International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.6., Issue.3, 2018
May-June

RESEARCH ARTICLE

ISSN: 2321-7758

# EXPERIMENTAL PARAMETRIC STUDIES ON MONEL USING ABRASIVE WATER JET MACHINING

**R.CHAITANYA*[1], G.SURESH[2], N.MAHESH BABU[3]**
[1]P.G.Scholar, [2]Associate Professor, [3]Assistant Professor
VEMU College of Engineering Department of Mechanical Engineering, Chittor-Dist,AP, India
*E-mail:chaithanyaroyal522@gmail.com


R.CHAITANYA


G.SURESH


N.MAHESH BABU

**ABSTRACT**

Abrasive water Jet Machining mainly adopted by aerospace industry for cutting high strength materials and other composites. It finds most of its applications in machining of gas turbines, rocket motors, space craft, nuclear power and pumps etc., very thin stream of about 0.004 to 0.010 dia. can be cut and material loss is also less due to cutting. The aim of the work is to analysis the effect of input process parameters such as Transverse speed, Abrasive flow rate and standoff distance for achieving optimum Processes responses such as Metal Removal Rate(MRR), Surface roughness (Ra), and Kerf width simultaneously while machining on the nickel-copper based super alloy Monel. The Design of Experiments are conducted to find the influence of processes parameters for setting optimal setting using Taguchi's concept. A series of experiments are conducted to find the optimum parameters. Optimization of processes parameters are predicted by using grey relational analysis. A conformation experiment is conducted to validate the optimal level of Processes parameters prediction.

Key words: Grey taguchi technique, Monel, Kerf Width, Metal Removal Rate & Surface Roughness.

## 1. INTRODUCTION

Water jets were introduced in the United States during the 1970's, and were utilized merely for cleaning purposes. As the technology developed to include abrasive water jets, new applications were disco verged [1]. The water jet process provides many unique capabilities and advantages that can prove very effective in the cost battle [2]. Learning more about the Water jet technology gives us an opportunity to put these cost-cutting capabilities to work[3]. Beyond cost cutting, the water jet process is recognized as the most versatile and fastest growing process in the world. No toxic gases or liquids are used in water jet cutting, and water jets do not create hazards or vapours. It is truly a versatile, productive, cold cutting process[4].

### 1.1 Working Principle of Abrasive Water Jet Machining

Water from the reservoir is pumped to the intensifier using a hydraulic pump. Water is pumped at a very high pressure about 2000-4000 bar using intensifier. When water at such pressure is issued through the orifice of about 0.2 – 0.4 mm diameter, converts the potential energy of water into kinetic energy, resulting a very high velocity jet of 1000 m/s. This high velocity of water jet when it comes out of the nozzle cuts the materials of the required size and a shape is shown in Fig. 1.

International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June


Fig. 1. Abrasive Water Jet Machining of Inconel-825

## II. LITERATURE SURVEY

A lot of contributions have been made on the optimization of process parameters of different materials by using Abrasive water jet machining and been reviewed. Some of them are discussed below. Divyansh Patel, Puneet Tandon [5] This work explores thermally enhanced abrasive water jet machining (TEAWJM) process to improve the machining capabilities of conventional abrasive water jet machine by heating the work by an external heat source. The present work describes an experimental study of thermally enhanced machining (TEM) by adding an oxy acetylene gas welding setup as an external heat source to the machine setup which heats the work locally and temperature is measured by non-contact laser thermometer. The experimental data of cutting parameters at critical temperatures of hard-to-machine metals Inconel-718, Titanium (Ti6Al4V) and mild Steel (MS-A36) (ductile in nature) with full factorial DOE is presented here. Further, the effect of thermal treatment (during cutting) on surface morphology of the material machined has been studied for analyzing the effectiveness of the proposed methodology. Due to TEM, an increase in material removal rate, reduction in power consumption machining time is observed.

