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A STUDY OF ABRASIVE WATERJET MACHINING ON BRASS AND GRANITE

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Abstract :- In advanced areas of space, missile and nuclear technologies, there arises a need for machining components to maintain exact sharp edges, high accuracy. In the present era of modern machining, these requirements can be achieved with the help of advanced machining processes like Abrasive Water Jet Machining. The objective of our project is to optimize the input parameters of AWJM, such as pressure within pumping system, abrasive material grain size, stand-off distance, nozzle speed, and abrasive mass flow rate for machining brass and granite. In our project, the performance optimization of abrasive waterjet technology in brass cutting was investigated through design of experiment techniques. Design of experiments was based on Taguchi $L_9(3^3)$ Orthogonal Array providing a decrease of the necessary number of experiments to a conventional full factorial design. The output parameters were evaluated by using the statistical method of signal-to-noise ratio for determination of the effects of each parameter on the cutting process. Also in our project, we used granite and aluminum to show contour cutting/curve cutting using Abrasive water jet machining.

I. INTRODUCTION

1.1 Need For Non-Conventional Machining Processes

The purpose of any machining process evolves when there is purpose to serve with dimensional and form accuracy and good surface finish. Components such as bearings, gears, clutches, tools, screws and nuts require good finishing. Manufacturing process is classified into primary and secondary; primary involves in providing basic shape and size to the material whereas the secondary involves in providing the final shape and size with high accuracy and surface requirements. If a product is machined to high accuracy, it is possible to fulfill its functional requirements, performance enhancement, prolongation in life. One of the classifications of secondary machining processes is the material removal process and the material removal process is further divided into conventional & unconventional. Material removal process in conventional machining is obtained by applying stress beyond the yield point. To achieve this tool material should be harder than a workpiece. The advent of advanced materials like fiber reinforced composites, titanium, ceramics and high strength temperature resistant (HSTR) alloys with improved properties in the areas such as defense, aerospace and automobile applications have made the removal processes by conventional method more difficult and time consuming because of decrease in material removal rate is obtained with an increase in hardness of work piece. Low tolerances, better surface finish complex intricate shapes, shallow entry angles, micro sized, non-circular, large aspect ratio etc., in difficult to machine materials is another important aspect to be considered in research work. The former characteristics are required in the advanced applications of missiles and turbines. Therefore to meet such demands, a different class of machining process known as advanced machining processes also called as non-traditional machining processes have been developed. These are placed in higher grade because of its specialty called ultra-precision machining. The non-conventional machining process is not affected by material properties like hardness, toughness, brittleness. The unconventional machining process uses techniques like mechanical, thermal, electrical, chemical or combinations of both. Any intricate shape on any material can be achieved with suitable control over the process parameters. Careful selection of the process for a particular manufacturing problem is quite important as a process which is much efficient under certain conditions will not yield the same results in other conditions. Many parameters like physical parameters, machine capability in handling different shapes of work material, economics involved, process parameters should be considered. As in conventional, material removal by chip formation can be totally avoided which happens in Electrochemical machining where dissolution at sub atomic level takes place. One more advantage with the unconventional machining process is that it handles work pieces which are too flexible in nature or slender to support the cutting or for other operations. In some of the unconventional machining processes, material removal takes place without the presence of tools. With the improvement in innovation of new geometric designs of products, the need for unconventional processes is in demand and they are the first choice and not the alternative of conventional processes.

1.2 History and about AWJM

Water jet cutting machines started to operate in the early 1970s for cutting wood and plastics material. Cutting by abrasive waterjet was first commercialized in the late 1980s as a pioneering breakthrough in the area of unconventional processing technologies. In AWJ machining process, the work piece material is removed by the action of a high-velocity jet of water mixed with abrasive particles based on the principle of erosion of the material upon which the water jet hits.

The process parameters in AWJPM are broadly classified into six categories namely :

1) Hydraulic parameters: waterjet pressure, orifice diameter and water flow rate

2) Mixing chamber and acceleration parameters: focus nozzle diameter and focus nozzle length.

3) Cutting parameters: traverse rate, number of passes, stand-off distance and impact angle

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4) Abrasive parameters: abrasive flow rate, abrasive particles diameter, abrasive size distribution, abrasive particle shape and abrasive particle hardness
5) Work material: composition, hardness and harder materials (6) Milling parameters: Step-over size, number of passes and nozzle path movement. The influence of these parameters on the output responses have to be studied for brass alloy.

The main aim of this work is to reduce the defects in AWJM such as taper in kerfs, surface finish etc., The mechanism and rate of material removal during AWJ cutting depends both on the type of abrasive and on a range of process parameters. Figure 1.3 shows the nozzle of abrasive water jet

II. PROPERTIES OF MATERIALS USED

2.1 Granite

Granite is the typical type of plutonic rocks, it consists of feldspar, quartz, a few dark—colored mineral, sand, mica. The main chemical propositions of the granite are SiO2 (65% ~ 70%), a little of Al2O3, Cao, MgO and Fe2O3, thus the granite is acid rock. Granite is used in buildings, bridges, paving, monuments, and many other exterior projects.

