PREDICTION OF OPTIMAL DESIGNS FOR MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS USING TAGUCHI'S ESTIMATED AVERAGES AND ANOVA

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MECHANICAL ENGINEERING

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ABSTRACT

Milling is one of the basic machining processes that allow large amounts of material to be removed quickly, especially where multipass operations are required such as external step turning, boring, face milling and deep shoulder milling etc. In the present work an investigation has been made to explore the effect of speed, feed and depth of cut on the multiple responses. A series of experiments were carried out on CNC milling machine using carbide end mill cutter. For the experiments a wrought alloy AA8011 has been taken as the work piece and L27 orthogonal array (OA) is employed. The effect of process parameters on the volume of material removal rate (VMRR) and surface roughness (R_a) are analyzed using single objective taguchi method and ANOVA. The optimal designs for the performance characteristics were predicted using the estimated averages of the responses.

Keywords: Volume of Material Removal Rate (VMRR), Surface Roughness (R_a), Taguchi method and ANOVA.

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NOMENCLATURE

v	Cutting speed, m/min
f	Feed, mm/rev
d	Depth of cut, mm
VMRR	Volume of Material Removal Rate, cm^3/min
R_a	Arithmetic Surface Roughness Average, µm
CNC	Computerized Numerical Control
DOE	Design of Experiments
OA	Orthogonal array
S/N	Signal to Noise ratio
ANOVA	Analysis of variance
DF	Degree of freedom
SS	Sum of squares
MS	Mean square
F	Variance ratio
P	Probability of significance
S	Variance
R^2	Coefficient of determination
R^2 (Adj)	Adjusted R^2

CHAPTER 1
INTRODUCTION

Milling is the process of machining flat, curved or irregular surfaces by feeding the work-piece against a rotating cutter containing a number of cutting edges. It consists of a motor driven spindle, which mounts and revolves the milling cutter; a reciprocating adjustable worktable, which mounts and feeds the work-piece. Milling allows large amounts of material to be removed quickly. In all types of milling machines, the cutting tool performs a rotational motion called the cutting motion. The rotation axis of the tool could be horizontal or vertical, depending on machine tool version. Geometrically complex & hard material components can be machined with an ease and high product accuracy, Surface finish can be achieved by milling operations. Better tool handling, less time consumption for tool changing, different operation on single work piece can be easily done by automatic tool changer in case of milling. Milling is most effectively used process for multipass operations. Some turning operations like external step turning and boring, and some of the milling operations, such as face milling and deep shoulder milling in which a significant amount of stock material is removed, are good examples of the operations which are commonly required to be machined using multipass operations. Industries strongly believed that only those capable of effective manufacturing would withstand international and global competition. In the modern machining the challenge is mainly focused on quality in terms of surface finishing. Surface texture is concerned with geometric irregularities. The quality of surface is most significant for any product. The surface roughness is main affecting thing such as for contact causing surface friction, wearing, holding the lubricant etc. There are many factors which affect the surface roughness (SR) and material removal rate (MRR), i.e. tool (material, nose radius, geometry, tool vibration), work piece (hardness, mechanical properties), cutting condition (speed, feed, depth)etc. Determination of the optimal cutting parameters (cutting conditions) like the number of passes, depth of cut for each pass, speed and feed is considered as a crucial stage of multipass machining as in the case of all chip removal processes and especially in process planning. The effective optimization of these parameters affects dramatically the cost and production time of machined components as well as the quality of the final products.

A systematic statistical approach to product and process improvement has developed by Dr. Genichi Taguchi. The technique emphasizes moving the quality issue upstream to the design stage and focusing on prevention of defects by process improvement. Taguchi has placed great emphasis on the importance of minimizing variation as the primary means of improving quality. Taguchi defines the quality level of a product to be the total loss incurred by society due to the failure of the product to deliver the expected performance and due to harmful side effect of the product, including the operating cost. In the concept some loss is unavoidable from the time a product is served to the customer and smaller loss provides desirable products. It is very important to quantify this loss for comparing various products designs and manufacturing processes. This is done with a quadratic loss function. In the usual practice of manufacturing quality control the producer specifies a target value of the performance characteristic and a tolerance interval around that value. Any value of the performance characteristics value which is within the tolerance range about 3σ is defined to be desirable product. With the loss function as a definition of quality the emphasis is on achieving the target value of the performance characteristic and deviation from that value are penalized. The greater deviation from the target value results with a greater quality loss.

The present work is to find the optimal combination of process parameters which maximize the material removal rate and minimize the surface roughness while milling of aluminium alloy 8011. Taguchi single objective method, concept of signal-to-noise ratios and analysis of variance (ANOVA) are used for the optimization of the performance characteristics and to know the influence of the process parameters on the responses.

CHAPTER 2

LITERATURE REVIEW

Yogendra Tyagi et.al. [1] in 2012, Investigated the effect of cutting parameters such as spindle speed, feed rate and depth of cut while milling Aluminium alloy 8081. Taguchi L9 orthogonal array (OA) has been used for conducting the experiments. Results of material removal rate (MRR) and surface roughness (R_a) are analyzed using Taguchi DOE software. They concluded that spindle speed and feed are the most significant factors for surface roughness and material removal rate respectively.

M Sandeep et.al. [2] in 2014, have done an experimental investigation on milling of AA 8081 using Taguchi L9 orthogonal array. Spindle speed, feed rate and mill diameter was taken as process parameter. It was found that spindle speed plays the most dominating role in affecting both the surface finish and material removal rate.

Kadam Shirish et.al. [3] in 2013, focused on optimization of milling parameters using the Taguchi technique. L9 orthogonal array has been used to perform milling on EN-24 steel blocks. Uncoated M20 carbide end milling cutter was used under dry condition. Cutting speed, feed rate were taken as process parameter. S/N ratio analysis was employed to get the optimal control factors and they found that cutting speed was the main significant factor for surface roughness and the tool life.

Turgay Kıvak et.al. [4] in 2012, investigated the effect of cutting parameters cutting tool, speed and feed rate on drilling of AA 8081. Experiments were done on CNC milling machine using Taguchi L16 orthogonal array. Coated and uncoated M20 carbide end milling cutters were used under dry condition for this purpose. Analysis of variance was done to know the effects of the control factors. It was found that cutting tool was the most significant factor on surface roughness and feed rate was the most significant factor on thrust force.

