# Experimental Investigations on Machinability of Aluminium6063 Alloy by Abrasive Water Jet Machining

[1]Guttikonda Venkata Mahesh, [2]Goteti Chaitanya
[1]Student, [2]Associate Professor
R.V.R.& J.C. College Of Engineering

**Abstract- The abrasive water jet machine has gained popularity over other non-conventional machining methods due to the absence of heat affected zone, hazardous gases and ability to cut in any direction without the requirement of secondary processing methods. This is also a productive and efficient alternative to the traditional machining methods. In the present work, the influence of abrasive water jet machining (AWJM) parameters such as water-jet pressure, Feed rate, abrasive flow rate and stand-off distance (SOD) on measured responses such as material removal rate (MRR), Surface roughness (SR) are studied. Experiments were conducted based on Taguchi's $L_9$ orthogonal arrays. Due to the sum of degrees of freedom of the four parameters was equal to the total degree of freedom, a Zero error case was raised. So, to proceed further calculations, the factors having least contributions were pooled to get the pooled ANOVA and to check the significance. The results showed that Feed rate was having the most significant effect on Material removal rate (MRR) among the four factors and for the surface roughness Abrasive flow rate was the most significant.**

**Index Terms— Abrasive water jet machining, Aluminium6063 alloy, MRR, SR.**

## I INTRODUCTION

The term abrasive water jet refers to the use of mixture of water and abrasive particles to cut the hard materials which are difficult to be machined by conventional machining processes and also abrasive water jet machining is mostly preferred because of its easy machining and effective productivity.

In the water jet machine, the process of machining is carried out due to the impact of high velocity jet containing a mixture of water and abrasive particles and making the jet to be projected on the workpiece.

The abrasive water jet machine is having several advantages like,

1. No thermal alterations
2. Flexible machining
3. Less sensitive to material properties
4. High machining versatility
5. It Prevents the formation of heat effected zone on work piece.

The main drawback of abrasive water jet machining is it can only machine soft materials, very thick materials cannot be machined easily and the initial investment for the installation is high.

Among the non-conventional machining techniques AWJM is being an eco-friendly machining, flexible and is capable of machining different types of materials and these qualities made AWJM suitable and important of several applications, such as aerospace, architectural, food processing, medical /surgical and automotive etc.

A literature review of the recently published research work on the abrasive water jet machine to understand the various research issues is presented here,

**Chithirai Pon Selvan M et al. [1]** carried out a study on the influence of process parameters on the irregularities of alumina ceramics surfaces, which are generated while machining by the abrasive water jet. Taguchi's design of experiment was conducted to obtain the surface roughness values. Experiments were conducted by varying water-jet pressure, nozzle traverse speed, abrasive mass flow rate and stand-off distance and the cutting process by abrasive water jet was carried out. They concluded that a combination of high water-jet pressure, more abrasive mass flow rate, low nozzle traverse speed and short stand-off distance must be used to produce more surface smoothness.

**D. Siddа Reddy et al**. **[2]** carried out a study on optimization of process parameters on abrasive water jet machining (AWJM) using the Taguchi method for the Inconel 800H material. The approach followed is analysis of variance (ANOVA) and signal to noise ratio(SN ratio) to optimize the AWJM process parameters for the effective material removal rate (MRR), and the surface roughness (SR).They confirmed that obtained optimal combination of AWJM process parameters satisfy the real need for the machining of Inconel 800H in the actual practice.

**Ramprasad et al. [3]** Investigated on optimizing the material removal rate (MRR) of stainless steel 403 by abrasive water jet machining using ANOVA and Taguchi method. Water-jet pressure, abrasive flow rate and stand-off distance were chosen as input parameters and $L_9$ Orthogonal array of Taguchi method was used to analyze the results.
They concluded that water-jet pressure was the most significant while influencing the MRR for stainless steel 403.

## II. WORKING PRINCIPLE

Abrasive water jet machining initially starts with the pump which pressurizes water and sends to the nozzle with high pressure and is mixed with abrasive particles and is forced through a nozzle having a fine orifice which imparts a lot of pressure to the water- jet mixture. This mixture is projected onto the workpiece which is to be machined. The high-pressure jet which is projected through a small nozzle onto the workpiece erodes the particles which are present on the workpiece surface and this jet makes the material crack. The pressurized jet removes the particles of the workpiece and there by eventually removes the material where the machining has to be done.
The workpiece is placed on the catcher tank containing water and debris. During the machining the material being removed falls down in the catcher tank containing water which can be cleaned later.
Water jet machining can be studied as four basic elements, which are pumping system, abrasive feed system, abrasive water jet nozzle and catcher.

