [4]. In general, the machining process is the most advantageous finishing operation in order to achieve greater dimensional accuracy and optimum surface finish in the area of manufacturing. Components, and the cost of production. Some analysis shows that the surface element is the most significant requirement, along with geometric and dimensional aspects. All manufacturing companies are looking for lower roughness, tool wear and higher rate of material removal to deliver a better product at a lower cost. Most of the manufacturing jobs involve turning. During turning, surface roughness is important factor. It is greatly affected by parameters such as cutting speed, feed rate, cutting depth, tool material and the effect of signature. Optimization of parameters in turning process was studied and analyzed by a variety of researchers regarding the choice of conditions for different materials using various methods. N V S Shankara et. al [5] optimized the machining parameters during turning of EN19 with coated carbide inserts on conventional lathe machine. They found that speed is the most influential when both vibrations and surface roughness are considered. M. S. Karthik et. al [6] experiments on hardened EN31 steel with hard turning machine Hardinge have been performed using BN tools under dry conditions to test the effect of cutting parameters on surface roughness. They found that EN31 steel surface roughness increases with feed increase for all the different cutting speed and cut depth values. They also found that feed is the most important and dominant parameter for surface roughness improvement. Palaniappan, et. al [7], In order to determine optimum parameters for the CNC turning process, aluminium 6082 alloy machining is investigated experimentally. They found that the most significant parameter for MRR was speed similarly feed was the most significant parameter for SR. Alagarsamy S.V. et al. [8] studied the application of Taguchi technique to minimize the necessary surface roughness and maximizing material removal rate of aluminium alloy 7075 in turning using the carbide tool TNMG 115 100 tungsten. The experimental results showed that the feed is the most critical parameter for surface roughness followed by speed and cutting depth. M Kumar Vinoth et. al [9] explores the impact of cutting parameters such as speed, feed and cut depth on AA2024 content removal rates. Taguchi methodology was applied to optimize the cutting parameters. The research reveals that speed, feed rate and cutting depth directly control the material removal rate. It has been found that the rate of material removal increases with feed rate, spindle speed and frequently for all cutting depth. Kumar, M et. al [10] investigate the influence of turning parameters feed rate, depth of cut and spindle speed. They observed that rate of material removal increases with increases in feed rate, MRR, cut depth and spindle speed, compared to coolant, when dry machining. The surface roughness often decreases with increased cutting depth and spindle speed, the surface roughness can be decreased by reducing the feed rate, and the surface roughness can be minimized at coolant condition.

A. Palanisamy et. al [11] determined the effect of optimal parameters for machining of Incoloy 800H. They used taguchi based grey relational method to investigate the effect of control parameters on surface roughness and material removal rate. They found that in turning process the most significant parameter is feed rate compared with cutting speed and depth of cut for multi response optimization. The percentage contribution of feed rate was 82.71 %, depth of cut was 10.11 % and cutting speed was 1.72 %. Das, Diptikanta et. al [12] analyse the Influence of machining process parameters on the surface roughness characteristics (i.e. Rz and Rt). Analysis of Variance (ANOVA) showed that for Rz, feed was the most