John A. Webster [6] The aerospace industry has experienced significant growth over the past decade and it is estimated that nearly 30,000 new commercial passenger aircraft will be required by 2030 to meet rising global demand. Abrasive machining is a key material removal process utilized in the production of aero engine components. Current industrial practice and perspectives relating to grinding in the aerospace sector are presented including general work piece surface integrity standards/requirements, fluid delivery systems, wheel preparation options and machine tool designs/configurations. Corresponding academic research on the mach inability of aerospace alloys and composites are critically reviewed together with recent developments involving novel/innovative grinding processes.

B.Satyanarayana, G.Srikar [7] Abrasive Water Jet Machining (AWJM) is a versatile machining process primarily used to machine hard and difficult to machine materials. The objective of this paper is to optimize material removal rate and kerf width simultaneously using AWJM process on INCONEL 718. The process parameters are chosen as abrasive flow rate, pressure, and standoff distance. Taguchi Grey Relational Analysis is opted because of multi response optimization.

From above Literature survey it is evident that work has been reported on Experimental Investigation on Inconel-825(Nickel,Iron & Chromium based alloy) material which is used for Aeronautical, Creogenics and Chemical processing applications. Design of Experiments (DOE) is prepared in Mini-Tab Software by using Taguchi for optimizing Processes parameters selected are Transverse speed, Abrasive flow rate and Stand-off Distance. These processes parameters are going to be optimized based on Maximum MRR, Minimum Surface Roughness & Minimum Kerf Width after Machining is completed by conducting ANOVA & Grey Taguchi Technique.

## III. EXPERIMENTAL SETUP

### 3.1 Work Piece Material

The material choosen is MONELis a super alloy which is precipitation hardened material and high level of corrosive resistance. It is a Nickel-Molybdenum-Chromium alloy with additions of copper and Titanium. It has good yield strength and mechanical properties even at cryogenic temperatures to moderately high temperatures. It is highly resistant to highly corrosive acids like sulphuric acid and phosphoric acids.

Table 1. Chemical Composition of Base Material(wt%)

| **Ni** | **Mo** | **Cr** | **Fe** | **W** | **Co** | **Mn** | **C** |
|---|---|---|---|---|---|---|---|
| Remainder | 15.0-17.0 | 14.5-16.5 | 4.0-7.0 | 3.0-4.5 | 2.5 max | 1.0 max | .01 max |
| **V** | **P** | **S** | **Si** | | | | |
| .35 max | .04 max | .03 max | .08 max | | | | |

International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June

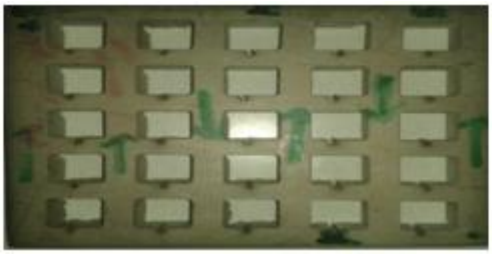

Fig. 2. MONEL Workpiece After & Before Machining

**3.2 Micro Structure of MONEL**

Microstructures are studied for Inconel-825 materials with Lens magnification of 5X, 10X & 20X.

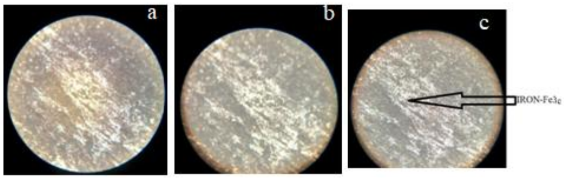


Fig.3. Microstructures of MONEL a.5X b.10X, c.15X

**3.3 Abrasive Water Jet Machine Set Up**


Fig.4. Excel Abrasive water Jet Machine Set up

All experimental runs were carried out on a CNC Abrasive Water Jet Machining setup available at "EXCEL WATERJET CUTTING"- SIDCO Industrial Estate, Thirumazhisai, Chennai – 602107, Tamil Nadu, India. The Abrasive Water Jet Machine has the following specifications.