- The pumping system produces a high pressure with jet by pressurizing the water coming from water reservoir up to a pressure up to 400 MPa by using a high -pressure motor and the velocity is of the order of 3.78 liters per minute.
- The abrasive feed system controls the quantity of abrasives to be mixed with water jet.
- The abrasives and pressurized water jet mixture flow through the nozzle having a fine orifice, there by the mixture acquires a lot of pressure.
- The catcher tank system is basically having two systems, one of which is a long narrow tube which is placed below the workpiece cutting point, which helps to remove the cutting obstructions and a tank which is underneath the work piece to catch the cutting debris and water.

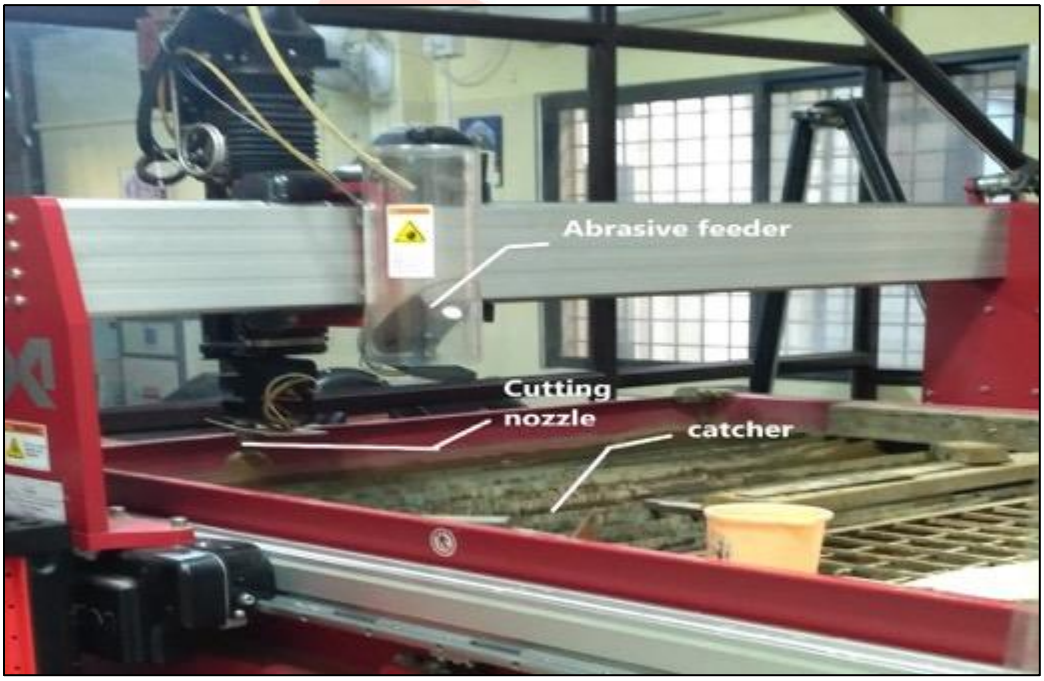


Figure 1. Setup of abrasive water jet machine

## III. EXPERIMENTATION

### A) MATERIAL:

Aluminium6063 alloy is an aluminium based alloy having magnesium and silicon as the alloying materials. It has generally good mechanical properties, heat treatable and is highly weldable.6063 is the most commonly used aluminium alloy for extrusion. It is suitable for the formation of complex shapes and is extensively used for architectural applications and aerospace applications.

### B) EXPERIMENTAL SETUP:

The equipment used for machining is Abrasive water jet model: MAXIEM 1515 which is equipped with 30HP drive pump with capacity of 15,000psi-50,000psi, compressor of 10bar capacity, air cooled chiller with cooling capacity up to 3°C, air drier with capacity 40CFM and a reverse osmosis water filtration system. The specifications of machine cutter travel are,

| | | |
|---|---|---|
| X-Y Travel | : | 1575mm×1575mm |
| Z-Travel | : | 150mm |

| | | |
|---|---|---|
| Cutting head | : | 5-axis machining up to 59° taper |
| Traverse speed | : | 8000mm/min |
| Frequency | : | 50Hz |
| Phases | : | 3 |
| Voltage | : | 380-480VAC. |

### C) TAGUCHI BASED DESIGN OF EXPERIMENTS:

Design of experiment is a systematic method to study the relationship between the input process parameters and the output parameters. Design of experiment helps to manage the input process parameters to optimize the output. This investigation was carried out by considering 4 input parameters such as water-jet pressure (WP), feed rate (FR), abrasive flow rate (AFR) and stand-off distance (SOD), the output parameters are material removal rate (MRR) and surface roughness (SR).