important parameter followed by spindle speed; and the effect of cut depth was negligible. Similarly, spindle speed was the most significant parameter for R_t , followed by depth of cut and feed. Kosaraju et. al. [13] investigate the effect of control parameters on surface roughness and cutting force in turning process. They used Inconel 625 as material and found that feed is identified as the most significant parameter for the tuning operation according to the weighted sum grade of the cutting force and surface roughness. Using Taguchi's Grey Relational Analysis, Ramana, M. Venkata et. al [14] analyzes the optimization of process parameters to simultaneously minimize surface roughness, machine wear and material removal rate (MRR) maximisation. The findings show that machining with MQL, cutting speed at 63 m/min, feed rate at 0.206 mm/rev, cutting depth at 1.6 mm, and uncoated tool was found to be satisfactory. Khare, Kumar, Sanchit et. al [15], In order to optimize minimum surface roughness on AISI 4340, al[15] examined the machining parameters, namely cutting speed, feed rate, cut depth and rake angle. It was observed that cutting speed and depth of cut was the most influential factors on the surface roughness. Rajesh, N. al[16] uses HSS tool with and without coolant to examine the effect of different cutting parameter values on Al6061 workpieces. Regression models for cutting temperature and surface roughness are developed to examine the effects on machining responses of cutting parameters speed, feed and cut depth. Ramana, M. Venkata et al.[17] used Taguchi 's robust design technique to optimize process parameters to reduce surface roughness when turning Titanium alloy (Ti-6Al-4V) with various tool materials under dry machining. The findings show that uncoated tool is suitable at low cutting speeds while PVD coated tools at high cutting speeds are suitable. Analysis of variance (ANOVA) shows that feed rate is more significant in minimizing surface roughness for uncoated and PVD-coated tools. Camposeco Negrete et al [18] examine the optimization of the cutting parameters during turning of AISI 6061 T6 under rough conditions with a view to achieving minimal energy usage. Results from this research work have shown that feed rate is the most significant factor in reducing energy consumption and roughness of surfaces. Nayak, Kumar, Shreemoy et. al [19] investigated the effect of various parameters of machining such as cutting speed, feed and cutting depth on different output measurements during dry turning of AISI 304 austenitic stainless steel. This measured three main features of machinability, such as rate of material removal, cutting force, and roughness of the surface. Jayaraman, P. et al. [20] provides a new method for optimizing the machining parameters while turning the aluminium alloy AA 6063 T6 With multiple orthogonal array-based responses with grey relational analysis. turning parameters such as cutting speed, feed rate and depth of cut are optimized considering the multiple responses such as surface roughness (R_a), roundness (ϕ) and material removal rate (MRR). It is discovered from this study that feed rate, cut depth are prominent factors influencing the aluminium alloy turning.

2. Experimental Details

2.1 Material

The material used in the experiment are aluminium 7068 alloy which is used in various applications such as aerospace, connecting rods, autoparts, gearbox etc.

2.2 Specimen Details

The aluminium 7068 rod raw material of 32 mm diameter was rough turned down to 30 mm using CNC Turning machine. Nine work pieces with a diameter of 30 mm and a length of 60 mm were prepared for machining as shown in figure. (2)(b)

Figure 2(a).

Figure 2(b).

2.3 Machining Process

The machining process was performed by using CNC Turning Machine “CNC Lathe Gildemeister CTX 400 ”shown in figure. 2 (a). The machine consists of powerful spindle which has a capacity of maximum 5000 rpm.

2.4 Cutting Tool

Throughout the experiment, the CBN insert was used. In all the 9 hard turning experiments combination 9 fresh cutting edges were used to allow measurements of the obtained values.

3 PROCESS PARAMETERS

In the present work, three process parameters, namely spindle speed, feed rate and cut depth were considered to be the predominant parameters based on the output performance characteristics of any materials turning process with the aim of minimizing surface roughness and maximizing the material removal rate.

Each parameter was assigned three level values and based on parameter and level values using Taguchi’s method, L9 orthogonal array as shown in table 3 was selected to produce turning for the analysis surface roughness.

Table 1: Chemical Composition of Aluminium 7068

Elements		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
Weight (%)	Min			1.60		2.20		7.30		0.05
	Max	0.12	0.15	2.40	0.10	3.0	0.05	8.30	0.10	0.15

Table 2: Properties of Aluminium 7068

Elements	Ultimate Tensile Strength, MPa	Yield Strength, MPa	Elongation
	641	590	8 %

Table 3: Parameter Level Value

Level	Spindle Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)
1	1500	0.1	0.4
2	2000	0.2	0.6
3	2500	0.3	0.8

Table 4: L9 Orthogonal Array

Exp. No	Control Factors			Responses	
	Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Surface Roughness (μm)	MRR (mm^3/min)
1	1500	0.1	0.4	1.948	5868.42
2	1500	0.2	0.6	3.892	15552.63
3	1500	0.3	0.8	7.83	32421.05
4	2000	0.1	0.6	1.732	9947.37
5	2000	0.2	0.8	3.662	27438.60
6	2000	0.3	0.4	5.126	22789.47
7	2500	0.1	0.8	1.212	16357.89
8	2500	0.2	0.4	1.923	19578.95
9	2500	0.3	0.6	6.132	31368.42

2.6 Surface Roughness Measurement

The surface roughness was measured at three different locations by using surface roughness tester (Mitutoyo Talysurf SJ-210) and the average surface roughness (SR) value is considered.

