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Optimization of Cutting Parameters for Turning A-356 Alloy using Taguchi Method

***Sulabh Pathak*[*]*, Rajeev Singh Chauhan*[**] *and Dr. V. N. Bartaria*[***]**
**Research Scholar, Department of Mechanical Engineering,*
Lakshmi Narain College of Technology, Bhopal, (Madhya Pradesh), India
***Associate Professor, Department of Mechanical Engineering,*
Lakshmi Narain College of Technology, Bhopal, (Madhya Pradesh), India
****Professor, Department of Mechanical Engineering,*
Lakshmi Narain College of Technology, Bhopal, (Madhya Pradesh), India

(Corresponding author: Sulabh Pathak)
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ABSTRACT: Turning is the removal of metal from the rotating work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. The material removal rate (MRR) is an important characteristic in turning operation and high MRR is always desirable. The material selected for the experiment is A-356. Experiments were conducted using Taguchi optimization technique. L9 orthogonal array is employed by considering three factors speed, feed and depth of cut. For each factor three different levels is selected. signal to noise ratio (S/N) and analysis of variance were employed to find the maximum material removal rate (MRR). The experimental results showed that that the optimal combination of parameters for material removal rate are at spindle speed of 400 rpm, feed rate of 3.00mm/rev, depth of cut 1.5 mm. Optimum results are finally verified with the help of confirmation experiment.

Keywords: Taguchi method, MRR, ANOVA, L-9 Orthogonal array, A-356

I. INTRODUCTION

Turning is the most widely used among all the cutting processes. The turning process defines as, "The process of removing unwanted material from rotating job which is fixed on chuck by using different cutting tool (Generally single point cutting tool). The excess amount of material has been removed by using cutting tool. The tool advances with respect to work for each revolution is called as feed. The distance that the tool moved in work is called as Depth of cut. And the rotation per unit time of spindle is considered as spindle speed. There are different methods used for the optimization of turning on different work metals. For optimization of turning process some input and output parameters are considered. In which some are theoretical and some are analytical. From all methods we pick one of the most preferred methods is TAGUCHI method. The increasing importance of turning operations is gaining new dimensions in the present industrial age. The manufacturing industries are trying to decrease the cutting costs, increase the quality of the machined parts and machine more difficult materials. Machining efficiency is improved by reducing the machining time with high speed machining. The material removal rate (MRR) is an important characteristic in turning operation and high MRR is always desirable. Hence, there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses by using experimental methods and statistical models. Dr. Taguchi employed design of experiments (DOE), which is one of the most important and efficient tools of total quality management (TQM) for designing high quality systems at reduced cost Optimization of a single response results the non-optimum values for remaining responses. In solving many problems in engineering, it is necessary to consider the application of multi response optimization, because the performance of the manufactured products is often evaluated by several quality characteristics. Though the Taguchi approach is used for a single response problem, most of the researchers proposed various methods for multiresponse problem by modifying it.

Taguchi method is used to obtain the improved quality of products and processes. Improved quality results when high performance levels are to be consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors. Performance consistency is obtained by making the product/process insensitive to the influence of the uncontrollable factors. In Taguchi's approach, an optimum design is determined using experimental design principles, and performance
consistency is achieved by carrying out trial conditions under the influence of noise factors.

1. Objectives of Experiment-

a. To determine the evaluation criterion and decide how each criterion is to be weighed and combined for the overall evaluation.

b. To identify all influencing factors and those to be included in the study

c. To determine the factor levels

d. To determine the noise factors and the repetition conditions.

2. Experiments design. The factors and levels employed are determined. The experiments are then designed, and the method of carrying them out is established. In designing the experiment, an orthogonal array is implemented as follows:

i. The appropriate orthogonal array is selected.

ii. The factors decided and their interaction with each other are assigned to columns.

iii. Each trial condition is mentioned.

iv. The order and repetition of trial conditions is described.

v. Running the experiments.