Adem Çiçek et.al. [5] in 2012, investigated the effect of deep cryogenic and cutting parameters on surface roughness as well as roundness error in milling of AA 8081 . Cutting tools, speed and feed rate was taken as control factors. M20 carbide end milling cutter were used for doing the experiment. L8 orthogonal array was used and multiple regression analysis was performed to find out predictive equation of surface roughness. A confirmation experiment has showed Taguchi method precisely optimized the milling Parameters in milling AA 8081.

A. Navanth et.al. [6] in 2013, focused on optimization of milling parameters for minimum surface roughness using Taguchi methodology. Aluminium 2014 material and carbide end milling cutter has been selected for performing the experiments. L18 orthogonal array has been used and the result obtained were analyzed in MINITAB 16 .Analysis of variance (ANOVA) was used to find out the optimal factors from cutting tool, spindle speed and feed rate.

J.Pradeep Kumar et.al. [7] in 2012, investigated the effect of cutting parameters such as cutting speed, feed on surface finish of OHNS material using end milling cutter. L18 orthogonal array, S/N ratio, ANOVA and Regression analysis has been employed to study the effect of milling parameters on surface roughness value. Experimental data was analyzed using MINITAB 13 and it was found that speed and feed plays most dominating factors in surface roughness, tool wear and material removal rate.

Reddy Sreenivasulu [8] in 2014, focused on optimization of surface roughness in drilling of Al 6061 using Taguchi design method and artificial neural network method. Cutting speed, feed rate, mill diameter, clearance angle and point angle were taken as cutting parameters and carbide as a tool. L27 orthogonal array, ANOVA, S/N ratio was employed to study the effects of the control factors.

B.Shivapragash et.al. [9] in 2013, investigated the effect of the process parameters spindle speed, feed rate and depth of cut in milling of composite Al-TiBr2. Taguchi method with grey relational analysis was used to optimize the factors. L9 orthogonal array has been used and optimal settings found for better surface finish is at spindle speed (1000 rpm), feed rate (1.5 mm/rev), depth of cut 6 mm.

Nalawade P.S. et.al. [10] in 2015, optimizes the cutting parameters speed, depth of cut, feed and type of tool to get better Surface finish and hole accuracy in dry milling of EN-31 material. Taguchi L9 orthogonal array, S/N ratio, ANOVA, Regression analysis was done to find out the optimal settings.

Sathish Rao U et.al. [11] in 2014, have made an attempt to study the effect of spindle speed, feed rate, mill diameter and fiber orientation on tool wear during milling GFRP components in dry condition. Carbide end milling cutter was used for the experiment. Taguchi L9 orthogonal array, S/N ratio, ANOVA and regression analysis was used to find out the optimal settings. It has been found that speed, feed rate, mill diameter has significant effect on tool wear.

Nisha Tamta et.al. [12] in 2015, analyzed the effect of spindle speed, feed rate and milling depth on milling Aluminium alloy 8081 with the help of CNC machine. Taguchi L9 orthogonal array was used to perform the experiment. Signal to noise ratio (S/N), analysis of variance (ANOVA) were used to analyze the effects milling parameters on surface roughness. For analyzing statistical software MINITAB-15 has been used. It has been found that spindle speed 3000 rpm, feed rate 15 mm/min were the optimal combination. According to the paper milling depth was the most significant factor for surface roughness followed by spindle speed.

Srinivasa Reddy et.al. [13] in 2014, investigated the impact of cutting parameters such as cutting speed, point angle and feed rate on surface roughness in milling of AL 8081 material. Carbide end milling cutter was used and the experiments were done on CNC milling machine using Taguchi L9 orthogonal array. Signal to noise ratio (S/N), analysis of variance (ANOVA) has been employed to find out the optimal drilling parameters. It was found that Cutting speed, feed rate and point angle plays significant role on surface roughness during drilling of AL 8081 material.

Arshad Noor Siddiquee et.al. [14] in 2014, focused on optimizing milling parameters such as cutting fluid, speed and feed for AL 8081 material. Experiments were done in CNC milling machine using solid carbide cutting tool. Taguchi L18 orthogonal array has been used for the experiment. Signal to noise ratio(S/N), analysis of variance (ANOVA) were used to find out the effects of cutting parameters on surface roughness. It has been found that in presence of cutting fluid, speed 500 rpm, feed .04 mm/sec, were the optimum value for surface roughness. Anova analysis showed that speed was the most significant factor followed by cutting fluid, feed for surface roughness value.

Vishwajeet N. Rane et.al.[15] in 2015, focused in optimizing drilling parameters such as cutting speed and feed using a carbide end milling cutter. Taguchi L16 orthogonal array has been used to perform the experiment in a milling machine. Analysis of variance was employed to find out effect of control factors on surface roughness. It was found that point angle was the main significant factor for tool wear and feed rate is for surface roughness.

C.C. Tsao. et.al. [16] predicts and evaluates the thrust force and surface roughness in milling of composite material using candle stick mill & by considering the milling parameters - feed rate, spindle speed and mill diameter. The approach is based on Taguchi method and the artificial neural network. Feed rate and the mill diameter are found to be the most significant factors affecting the thrust force, where as feed rate and spindle speed are most significant factors on the surface roughness.

J.Pradeep Kumar et.al. [17] utilized taguchi method to investigate the effects of milling parameters- cutting speed, feed rate and mill diameter on surface roughness, tool wear by weight, material removal rate and mill diameter error in milling of OHNS material using carbide cutter. It was found that, Feed rate and Spindle speed are important process parameters to control surface roughness, tool wear, material removal rate and slot diameter error. Suitable combination of cutting speed and feed rate should be used so as to reduce the variations that can affect the quality of the slots that are milled on OHNS material.

Kunal Sharma et.al. [18] have conducted the experiments to study the performance characteristics of AISI 304 stainless steel using CNC milling process, with an input parameters of spindle speed, feed rate and point angle to minimize the surface roughness and ovalty. Experiments are conducted based on Taguchi L16 orthogonal array by taking point angle, mill diameter, feed rate and spindle speeds at two levels. The Taguchi based signal-to-noise ratio analysis is used to obtain the relation between the machining parameters and performance characteristics. The feed is the most effective parameter and it is clearly observed that a small variation in feed will shows large increase in surface roughness.