2.7 Material Removal Rate

The work piece weight is measured using a high precision digital balance meter which can measure up to 10^{-3} gms of accuracy and thus eliminate the possibility of large errors when calculating the Material Removal Rate (MRR) in straight turning operation.

Material Removal Rate is calculated using equation (1) i.e., the difference of weight of work piece before and after experiment.

$$\text{MRR} = \frac{1000 * W_w}{\rho_w * t} \text{ mm}^3/\text{min eq.} \quad (1)$$

Where, $W_w = W_i - W_f$,

W_i is the initial weight of the workpiece in gms; W_f is the final weight of work piece in gms; t is the machining time in minutes; ρ_w is the density of aluminium 7068 (2.85 g/cc).

3. EXPERIMENTAL DESIGN & OPTIMIZATION

Three control factors for each control factor are considered in the analysis, with three levels. Thus L9 (33) Taguchi orthogonal array is used for the experimental analysis according to the DOE study. Therefore, the analysis includes 9 trails, and the model for the experiment is shown in table 4.

3.1 Taguchi Technique

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulates the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter.

Taguchi recommend signal to noise (SN) ratio which is the logarithmic function of desired response act as the objective function for optimization. The level at which the highest SN ratio is the level of optimal combination of machining parameters.

The overview statistic (η) in Taguchi system is called signal-to - noise (S / N) ratio. The value of (η) is an important

index for evaluating the impact of parameters of processing on property.

The summary statistic (η) is defined as the following formula:

$$\eta = 10 \log(\text{S/N ratio}) = 10 \log 1/\sigma^2 = -10 \log \sigma^2 \text{ eq.} \quad (2)$$

$$\text{For, Smaller-the-better (SB)} \sigma^2 = 1/n (y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2) \text{ eq.} \quad (3)$$

$$\text{For, Larger-the-better (LB)} \sigma^2 = 1/n (1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \dots + 1/y_n^2) \text{ eq.} \quad (4)$$

Where (η) denotes the calculated value of S/N ratio (unit: dB) y_n represents the measured experimental value and n is a repeated number. Surface roughness are in the category of smaller the better performance characteristics and material removal rate (MRR) are in larger the better category.

3.2 Grey Relational Analysis

Grey relational analysis with Taguchi design is the best solution to know the parameters of the combined response. GRA involves three main steps for analysis. The first stage is for individual normalize of the measured output function. Since the goal is to minimize surface roughness, the equation 'smaller is better' is chosen and can be expressed as

$$x_i(k) = \frac{\max z_i(k) - z_i(k)}{\max z_i(k) - \min z_i(k)} \quad (5)$$

The normalized data processing for MRR corresponding to larger-the-better criterion can be expressed as:

$$x_i(k) = \frac{z_i(k) - \min z_i(k)}{\max z_i(k) - \min z_i(k)} \quad (6)$$

Where $Z_i(K)$ the value obtained from the experiment data, $\min Z_i(K)$ is the minimum value from the experiment. Similarly, $\max Z_i(K)$ is the maximum data obtained from L9 Taguchi design.

The Grey Relational Coefficient is obtained by:

$$\xi_i = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{oi}(k) + \xi \Delta_{\max}} \quad (7)$$

$$\Delta_{oi}(k) = \|x_o(k) - x_i(k)\| \quad (8)$$

where $\Delta_{oi}(k) = \|x_o(k) - x_i(k)\|$ is difference of the absolute value between $x_o(k)$ and $x_i(k)$, $x_o(k)$ is the reference sequence of the k^{th} quality characteristics.