An orifice diameter of 0.76mm, jewel diameter of 0.34mm, 60 mesh size, impact angle 90°, abrasives and abrasive index of 1.00 were taken as constants for all the experiments. In this investigation totally four factors were chosen at 3 levels for which the degree of freedom was 8 which is nearer to $L_9$ orthogonal array. The parameters and levels were selected based on the literature review of some studies those had been documented on the AWJC on graphite/epoxy laminates [4], metallic coated sheet steels [5] and fiber-reinforced plastics [6] So, Taguchi based $L_9$ orthogonal array was considered for which a total of 9 experiments are to be conducted. Taguchi's design of experiments makes use the orthogonal arrays which decrease the number of experiments and there by reduces the cost of the experiments. Taguchi method $L_9$ Orthogonal array provides a set of well-balanced experiments, and Taguchi's signal-to-noise (S/N) ratios, which are logarithmic functions of the desired output, serve as the objective functions for optimization [7]. Taguchi's DOE includes an outer array approach which enables a smaller study size to determine the effects of large number of noise factors. The main disadvantage of Taguchi method is for its difficulty in accounting for interactions between parameters. This is because the results obtained are only relative and do not exactly indicate which parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables are needed.

The process parameters those are chosen for the experimentation are:

a) Water jet pressure (WP),
b) Feed rate (FR),
c) Abrasive flow rate (AFR),
d) Stand-off distance (SOD).

The output parameters are:

a) Material removal rate (MRR),
b) Surface roughness (SR).

Table 1. Level values of input factors

| Factors | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Water-jet pressure | (MPa) | 150 | 200 | 250 |
| Feed rate | (mm/min) | 50 | 100 | 150 |
| Abrasive flow rate | (gm/min) | 200 | 300 | 400 |
| Stand-off distance | (mm) | 2 | 4 | 6 |

The experimental layout for a Taguchi based $L_9$ orthogonal array is shown in Table 2.

Table 2. Taguchi $L_9$ orthogonal array with four factors

| Exp. No: | Water-jet pressure (MPa) | Feed rate (mm/min) | Abrasive flow rate (gm/min) | Stand-off distance (mm) |
|---|---|---|---|---|
| 1. | 150 | 50 | 200 | 2 |
| 2. | 150 | 100 | 300 | 4 |
| 3. | 150 | 150 | 400 | 6 |
| 4. | 200 | 50 | 300 | 6 |
| 5. | 200 | 100 | 400 | 2 |
| 6. | 200 | 150 | 200 | 4 |
| 7. | 250 | 50 | 400 | 4 |
| 8. | 250 | 100 | 200 | 6 |
| 9. | 250 | 150 | 300 | 2 |

### D) EXPERIMENTAL PROCEDURE:

According to the $L_9$ orthogonal array experiments were conducted. Workpiece of dimensions 150mm×130mm×10mm was taken. For each parametric combination the cutting tool path is constant and for every experiment, the machining time is noted as a timer is present in the AWJM. Workpieces were cleaned properly before and after the experiment and the respective weights of workpieces were determined by an electronic weighing machine and the values are used to find the material removal rate (MRR).

