An Experimental Investigation and Parametric Study of Abrasive Water Jet Cutting Process

[1]Dhruv Soni,[2]Pritesh R. Patel
[1]PG Student,[2]Asst. Prof.
[1]Department of Mechanical Engineering,
[1]Babaria Institute of Technology, Vadodara,India

***Abstract*—Abrasive water jet (AWJ) cutting is one of the most recently developed non- traditionalmanufacturing technologies. Among many of the non-conventional methods, Abrasivewater jet machining (AWJM) is a relatively new machining technique. Abrasive WaterJet Machining is extensively used in many industrial applications. There are so manyprocess parameter affect quality of machined surface cut by AWJM. Important processparameters which mainly affect the quality of cutting are traverse speed, hydraulicpressure, stand-off distance, abrasive flow rate and types of abrasive. Important qualityparameters in AWJM are Material Removal Rate (MRR), Surface Roughness (SR), kerfwidth, tapering of kerf. The objective of this thesis is to develop an ExperimentalInvestigation of the process that can be used for a better understanding of the process.The factors affecting water jet and abrasive water jet performance are found fromreview & the effect of same is to be experimentally investigated.**

***Index Terms*—Abrasive water jet cutting, low carbon steel, top kerf width, stand-off distance, MRR, AWJM**

I. INTRODUCTION

The basic technology is both simple and extremely complex. At its most basic, water flows from a pump, through plumbing and out a cutting head. It is simple to explain, operate and maintain. The process, however, incorporates extremely complex materials technology and design. To generate and control water at pressures of 60,000 psi requires science and technology not taught in universities. At these pressures a slight leak can cause permanent erosion damage to components if not properly designed. The user need only be knowledgeable in the basic water jet operation.

Essentially, there are two types of water jets;
(1) Pure Water jet and
(2) Abrasive Water jet.

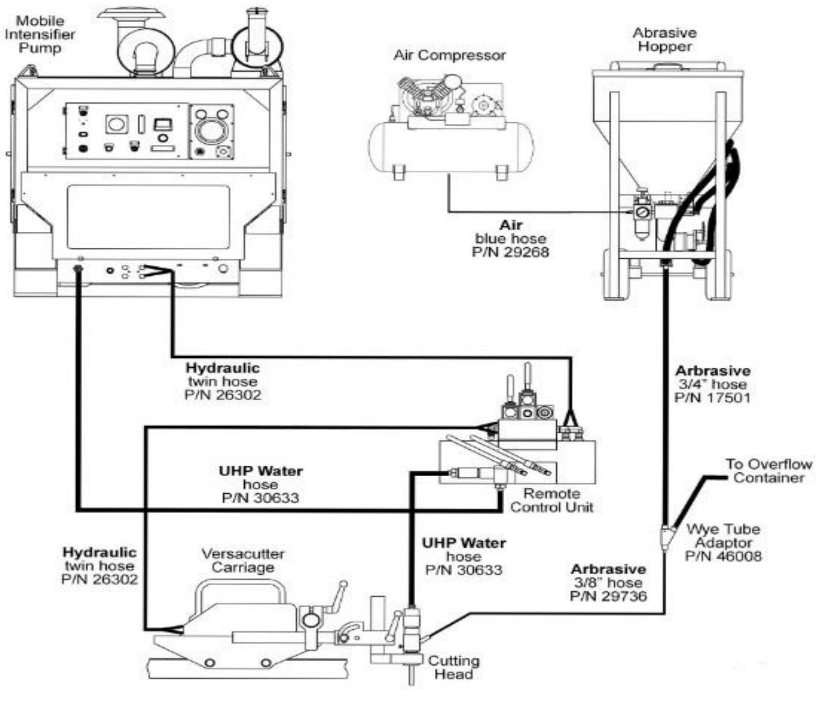


Fig. 1.1 Schematic Diagram of AWJM [13]

II. DIFFERECE BETWEEN PURE WATER JET AND ABRASIVE WATER JET CUTTING

The abrasive water jet differs from the pure water jet in just a few ways. In pure water jet, the supersonic stream erodes the material. In the abrasive water jet, the water jet stream accelerates abrasive particles and those particles, not the water, erode the material. The abrasive Water jet is hundreds, if not thousands of times more powerful than a pure Water jet. Both the water jet and the abrasive water jet have their place. Where the pure water jet cuts soft materials, the abrasive water jet cuts hard materials, such as metals, stone, composites and ceramics. Abrasive water jets using standard parameters can cut materials with hardness up to and slightly beyond aluminum oxide ceramic. Abrasive water jet machining technology is one of the fastest growing non-traditional machining processes. It can machine almost any engineering materials, irrespective of material properties. Compared with traditional and most non-traditional machining technologies, AWJM exhibits better performance in the machining of difficult to machine materials such as ceramics, glass and rocks.