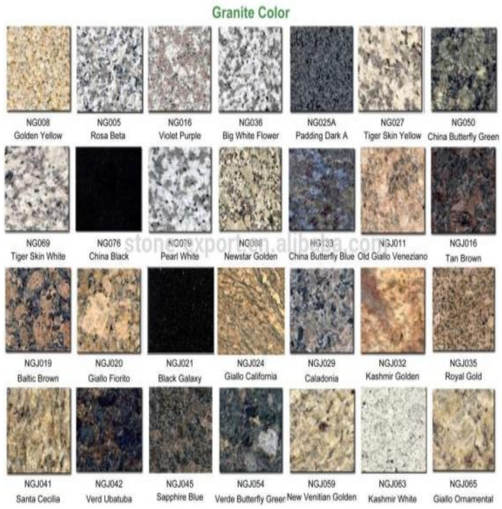

FIGURE 1.1: GRANITE

2.2 Abrasive Water Jet Machining

The term abrasives are used in machining processes such as abrasive jet machining, abrasive flow machining and ultrasonic machining but usage of abrasives differs based on area of work. In AJM air is driven with abrasive to strike the work piece while in USM abrasive grains in liquid slurry and it strikes the work piece at ultrasonic frequency. Recently developments were processed in jet cutting technology by using abrasive water jets with water as a carrier fluid. The mechanical energy of water and abrasive particles are used to achieve material removal or machining. Figure 1.6 shows Addition of hard abrasive particles into the water jet will improve the machining process drastically. Abrasive water jet cutting machine equipped with an ultrahigh pressure pump of 4100 bar/60000 PSI.as shown. A pneumatically controlled valve and a workpiece table with dimensions of 3000 mm x2000 mm.

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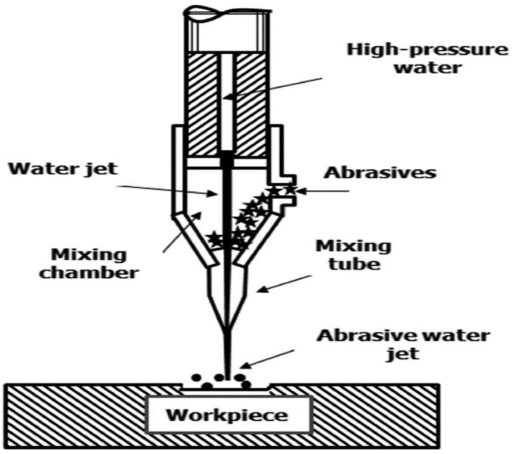

FIGURE 1.2 : SCHEMATIC DIAGRAM OF ABRASIVE WATER JET MACHINE

A 0.35 mm diameter orifice was used to transform high pressure water into a collimated jet with a carbide nozzle of 0.76 mm diameter to form an abrasive water jet. The nozzle is frequently checked and is replaced with a new one whenever the nozzle was worn out significantly. The abrasives used were 80 mesh garnet particles with the average diameter of 0.18 mm and density of 4100 kg/m3. The abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc.
The standoff distance within the range of 2-3 mm is controlled through the controller in the operator control stand. Abrasive flow rate is controlled in system settings. The debris of material and the slurry were collected into a catcher tank.

III. CUTTING PROCESS IN ABRASIVE WATER JET

In abrasive water jet machining water and a stream of abrasives from two different directions mix up and pass through jet nozzle where a part of momentum of water jet is transferred to abrasives, which results in increase in velocity and material is removed through erosion at uppermost position of work piece whereas at depth by deformation wear. As mentioned earlier, the abrasives are gradually released into the water jet where the momentum transfer takes place from water to abrasive particles [1]. Finally, the abrasive particles achieve the acceleration of the jet and come out at which the velocity is assumed to be the same. This cutting process is shown in Figure: 1.7 where a trajectory is formed by abrasives along with a water jet.

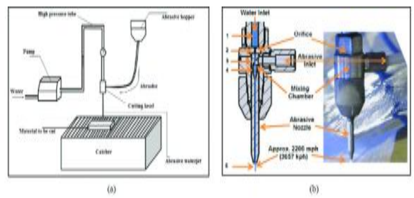

FIGURE 1.3: CUTTING PROCESS IN AWJM

3.1 Principle of Abrasive Water jet Machine

This process works on the basic principle of water erosion. In this process, a high-speed well-concentrated water jet is used to cut the metal. It uses the kinetic energy of water particle to erode metal at the contact surface. The jet speed is almost 600 m/s. It does not generate any environmental hazards. For cutting hard materials, abrasive particles are used in the water jet. These abrasive particles erode metal from the contact surface. Figure 1.8 shows the principle working process of AWJM.

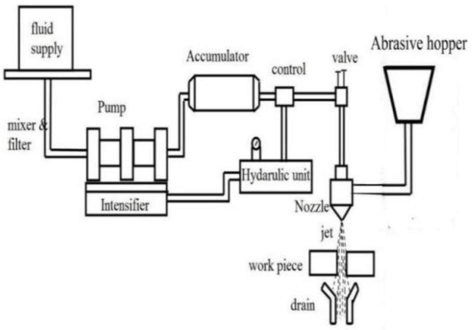

FIGURE 1.8: PRINCIPLE WORKING PROCESS OF AWJM

3.2 Working of Abrasive Water Jet Machine

The working of water jet machining can be summarized as follows:

1) First water is filled in water reservoir. It provides water for cutting operation as shown in figure 1.11.
2) A pump sucks water from water reservoir and send it to intensifier.
3) Intensifier increases the water pressure from 4 bar to 4000 bars. It sends water to accumulator which store some pressurize water.
4) This high-pressure water now sends through tubing system to nozzle. The water passes through flow regulator valve which regulate the flow.
5) Now this high-pressure water enters into nozzle. Nozzle converts some pressure energy of water into kinetic energy.
6) A high-speed high pressurize water jet is available at nozzle exit.
7) This water jet sends to strike at work surface. It erodes metal from the contact surface. Thus, metal removal take place.