3. Result analysis

- Optimum design factors

-Influence of individual factors

-Performance at optimum conditions

-Relative influence of individual factors

4. Running a confirmation experiment Running the experiments at the optimum condition is the final step in the study.

II. LITERATURE REVIEW

[1] Sujit Kumar Jha (2014) conducted an experiment on turning of Mild Steel using tin coated carbide tool with depth of cut, spindle speed and feed rate as cutting parameters. He investigated that feed is the most relevant factor for mrr using Taguchi method.

[2] Ali Abdallah *et al* (2014) has investigated on turning of Aluminum alloy *i.e.* AL 6061 using Taguchi method with depth of cut, spindle speed and feed rate as cutting parameters using uncoated inserts for tool.

[3] Kamal Hassan (2012) conducted an experiment using medium Brass alloy (C34000) as work piece. The process parameters are cutting speed, feed and depth of cut. This study investigates the effects of process parameters on Material Removal Rate (MRR) in turning of C34000. Optimization of MRR is solved by using Taguchi method. The optimization of MRR is done using twenty seven experimental runs based on L'27 orthogonal array of the Taguchi method. The optimum levels of process parameters for simultaneous optimization of MRR have been identified. Optimal results were verified through confirmation experiments. Parameters making significant effect on material removal rate feed rate, and interaction between feed rate& cutting speed were found to be significant to Material removal rate for reducing the variation.

[4] N Ramesh *et al* (2016) conducted a study to optimize the process parameters *i.e*, Cutting Speed, and Depth of Cut maximizing material removal rate (MRR) and minimizing Surface Roughness (Ra) of AA 6061 using PSO. Taguchi method has been employed with an orthogonal array L9 was used to conduct the experiments. Carbide cutting tool was used. The study shows that PSO technique can be applied for different predicted Ra values that are modeled by using different conventional approaches (such as DP, and RSM) and non-conventional approaches (such as ANN, and PSO itself). It is important for researchers to provide many alternatives by using various matching approaches between modeling and optimizing approaches to give the best result of Ra and MRR value in an optimization problem.

[5] Sidda Reddy *et al.* (2009) has investigated on turning of Aluminum alloy using carbide cutting tool. The cutting parameters focused on this work are cutting speed, feed, depth of cut and the response is surface roughness. Adaptive Neuro Fuzzy Inference System (ANFIS) and Response Surface Methodology (RSM) are applied to predict the surface roughness.

[6] Surlimani *et al* (2016) investigates the machining of EN36B steel to find optimal parameters for CNC turning process. The Taguchi's L9 Orthogonal array is used. The cutting parameters are Speed, Feed and Depth of cut. The Analysis of Variance (ANOVA) and Signal-to-Noise ratio are used to study the performance characteristics in turning operation.

The results reveal that the primary factor affecting the Material removal rate is feed rate, subsequently followed by speed and depth of cut. (ii) The results reveal that the primary factor affecting the surface roughness is feed rate, subsequently followed by depth of cut and speed.

[7] Dr. S S Mahapatra (2006) conducted an experiment using Taguchi method and Genetic Algorithm. The cutting parameters taken were depth of cut, spindle speed and feed rate. Work piece was of material S45C. The highest optimal parameter influencing surface roughness is cutting velocity followed by feed rate. Also cutting velocity and feed rate is having high influence on tool life.

[8]D. Philip Selvaraj *et al.* (2010) investigated that in turning of AISI-304 austenitic steel using TiCS and TiCN coated tungsten carbide cutting tool and the cutting parameters are cutting speed, feed rate and depth of cut, feed rate followed by cutting speed are the optimal parameter for surface roughness.

[9] Shivam Goyal *et al.*, (2016) conducted an experiment. Work piece used was AISI 2010 mild steel. Cutting tool as WNM G32 RP carbide insert with a nose radius 0.8. Cutting parameters are cutting speed, depth of cut, feed rate. Taguchi methodology was employed. Cutting speed followed by feed rate was highest optimal value for surface roughness and depth of cut followed by cutting speed are the highest optimal value for mrr.

[10] Vishal Francis *et al.,* (2013) conducted an experiment using mild steel 0.18%C. Tool used was mild steel. Cutting parameters were feed rate, depth of cut and spindle speed. The methodology used was Taguchi. The highest optimal parameter for surface roughness and mrr are feed rate and spindle speed respectively.