Abrasive water jet (AWJ) machining is carried out by erosion of material by solid particles accelerated by high speed water jet. A typical commercial AWJ system consists of a pump, a mixing and acceleration section, a positioning system, and a catcher. Depending on the method of dosage of abrasive particles into the water jet, AWJs can be classified as injection jets or suspension jets. For practical cutting applications, injection jets are more commonly used, wherein an AWJ is formed by accelerating small solid particles (typically Garnet) through contact with a high-speed water jet. The high-speed water jet, in turn, is formed in an orifice placed on top of the mixing and acceleration head. The solid particles are dragged into the mixing chamber through a separate inlet by the low pressure created by the water jet in the mixing chamber. Mixing between the solid particles, water jet and air takes place in the mixing chamber, and the acceleration process occurs in the focusing tube. After the mixing and acceleration process, a high speed three-phase mixture leaves the tube at velocities of several hundred meters per second.

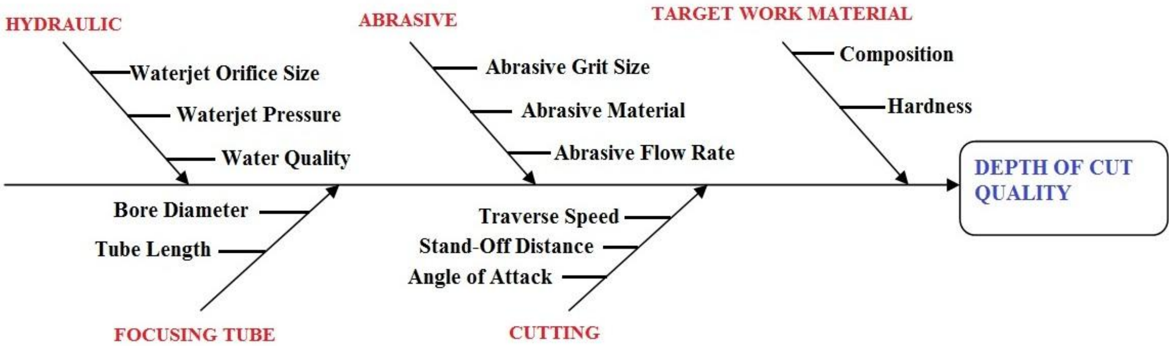


Fig. 1.2 Process Parameters of AWJM [11]

Abrasive water jet machining is considered to be a rapidly growing technology capable of processing a variety of materials. Since AWJ machining relies on erosion by fine abrasive particles, mechanical loads exerted on the work piece are small, and the flow of water leads to very low thermal stress on the work piece. For the application of the abrasive jet as a milling tool, the capability of the AWJ technology for accurate depth cutting is still a challenge. Since there are several parameters that affect the material removal rate and profile, such as pump pressure, jet feed rate, abrasive mass flow rate, stand-off distance, and abrasive breakage inside the cutting head, it becomes difficult to obtain the desired local material removal. Therefore, one of the main factors of the success of this process is an accurate understanding of the jet properties at the exit of the cutting head.

Typical process variables include pressure, nozzle diameter, stand-off distance, abrasive type, grit number, and work piece feed rate. An abrasive water jet cuts through 356.6-mm-thick slabs of concrete or 76.6-mm-thick tool steel plates at 38 mm/min in a single pass. The produced surface roughness ranges between 3.8 and 6.4 µm, while tolerances of ±0.13 mm are obtainable. Repeatability of ±0.04 mm, squareness of 0.043 mm/m, and straightness of 0.05 mm per axis are expected. Foundry sands are frequently used for cutting of gates and risers [15].

III. LITERATURE REVIEW

Various researchers are working on laser cutting process to cut various materials. They are working on various parameters.

