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Optimization of Machining Process Parameters in Abrasive Water Jet Machining

Thilak.M¹, Anandan A², Arockia George G³, Elangovan A⁴, Karthikeyan S⁵

Assistant Professor, Department of Mechanical Engineering, TRP Engineering College, Tiruchirapalli, India¹

UG Scholars, Department of Mechanical Engineering, TRP Engineering College, Tiruchirapalli, India^{2,3,4,5}

ABSTRACT: This paper attempts to select the significant process parameters by Taguchi methodology while machining of Aluminium 6063 by AWJM. Different process parameters like pressure, feed rate, standoff distance and abrasive flow in three different levels are selected for optimization with two contravene responses, higher MRR and lower Ra by a single parametric combination. For Design of experiment L16 orthogonal array is prepared to set the input significant parameters for final product is calculated for better optimization purpose also different combinations of the factors are ranked on basis of grey relational grade.

1. INTRODUCTION

Abrasive water jet machining also known as a water jet is an industrial tool capable of cutting a wide variety of materials using a very high-pressure jet of water, or a mixture of water and an abrasive substance. The term abrasive jet refers specifically to the use of a mixture of water and abrasive to cut hard materials such as metal or granite, while the terms pure water jet and water-only cutting refer to water jet cutting without the use of added abrasives, often used for softer materials such as wood or rubber. Water jet cutting is often used during fabrication of machine parts. It is the preferred method when the materials being cut are sensitive to the high temperatures generated by other methods. Water jet cutting is used in various industries, including mining and aerospace, for cutting, shaping, and reaming. Water jet technology evolved in the post-war era as researchers around the world searched for new methods of efficient cutting systems. This system used a 100,000 psi (690 MPa) pump to deliver a hypersonic liquid jet that could cut high strength alloys such as PH15-7-MO stainless Aluminium 6063. Used as a honeycomb laminate on the Mach 3 North American XB-70 Valkyrie, this cutting method resulted in delaminating at high speed, requiring changes to the manufacturing process. While not effective for the XB-70 project, the concept was valid and further research continued to evolve water jet cutting.

II. LITERATURE REVIEW

Ruzhong Yan et al used high speed abrasive jet charges into the clearance between the constrained wheel and optical glass, and a high- energy velocity field has been formed under the centrifugal force of wheel and the hydrodynamic pressure. E Lemma, L. chen, July 2002 introduced a new technique which is a variant of the traditional AWJ cutting technique, makes use of a back and forth motion of the cutting head which is superimposed on the normal linear motion to effect optimum loading of the cutting forces on the workpiece material and scan the cut-wall surface to also improve surface finish. K. S. Jai Aultrin and M. Dev Anand -2014 reviewed of such past studies have prominent decision variables, objective functions, constraints, variable bounds, remarks and their limitation. Kovacevic, M. Fang made few attempts have been made to model and optimize the process parameters in AWJC. The approaches employed in this direction include Design of Experiments (DOE), regression modeling, Analysis of Variance (ANOVA), fuzzy logics and artificial neural networks. K.Kalpna et al reviewed on the research aspects in the condition monitoring of Abrasive Water Jet Machining (AWJM) system. Condition monitoring of the AWJM system helps to achieve an effective utilization of the machine in order to increase productivity. From the review, it is observed that the future work recommends the condition monitoring of AWJM system using multi-sensory approach with suitable sensors. T.Nguyen

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et al. developed the predictive models for estimating the characteristics of the channels milled by an AWJ. The models are verified and found to agree well with the experimental data. M. M. Korat, et al. reviewed the research work carried out from the inception to the development of AWJM within the past decade. It reports on the AWJM research relating to improving performance measures, monitoring and control of process, optimizing the process variables. A wide range of AWJM industrial applications for different category of material are reported with variations. Dixit et al examined the role of water jet in

heavy construction in general and particularly how it affects the regional contractors in the northeast. M. Uthayakumaret al considered the assessment of the process parameters in abrasive waterjet cutting of redmud reinforced banana/polyester hybrid composite. Jiazhong Xu et al. conducted experimental research on several typical materials cut by water-jet cutting machine equipped with phased intensifier is conducted, which is valuable for design, manufacture and technological application of high pressure water equipment. M.A. Azmir et al., conducted a practical study for analyzing the surface roughness and kerf taper ratio of glass/epoxy composite laminate machined using abrasive water jet machine.