S.V. Alagarsamy et. al. [19] used Taguchi method to study the effects of milling parameters such as cutting speed, feed and depth of cut on surface roughness and material removal rate in milling of Aluminum alloy 8081 using carbide end milling cutter. Orthogonal arrays, the signal- to -noise ratio, the analysis of variance are used to analyze the effect of milling parameters on the quality of milled slots and experiment results are collected and analyzed using statistical software Minitab16. ANOVA software is used to study the most significant control factors affecting the surface roughness and material removal rate and it is concluded that the depth of cut has significant role to play in producing higher material removal rate and cutting speed has significant role to play for producing lower surface roughness.

CHAPTER 3

METHODOLOGY

Introduction

In this present chapter methodology used for obtaining better response parameters is briefly discussed. In modern industrial environment a numerous kinds of Investigations have been done for the improvement of product quality in the field of manufacturing. Some have few factors to be considered, some have many. While there are others, that demand factors to have mixed levels. A vast majority of experiments however fall in the category where all factors possess the same number of levels. In the conventional technique of varying one factor at a time, lot of experimental data can be obtained. This way of experimentation not only consumes lot of time but also poses a challenge to the investigator for deriving appropriate conclusion from the huge experimental data. Design of Experiments (DOE) is at ever rescue for planning systematic experimentation and arriving at meaningful conclusion without being inundated in huge set of experimental data. DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of factors. There are number of statistical techniques available for engineering and scientific studies. In the present investigation Taguchi approach is used.

3.1 Design of Experiments (DOE)

Design of Experiments is a powerful statistical technique introduces by R.A. Fisher in England in the 1920's to study the effect of multiple variables simultaneously. The DOE using Taguchi approach can be economically satisfy the needs of problem solving and product/process design optimization projects. DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this different factors and their levels are identified. Design of Experiments is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance in products.

Advantages of Design of Experiments (DOE)

- Number of trails is significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- Optimal setting of the parameters can be found out.
- Qualitative estimation of parameters can be made.
- Experimental errors can be estimated.
- The effect of parameters on the characteristics of the process can be found out.

The DOE techniques used for process parameter optimization

- Full factorial technique
- Fractional factorial technique
- Taguchi orthogonal array
- Response surface method (central composite design).

3.2 Taguchi Optimization Method

Taguchi techniques are statistical methods developed by Genichi Taguchi to improve the Quality of manufacturing goods. Basically, classical experimental design methods are to complex and not easy to use. A large number of experiments have to be carried out when the number of the process parameter increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Taguchi proposed that engineering optimization of a process or product should be carried out in a three step approach i.e. System design, parameter design and tolerance design. In system design the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and process design stage. In the product design stage the selection of material components tentative product parameter values, etc., are involved as to the process design stage the analysis of processing sequences, the selection of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design it may be far from optimum in terms of quality and cost. Following on from system design is parameter design. The objective of parameter design is to optimize the settings of the process parameter values for improving quality characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from parameter design are insensitive to variation in the environmental conditions and other noise factors. Finally, tolerance design is used to determine and analyze tolerances around the optimal settings recommend by parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the required performance. However based on above discussion, parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. To obtain high cutting performance, the parameter design proposed by Taguchi method is adopted in this project work.

The general steps involved in the Taguchi Method

- Selection of factors for the study
- Selection of the number of levels for the factors
- Selection of appropriate orthogonal array
- Assignment of factors to columns
- Conduct the test
- Analysis of the results.

Optimization of process parameters is the key step in the Taguchi method to achieve high quality without increasing cost. Originally Taguchi method was designed to optimize single performance characteristic. According to Taguchi method, the S/N ratio is the ratio of Signal to Noise where signal represents the desirable value and noise represents the undesirable value. For the experimental responses Signal-to-Noise Ratio(S/N) are calculated by using the Equations 3.1, 3.2 and 3.3. The experimental results are now transformed into a signal-to-noise (S/N) ratio. Since the Material Removal Rate is desired to be at maximum, so higher the better characteristic is used for S/N ratio calculation and similarly for Surface Roughness is desired to be minimum, so lower the better characteristic is used for S/N ratio calculation. After calculating the S/N ratios of responses, the Mean values of S/N ratio for each response are calculated for different levels of process parameters and optimum conditions are found by taking the maximum value of mean S/N ratio.

Upper –bound effectiveness (i.e. higher-the-better)

$$\frac{S}{N}\text{ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eq (3.1)}$$

Where y_{ij}= i^{th} replicate of j^{th} response

n =number of replicates, i=1,2,3……n; j=1,2,3……k.

Equation (3.1) is applied for problem where Maximization of the quality characteristic of interest is required.

Lower-bound effectiveness (i.e. lower-the-better)

$$\frac{S}{N}\text{ ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_{ij}^{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq (3.2)}$$

Equation (3.2) is applied for the problem where minimization of the quality characteristic is required.

Moderate effectiveness (i.e. nominal-the –better)

$$\frac{S}{N}\text{ ratio} = 10\log\left(\frac{y2}{s2}\right) \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq (3.3)}$$

Where, $\bar{y} = \frac{y_1+y_2+y_3\ldots+y_n}{n}$ and $s^2 = \frac{\Sigma(y_i-\bar{y})2}{n-1}$

Equation (3.3) is used where minimization of the mean squared error around a specific target value is desired.

3.3 Analysis of Variance (ANOVA)

In the Taguchi method the result of the experiments are analyzed to achieve one or more of following objectives

- To establish the best or the optimum condition for a product or a process
- To establish the contribution of individual factors
- To estimate the response under the optimum conditions.

The optimum condition is identified by studying the Main effects of each of the factors. The Main effects indicate the general trend of the influence of the factors. The levels of the factors which are expected to produce the best results can be predicted by knowing the characteristics, i.e., whether a higher or lower value produces the best results. The nature of control to be established on production process can be decided by knowing the contribution of individual factors. The analysis of variance is the statistical treatment most generally applied to the results of the experiment to determine the percent contribution of each factor. Study the ANOVA table for a given analysis to determine which of the factors need control and which are not. Once the optimum condition is determined, it is usually a good practice to run a confirmation experiment. Taguchi suggested two different routes to carry out complete analysis.