[11] W. Bouzid Sai have investigated A commercially available insert has been used to turn an AISI 4340 steel at speeds placed between 325 and 1000 m/min. The flank wear was measured in connection to cutting time. This is to determine the tool life defined as the usable time that has elapsed before the flank wear has reached the criterion value. It is shown that an increase in cutting speed causes a higher decrease of the time of the second gradual stage of the wear process. This is due to the thin coat layer which is rapidly peeled off when high-speed turning. The investigation included the realization of a wear model in relation to time and to cutting speed. An empirical model has also been developed for tool life determination in connection with cutting speed. On the basis of the results obtained it is possible to set optimal cutting speed to achieve the maximum tool life.

[12] Jeong Suk Kim *et al* investigated that hard coatings improve the performance of cutting tools in aggressive machining applications, such as high-speed machining. Additionally, the relationship between the machining characteristics and the Si contents were investigated under various high-spindle speeds. It has shown that the tool life was improved up to 50% for the Si content

III. EXPERIMENTATION

For performing the experiment we have selected the manual lathe machine and useits parameters for optimization .The parameters that we have selected for the experiment are:

i. Speed
ii. Depth of cut
iii. Feed rate

The effect of the above three parameters are well studied i.e. the effect of speed, feedrate and depth of cut on the tool wear and the material removal rate.

Work piece:For the analysis of the MRR we have selected the aluminum alloy (A 356).The purpose of this project is to efficiently determine the optimum machining operation for parameters of the aluminum alloy to achieve the maximum MRR in that range of parameter. Properties of A-356are:

A356.0 ALUMINIUM CASTING ALLOY

(7Si-0.3Mg)

Specifications:

AMS 356.0: 4217, 4260, 4261, 4284, 4285, 4286, A356.0: 4218
Former ASTM 356.0, SG70A; A356.0, SG70B
SAE 356.0: J452, 323
UNS number 356.0: A03560. A356.0: A13560
Government 356.0: QQ-A-601, QQ-A-596.
A356.0: MIL-C-21180 (Class 12)
Foreign ISO: AlSi7Mg

Chemical Composition:

Composition limits. 356.0: 0.25 Cu max,
0.20 to 0.45Mg,
0.35 Mn max,
6.5 to 7.5 Si,
0.6 Fe max,
0.35 Zn max,
0.25 Ti max,
0.05 other (each) max,
0.15 others (total) max, Rest is Al.

Consequence of exceeding impurity limits.

High copper or nickel decreases ductility and resistance to corrosion

Applications: Typical uses of A-356.0 aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water-cooled cylinder blocks. Other applications where excellent cast ability and Good weld ability, pressure tightness, and good resistance to corrosion are required. A356.0: Aircraft structures and engine controls, nuclear energy installations, and other applications where High-strength permanent mold or investment castings are required.

Mechanical Properties:
0.2%. Proof Stress (N/mm^2) 185 Tensile stress (N/mm^2) 230 Elongation (%) 2 Impact - Brinell hardness 75 Endurance Limit 56 Modulus of Elasticity 71 Shear strength 120
Properties in excess of those quoted can be obtained with Strontium additions e.g.-Elongation 5%
Cutting Tool Used: Tool material-HSS Steel, which has a hot hardness value of about 600° C, possesses good strength and shock resistant properties. It is commonly used for single point lathe cutting tools and multi point cutting tools such as drills, reamers and milling cutters. The main use of high speed steels continues to be in the manufacture of various cutting tools: drills, tapes, milling cutters, tool bits, gear cutters, saw blades, etc., although usage for punches and diesis increasing. High speed steels also found a market in fine hand tools where their relatively good toughness at high hardness, coupled with high abrasion resistance, made them suitable for low speed applications.
Machine Used:
Lathe used: PL-4 Bench Lathe
Close grained ground alloyed Cast Iron bed with hardness of 190 -200 BH.
Totally enclosed dial type Gear Box with hardened and ground shafts running in Ball Bearing. Spindles and Shafts ground and wearable parts standardized for interchange ability. The spindle is driven, either by foot power from a treadle and flywheel or by a belt or gear drive to a power source.
Calculation of Material removal rate: Material removal rate (MRR) has been calculated from the difference of weight of work piece before and after experiment
Control parameter and their values:

Table 1: Control parameters.