III. PROBLEM IDENTIFICATION

Taguchi method is applied to find optimum process parameter for Abrasive water jet machining (AWJM). Abrasive water jet machining is a non-traditional process of removal of material by impact erosion of high pressure, high velocity of water and entrained high velocity of grit abrasives on a work piece. Experimental investigation were conducted to assess the influence of abrasive water jet machining (AWJM) process parameters on MRR of Aluminium. The approach was based on Taguchi's method and analysis of variance (ANOVA) to optimize the AWJM process parameter for effective machining and to predict the optimal choice for each AWJM parameter such as pressure, standoff distance, Abrasive flow rate and Traverse rate. For each combination of orthogonal array we have Conducted three experiments and with the help of ANOVA it is found that these parameters have a significant influence on machining characteristics such as metal removal rate (MRR). The analysis of the Taguchi method reveals that, in general the standoff distance significantly affects the MRR while, Abrasive flow rate affects the surface Roughness. Experiments are carried out using orthogonal array by varying pressure, standoff distance, Abrasive flow rate and Traverse rate respectively. Experimental results are provided to verify this approach..

IV. METHODOLOGY

A well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically speaking, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources (materials and time) required are prohibitively large. Often the experimenter decides to perform a subset of the complete set of experiments to save on time and money! However, it does not easily lend itself to understanding of science behind the phenomenon. The analysis is not very easy (though it may be easy for the mathematician/statistician) and thus effects of various parameters on the observed data are not readily apparent. In many cases, particularly those in which some optimization is required, the method does not point to the BEST settings of parameters. A classic example illustrating the drawback of design of experiments is found in the planning of a world cup event, say football. While all matches are well arranged with respect to the different teams and different venues on different dates and yet the planning does not care about the result of any match (win or lose)!!!! Obviously, such a strategy is not desirable for conducting scientific experiments.

4.1 PROPERTIES OF AN ORTHOGONAL ARRAY

The orthogonal arrays have the following special properties that reduce the number of experiments to be conducted.

1. The vertical column under each independent variables of the above table has a special combination of level settings. All the level settings appear an equal number of times. For L9 array under variable 4, level 1, level 2 and level 3 appears thrice. This is called the balancing property of orthogonal arrays.
2. All the level values of independent variables are used for conducting the experiments.

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3. The sequence of level values for conducting the experiments shall not be changed. This means one cannot conduct experiment 1 with variable 1, level 2 setup and experiment 4 with variable 1, level 1 setup. The reason for this is that the arrays of each factor columns are mutually orthogonal to any other column of level values. The inner product of vectors corresponding to weights is zero. If the above 3 levels are normalized between -1 and 1, then the weighing factors for level 1, level 2, level 3 are -1, 0, 1 respectively. Hence the inner product of weighing factors of independent variable 1 and independent variable 3 would be $(-1 * -1 + -1 * 0 + -1 * 1) + (0 * 0 + 0 * 1 + 0 * -1) + (1 * 0 + 1 * 1 + 1 * -1) = 0$

4.2 TAGUCHI'S METHOD - EFFECT OF SIGNAL TO NOISE RATIO

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation (1)

$$L(Y) = K(Y - KT)^2 \dots\dots\dots (1)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be K and standard deviation to be σ . Let desired performance be K1. Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor . Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation (2):

$$K (\mu_0 / \mu_2) \sigma^2 \dots\dots\dots (2)$$

4.3 GREY RELATIONAL ANALYSIS

The Grey theory established by Dr. Deng includes Grey relational analysis, Grey modeling, prediction and decision making of a system in which the model is unsure or the information is incomplete. It provides an efficient solution to the uncertainty, multi-input and discrete data problem. The relation between machining parameters and machining performance can be found out using the Grey relational analysis. And this kind of interaction is mainly through the connection among parameters and some conditions that are already known. Also, it will indicate the relational degree between two sequences with the help of Grey relational analysis. Moreover, the Grey relational grade will utilize the discrete measurement method to measure the distance. When the range of the sequence is too large or the standard value is too enormous, it will cause the influence of some factors to be neglected. Also, in the sequence, if the factors' goals and directions are different the relational analysis might also produce incorrect results. Therefore, preprocessing of all the data is necessary. This process is so called as Grey relational analysis generation. There are 3 types generation

(1) The higher is better :

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad [1]$$

(2) The lower is better :

$$x_i^*(k) = \frac{\max x_i^{(0)}(k) - x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad [2]$$