- First, the standard approach, where the results of a single run, or the average of repetitive runs, are processed through Main effect and ANOVA analysis as identified above.
- The second approach, which he strongly recommended for multiple runs, is to use Signal to noise ratio(S/N) for the same steps in the analysis.

In ANOVA table mainly consists of six columns will be there, column 1 represents Source of variation (speed, feed and depth of cut). Column 2 represents Degree of freedom (DF) of each control factor, column 3 represents Sum of squares, column 4 represents Mean of square, column 5 represents F-distribution and column 6 represents the Probability.

- **Degree of Freedom (DF)** indicates the number of independent pieces on information involving the response data needed to calculate the Sum of squares. Degree of freedom of each component is (n-1). Where, n is the number of observations.
- **Sum of Squares (SS)** is used to find amount of variation that can be explained by each factor.
- **Mean Square (MS)** refers to an estimate of population variance based on the variability among given set of measures.

$$MS_{Term} = \frac{SS_{Term}}{DF_{Term}}$$

- **F- Value** is the measurement of the distance between individual distributions. As the F-value goes up the P-value goes down. F is the test to determine whether the Interaction and Main effects are significant. Based on F-value we can judge, which parameter is most significant and which is least significant for the response.

$$F = \frac{MS_{Term}}{MS_{Error}}$$

- **P-value** is the probability of obtaining a test static that is at least as extreme as actual calculated value, if null hypothesis is true. A commonly used cut-off value for p value is 0.05.

Conditions to be satisfied for ANOVA

- The higher the value of R^2, the more successful is the simple Linear Regression model in the desired level of confidence (95%).
- Adjusted $R^2 < R^2$
- Model p-values less than the p-values in the desired level of confidence ((95%).
- The calculated F-ratio is higher than the tabulated value of F-ratio, and then the model is significant.
- Variance should be minimal.

With the ANOVA results for the experimental values and various plots like Main effect plots, Normal probability plot, Interaction graphs generated by using Minitab-17 we can give the conclusions on how the process parameters are affecting the responses of the experiment.

CHAPTER 4
EXPERIMENTAL DETAILS

Properties such as low weight, corrosion resistance, and easy maintenance of final product, have ensured that aluminium and its alloys are using extensively in the market. In the present work wrought alloy AA8011 has been selected as a work piece in the shape of a plate having thickness of 10 mm shown in the figure 4.1. The chemical composition and mechanical properties of AA8011 is given in the table 4.1 and 4.2.

Table 4.1 Chemical Properties of AA8011

Element	Content (%)
Aluminium, Al	97.3-98.9
Iron, Fe	0.60-1
Silicon, Si	0.5-0.90
Manganese, Mn	≤0.20
Zinc, Zn	≤0.10
Copper, Cu	≤0.10
Titanium, Ti	≤0.080
Chromium, Cr	≤0.050
Magnesium, Mg	≤0.050
Remainder (each)	≤0.050
Remainder (Total)	≤0.15

Table 4.2 Physical Properties of AA8011

Density	2.7 gm/cm3
Hardness	25-50 BHN
Tensile strength	100-180 MPa

Yield strength	34-170 MPa
Poisson's ratio	0.33
Elongation	1.7-2.8%

Figure 4.1 AA8011 Work Piece

The experiments were done on CNC milling machine using carbide end mill cutter of 20 mm in size and the length of machining was fixed to 50 mm. The experiments were carried out by taking three process parameters at three different levels as given in the table 4.3 and L27 OA has been followed as per the table 4.4. The work piece after machining was shown in the figure 4.2

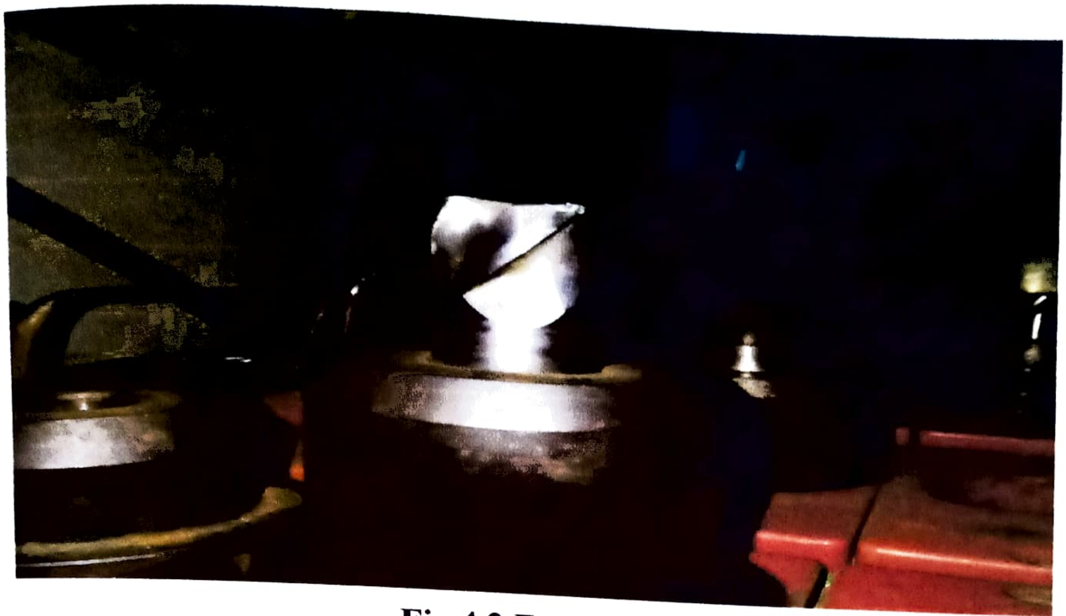

Fig 4.2 End Mill Cutter

Table 4.3 Process Parameters and Their Levels

Parameter	Level-1	Level-2	Level-3
Speed, rpm	1500	3000	4500
Feed, mm/min	150	600	1350
Depth of cut, mm	0.5	1	1.5

Table 4.4 L27 OA

S.No.	s, rpm	f, mm/min	d, mm
1	1500	150	0.5
2	1500	150	1
3	1500	150	1.5
4	1500	600	0.5
5	1500	600	1
6	1500	600	1.5