The work piece was mounted and clamped on the work table. A reference point on the work piece was set for setting work co-ordinate system (WCS). The programming was done with the reference to the WCS. The reference point was defined by the ground edges of the work piece. The cutting operation is done by a jet of abrasive particles and water mixture on the work piece. The input parameters like Traverse speed, Abrasive flow rate, Standoff distance are given to the CNC machine in the input panel.

Table 2. Specifications of Abrasive Water Jet Machine

| S.No | Description | Range |
|---|---|---|
| 1 | Controlling of Machine | CNC |
| 2 | Voltage | 415 V |
| 3 | Frequency | 50 Hz |
| 4 | Phases | 3 |
| 5 | Power | 547 W |
| 6 | Current | 1.8 A |
| 7 | Table size | 3 * 3 * 1.5 |
| 8 | Travel | X-axis – 3000mm, Y-axis – 3000mm, Z-axis – 260mm |
| 9 | Nozzle diameter | 1.1 mm |
| 10 | Abrasive type | Garnet |
| 11 | Abrasive size | 80 Mesh |
| 12 | Orifice diameter | 0.35 mm |
| 13 | Focusing tube diameter | 8 mm |
| 14 | Water pressure | 3500 bars |
| 15 | Water flow rate | 3.5 litre/min |

**3.4 Design of Experiment-DOE**

The process of planning the experiment is carried out, so that appropriate data will be collected and analyzed by statistical methods resulting in valid and objective conclusions. The method of analysis depends directly on the design of experiments employed.

Most researchers identified Abrasive water jet machining process parameters that greatly affect Response parameter. The Process Parameter like Standoff distance, impact angle, traverse rate, number of passes, abrasive material, abrasive particle size, abrasive shape, and abrasive mass flow rate, focusing tube diameter and focusing tube length water pressure orifice diameter etc. In this paper we have selected process parameter as Traverse Rate (mm/min), Abrasive flow rate (gm/min) and Stand of distance (mm) to analyze its effect on MRR (gm/min) and Surface Roughness ( μm) Kerf width(mm).

**3.5 Control Parameters**

**Factor A:** Transverse speed (mm/min)

**Factor B:** Abrasive flow rate (gm/min)

International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June

**Factor C:** Stand of distance (mm)

Table 3. AWJM Processes Parameters and their Levels.

| Parameter | Notation | Units | Levels | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 |
| Transverse Speed | TS | mm/min | 40 | 50 | 60 | 70 | 80 |
| Abrasive flow rate | AFR | gm/min | 50 | 100 | 150 | 200 | 250 |
| Stand-off distance | SOD | mm | 1 | 2 | 3 | 4 | 5 |

### 3.6 Selection of Orthogonal Array-OA

In Taguchi method Control factors refers to input parameters for the process, and Response factors refers to corresponding output parameters for the process.

DOF for a Control Factor = No. of Levels – 1

DOF for AB = (No. of Levels in A-1)*

(No.pf Factors-1) =2*4= 8

Total DOF = 8*No.of factors=8*3=24

As per Taguchi technique, the processes parameters of 5 level design has two degree of freedom (DOF) this gives a total of 8. 3 parameters are considered DOF for three processes variables for this research. The condition for selecting OA is the DOFs for selected OA must be higher than DOFs required for experiment is 24 so, the nearest OA available for satisfying the condition of selecting OA is L25

Table 4. Taguchi $L_{25}$ DOE in terms of Coading Factors.

| S.NO | TRANSVERSE SPEED (mm/min) | ABRASIVE FLOW RATE (gm/min) | STAND OFF DISTANCE (mm) |
|---|---|---|---|
| 1 | 40 | 50 | 1 |
| 2 | 40 | 100 | 2 |
| 3 | 40 | 150 | 3 |
| 4 | 40 | 200 | 4 |
| 5 | 40 | 250 | 5 |
| 6 | 50 | 50 | 2 |
| 7 | 50 | 100 | 3 |
| 8 | 50 | 150 | 4 |
| 9 | 50 | 200 | 5 |
| 10 | 50 | 250 | 1 |
| 11 | 60 | 50 | 3 |
| 12 | 60 | 100 | 4 |
| 13 | 60 | 150 | 5 |
| 14 | 60 | 200 | 1 |
| 15 | 60 | 250 | 2 |
| 16 | 70 | 50 | 4 |
| 17 | 70 | 100 | 5 |
| 18 | 70 | 150 | 1 |
| 19 | 70 | 200 | 2 |
| 20 | 70 | 250 | 3 |
| 21 | 80 | 50 | 5 |
| 22 | 80 | 100 | 1 |
| 23 | 80 | 150 | 2 |
| 24 | 80 | 200 | 3 |
| 25 | 80 | 250 | 4 |