(3) A desired value $x^{(0)}$:

$$x_i^*(k) = 1 - \frac{|x_i^{(0)}(k) - x^{(0)}|}{\max x_i^{(0)}(k) - x^{(0)}} \quad [3]$$

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4.4 VARIABLES USED

Table 5.1 Variable process parameters

	1	2	3	4
Pressure (bar)	400	-	6000	-
Stand off distance (mm)	1	1.5	2	2.5
Abrasive flow rate (g/sec)	175	200	225	250
Cutting speed (mm/min)	300	350	400	450

Table 5.2 Machining array

EX NO	FLOW RATE	SPEED	PRESSURE	STAND OFF DISTANCE	TIME	TOP KERF WIDTH	BOTTO M KERF WIDTH	KERF RATIO
1	175	300	400	1	28.1	2.02	1.96	0.970
2	175	350	6000	1.5	21.38	2	1.85	0.925
3	175	400	400	2	24.24	2.12	1.96	0.924
4	175	450	6000	2.5	18.83	1.96	1.95	0.995
5	200	300	400	1	27.72	1.85	1.86	1.005
6	200	350	6000	1.5	23.26	2.1	2	0.952
7	200	400	400	2	22.41	2	1.75	0.875
8	200	450	6000	2.5	18.73	1.95	1.95	1
9	225	300	400	1	27.06	2.1	2	0.952
10	225	350	6000	1.5	36.63	1.85	1.8	0.972
11	225	400	400	2	24.04	2.1	2	0.952
12	225	450	6000	2.5	17.63	2	1.9	0.950
13	250	300	400	1	27.84	1.9	1.85	0.973
14	250	350	6000	1.5	11.55	2.12	2.03	0.957
15	250	400	400	2	23.95	1.98	1.92	0.969
16	250	450	6000	2.5	6.05	2.10	1.91	0.905

5. RESULTS AND DISCUSSION

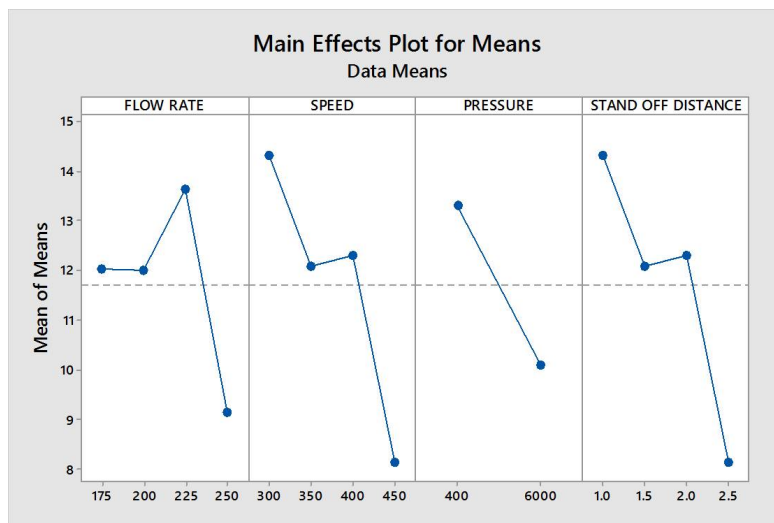
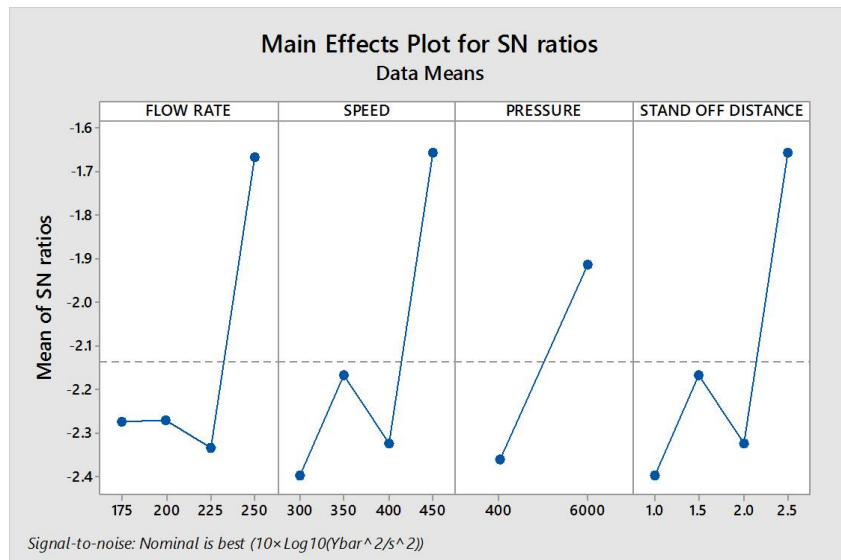
An objective of this study is to find out optimal conditions of Abrasive water jet machining machine for minimizing machining time and kerf width. For this single specimen of Aluminium 6063-T6 was bought in which 16 cuts were made. The mechanical properties of Aluminium 6063 are given in table 1.1 As per the literature review Water pressure, cutting speed, abrasive flow rate, and standoff distance were considered as most important parameters. In order to perform minimum experiments Taguchi method has been employed. For this L16 orthogonal array is considered. Experiment results and various response graph for machining time, Kerf width were obtained.