7	1500	1350	0.5
8	1500	1350	1
9	1500	1350	1.5
10	3000	150	0.5
11	3000	150	1
12	3000	150	1.5
13	3000	600	0.5
14	3000	600	1
15	3000	600	1.5
16	3000	1350	0.5
17	3000	1350	1
18	3000	1350	1.5
19	4500	150	0.5
20	4500	150	1
21	4500	150	1.5
22	4500	600	0.5
23	4500	600	1
24	4500	600	1.5
25	4500	1350	0.5
26	4500	1350	1
27	4500	1350	1.5

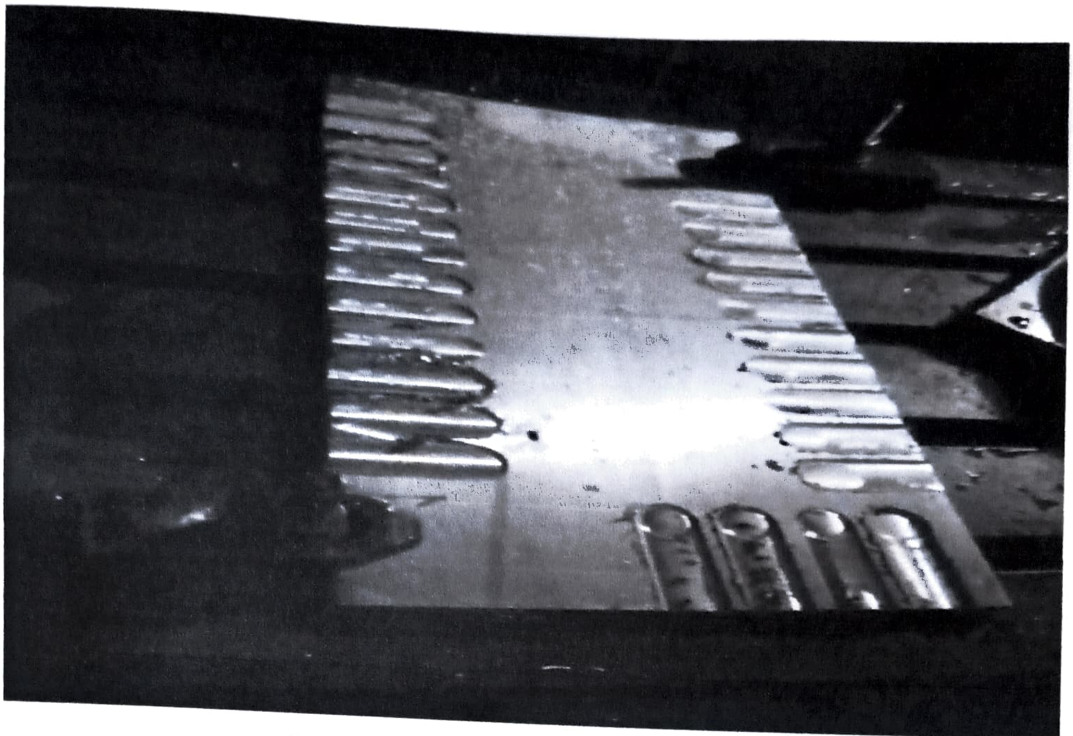

Figure 4.3 AA8011 After Machining

After machining the machined portions shown in figure 4.3 are tested for measuring the surface roughness using SJ-210 tester shown in the figure 4.4. The roughness values were taken at three different places for each experiment and the average is taken as the final value.

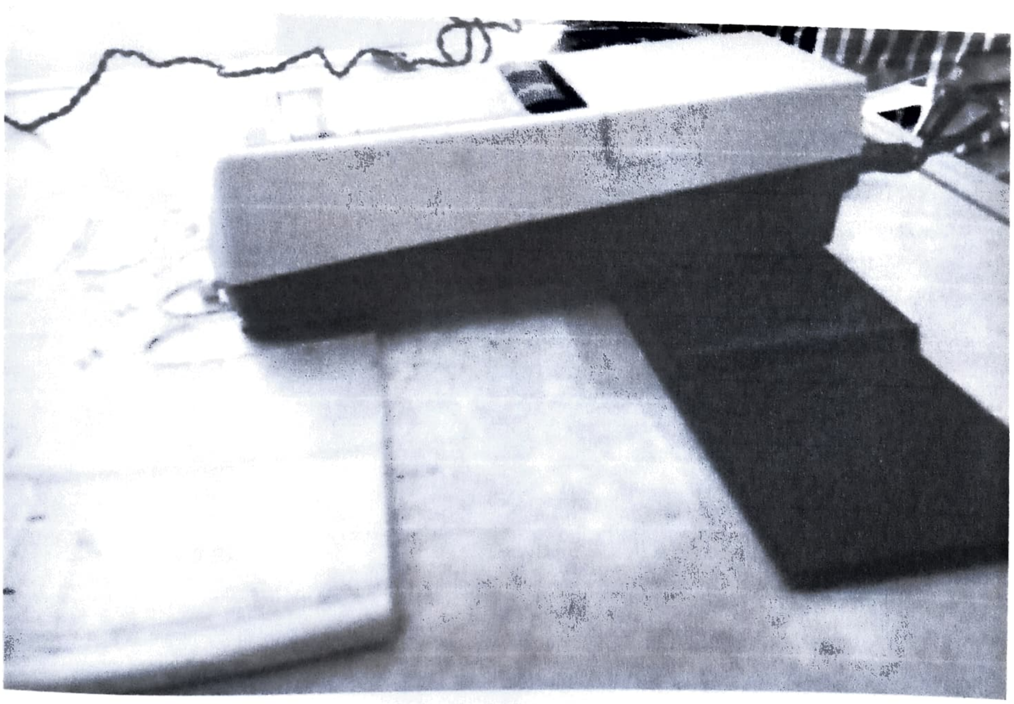

Figure 4.4 The SJ-210 Surface Tester

CHAPTER-5

EXPERIMENTAL RESULTS

This chapter presents the experimental results and the analysis of the experimental results using single objective taguchi method and ANOVA. The results of Volume of material removal rate (VMRR) and surface roughness (R_a) for each experiment were given in the table 5.1. The experimental results of the responses were analyzed using larger-the-better and smaller-the-better characteristics given by taguchi.