Fig.5. Control Panel for Abrasive water jet Machine

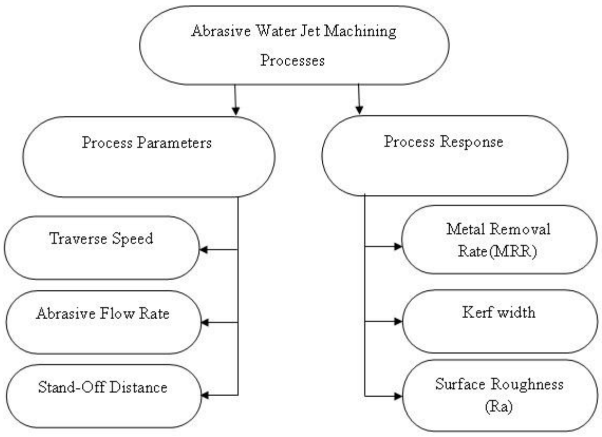


Fig.6. Flowchart represnts Processes Parameters & Processes Responses of Experimentation.

## IV. RESULTS & DISCUSSIONS

Metal Removal Rate & Surface Roughness are most important criteria's, which help us determine how rough a work piece material is machined. In all the investigations it was found that the machined smoother near the jet entrance and gradually becomes rougher towards the jet exit. This is due to the fact that as the particles moves own they lose their kinetic energy and their cutting ability deteriorates. By analyzing the experimental

International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June

data of the selected material, it has been found that optimum selection of the three basic parameters, i.e, Transverse speed, abrasive mass flow rate and nozzle standoff distance are very important on controlling the processes outputs such as Metal Removal Rate (MRR), Surface Roughness (Ra) & Kerf width. The effect of these parameters are studied while keeping the other parameters considered in this study as constant.

Table 5. Taguchi'S $L_{25}$ OA with Experimental Results

| S.No | Transverse speed (mm/min) | Abrasive flow rate (gm/min) | Stand off Distance (mm) | Kerf width-mm | MRR-gm/sec | Surface roughness (Ra) µm |
|---|---|---|---|---|---|---|
| 1 | 40 | 50 | 1 | 0.66 | 0.044 | 3.016 |
| 2 | 40 | 100 | 2 | 0.56 | 0.057 | 2.805 |
| 3 | 40 | 150 | 3 | 0.5 | 0.037 | 3.021 |
| 4 | 40 | 200 | 4 | 1.01 | 0.068 | 3.237 |
| 5 | 40 | 250 | 5 | 1 | 0.089 | 3.300 |
| 6 | 50 | 50 | 2 | 0.96 | 0.068 | 3.902 |
| 7 | 50 | 100 | 3 | 0.57 | 0.035 | 5.300 |
| 8 | 50 | 150 | 4 | 1.02 | 0.076 | 3.676 |
| 9 | 50 | 200 | 5 | 0.94 | 0.061 | 2.257 |
| 10 | 50 | 250 | 1 | 0.82 | 0.055 | 2.589 |
| 11 | 60 | 50 | 3 | 1 | 0.089 | 2.106 |
| 12 | 60 | 100 | 4 | 0.91 | 0.060 | 2.500 |
| 13 | 60 | 150 | 5 | 0.96 | 0.075 | 3.536 |
| 14 | 60 | 200 | 1 | 0.55 | 0.037 | 2.740 |
| 15 | 60 | 250 | 2 | 0.93 | 0.060 | 2.551 |
| 16 | 70 | 50 | 4 | 0.44 | 0.031 | 2.756 |
| 17 | 70 | 100 | 5 | 0.78 | 0.067 | 3.928 |
| 18 | 70 | 150 | 1 | 0.49 | 0.057 | 3.410 |
| 19 | 70 | 200 | 2 | 0.68 | 0.056 | 2.791 |
| 20 | 70 | 250 | 3 | 0.44 | 0.037 | 2.742 |
| 21 | 80 | 50 | 5 | 0.67 | 0.054 | 2.857 |
| 22 | 80 | 100 | 1 | 0.34 | 0.039 | 3.984 |
| 23 | 80 | 150 | 2 | 1.01 | 0.071 | 4.116 |
| 24 | 80 | 200 | 3 | 0.99 | 0.085 | 2.712 |
| 25 | 80 | 250 | 4 | 0.57 | 0.043 | 2.606 |