5.1 TAGUCHI'S METHOD - EFFECT OF SIGNAL TO NOISE RATIO

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Taguchi Analysis: TIME, KERF RATIO versus FLOW RATE, SPEED, PRESSURE, STAND OFF DISTANCE

* NOTE * Design is not orthogonal.

* ERROR * Factor PRESSURE is highly correlated with other terms. No calculations were done.

Response Table for Signal to Noise Ratios

Nominal is best ($10 \times \log_{10}(\bar{Y}^2 / s^2)$)

STAND OFF

Level FLOW RATE SPEED PRESSURE DISTANCE

1 -2.277 -2.398 -2.362 -2.398

2 -2.273 -2.168 -1.914 -2.168

3 -2.336 -2.327 -2.327

4 -1.667 -1.659 -1.659

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Delta 0.669 0.739 0.449 0.739

Rank 3 1.5 4 1.5

RESPONSE TABLE FOR MEANS

STAND OFF

Level FLOW RATE SPEED PRESSURE DISTANCE

1 12.046 14.328 13.311 14.328

2 11.994 12.078 10.107 12.078

3 13.648 12.295 12.295

4 9.150 8.136 8.136

Delta 4.499 6.191 3.204 6.191

Rank 3 1.5 4 1.5

5.2 GREY RELATIONAL ANALYSIS

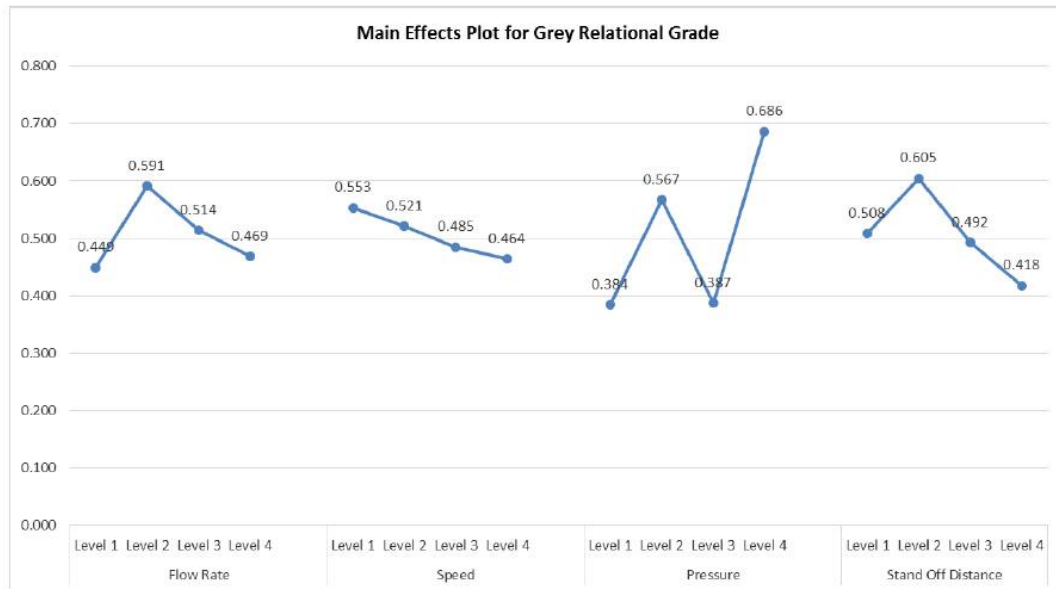
Response Table for Grey Relational Grade					
Factors	Level 1	Level 2	Level 3	Level 4	Max – Min
Flow Rate	0.449	0.591	0.514	0.469	0.142
Speed	0.553	0.521	0.485	0.464	0.089
Pressure	0.384	0.567	0.387	0.686	0.302
Stand Off Distance	0.508	0.605	0.492	0.418	0.187