$\Delta_{\min}$ and $\Delta_{\max}$ are respectively the minimum and maximum values of the absolute differences (Δ_{oi}) of all comparing sequences.

ξ is a distinguishing coefficient, $0 \leq \xi \leq 1$, the purpose of which is to weaken the effect of $\Delta_{\max}$ when it gets too big and thus enlarges the difference significance of the relational coefficient. In the present case, $\xi = 0.5$ is used due to the moderate distinguishing effects and good stability of outcomes.

After averaging the Grey relational coefficients, the Grey relational grade γ_i can be calculated as follows:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k) \quad (9)$$

where, $i = 1, 2, 3 \dots 9$, (L9 orthogonal array is selected), $\xi_i(k)$ is the Grey relational coefficient of k^{th} response in i^{th} experiment and n is the number of responses. The optimum level of the process parameters is the level with the highest Grey relational grade.

4. RESULTS & DISCUSSION

4.1 Effect of Parameters on Surface Roughness

4.1.1 S/N Ratio Analysis

The main effects plot gives the optimal combination of turning process parameters. Since the Taguchi approach yields the optimal level combination by choosing the levels at which the S/N ratio is maximum. Figure 3 illustrates the main effect on surface roughness of process parameters such as spindle speed, feed rate and depth of cut. The plot having higher inclination will have higher influence. It is clearly noticed that, high level of spindle speed, low level of feed rate and low level of depth of cut decreases the surface roughness. The mean S/N ratio for surface roughness is given in Table 5. From the Table, feed rate is most influencing parameters for surface roughness followed by speed and depth of cut. The minimum surface roughness is obtained for the optimal combination of parameters (A3B1C1).

Figure 3: S/N Plot of Surface Roughness.

Table 5: S/N Table for Surface Roughness

Level	Speed (A)	Feed Rate (B)	DOC (C)
1	11.823	4.078	8.556
2	10.080	9.586	10.775
3	7.701	15.941	10.273
Delta	4.123	11.863	2.220
Rank	2	1	3

4.1.2 ANOVA Analysis

ANOVA is used to investigate the significant effect on responses of the machining parameters. The table on ANOVA contains the degrees of freedom, the sum of squares, the mean square and the contribution percentage of parameters. In terms of experimental significance, the parameters with higher percentage contribution are ranked higher and also have significant effects in controlling the overall response.

ANOVA has been applied in this analysis to analyze the effect of the turning parameters, namely spindle speed, feed rate and cut depth, which greatly affects surface roughness (SR) and material removal rate (MRR).

Table 6 shows the ANOVA results of surface roughness. From the table, it is observed that the feed rate has greater influence on controlling the surface roughness of aluminium 7068 alloy ($P = 84.66\%$), followed spindle speed ($P = 8.301\%$)

and depth of cut ($P = 5.982\%$).

Table 6: ANOVA Table for Surface Roughness

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Speed	2	3.4310	1.7155	7.86	0.113	8.301
Feed Rate	2	34.9911	17.4956	80.19	0.012	84.66
Depth of Cut	2	2.4725	1.2363	5.67	0.150	5.982
Error	2	0.4364	0.2182			1.055
Total	8	41.3310				

4.2 Effect of parameters on Material Removal Rate

4.2.1 S/N Ratio Analysis

Figure 4 highlights the main effect plot of process parameters, such as spindle speed, feed rate and depth of cut on material removal rate. It is clearly observed that high level of feed rate, depth of cut and speed results in higher material removal rate. The mean S/N ratio for MRR is given in Table 7. From the Table, feed rate is most influencing parameters for MRR followed by depth of cut and spindle speed. The maximum MRR is obtained for the optimal combination of parameters (A3B3C3).

Figure 4: S/N Plot of MRR.