### 4.1 Grey Taguchi Technique

In order to investigate the significance of the process parameters on Metal Removal Rate, Kerf Width, Surface Roughness. ANOVA was performed. ANOVA table for the Grey relational grade are shown in Table 6. From these it is shows that Transverse Speed has most effecting parameter which is about 15.88% it shows much contribution on grey relational grade and following with Abrasive Flow Rate and Stand-off Distance has effect on grey relational grade with contribution of 13.01% and 13.48%.

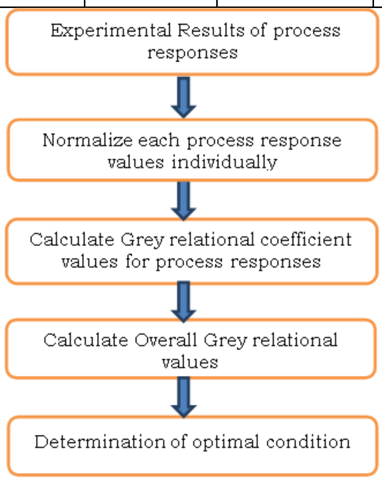


Fig.7.Flow Chart represnts the GreyTaguchi Technique

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June

### 4.2 Normalization of Experimental Results

The first step in Grey-Taguchi analysis is to normalize the experimental results of Metal Removal Rate, Kerf Width, Surface Roughness. Each response value is normalized in the range of 0 to 1. For normalizing Metal Removal Rate 'Higher-the-better' is to select represent in (equ.1) in machining of work pieces manufacturers will target Maximum Metal Removal Rate in short period of time, Kerf Width, Surface Roughness 'Lower-the-better' is to be selected such that work pieces will cut accurate and good surface finish will be obtained (equ.2) criterion is used.

$$X_j(v) = \frac{y_j(v) - \min y_j(v)}{\max y_j(v) - \min y_j(v)} \quad \text{------------1.}$$

$$X_j(v) = \frac{\max y_j(v) - y_j(v)}{\max y_j(v) - \min y_j(v)} \quad \text{------------2}$$

Where, $X_j(v)$= value after normalizing data/ Grey relations generation value,

Min $y_j(v)$=smallest value of $y_j(v)$

Max $y_j(v)$=Largest value of $y_j(v)$

### 4.3 Grey Relational Coefficient

After normalizing the results of Metal Removal Rate, Kerf Width, Surface Roughness, the next step is calculation of grey relational coefficient values for Metal Removal Rate, Kerf Width, Surface Roughness. The grey relational coefficient $\varepsilon_j$ (v) can be calculated by using equ.3 this grey relational coefficient value is used to get grey order.

$$\varepsilon_j(v) = \frac{\Delta_{min} + \phi\Delta_{max}}{\Delta_{oj}(v) + \phi\Delta_{max}} \quad \text{--------3}$$

### 4.3 Grey Relational Grade and Order

Grey relational grade for each experimental run is the average of grey relational coefficient value for a particular experimental run. Grey relational grade can be calculated by using equ.4. Higher value of grey relational grade indicates the best value, so highest grade value gives the higher order. The grey relational grade and their order is given in Table5.