Input Control Parameters					Output responses		Normalizing Sequence		Deviation Sequence		Grey Relational Coefficient		Grey Relational Grade
Trial No	Flow Rate	Speed	Pr	SOD	Top Kerf Width	Bottom Kerf Width	Top Kerf Width	Bottom Kerf Width	Top Kerf Width	Bottom Kerf Width	Top Kerf Width	Bottom Kerf Width	
1	175	300	400	1.00	2.02	1.96	0.37	0.250	0.630	0.750	0.443	0.400	0.421
2	175	350	6000	1.50	2	1.85	0.44	0.643	0.556	0.357	0.474	0.583	0.529
3	175	400	400	2.00	2.12	1.96	0.00	0.250	1.000	0.750	0.333	0.400	0.367
	175	450	6000	2.50	1.96	1.95	0.59	0.286	0.407	0.714	0.551	0.412	0.481
5	200	300	400	1.00	1.85	1.86	1.00	0.607	0.000	0.393	1.000	0.560	0.780
6	200	350	6000	1.50	2.1	2	0.07	0.107	0.926	0.893	0.351	0.359	0.355
7	200	400	400	2.00	2	1.75	0.44	1.000	0.556	0.000	0.474	1.000	0.737
8	200	450	6000	2.50	1.95	1.95	0.63	0.286	0.370	0.714	0.574	0.412	0.493
9	225	300	400	1.00	2.1	2	0.07	0.107	0.926	0.893	0.351	0.359	0.355
10	225	350	6000	1.50	1.85	1.8	1.00	0.821	0.000	0.179	1.000	0.737	0.868
11	225	400	400	2.00	2.1	2	0.07	0.107	0.926	0.893	0.351	0.359	0.355
12	225	450	6000	2.50	2	1.9	0.44	0.464	0.556	0.536	0.474	0.483	0.478
13	250	300	400	1.00	1.9	1.85	0.81	0.643	0.185	0.357	0.730	0.583	0.657
14	250	350	6000	1.50	2.12	2.03	0.00	0.000	1.000	1.000	0.333	0.333	0.333
15	250	400	400	2.00	1.98	1.92	0.51	0.393	0.481	0.607	0.509	0.452	0.481
16	250	450	6000	2.50	2.109	1.91	0.04	0.429	0.959	0.571	0.343	0.467	0.405

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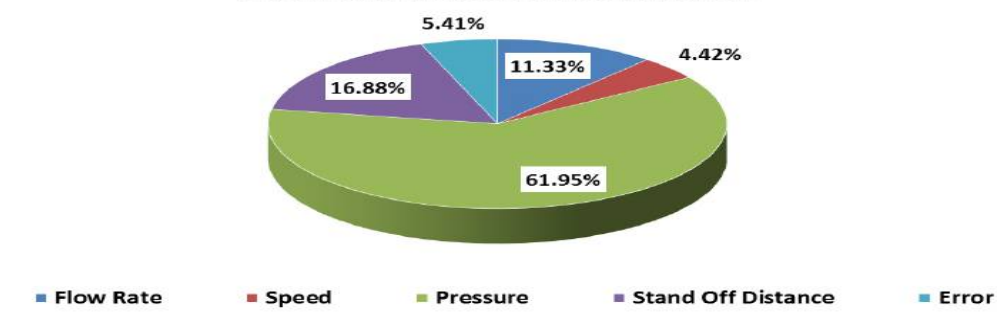
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Analysis of Variance

Factors	DoF	SS	MS	F Value	P Value	% Contribution
Flow Rate	3	0.0476	0.0159	2.7913		11.33%
Speed	3	0.0186	0.0062	1.0892		4.42%
Pressure	3	0.2604	0.0868	15.2632		61.95%
Stand Off Distance	3	0.0710	0.0237	4.1597		16.88%
Error	4	0.0227	0.0057			5.41%
Total	16	0.4203	0.0263			100.00%

ANOVA % Contribution of Input Parameters



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VI. CONCLUSION

A grey relational grade obtained from the grey relational analysis and Taguchi's method were used to optimize the process parameters of abrasive water jet machine with multiple characteristics (Flow rate, Cutting speed, Standoff distance, Pressure) the experimental results shows that the parameters pressure plays a predominant role in machining. Based on the pressure the responses (machining time, Kerf width) can be optimized.

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