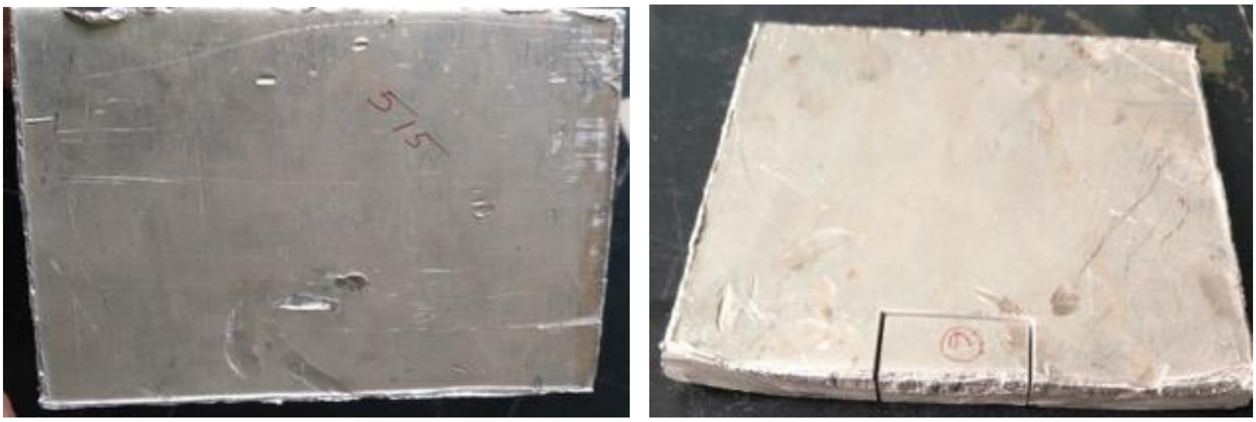

Figure 2**.** Workpiece before and after machining for illustration

During the AWJM machining minute craters are formed on the machined surface.so, surface roughness of the surface can be measured for each and every specimen, for this purpose (MITUTOYO-Japan make) is used to measure the surface roughness of the machined face. Surface roughness for each specimen are determined.


Figure 3. Surface roughness tester

## IV. RESULTS AND DISCUSSION

After completing the experiments according to the $L_9$ orthogonal array parametric combinations, material removal rate (MRR) and surface roughness (SR) for each workpiece were calculated. For the calculated values of MRR, signal to noise ratios (S/N ratio) were obtained by using statistical tool MINITAB 19 software.

Table 3. Calculated values of MRR and SR

| Exp. No | MRR (gm/min) | SR (μm) |
|---|---|---|
| 1. | 2.7352 | 4.085 |
| 2. | 6.2565 | 4.380 |
| 3. | 7.4626 | 3.875 |
| 4. | 5.1969 | 4.205 |
| 5. | 8.8633 | 3.740 |
| 6. | 8.9552 | 5.045 |
| 7. | 3.8293 | 3.800 |
| 8. | 5.2137 | 6.145 |
| 9. | 11.1940 | 4.970 |

SN ratios can be calculated for the material removal rate (MRR) and surface roughness (SR). For the material removal rate (MRR) always Larger is better static is preferred and for the surface roughness value smaller is better test static is preferred [8]. According to Taguchi technique MRR is calculated based on Larger is better and surface roughness as smaller is better. The analysis carried out on MINITAB 19 software.

Table 4. Signal to noise ratios for MRR and SR

| Expt. No | S/N ratio for MRR | S/N ratio for SR |
|---|---|---|
| 1. | 8.7398 | -12.2338 |
| 2. | 15.9266 | -12.8295 |
| 3. | 17.4578 | -11.7654 |
| 4. | 14.3149 | -12.4753 |
| 5. | 18.9519 | -11.4574 |
| 6. | 19.0415 | -14.0572 |
| 7. | 11.6624 | -11.5957 |
| 8. | 14.3429 | -15.7704 |
| 9. | 20.9797 | -13.9271 |

## 1. EFFECT OF INPUT FACTORS ON MRR

The effect of input parameters on the material removal rate can be analysed by using MINITAB 19 software and the repsonse table,response graph and ANOVA can be obtained.