Table 7: S/N Table for MRR

Level	Speed (A)	Feed Rate (B)	DOC (C)
1	83.14	79.87	82.79
2	85.29	86.15	84.57
3	86.68	89.10	87.75
Delta	3.54	9.23	4.97
Rank	3	1	2

4.2.2 ANOVA Analysis

Table 8 shows the results of ANOVA and contribution of each individual parameter on MRR. It is also confirmed that feed rate is most influencing parameters with contribution of 72.84% and followed by depth of cut 20.11% and speed 4.45%. Increase in feed rate and depth of cut increases the MRR.

Table 8: ANOVA Table for MRR

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Speed	2	30244681	15122341	1.71	0.369	4.45
Feed Rate	2	495588941	247794470	27.97	0.035	72.84

Depth of Cut	2	136868042	68434021	7.72	0.115	20.11
Error	2	17719566	8859783			
Total	8	680421230				

4.3 Grey Relational Analysis

Table 9: Normalized Value & Deviation Sequence for Response Parameter

Exp. No	Normalized Value		Deviation Sequence	
	Surface Roughness	Material Removal Rate	Surface Roughness	Material Removal Rate
1	0	0.888788	1	0.111212
2	0.364718	0.595044	0.635282	0.404956
3	1	0	0	1
4	0.153617	0.921426	0.846383	0.078574
5	0.812355	0.629798	0.187645	0.370202
6	0.637265	0.408583	0.362735	0.591417
7	0.395045	1	0.604955	0
8	0.516353	0.892566	0.483647	0.107434
9	0.960357	0.256573	0.039643	0.743427

Table 10: Grey Relational Co-Efficient and Grades

Exp. No	Grey Relational Co-efficient		Grey Relational Grade (GRG)	Rank
	Surface Roughness	Material Removal Rate		
1	0.333333	0.818047	0.57569	7
2	0.440419	0.552513	0.496466	9
3	1	0.333333	0.666667	2
4	0.371365	0.864194	0.61778	6
5	0.72712	0.574579	0.650849	5
6	0.579552	0.45812	0.518836	8
7	0.452507	1	0.726253	1
8	0.508312	0.823134	0.665723	3
9	0.926538	0.402114	0.664326	4

4.3.1 Results of Grey Relational Analysis

It is clear from the table 10 that experiment No 7 gives the optimum results because the grey relational grade for that experiment is highest. The optimized values corresponding to experiments no 7 are speed 2500 rpm; feed rate 0.1 mm/rev; depth of cut 0.8 mm. Therefore, the experiment no 7 gives the optimum condition of minimum surface roughness and maximum material removal rate. The optimised value of surface roughness is 1.212 μm and material removal rate are 16357.89 mm^3/min .

5. CONFIRMATION TEST FOR OPTIMUM CUTTING PARAMETERS

Experiment was conducted for the obtained optimum cutting parameters values i.e. for speed = 2500 rpm, Feed = 0.1 mm / rev and cutting depth = 0.8 mm under dry machining conditions using a CBN insert not used in the original L9 orthogonal array experiments. The results obtained for optimum conditions for surface roughness are 1.233 μm was compared with predicted values 1.212 μm from grey relational analysis method and the result was very close to the predicted value 1.212.

6. CONCLUSIONS

The following conclusions were drawn:

- By Taguchi's single objective function the result shows that an increase in speed, cutting depth level and decrease in FR level results in lower SR.
- Higher level of FR, speed and cutting depth results in increase in MRR.
- Results of ANOVA show that feed rate are the most influential parameters for SR with a percentage contribution of 84.66 (P = 84.66%), followed spindle speed (P = 8.301%) and depth of cut (P = 5.982%).
- ANOVA results also shows that FR are the most important parameters for MRR with a percentage contribution of 72.84% and followed by depth of cut 20.11% and speed 4.45%.
- The optimum parameters obtained by using grey relational analysis for minimum SR and maximum MRR are tool speed 2500 rpm, FR 0.1 mm/min and cutting depth 0.8 mm.
- Confirmation test is performed with optimum parameter. The difference between experimental outcome and expected result is well within the calculated interval confidence.

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