Parameters	Unit	Level 1	Level 2	Level 3
Speed (A)	rpm	200	400	600
Depth Of Cut(B)	mm	0.6	1.5	2.0
Feed (C)	mm/rev	2.0	2.5	3.0

The experiment is being conducted according to the L-9 orthogonal array.

Table 2.

S.No.	Speed(A) rpm	Depth(B)mm	Feed(C) mm/rev
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The L9 array is denoted as L9 (3^3) in DOE. L9 means the array requires 9 runs. 3^3 indicates that the design estimates up to four main effects at 3 levels each. The L9 array can be used to estimate three main effects using four runs provided that the three factor and four factor interactions can be ignored.
L9 means the array requires 9 runs. 3^3 indicates that the design estimates up to three main effects at three levels each.
The experimentation included turning of Aluminum alloy A-356 specimen on lathe which was done in an orderly manner that can be briefed under following main headings:
(a) Deciding the control parameter to be analyzed.
(a) Conducting actual experiment as per the L9 Orthogonal Array.
(a) Analysis of results and conclusion.
We used an Aluminum alloy A-356 rod having a diameter of 3.8cm and weighted 1.62kg on which further tests were done to check its mechanical properties.
After setting the parameters in the required format we have started doing the main experiments on the basis of Taguchi's L9 format and the length of each specimen turned is about 1.5 cm and the other parameters kept varying according to the table of Taguchi's L9 setting at different parameters that are termed as

1. for low (speed, feed, depth of cut)
2. for medium (speed, feed, depth of cut)
3. for high (speed, feed, depth of cut)

The combination of different parameters is decide as per given in the table and considerable MRR is measured each time during each experiment. The value of material removal rate MRR is calculated which is given in the table-

Table 3: Experiments performed.

Trial No.	Levels			
	(SPEED) A(rpm)	(DEPTH OF CUT) B(mm)	(FEED) C(mm/rev)	MRR(g/sec)
1	1	1	1	0.14437
2	1	2	2	0.19782
3	1	3	3	0.32661
4	2	1	2	0.31994
5	2	2	3	0.59102
6	2	3	1	0.50613
7	3	1	3	0.40912
8	3	2	1	0.53604
9	3	3	2	0.48102

Analytical Analysis of Variance (ANOVA):

The analysis of variance (ANOVA) is another optimizing tool mentioned in the factorial design method to further optimize above parameters as discussed in section.

ANOVA is a statically based, objective decision making tool for detecting any differences in average performance of groups of items tested. An ANOVA table consists of sum of squares, corresponding degree of freedom, the F-ratio corresponding to the ratios of two mean squares, and the contribution proportions from each of the control factors. These contribution proportions can be used to assess the importance of each factor for interested multiple performance characteristics (MPCs).

Analysis of Material Removal Rate

After selecting the factors to be considered for the result analysis:

Degree of freedom

Variance

Sum of Squares are calculated

We apply these factors and on the basis of these factors we have formulated a table that shows the values of all these factors for different parameters that we have selected in our study in a order of:

Table 4: Variance of means.

Factors	DOF	SS	V	F-RATIO	P%
Speed(A)	2	0.125964	0.062982	68.08	65.29%
DOC(B)	2	0.044204	0.022102	23.89	22.28%
Feed(C)	2	0.018053	0.009027	9.76	8.52%
Error	2	0.001850	0.000925		
Total	8	0.190072			

The above table is used to show the variance of means for the different parameters that we have selected for our experiment and the contribution P% shows that which factor is mainly required as the driving force for the whole experiment.