Table 6. Grey Relational Grade and Order

| EXP. No. | Grey Relational Grade | Order |
|---|---|---|
| 1 | 0.514686587 | 19 |
| 2 | 0.592703395 | 8 |
| 3 | 0.557924366 | 12 |
| 4 | 0.500681407 | 21 |
| 5 | 0.637398782 | 3 |
| 6 | 0.468280529 | 24 |
| 7 | 0.426407384 | 2 |
| 8 | 0.509357411 | 20 |
| 9 | 0.594696539 | 7 |
| 10 | 0.547580023 | 16 |
| 11 | 0.780000000 | 1 |
| 12 | 0.558578622 | 13 |
| 13 | 0.518723446 | 18 |
| 14 | 0.564009670 | 11 |
| 15 | 0.549222598 | 15 |
| 16 | 0.605595339 | 6 |
| 17 | 0.490540176 | 22 |
| 18 | 0.573262405 | 10 |
| 19 | 0.555855550 | 14 |
| 20 | 0.615311111 | 4 |
| 21 | 0.546913670 | 17 |
| 22 | 0.608885651 | 5 |
| 23 | 0.465468383 | 23 |
| 24 | 0.649047595 | 2 |
| 25 | 0.581574011 | 9 |

$$\gamma_j = \frac{1}{n}\sum_{v=1}^{n} \varepsilon j(k) \quad \text{-----------------4}$$

Where, n = number of process responses

$\varepsilon_j(v)$ = Grey relational coefficient

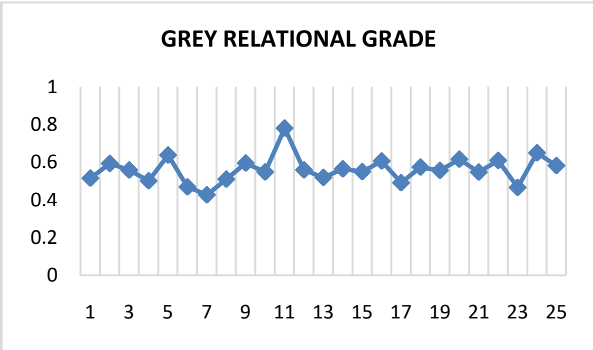


Fig.8.Graph drawn between Grey Relational Grade Vs Grey Order.

From above graph represents the best grade is obtained at Experiment No.24 it is has best optimal processes parameters combination.

International Journal of Engineering Research-Online
*A Peer Reviewed International Journal*
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.6., Issue.3, 2018
May-June

Table 7. ANOVA for Grey Relational Grade

| Source | DF | Seq. SS | Seq. MS | F-Value | % Contribution |
|---|---|---|---|---|---|
| A | 4 | 0.01955 | 0.004888 | 0.83 | 15.88 |
| B | 4 | 0.01609 | 0.004022 | 0.68 | 13.01 |
| C | 4 | 0.01656 | 0.004141 | 0.70 | 13.48 |
| Error | 12 | 0.07090 | 0.005908 | -- | 57.59 |
| Total | 24 | 0.12310 | -- | -- | 100 |

## V. PREDICTION OF RESPONSE VALUES FOR OPTIMUM LEVELS AS PER GREY-TAGUCHI TECHNIQUE

From means of each level of process parameters we will construct a response table. For grey-relational grade. The response table for grey-relational grade is given in Table.8.

Table 8. Response Table for means of Grey-Relational Grade.

| Level | Transverse Speed (A) | Abrasive Flow Rate (B) | Stand Off Distance (C) |
|---|---|---|---|
| 1 | 0.5607 | 0.5831 | 0.5617 |
| 2 | 0.5093 | 0.5354 | 0.5263 |
| 3 | 0.5941* | 0.5249 | 0.6057* |
| 4 | 0.5681 | 0.5729 | 0.5512 |
| 5 | 0.5704 | 0.5862* | 0.5577 |
| Delta | 0.0848 | 0.0613 | 0.0794 |
| Rank | 1 | 3 | 2 |

From above table the optimum processes Parameters order Transverse speed shows its effect majorly on Processes response because MRR,Surface Roughness and Kerf width is directly proportional to its Transverse speed.Such that Transverse speed A is major value 0.5941.