Table 5.1 Experimental Results of VMRR and R_a

S.No.	VMRR, cm^3/min	R_a, µm
1	0.94	1.00
2	1.88	0.97
3	2.57	1.01
4	2.31	0.66
5	4.62	0.66
6	7.50	0.81
7	3.75	0.98
8	6.00	0.94
9	12.86	1.36
10	1.00	1.10
11	2.00	2.11
12	2.65	1.63
13	2.73	0.64
14	5.00	0.59
15	6.43	0.50

16	4.29	0.62
17	7.50	0.55
18	11.25	0.50
19	0.83	1.30
20	1.67	1.20
21	2.43	1.35
22	2.50	0.50
23	5.00	0.38
24	7.50	0.57
25	3.75	0.53
26	7.50	0.45
27	11.25	0.35

The experimental results were analyzed using the MINITAB-17 software. As per Taguchi's S/N ratios, the term signal represents desirable value and noise being undesirable and response considering highest S/N ratio is close to optimal. The mean S/N ratio of Material Removal Rate for cutting speed at levels 1, 2, 3 can be calculated by averaging the S/N ratios for the experiments 1-9, 10-18, 19-27 respectively. Similarly, the mean values for other levels of the process parameters can be computed and given in the tables 5.2 and 5.3 for material removal rate and surface roughness respectively.

Table 5.2 Response Table for Means of VMRR

Level	s	f	d
1	4.713	1.774	2.455
2	4.760	4.842	4.573
3	4.715	7.571	7.160
Delta	0.047	5.798	4.705
Rank	3	1	2

Table 5.3 Response Table for Means of R_a

Level	s	f	d
1	0.9322	1.2967	0.8144
2	0.9156	0.5900	0.8722
3	0.7367	0.6978	0.8978
Delta	0.1956	0.7067	0.0833
Rank	2	1	3

5.1 Main Effect Plots Analysis

Optimal results can be found out from the Main effect plots shown in the Figures 5.1 and 5.2 they are generated from the mean S/N ratios of the process parameters given in the tables 5.2 and 5.3 respectively. It is clear that the main effect on the Material Removal Rate which is primarily due to feed and depth of cut as with an increase in the feeds and depth of cut levels we can observe a significant effect in response. The speed is found to be least significant as the change in response with the increasing levels is comparatively less when compared to feed and depth of cut effects. Optimal combination of process parameters for Material Removal Rate is v2-f3-d3 i.e.

Speed: level2, 3000 rpm,

Feed: level3, 1350 mm/min

Depth of cut: level3, 1.5mm.

Similarly, the main effect on the Surface Roughness which is primarily due to feed and speed as with an increase in the feeds and speed levels we can observe a significant effect in response. The depth of cut is found to be least significant as the change in response with the increasing levels is comparatively less when compared to cutting speed and feed effects. The optimal condition for minimum surface roughness (R_a) is found at v1-f2-d1.