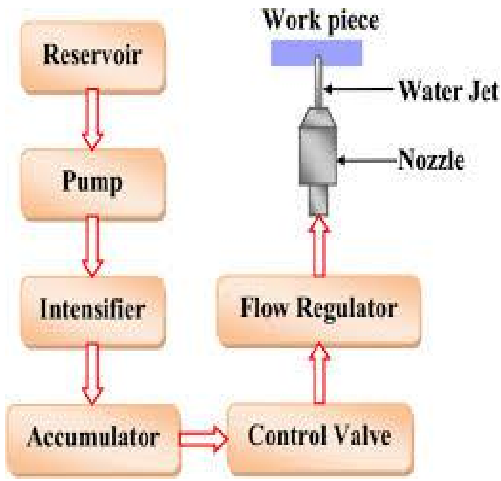

FIGURE 1.4: WORKING OF AWJM

3.3 Operations on AWJM

Based on the applications some of the recent developments in operations using AWJM are listed below [4]:

- ✓ Straight line cutting.
- ✓ Curved and corner cutting
- ✓ Honeycomb cutting
- ✓ Turning
- ✓ Segmental turning
- ✓ Water slicing
- ✓ Spiral and thread machining
- ✓ Small hole drilling
- ✓ Shaped holes
- ✓ Trepanning
- ✓ Uniform depth milling
- ✓ Variable depth milling
- ✓ Polishing

3.4 Applications of Abrasive Waterjet Machine

The applications of Abrasive Water Jet Machining are as follows:

This process has been employed to cut a wide range of materials including both metals and nonmetals. The process has been applied to machine the sandwiched honeycomb structural materials currently used in the aerospace industries [1].

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This technique is getting acceptance as a standard tool for cutting materials in a number of industries like Aerospace, Nuclear, Oil, Foundry, Automotive, Construction and Glass.

It is highly used in the automotive, and electronics industries. In aerospace industries, parts such as engine components (aluminum, titanium, and heat resistant alloys), aluminum body parts, titanium bodies for military aircraft, etc. are made using abrasive water jet machining process.

3.5 Advantages of Abrasive Waterjet Machine

Advantages of AWJM are as follows [1]:

- ✓ It does not change mechanical properties of the workpiece. It is useful for machining heat sensitive material.
- ✓ It is environment-friendly because it does not form any dust particle and used water as cutting fluid.
- ✓ Good surface finish.
- ✓ No physical tool is required.
- ✓ It can cut both soft and hard material. For machining soft materials, water jet machining is used and for machining hard materials, abrasive water jet machining is used.
- ✓ It is ideal process for laser reflective materials where laser beam machining cannot be used.
- ✓ Lower cost of machining.
- ✓ Low power consumption
- ✓ East Adaption over remote control and Recycling of abrasive particles.

IV. LITERATURE REVIEW

Abrasive water jet cutting machines emerged in the early 1970s for cutting wood and plastic materials. It was first commercialized in the 1980s as a pioneering breakthrough in the area of non-traditional processes. In the early 1980s abrasive water jet machine was considered as an impractical application. Today it has grown into full-scale production with ultra-precession results.

4.1 Major Areas of Research

The authors have organized the various AWJM research into two major areas namely AWJM process modeling and optimization together with AWJM process monitoring and control. Figure 2.1 shows fish bone diagram of process parameters.

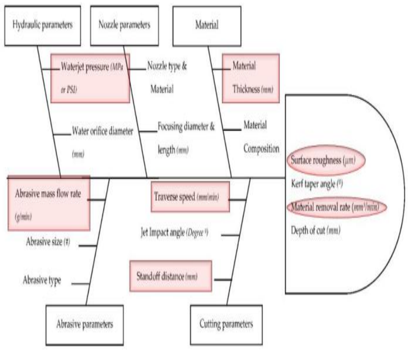

FIGURE 1.5: FISH BONE DIAGRAM

4. 2. Modelling and Optimization

Modeling in AWJM helps us to get a better understanding of this complex process. Modeling studies are the scientific ways to study the system behaviors. A mathematical model of a system is the relationship between input and output parameters in terms of mathematical equations. The literature found related to modeling and optimization of AWJM is mainly based on statistical design of experiments (DOE) such as the Taguchi method and response surface method. Few researchers concentrated on modeling and optimization of AWJM through other techniques such as artificial neural network (ANN), fuzzy logic (FL), genetic algorithm, grey relational analysis, simulated annealing, artificial bee colony etc. The intensity and the efficiency of the machining process depend on several AWJ process. parameters. They are classified as hydraulic, work material, abrasive, and cutting parameters. Depth of cut, surface roughness, material removal rate, kerf geometry and nozzle wear are often used as target parameters. The selection of appropriate machining conditions for the AWJM process is based on the analysis relating the various process parameters to different performance measures. The work carried out by researchers on effects of various process parameters on different performance measures are discussed in the subsequent sections.

GulayCosansu and Can Cogun investigated the effect of colemanite powder used as an abrasive in abrasive water jet machine when perform at the different materials such as aluminum 7570, marble, glass, Ti6Al4V and composite selected as sample materials in the experiment. They have studied what is the effect of output parameters such as surface roughness, surface waviness and kerf taper angle when used a mixture of colemanite powder and garnet as an abrasive. The experiments of A17075 with colemanite powder were started at 80 mm/min traverse rate and 5 g/s abrasive flow rate. They found that increase in abrasive flow rate also reduces the jet deflection sand burr formation at the jet exit region. That is mainly due to the improved cutting ability of the jet with increasing amount of abrasive impinges to the work surface in unit time

John Kechagias et.al studied for quality characterization of abrasive water jet machining of steel sheets with dimension 10x10cm2 by using the Taguchi method L18. They have found out that signal to noise (S/N) ratio represents the response of the data observed in the Taguchi design of experiments. Both, the arithmetic means roughness and the mean kerf width was characterized as "the smaller the better" quality characteristics since lower values are desirable”.