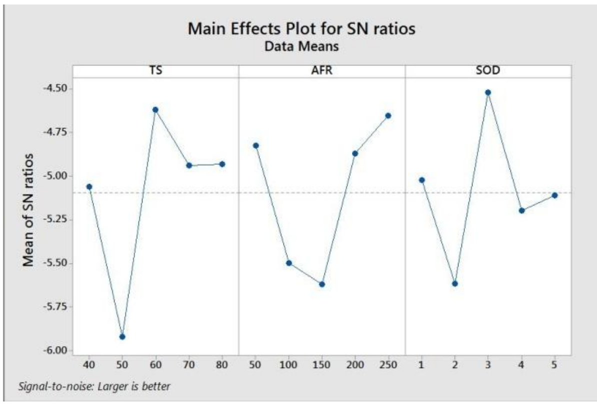


Fig.9. Main effect plot S/N Ratio for Grey Relational Grade.

From the below Response table the optimal condition for maximizing Metal Removal Rate, minimum Kerf Width and Surface roughness simultaneously in Abrasive Water Jet Machining (AWJM) process, is found to be A3 B5 C3 i.e. Transverse speed is 60 mm/min, Abrasive Flow Rate is 250 gm/min and Stand Off Distance is 3 mm. For this optimal setting A3 B5 C3 conducted experimentation for validating results to get best processes responses.

**Regression Equation**

Regression equation is find from MiniTab-17 Software optimum processes responses are obtained by substituting optimum processes parameters which are obtained from regression analysis in regression equations 5,6&7.

lN(MRR) = -2.87 - 0.106 lN(TS) + 0.053 lN(AFR) + 0.161lLN(SOD)-------------5

lN(KW) = 0.36 - 0.305 lN(TS) + 0.069 lN(AFR) + 0.217 lN(SOD)----------------6

lN(SR) = 1.458 - 0.019 lN(TS) - 0.0492 lN(AFR) – 0.0208 lN(SOD)---------------7

Table 9. Optimum Parameter control level.

| S.No | Process response | Optimal setting | Actual Value | Experimental Value | % of Error |
|---|---|---|---|---|---|
| 1 | Metal Removal Rate | $A_3$ $B_5$ $C_3$ | 0.05877 | 0.0573 | 2.5 |
| 2 | Kerf width | | 0.7638 | 0.7643 | -0.06 |
| 3 | Surface Roughness | | 2.9615 | 2.9610 | 0.016 |

$$\text{Experimental Error} = \frac{Actual - Experimental}{Actual} * 100 \quad \text{--------8}$$

From the confirmation experiments, the error percentage of process responses from the predicted responses is less than ±5% is acceptable.

## VI. CONCLUSIONS

In this present analysis of various parameters and on the basis of experimental results, analysis of variance (ANOVA), and SN Ratio the following conclusions can be drawn for effective machining of MONEL by AWJM process as follows:

1. Traverse Speed (TS) is the most significant factor on MRR during AWJM. Meanwhile Abrasive Flow Rate and Standoff distance is sub significant in influencing.
2. In case of surface Roughness Abrasive Flow Rate is most significant control factor.
3. In case of Metal Remove Rate (MRR) & Surface Roughness Transverse speed &

Abrasive Flow Rate are most significant control factors.

4. The optimal condition for maximizing Metal Removal Rate, minimum Kerf Width and Surface roughness simultaneously in Abrasive Water Jet Machining (AWJM) process, is found to be A3 B5 C3 i.e. Transverse speed is 60 mm/min, Abrasive Flow Rate is 250 gm/min and Stand Off Distance is 3 mm.

**Acknowledgements**

Our sincere thanks to "EXCEL WATERJET CUTTING"- SIDCO Industrial Estate, Thirumazhisai, Chennai – 602107, Tamil Nadu, India. Extended our beloved thanks to our honorouble H.O.D Dr.M.chandrasekhara Reddy garu & Teaching and Non-Teaching staff.