S/N Ratio. In the present work the first criteria selects larger the better type for MRR. Larger the better type S/N ratio for MRR.

$$n=-10\log(1/n\sum_{i-1}^{n} 1/mrr^2)$$

Signal-to-noise ratio is also called as SNR or S/N, is defined as the ratio of signal power to the noise power corrupting the signal. The Signal to Noise Ratio (SNR) is the defining factor when it comes to quality of measurement. A high SNR guarantees clear acquisitions with low distortions and artifacts caused by noise. The better your SNR, the better the signal stands out, the better the quality of your signals, and the better you ability to get the results you desire.

Table 5: Calculation of s/n ratio.

MRR	MRR^2	$1/MRR^2$	S/N Ratio(n)
0.14437	0.020843	47.97844	-16.8105
0.19782	0.039133	25.55404	-14.0746
0.32661	0.106674	9.374347	-9.7194
0.31994	0.102362	9.769288	-9.8986
0.59102	0.349305	2.862831	-4.568
0.50614	0.256178	3.90354	-5.9146
0.40912	0.167379	5.974459	-7.763
0.53605	0.28735	3.480081	-5.4159
0.48102	0.23138	4.32189	-6.3567

Response Table:

Table 6: Response Table.

SPEED(A)	DOC(B)	FEED(C)	MRR(g/sec)	S/N Ratio(n)
1	1	1	0.14437	-16.8105
1	2	2	0.19782	-14.0746
1	3	3	0.32661	-9.7194
2	1	2	0.31994	-9.8986
2	2	3	0.59102	-4.568
2	3	1	0.50614	-5.9146
3	1	3	0.40912	-7.763
3	2	1	0.53605	-5.4159
3	3	2	0.48102	-6.3567

Graphs of Mean Values: The different graphs for the various parameters are drawn and these graphs are used to find out the combination of parameters that are required to achieve a maximum MRR.

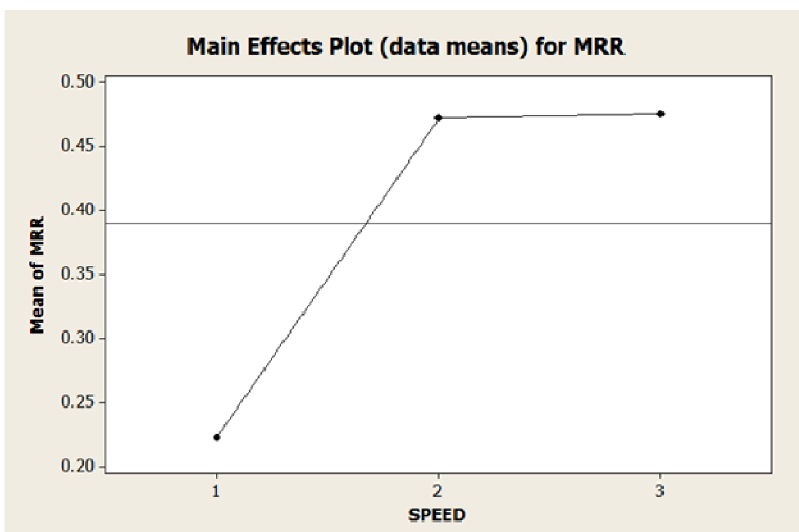

Fig. 1.

From the above graph we can conclude that the maximum value of material removal rate occurs at the level 2 of the experiment i.e. the optimum value is A2.