4.3 OBJECTIVES OF THE WORK

The basic objectives of the present work are as follows:

- ✓ To reduce the defects in AWJM such as taper in kerfs, decrease in surface roughness.
- ✓ To investigate the various process parameters on performance measures.
- ✓ To perform modelling of the process using regression analysis and developing empirical relations.
- ✓ To optimize input parameters of AWJM, such as, Abrasive Mass Flow Rate, Transverse Speed, Pressure for machining Granite and Brass.
- ✓ To validate the experimental values with that of the generated values from the regression equation.
- ✓ The Taguchi design of experiment, the signal to noise ratio, and analysis of variance are employed to analyze the effect of input parameters.

- ✓ To achieve good surface finish at optimum cost of MRR.
- ✓ Investigating Abrasive Water Jet Machining on Brass and Granite.
- ✓ To study the interaction between control parameters and response parameters after contour cutting of the material.
- ✓ Prediction of optimum machining conditions for maximization of material removal rate and minimization of surface roughness

V. RESEARCH METHODOLOGY

The main aim of this project is to reduce the defects in AWJM such as taper in kerfs, decrease in surface roughness in order to find the conditions favouring the improvement in the product quality and to decrease the cutting time, experiments are conducted by varying process parameters such as thickness, abrasive flow rate, water pressure, standoff distance and considering abrasive size and nozzle diameter as constant.

Later an empirical model is developed for the prediction of material removal rate and surface roughness for brass by using regression analysis. The model is verified with experimental results that reveals high applicability of the model within the experimental range. Finally, the process parameters are optimized to achieve the targets such as maximization of MRR and minimization of surface roughness (Ra).

VI. OPTIMIZATION TECHNIQUE

6.1 Design of experiments via Taguchi Methods

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, arrays can be found online. The arrays are selected by the number of parameters (variables) and the number of levels (states). This is further explained later in this article. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The data from the arrays can be analyzed by plotting the data and performing a visual analysis, ANOVA, bin yield and Fisher's exact test, or Chi-squared test to test significance.

VII. EXPERIMENTAL DETAILS

7.1 MACHINE SPECIFICATIONS

7.1.1 Introduction

AQUAJET MACHINE TOOL G3020 is the equipment used in the experimentation phase, this chapter gives the complete information on the technical aspects. This equipment is equipped with an ultrahigh pressure pump of 4100 bar/60000 PSI. Figure 3.1 shows the schematic of the abrasive water jet cutting machine. The machine is equipped with a gravity feed type of abrasive hopper, an abrasive feeder system, a pneumatically controlled valve and a workpiece table with dimensions of 3000 mm x 2000 mm. A 0.35 mm diameter sapphire orifice was used to transform high pressure water into a collimated jet with a carbide nozzle of 0.76 mm diameter to form an abrasive water jet. Throughout the experiments, the nozzle is frequently checked and is replaced with a new one whenever the nozzle was worn out significantly. The abrasives used were 80 mesh garnet particles with the average diameter of 0.18 mm and density of 4100 kg/m3 the abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The abrasive water jet pressure is manually controlled using the pressure gauge or even it can be controlled in the system. The standoff distance within the range of 2-3 mm is controlled through the controller in the operator control stand. Abrasive flow rate is controlled in system settings. The debris of material and the slurry were collected into a catcher tank

FIGURE 1.6: AQUAJET MACHINE TOOL G3020 AWJM [17]

7.1.2 Drive description

Closed loop digital drives were used with brushless servo motors, Preloaded ball screws, recirculating ball bearings and Linear bearings with hardened, precision ground ways.

7.1.3 Machine dimensions

In terms of operating weight and height, dimensions are shown in Table 3.1 along with details of its weight and height.

S.No.	Components	Dimensions
1	Footprint (with controller)	3937mm X 2388mm
2	Weight (tank empty)	3823 kg
3	Height (with scissor plumbing)	2887 mm
4	Operating weight	10000 kg

7.1.4 Work envelope

X-Y travel of the nozzle is shown in table and Galvanized steel is used for material supported slats. Details of Maximum supported Load is given in Table 3.2.

TABLE 1.2: WORK ENVELOPE OF AQUAJET MACHINE TOOL

1	X-Y Travel	3000 mm x 2000 mm
2	Table Size	3860 mm x 2450 mm
3	Material Supported Slats	Galvanized Steel
4	Maximum Supported Material Load	1500 kg/m²

7.1.5 Abrasive water jet cutting head

Figure 3.2 shows the nozzle assembly of Aquajet Machine Tool. material used for nozzle is tungsten carbide and its life is 80-100 hours. Diameter of the nozzle is 0.76mm.

Pure waterjet and Abrasive water jet can be adjusted in Aquajet Machine. Its cutting mode and details of Nozzle is

TABLE 1.3: ABRASIVE WATER JET CUTTING HEAD OF

1	Type of cutting	Pure water jet and abrasive water jet
2	Type of head for abrasive water jet	Injection type with orifice and focusing nozzle
3	Cutting mode	Open and submerged jet cutting
4	Orifice diameter	0.35 mm or lesser
5	Mixing/focusing nozzle (Tungsten carbide)	Ø1.0 mm
6	Catcher	Mild steel of 0.6 mm thickness with corrosion resistant paint

7.1.6 Abrasive delivery system

GARNET-80 MESH is used as abrasives and details of its size and capacity is given in Table 3.4.

TABLE 1.4: ABRASIVE DELIVERY SYSTEM

1	Capacity	200 kg or more
2	Abrasive	GARNET -80 MESH
3	Size	<198μm

7.1.7 Physical characteristics

Physical characteristics of abrasives such as Specific weight, Hardness, Specific gravity is given in Table 3.5 It is in crystalline structure.