**REFERENCES**

[1]. Sruthi, B., Kilari, N., Kishore, J.S. "Experimental Investigation of Abrasive Water Jet Machining Processes Parameters & Its Effects on Processes Responses Using Grey Taguchi Optimization Technique" Journal of Production Engineering JPE(2016) Vol.19 (2), 10 October 2016

[2]. N. Tamannaee, J.K. Spelt, M. Papini," Abrasive slurry jet micro-machining of edges, planar areasand transitional slopes in a talc-filled co-polymer", Precision Engineering, , Issue 24, June 2015.

[3]. Fritz Klocke, Sein Leung Soo , Bernhard Karpuschewski, John A. Webster, Donka Novovic, Amr Elfizy, Dragos A. Axinte, Stefan Tönissen,"Abrasive machining of advanced aerospace alloys and composites",CIRP Annals – Manufacturing Technology, Volume 64,Issue 2, May 2015.

[4]. Fang-Jung Shiou, Assefa Asmare "Parameters optimization on Surface roughness improvement of Zerodur optical glass using an Innovative rotary abrasive fluid multi-jet polishing process", Precision Engineering, Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taiwan, Issue 17, April 2015

[5]. Derzija Begic-Hajdarevic, Ahmet Cekic, Muhamed Mehmedovic, Almina Djelmic "Experimental Study on Surface Roughness in Abrasive Water JetCutting" 25th DAAAM International symposium On Intelligent Manufacturing and Automation, ISSN: 1877-7058, 2015.

[6]. B. Satyanarayana, G. Srikar," Optimization of abrasive water jet machining process parameters using Taguchi Grey Relational Analysis(TGRA)", Proceedings of 13th IRF International Conference, Pune , India, ISBN: 978-93-84209-37-7, Issue 20,July 2014.

**[7].** Debasish ghosh, probal k. das, b.doloi "parametric studies of abrasive water jet cutting on surface roughness of silicon nitride materials" all India manufacturing technology, design and research conference (aimtdr), December 12th–14th, 2014.

[8]. Vijay kumar pal, s.k.choudhury "application of abrasive water jet machining in fabricating micro tools for edm for producing array of square holes" all India manufacturing technology, design and research conference (aimtdr), december 12th–14th, 2014.

**[9].** Sreekesh K and Dr. Govindan P"A REVIEW ON ABRASIVE WATER JET CUTTING" International Journal of Recent advances in Mechanical Engineering (IJMECH), Vol.3, No.3, August 2014.

[10]. M.Uthayakumar, V.Arumugaprabu, M.Kathiresan "Experimental Investigation Of The Process parameters In Abrasive Waterjet Cutting Of Redmud Reinforced Banana/Polyester Hybrid Composites"All India Manufacturing Technology, Design And Research Conference (AIMTDR), December 12th–14th, 2014.

[11]. S. R. Patel, Dr. A. A. Shaikh ,"Control and measurement of abrasive flow rate in an Abrasive Waterjet Machine",International journal of innovative Research in Science, Engineering and Technology, ISSN: 2319-8753 ,Volume 2,Issue 12,December 2013.

[12]. Cristian Birtu, Valeriu Avramescu," Abrasive water jet cutting- Technique, Equipment, Performances", on conventional Technologies Review,Romania, Issue March ,2012.

[13]. Veselko Mutavgjic,Zoran Jurkovic, Marina Franulovic, Milenko Sekulic, "Experimental investigation of surface roughness obtained by Abrasive Water jet machining", 15th International Research/Expert Conference ,"Trends in the Development of Machinery and Associated Technology", Prague, Czech Republic , Issue 12,September 2011.

[14]. M. Chithirai pon selvan and n. Mohana sundara raju "assessment of process parameters in abrasive water jet cutting ofstainless steel" international journal of advances in engineering & technology (ijaet), issn: 2231-1963, july 2011.
[15]. Krushna Prasad Pradhan"DESIGN AND FABRICATION OFABRASIVE JET MACHINE" May 11, 2009.