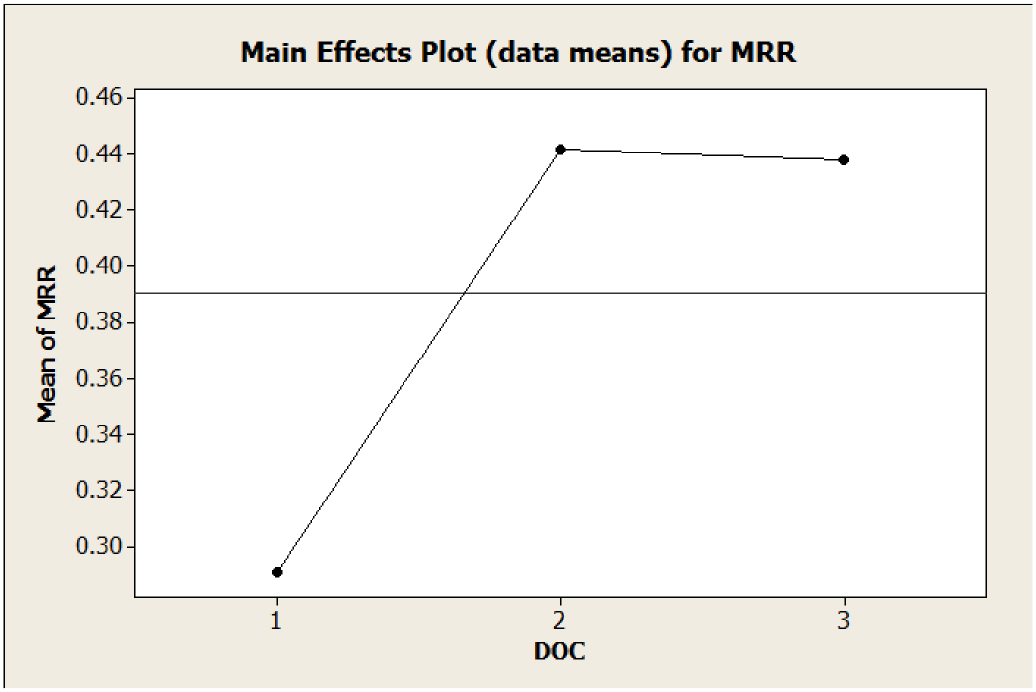

Fig. 2. Variation of means and the factor B (depth of cut).

The graph shows that maximum value of material removal rate occurs at the level 2 of the experiment i.e. the optimum value is B2.

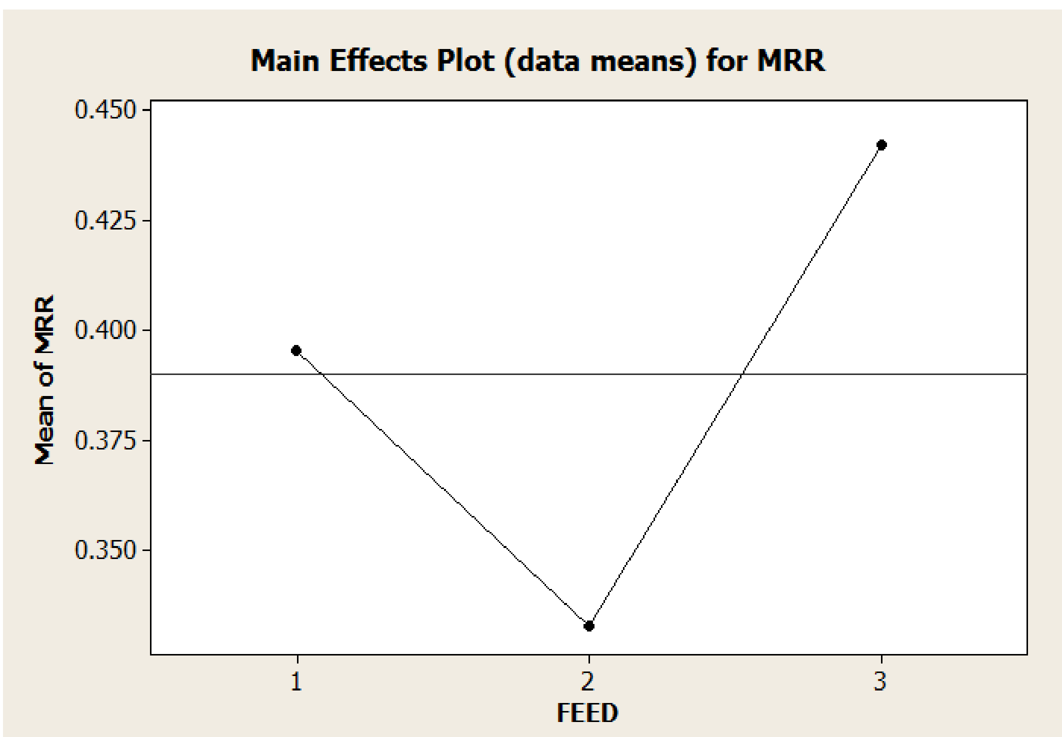

Fig. 3. Graph between the mean and the factor C (feed rate).