TABLE 1.5: PHYSICAL CHARACTERISTICS

1	Specific weight	4.1 g/cm³
2	Hardness	7.5 to 8 (Mohs scale)
3	Melting point	>1200°C
4	Specific gravity	4.1 g/cm³
5	Solubility in water	Insoluble
6	Appearance	Crystalline(cubic), Sharp, Angular, Deep red/reddish
7	Odour	No odour

7.1.8 Mineral composition

Details of Mineral composition of abrasives are shown in table 3.6 Among all Garnet is about 98%

TABLE 1.6: MINERAL COMPOSITION

1	Garnet (Almandite)	97.98%
2	Limonite	1.2%
3	Quartz	0.5%
4	Others	0.5%

7.1.9 Design phase

Drafting is done in Solid Works, and these are converted in DXF files. AQUAJET is integrated with the CAM system Which directly uses DXF files.

Figure 1.6 shows 2D Drafting of Brass and this DXF file is load in SIEMENS Software. Three circles were cut in AWJM by maintaining a gap of 27.5 mm from right for 1st circle, 33.50 mm from left for the 2nd circle and 46.5 mm from right for the 3rd circle at the top from the rectangular block. A total of 3 circles of 25 mm diameter were cut by AWJM. The gap between centers of circles at the bottom

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was maintained at 39 mm. A rectangular block of 100 x 75 mm was employed for cutting. The thickness of the specimen is 15mm**.**

Figure 1.7 shows 2D Drafting of Brass and this DXF file is load in SIEMENS Software. Three circles were cut in AWJM by maintaining a gap of 27.5 mm from right for 1st circle, 33.50 mm from left for the 2nd circle and 46.5 mm from right for the 3rd circle at the top from the rectangular block. A total of 3 circles of 25 mm diameter were cut by AWJM. The gap between centers of circles at the bottom was maintained at 39 mm. A rectangular block of 100 x 75 mm was employed for cutting. The thickness of the specimen is 20mm**.**

Figure 1.8 shows 2D Drafting of Brass and this DXF file is load in SIEMENS Software. Three circles were cut in AWJM by maintaining a gap of 27.5 mm from right for 1st circle, 33.50 mm from left for the 2nd circle and 46.5 mm from right for the 3rd circle at the top from the rectangular block. A total of 3 circles of 25 mm diameter were cut by AWJM. The gap between centers of circles at the bottom was maintained at 39 mm. A rectangular block of 100 x 75 mm was employed for cutting. The thickness of the specimen is 25mm**.**

Figure 1.9 shows 2D drafting of granite and this DXF file was loaded in SIEMENS software for cutting in Aquajet Machine and to show the contour cutting through Abrasive waterjet cutting machine. The thickness of the specimen is 15mm.

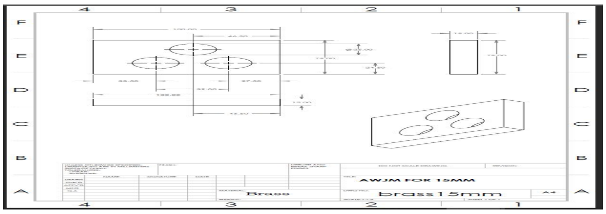

FIGURE 1.7: 2D DRAFTING OF BRASS 15MM THICKNESS.

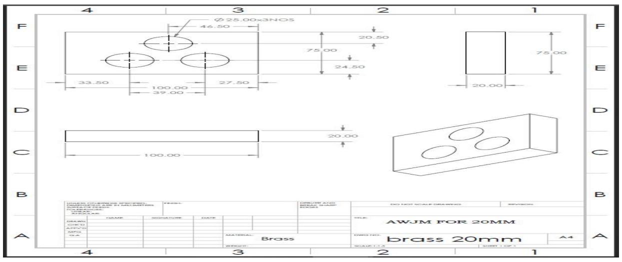

FIGURE 1.8: 2D DRAFTING OF BRASS 20MM THICKNESS.

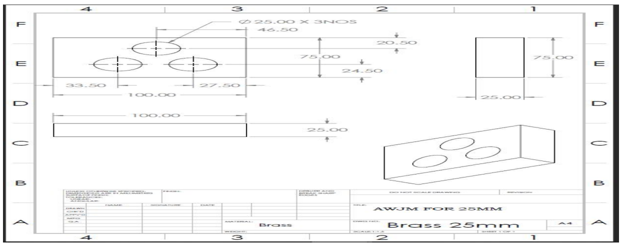

FIGURE 1.9: 2D DRAFTING OF BRASS 25MM THICKNESS.

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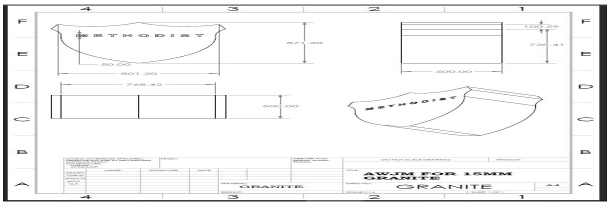

FIGURE 1.10: 2D DRAFTING OF GRANITE 15MM THICKNESS.

7.3.3 Manufacturing phase

After design a process plan is written. The whole process is divided in three stages.

1.Pre experimentation stage
2. Experimentation stage
3. Post experimentation stage

7.3.3.1 Pre-experimentation stage:

Each stage is described in steps along with machine specifications. In this stage the materials are polished with emery papers of different grade.

Materials

Table 3.15 shows the dimensions of specimens that are to be sent to the HMT milling machine in the Pre experimentation stage.