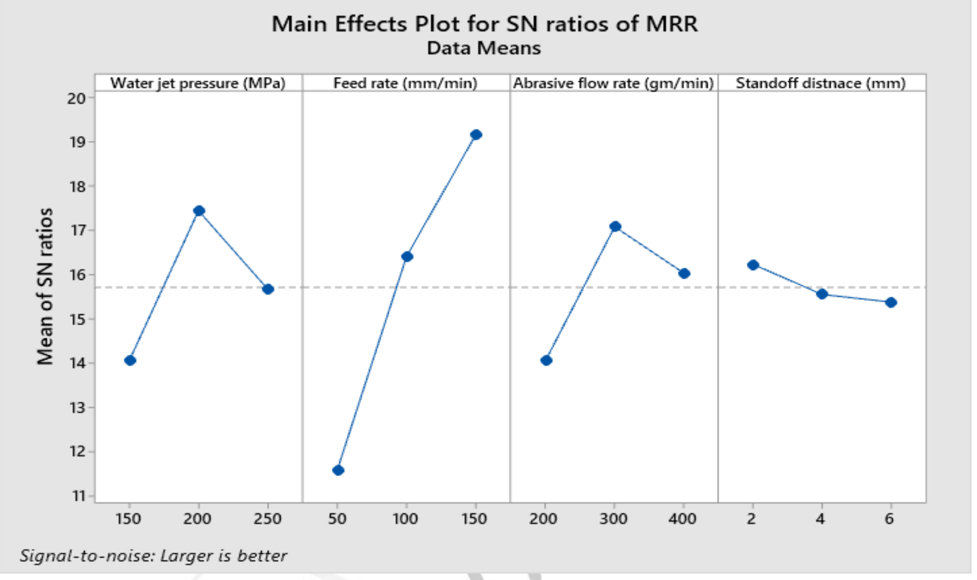


Figure 4. Main effects plot for SN ratios of MRR v/s factors

Table 5. Response table for MRR

| Level | WP | FR | AFR | SOD |
|---|---|---|---|---|
| 1 | 14.04 | 11.57 | 14.04 | 16.22 |
| 2 | 17.44 | 16.41 | 17.07 | 15.54 |
| 3 | 15.66 | 19.16 | 16.02 | 15.37 |
| Delta | 3.39 | 7.59 | 3.03 | 0.85 |
| Rank | 2 | 1 | 3 | 4 |

Table 6. Analysis of variance for MRR

| Source | DF | SS | MS | Contribution |
|---|---|---|---|---|
| WP | 2 | 7.231 | 3.615 | 12.33% |
| FR | 2 | 41.966 | 20.983 | 70.97% |
| AFR | 2 | 5.530 | 2.765 | 9.35% |
| SOD | 2 | 4.404 | 2.202 | 7.45% |
| Error | 0 | | | |
| Total | 8 | 59.130 | | 100% |

Here, the ANOVA table is having a zero error, this because, totally four factors are taken at three levels so each factor is having a degree of freedom of 2 so for four factors the degrees of freedom are 8 and total degrees of freedom is also 8, by this reason the error becomes zero.
To proceed with the calculations, the smaller effects of sum of squares are added together in order to get a non-zero estimate of the error variance, this is called pooling of an error which can be used to combine factor effects of factor and low magnitude of sum of squares. The pooling process is done by taking the factors having a least contribution and those factors are pooled to get the pooled ANOVA without a zero error.

Table 7. Pooled analysis of variance (ANOVA) for MRR

| Source | DF | SS | MS | F-value | P-value | Confidence | Significance |
|---|---|---|---|---|---|---|---|
| WP | 2 | 7.231 | 3.615 | 1.46 | 0.335 | 100% | Yes |
| FR | 2 | 41.966 | 20.983 | 8.45 | 0.037 | 100% | Yes |
| AFR | Pooled | | | | | | |
| SOD | Pooled | | | | | | |
| Error | 4 | 9.934 | 2.483 | | | | |
| Total | 8 | 59.130 | | | | | |

Table depicts the MRR for different levels of the input parameters water jet pressure (WP), feed rate (FR), Abrasive flow rate (AFR), Stand-off distance (SOD) and from the plot the MRR is maximum for water jet pressure at level-2 (200MPa), feed rate at leve-3 (150mm/min),Abrasive flow rate at level-2 (300gm/min) and stand-off distance at level-1 (2mm).
From Table 7 Pooled ANOVA, by observing F-Test values it is clear that water jet pressure and feed rate had the most significant effect on material removal rate (MRR), whereas the other parameters abrasive flow rate and stand -off distance do not affect much the MRR by considerable amount.

## 2. EFFECT OF INPUT PARAMETERS ON SR

The effect of input parameters on the surface roughness can be studied by analyzing the data in MINITAB19 and can obtain the response table, response graph and ANOVA by which the effects of input parameters can be studied.