Speed: level3, 4500 rpm

Feed: level2, 600 mm/min

Depth of cut: level1, 0.5 mm

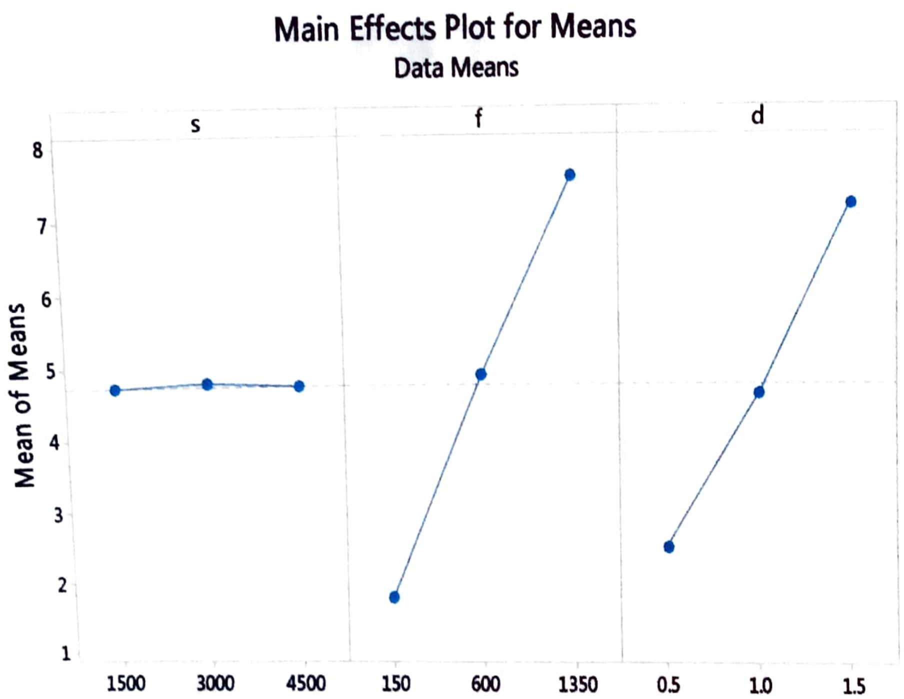

Figure 5.1 Main Effect Plot for Means of VMRR

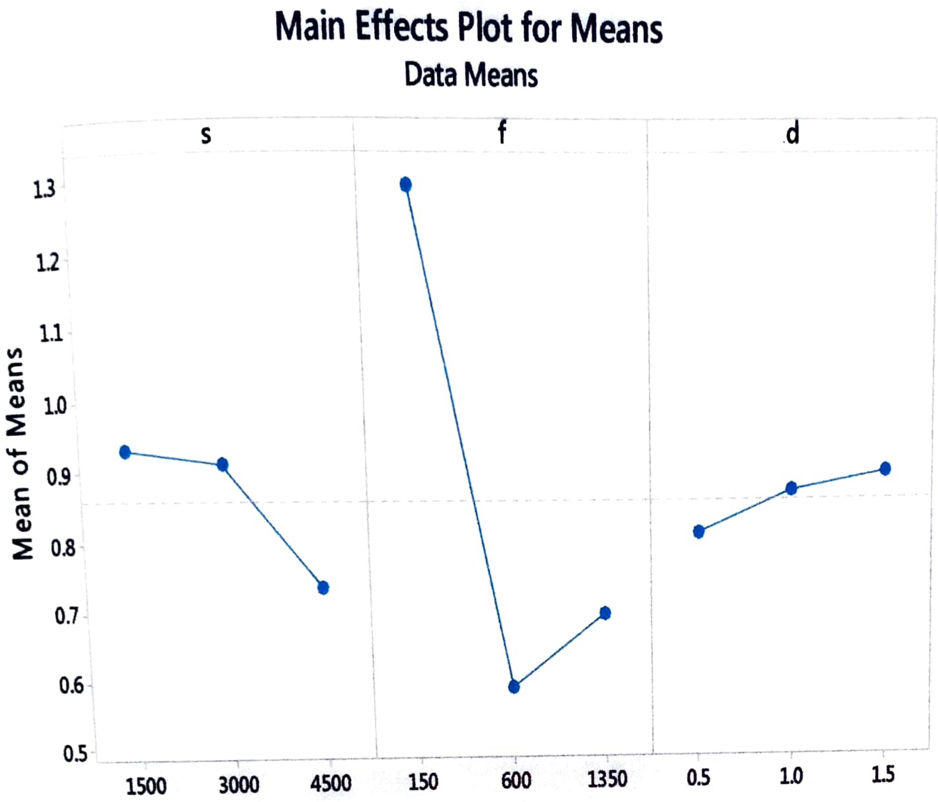

Figure 5.2 Main Effect Plot for Means of R_a

5.2 ANOVA Results of VMRR and R_a

Analysis of variance is employed to check the significance of the parameters at a confidence level of 95% i.e. 0.05 and the obtained results were given in the tables 5.4 and 5.5. ANOVA results showed that the feed is the most influencing factor in effecting both VMRR and surface roughness.

Table 5.4 ANOVA Results of VMRR

Source	DF	Adj SS	Adj MS	F	P
S	2	0.013	0.0064	0.00	0.996
F	2	151.433	75.7165	43.59	0.000
D	2	99.946	49.9730	28.77	0.000
Error	20	34.742	1.7371		
Total	26	286.134			

Table 5.5 ANOVA results of R_a

Source	DF	Adj SS	Adj MS	F	P
S	2	0.21156	0.10578	1.15	0.335
F	2	2.60899	1.30449	14.24	0.000
D	2	0.03281	0.01640	0.18	0.837
Error	20	1.83179	0.09159		
Total	26	4.68514			