TABLE 1.7: DIMENSIONS OF MATERIALS

RECTANGULAR BLOCK	BRASS	100x75x15	Qty- 1
		100x75x20	Qty- 1
		100x75x25	Qty- 1

Specifications Of Aquajet Machine Tool

Specifications of AQUAJET MACHINE TOOL are given in Table 3.16 with a pressure of 4100 bar.

TABLE 1.8: SPECIFICATIONS OF AQUAJET MACHINE TOOL

1	High Pressure	4100 bar
2	Low Pressure	1500 bar
3	Time	1 min
4	Mixing tube diameter	0.762 mm
5	Jewel Diameter	0.35 mm
6	Abrasive flow rate	0.45 kg/min
7	Standoff Distance	3 mm
8	Nozzle diameter	0.76 mm

Selection of a particular orthogonal array from all the standard OA depends on the number of factors, levels of each factor and orthogonal array was selected using Taguchi technique. L9 OA was selected shown in Table 3.18 and Specimens cut in AWJM is shown in Figure 3.11. The process parameters considered are Water pressure at three levels, Abrasive mass flow rate at three levels, Speed/Feed Rate at three levels and thickness of the specimens at three levels shown in Table 3.18. Experimental sheet for Brass is given in Table 3.19.

TABLE 1.9: VALUES OF PROCESS PARAMETERS FOR BRASS

Levels	Factors			
	Thickness (mm)	Pressure (bar)	Abrasive flow rate (kg/min)	Speed/Feed Rate (mm/min)
L1	15	3000	400	18
L2	20	3300	450	27
L3	25	3600	500	36

TABLE 1.10: L9 SINGLE 2-4 LEVEL ORTHOGONAL ARRAY

Experiment Number	Thickness	Pressure	Abrasive flow rate (kg/min)	Speed/Feed Rate
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	2
5	2	2	2	3
6	2	3	1	3
7	3	1	3	3
8	3	2	1	2
9	3	3	2	1

TABLE 1.11: EXPERIMENTAL SHEET FOR BRASS

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Experiment Number	Thickness (mm)	Pressure (bar)	Abrasive Flow Rate (kg/min)	Speed/Feed Rate (mm/sec)	Time for Cutting (sec)
1	15	3000	400	18	345
2	20	3300	450	18	345
3	25	3600	500	18	345
4	25	3300	400	27	240
5	15	3600	450	27	240
6	20	3000	500	27	240
7	20	3600	400	36	183
8	25	3000	450	36	183
9	15	3300	500	36	183

Samples are cut in the AQUAJET Machine Tool. At first Brass is cut by known process parameters shown in Figure 3.11 and samples are studied further. After measuring the performance measure such as Surface Roughness and Material Removal Rate.

FIGURE 1.11: BRASS AND GRANITE SAMPLES CUT IN AQUAJET MACHINE

7.3.3.3 Post experimentation stage:

During this stage performance measures considered in the present study i.e., surface roughness and material removal rate are studied for their variation with respect to input parameters.

TABLE 1.12: TECHNICAL SPECIFICATIONS OF MITUTOYO

Measuring range X axis	0.69" (17.5mm)
Make	Mitutoyo
model	SJ-210
Filters	Gaussian, 2CR75, PC75
Sampling length	0.003, 0.01, 0.03, 0.1" (0.88, 0.25, 0.8, 2.5mm)
Display languages	Japanese, English, German, French, Italian, Spanish, Portuguese, Korean, Traditional Chinese.
Power-saving function	Auto-sleep off function (910-600 sec) *3
Stylus	Diamond Tip

FIGURE 1.12: MITUTOYO DIGITAL SURFACE ROUGHNESS TESTER.

SUMMARY

This chapter reviews the machine set up and its assembly. A clear idea is given on technical aspects as well as accessories one must consider during machining. It also reviews the application of brass alloys in Aerospace and Automotive industries. Physical and chemical composition details are listed in brief. Before experimentation one must know about the properties of material and its compatibility in AWJC. A Process plan is written for experimentation. A clear idea is given on how to select an orthogonal array based on number of levels and parameters. Performance measures are also examined through different appliances. Finally, introduction is given to the equipment used for Surface Roughness measurement.

VIII. RESULTS & DISCUSSION

The experiments conducted as mentioned in chapter 3 and the results are presented and discussed in the subsequent sections.

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8.1 Analysis of Results for Brass

Experimental results of brass are shown in Table 4.1. Minitab 20.3 software is used for the analysis of results and obtaining the relationship of performance measures with input parameters.

TABLE 1.13 EXPERIMENTAL RESULTS FOR BRASS.

Experiment No	Mass Of Workpiece Before Machining (grams)	Mass Of Workpiece After Machining (grams)	MRR (g/sec)	Surface Roughness (µm)
1	950	805	0.420	3.125
2	950	805	0.604	1.705
3	950	805	0.792	2.755
4	1270	991	0.806	2.600
5	1270	991	1.162	1.915
6	1270	991	1.524	2.300
7	1560	1316	0.707	2.161
8	1560	1316	1.016	1.112
9	1560	1316	1.333	2.890