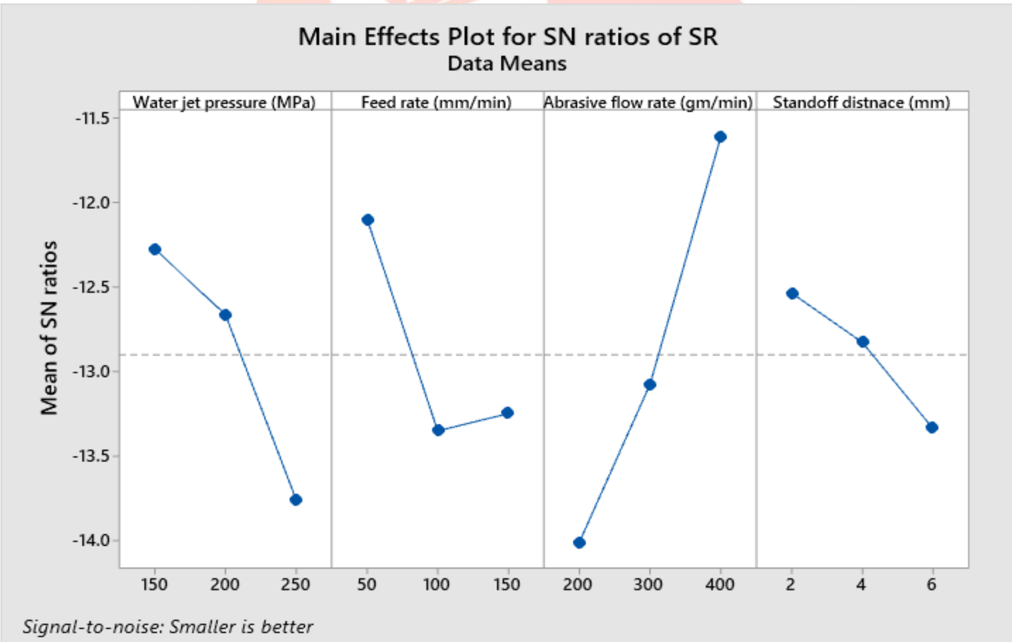


Figure 5. Main effects plot for SN ratios of SR v/s factors

Table 8. Response table for SR

| Level | WP | FR | AFR | SOD |
|---|---|---|---|---|
| 1 | -12.27 | -12.10 | -14.02 | -12.54 |
| 2 | -12.66 | -13.35 | -13.08 | -12.83 |
| 3 | -13.76 | -13.25 | -11.61 | -13.34 |
| Delta | 1.49 | 1.25 | 2.41 | 0.80 |
| Rank | 2 | 3 | 1 | 4 |

Table 9. Analysis of variance for SR

| Source | D.F | S. S | M.S | Contribution |
|---|---|---|---|---|
| WP | 2 | 1.1954 | 0.5977 | 24.16% |
| FR | 2 | 0.9012 | 0.4506 | 18.21% |
| AFR | 2 | 2.4931 | 1.2465 | 50.38% |
| SOD | 2 | 0.3589 | 0.1794 | 7.25% |
| Error | 0 | | | |
| Total | 8 | 4.9486 | | 100% |

Table depicts the response table showing the rank of order for the effect of the four input factors on the response surface roughness and the Figure 5 shows the variation of input parameters with the surface roughness from level-1 to level-3.The ANOVA table is having a zero error because combined degrees of freedom of four factors, which is 8 is equal to the total degree of freedom.so, In order to proceed to the calculations, pooling is done, in which the factors with the least contribution are pooled to get the pooled ANOVA.

Table 10. Pooled analysis of variance for surface roughness

| Source | DF | SS | MS | F-value | P-value | Confidence | Significance |
|---|---|---|---|---|---|---|---|
| WP | 2 | 1.195 | 0.5977 | 1.90 | 0.263 | 100% | Yes |
| FR | Pooled | | | | | | |
| AFR | 2 | 2.493 | 1.2465 | 3.96 | 0.113 | 100% | Yes |
| SOD | Pooled | | | | | | |
| Error | 4 | 1.260 | 0.3150 | | | | |
| Total | 8 | 4.949 | | | | | |

From the pooled ANOVA table, it can be observed that water je pressure and abrasive flow rate have significant effect on the surface roughness and the other parameters like feed rate and stand-off distance do not have significant impact on the surface roughness. From the response table the minimum surface roughness values can be observed for water jet pressure at level-3 (250MPa), for feed rate at level-3 (150mm/min), for abrasive flow rate at level-1 (200gm/min) and for stand-off distance at level-3 (6mm).

## V. CONCLUSION

In this analysis of various process parameters and on the experimental results, SN ratio, response graphs, response tables and the analysis of variance (ANOVA), the following conclusions can be drawn for investigations on machinability of the aluminium6063 alloy by abrasive water jet machining.

- Feed rate was found to be the most significant parameters effecting MRR. Meanwhile, water jet pressure, abrasive flow rate and stand-off distance were found to be the sub significant in influencing MRR.
- The parametric combination for optimum material removal rate was found to be WP2- FR3- AFR2- SOD1.The optimal parameter setting for the MRR was (200MPa-150mm/min-300gm/min-2mm).
- In the case of surface roughness Abrasive flow rate was the most significant factor while the water jet pressure, feed rate and stand-off distance were the sub significant in influencing the surface roughness.
- The parametric combination for optimal surface roughness was WP1- FR1- AFR3- SOD1. The optimal setting for the SR was (150MPa-50mm/min-400gm/min-2mm).

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