From the graph we have conclude that the optimum value of the maximum MRR occurs at level 3 i.e. C3.

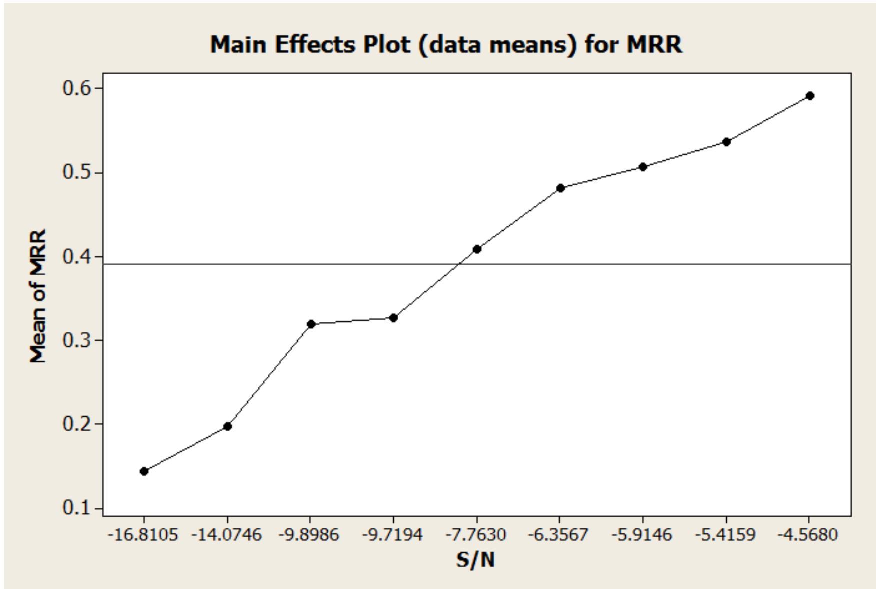

Fig. 4. Graph between the mean and the S/N RATIO.

IV. RESULT AND DISCUSSION

The optimal values of individual parameters and the corresponding setting of the parameters are given in the table below-

Table 7: Result table.

Performance characteristics	Optimal parameter level	Predicted parameter level
Material removal rate	A2,B2,C3	0.59102

Confirmation Test: The confirmation experiment is the final step in the first iteration of the design of the experiment process. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. The confirmation experiment is performed by conducting a test with a specific combination of the factors and levels previously evaluated.

In this study, after determining the optimum conditions and predicting the response under these conditions, a new experiment was designed and conducted with the optimum levels of the turning parameters. The final step is to predict and verify the improvement of the performance characteristic. The results of experimental confirmation using optimal turning parameters and comparison of the predicted material removal rate with the actual material removal rate using the optimal turning parameters are shown in Table-

Table 8: Confirmation table.

Performance characteristics	Optimal parameter level	Predicted parameter level
Material removal rate	A2,B2,C3	0.61080

V. CONCLUSION

The above study and graphs gave us the results which yields the maximum material removal rate at a specific combination. By using these combinations of parameters of machining using the selected parameters of the machining we can optimize the material removal rate to a value. The metal considered by us in this experiment is Aluminum alloy A-356 which is cast alloy and ductile material to machine.

Table 9: Selected parameter and their values at optimum levels.

Parameters	Units	Optimum Levels	Values
SPEED- A	rpm	2	400
DOC- B	mm	2	1.5
FEED- C	mm/rev	3	3.00

We have performed 9 experiments and on the basis of those experiments and the post experiment analysis we came to the conclusion that the MRR can be maximized at a considerable in the following combination of parameters.

In the optimization process we also consider different graphs and figures and from the main effect plot of mean values the optimal combination is-A2, B2, C3. This shows that the optimum tool wear is obtained only at the above combination of parameters.

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