8.2 Taguchi Analysis:

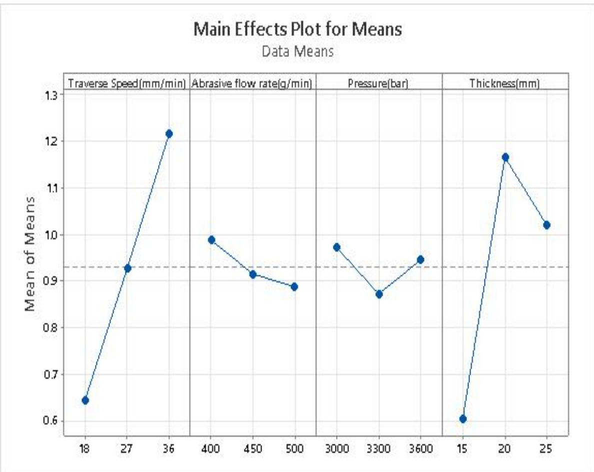

FIGURE 1.13: VARIATION OF MRR WITH PROCESS PARAMETERS

8.3 Taguchi Analysis:

Variation of Surface Roughness with process parameters

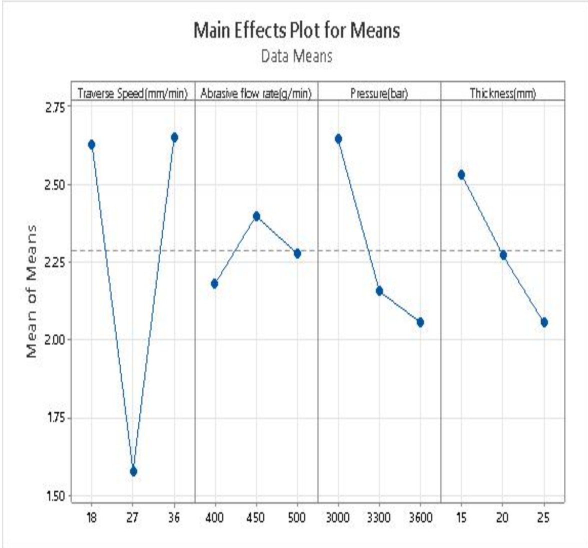

FIGURE 1.14 VARIATION OF SURFACE

8.4 Summary

This chapter reviews the results in graphical form and explains about the influence of process parameters on target measure. This information is carried forward in chapter 5 for modeling the equation and optimization.

IX. DEVELOPMENT OF EMPIRICAL RELATION AND OPTIMIZATION

9.1 Analysis of Variance (ANOVA)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.76248	74.21%	0.762476	0.190619	2.88	0.165
Traverse Speed(mm/min)	1	0.48986	47.68%	0.489857	0.489857	7.39	0.053
Abrasive flow rate(g/min)	1	0.01493	1.45%	0.014926	0.014926	0.23	0.660
Pressure(bar)	1	0.00107	0.10%	0.001067	0.001067	0.02	0.905
Thickness(mm)	1	0.25663	24.98%	0.256626	0.256626	3.87	0.120
Error	4	0.26500	25.79%	0.264997	0.066249		
Total	8	1.02747	100.00%				

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Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.257389	74.21%	48.42%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.16	1.59	-0.10	0.925	
Traverse Speed(mm/min)	0.0317	0.0117	2.72	0.053	1.00
Abrasive flow rate(g/min)	-0.00100	0.00210	-0.47	0.660	1.00
Pressure(bar)	-0.000044	0.000350	-0.13	0.905	1.00
Thickness(mm)	0.0414	0.0210	1.97	0.120	1.00

Regression Equation

MRR (gm/sec) = -0.16 + 0.0317 Traverse Speed(mm/min) - 0.00100 Abrasive flow rate(g/min) - 0.000044 Pressure(bar) + 0.0414 Thickness(mm) – **(1)**

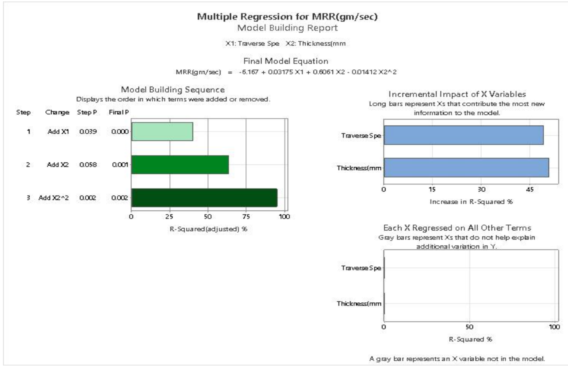

FIGURE 1.15: MULTIPLE REGRESSION

Analysis of Variance (ANOVA) for Surface Roughness Regression Analysis: Surface Roughness(micrometers) versus Traverse Speed(mm/min), Abrasive flow rate(g/min), Pressure(bar), Thickness(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.87062	26.73%	0.87062	0.217654	0.36	0.824
Traverse Speed(mm/min)	1	0.00058	0.02%	0.00058	0.000580	0.00	0.977
Abrasive flow rate(g/min)	1	0.01441	0.44%	0.01441	0.014406	0.02	0.884
Pressure(bar)	1	0.51862	15.93%	0.51862	0.518616	0.87	0.404
Thickness(mm)	1	0.33701	10.35%	0.33701	0.337014	0.56	0.494
Error	4	2.38596	73.27%	2.38596	0.596491		
Total	8	3.25658	100.00%				

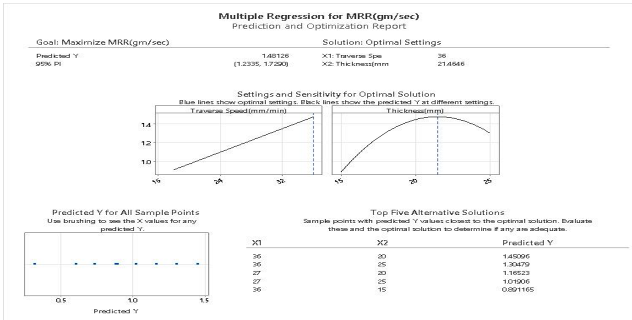

FIGURE 1.16: MULTIPLE REGRESSION

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.772328	26.73%	0.00%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	V
Constant	6.00	4.76	1.26	0.276	
Traverse Speed(mm/min)	0.0011	0.0350	0.03	0.977	1
Abrasive flow rate(g/min)	0.00098	0.00631	0.16	0.884	1
Pressure(bar)	-0.00098	0.00105	-0.93	0.404	1
Thickness(mm)	-0.0474	0.0631	-0.75	0.494	1