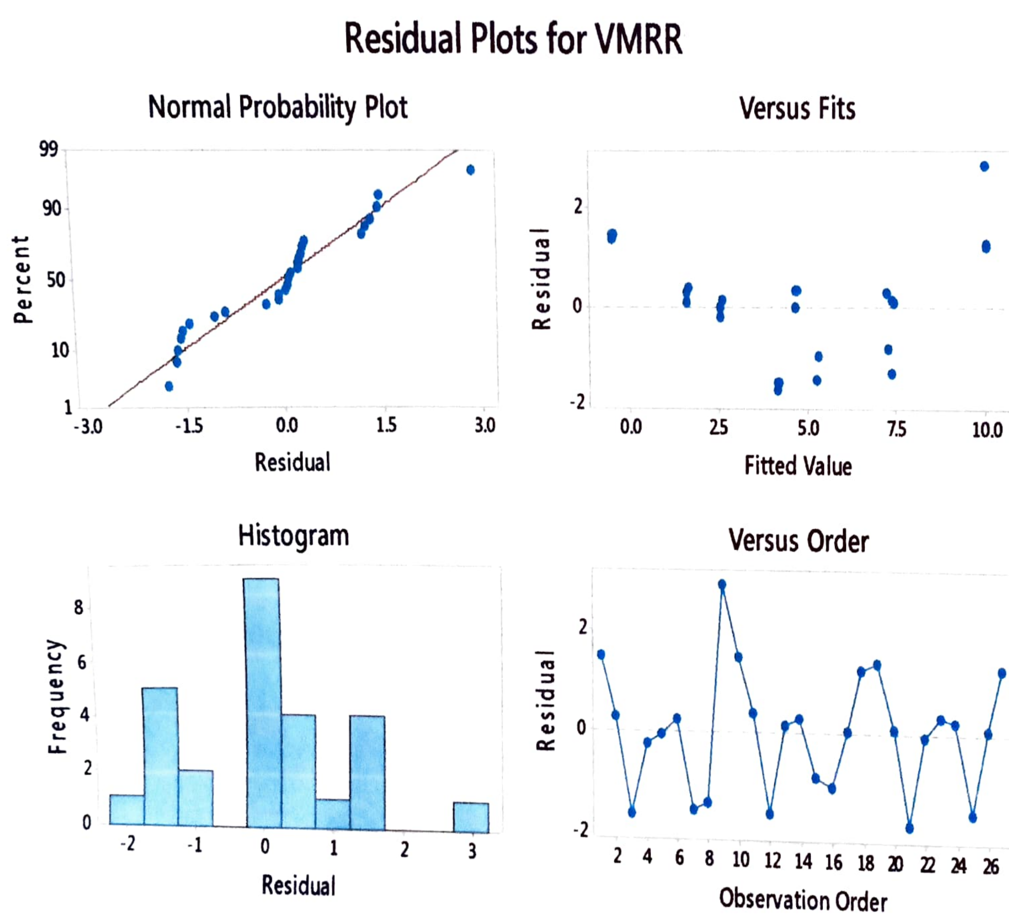

Figure 5.3 Residual Plots for VMRR

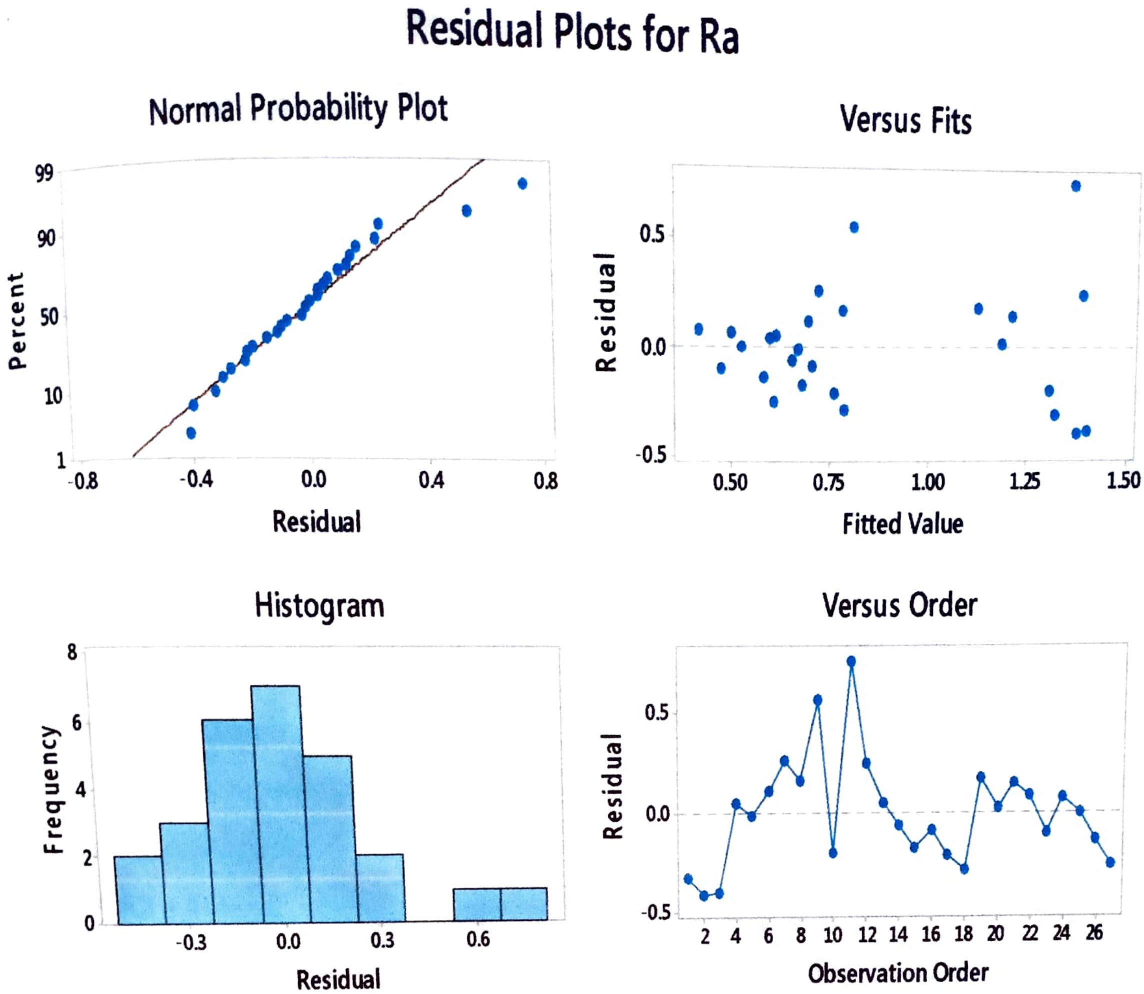

Figure 5.4 Residual Plots for R_a

Figures 5.3 and 5.4 representing the residual plots for VMRR and surface roughness. From the figures it is clear that the residuals are following the normal distribution and the constant variance assumptions of ANOVA as they are lying on the straight line and do not representing any of the regular patterns.

5.3 Prediction of Optimal Designs for VMRR and R_a

5.3.1 Optimal design for VMRR

For VMRR the two most significant factors i.e. feed and depth of cut at their better levels are considered.

$\mu_{A3B3} = A3 + B3 - T$

$A3 = 7.571; B3 = 7.160; T = 4.73$

$\mu_{A3B3} = 7.571 + 7.160 - 4.73 = 10.001$

$$CI = \sqrt{\frac{(F_{95\%,1,doferror} * V_{error})}{(\eta_{efficiency})}}$$

Where, $\eta_{efficiency} = \frac{N}{(1+dof)}$ = 27/(1+2+2)

= 27/5 = 5.4

V_{error} = 1.7371

$F_{95\%,1,20}$ = 4.3512

$CI = \sqrt{\frac{4.3512*1.7371}{5.4}} = 1.1830$

The predicted optimal range of VMRR at 95% of confidence level is obtained as

$\mu_{A3B3} - CI \leq \mu_{A3B3} \leq \mu_{A3B3} + CI$

$10.001 - 1.1830 \leq \mu_{A3B3} \leq 10.001 + 1.1830$

$8.818 \leq \mu_{A3B3} \leq 11.184$

5.3.2 Optimal design for R_a

For R_a the two most significant factors i.e. feed and speed at their better levels are considered.

μ_{A2B3} = A2 + B3 – T

A2 = 0.5900; B3 = 0.7367; T = 0.86

μ_{A3B3} = 0.5900 + 0.7367 – 0.86 = 0.4667

$CI = \sqrt{\frac{(F_{95\%,1,doferror} * V_{error})}{(\eta_{efficiency})}}$

Where, $\eta_{efficiency} = \frac{N}{(1+dof)}$ = 27/(1+2+2)

= 27/5 = 5.4

V_{error} = 0.09159

$F_{95\%,1,20}$ = 4.3512

$CI = \sqrt{\frac{4.3512*0.09159}{5.4}} = 0.2714$

The predicted optimal range of R_a at 95% of confidence level is obtained as

$\mu_{A3B3} - CI \leq \mu_{A3B3} \leq \mu_{A3B3} + CI$

$0.4667 - 0.2714 \leq \mu_{A3B3} \leq 0.4667 + 0.2714$

$0.1953 \leq \mu_{A3B3} \leq 0.7381$

CHAPTER-6

CONCLUSIONS

From the Taguchi and ANOVA results the following conclusions can be drawn

- The optimal condition for maximum volume of material removal rate (VMRR) is found to be at
  Speed: level2, 3000 rpm,
  Feed: level3, 1350 mm/min
  Depth of cut: level3, 1.5mm.
- The optimal condition for minimum surface roughness (R_a) is found to be at
  Speed: level3, 4500 rpm
  Feed: level2, 600 mm/min
  Depth of cut: level1, 0.5 mm.
- ANOVA results concluded that the feed is the most influencing factor in effecting both VMRR and surface roughness (R_a).
- The errors are following the normal distribution and the constant variance assumptions of ANOVA.
- The optimal design for VMRR and R_a are predicted from the estimated mean averages and they are accurate.

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