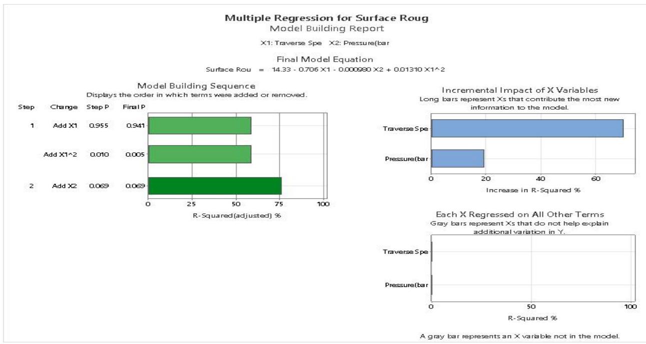

FIGURE 1.17: MULTIPLE REGRESSION OF

Regression Equation

Surface Roughness(micrometers) = 6.00 + 0.0011 Traverse Speed(mm/min) + 0.00098 Abrasive flow rate(g/min) - 0.00098 Pressure(bar) - 0.0474 Thickness(mm) – **(2)**

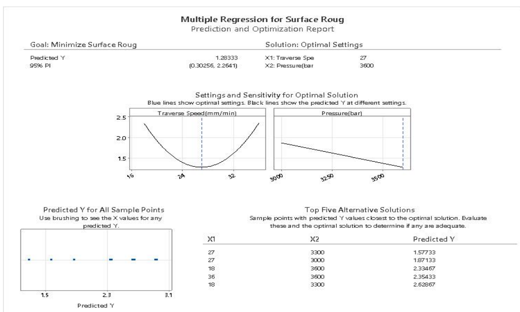

FIGURE 1.18: MULTIPLE REGRESSION OF

X. CONCLUSION

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

1. Maximized value of MRR is 1.48126 gm/sec at Traverse speed 36 mm/min, and thickness 20 mm. Abrasive flow rate and Pressure are the least influential parameters as they have insignificant impact on MRR.
2. Minimized value of SR is 1.28333 µm at Pressure 3600 bar and Traverse speed 27 mm/min. Thickness, and Abrasive flow rate are the least influential parameters as they have insignificant impact on SR.
3. Regression is a promising tool for mathematical modelling as high values of the correlation coefficient, R-squared is obtained.

References

[1] Advanced machining processes by V.K. Jain Allied publishers private Limited

[2] Water jet tutorial wiki.harvard.edu

[3] http://www.nptel.ac.in/courses/112105127/pdf/LM-37.pdf

[4] Hashish M., QUEST Integrated, Inc, Kent, Washington, USA Three-Dimensional Machining with Abrasive water jets

[5] Chithirai Pon Selvan M., Mohana Sundara Raju N. and Sachidananda H.K. Effects of process parameters on roughness in abrasive aluminium (2012),7(4):439-444

[6] Zhong Bo Yue, Chuan Zhen Huang, Hong Tao Zhu, Jun Wang, Peng Yao and Zeng Wen Liu Optimization of machining parameters in the abrasive water jet turning of alumina ceramic based on the response. surface methodology International Journal of Advances Manufacturing & Technology 71:2107-2114

[7] Derzija Begic-Hajdarevic, Ahmet Cekic, Muhamed Mehmedovic and Almina Djelmic (2014) Experimental Study on Surface Roughness in Abrasive Water Jet Cutting International Symposium on Intelligent Manufacturing and Automation 100(2015)394-399

[8]www.thefabricator.com Recent developments in Abrasive Water jet software

[9] Korat M.M. and Dr. Acharya G.D. (2014) A Review on Current Research and Development in Abrasives Waterjet Machining Journal of Engineering Research and Applications ISSN:2248-9622, Vol 4

[10] Ushasta Aich, Simul Banerjee, Asish Bandyopadhyay, and Probal Kumar Das (2014) Abrasive water jet cutting of Borosilicate Glass. International Conference on Materials Processing and Characterisation,6(2014)775-785

[11]Chitirai Pon Selvan.M. and Mohana Sundara Raju.N.(2011) Assessment of process parameters in abrasive waterjet cutting of stainless steel International Journal of Advances in Engineering & Technology ISSN:2231-1963

ISSN: 2057-5688

[12]Alberdi.A., Artaza.T., Suarez.A, Rivero.A. and Girot.F. (2015) An experimental study on abrasive waterjet cutting of CERP/Ti6Al4V stacks for drilling operations International Journal of Advances in Manufacturing & Technology DOI 10.1007/s00170-015-8192-x

[13] Jai Aultrin.K.S., Dev Anand.M. and Jerald Jose.P(2012) Modelling the cutting process and cutting performance in abrasive water jet machining using Genetic-Fuzzy Approach International conference on modelling optimization and computing 38(2012)4013-4020

[14]Wei Zhao and Chuwen Guo(2014) Topography and microstructure of the cutting surface machined with abrasive water jet International Journal of Advanced Manufacturing Technology 73:941-947

[15]Gokhan Aydin, Izzet Karakurt and Kerim Aydıner(2010) An investigation on surface roughness of granite machined by abrasive water jet Indian Academy of Science pp.985-992

[16]Zheng.X., Chen.L., Siores.E. and Crothers.P.(2002)Shape machining of Aerospace composite components using Non Traditional Abrasive Water jet cutting process Advance Manufacturing systems and Technology CISM courses and Lecture No.437,Springer Wien New York

[17] https://www.http://aquajet.co.in/machines.html