M.A. Azmir et al. [1] reported on abrasive water jet machining process on glass/epoxy composite laminate. It was measured surface roughness (Ra) and kerf taper ratio (TR) through using control parameter hydraulic pressure and type of abrasive materials. Increasing the hydraulic pressure and abrasive mass flow rate may result in a better machining performance for work-piece. The experiment obtained the decreasing the standoff distance and traverse rate may improve both criteria of machining performance. So, it was confirmed that increasing the kinetic energy of abrasive water jet machining (AWJM) process may produce a better quality of cuts.

MahabaleshPalleda [3] studied the effect of using different chemicals on material removal rate, with varied stand-off distances and chemical concentration in abrasive water jet machining. The use of such chemicals on the taperness of drilled holes is also studied. It was revealed that the use of polymer can reduce the taper of the holes drilled. The material removal increases with the increase in Stand-off Distance, up to certain limit and further increase in the Stand-off Distance beyond the limit results in decrease of the material removal. It was founded that the material removal to be more in presence of chemically active liquids such as acetone and phosphoric acid rather than plain water in the slurry.

Divyansh Patel et al. [4] studied by 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 carried out 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 experiment was conducted at critical temperatures of hard-to-machine metals Inconel 718, Titanium (Ti6Al4V) and mild Steel (MS-A36) (ductile in nature) with full factorial DOE. They strictly revealed that the instead of increasing material removal rate, machining time can also be reduced, which is one the greatest need of the global manufacturing industries; using a laser heating attachment to AWJ to avoid the preheating.

DerzijaBegic-Hajdarevic et al. [5] investigated on surface roughness through effects of material thickness, traverse speed and abrasive mass flow rate during abrasive water jet cutting of aluminium. It was shown that traverse speed has great effect on the surface roughness at the bottom of the cut. The discussion of the correlation between the surface roughness and other abrasive water jet cutting variables was carried out. The surface being cut by the abrasive water jet was characterized by two types of surface texture. The first texture was located at the beginning of the cut and was characterized by the smooth surface. The second texture was located at the bottom of the cut and was characterized by the rough surface. It was suggested that the optimal solution is the choice of medium traverse speed with which can be achieved higher productivity with acceptable surface roughness.

AzlanMohd Zain et al. [6] presented optimization of process parameters in the abrasive water jet machining using integrated Simulated Annealing (SA) and Genetic Algorithm (GA). It was proposed that the integrated SA–GA-type1 and integrated SA–GA-type2 are to estimate the minimum value of the machining performance compared to the machining performance value of the experimental data and regression modelling, to estimate the optimal process parameters values that has to be within the range of the minimum and maximum process parameter values of experimental design, and to estimate the optimal solution of process parameters with a small number of iteration compared to the optimal solution of process parameters with SA and GA optimization. The process parameters and machining performance considered in this work deal with the real experimental data in the abrasive water jet machining (AWJ) process. It was showed that both of the proposed integration systems managed to estimate the optimal process parameters, leading to the minimum value of machining performance when compared to the result of real experimental data.

LeeladharNagdeve et al. [7] conducted experiment on aluminium for investigated Material removal rate and surface Roughness (Ra). The taken process parameter such as pressure, standoff distance, Abrasive flow rate and Traverse rate to 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) and surface roughness (SR). 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 (L9) orthogonal array by varying pressure, standoff distance, Abrasive flow rate and Traverse rate respectively.

M. ChithiraiPonSelvan et al.[8] influenced of process parameters on surface roughness (Ra) which is an important cutting performance measure in abrasive water jet cutting of cast iron. The experiments were conducted in varying water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance for cutting cast iron. The effects of these parameters on surface roughness have been studied based on the experimental results. It was showed that the use of high water pressure is preferred to obtain good surface finish. Surface roughness constantly decreases as mass flow rate increases. It is recommended to use more mass flow rate to decrease surface roughness.

ZoranJurkovic et al. [9] conduct the experimental research of process parameters influence on surface roughness of the machined parts, and to study the effects of selected process parameters on the surface roughness. The research was carried out for two different materials (stainless steel and aluminium alloy) using orthogonal experiment plan and factorial design. It revealed that the influence of abrasive flow rate and traverse rate are also considerable between 34% and 19% of contribution for Ra and Rz.

Vijay Kumar pal et al. [10] carried out experiment on abrasive water jet machining on Ti6Al4V material by varying the input process parameters like pressure, standoff distance and abrasive size. Coordinate measuring machine used for measure depth of pockets. It was observed that the higher waviness found at corners of pockets. The depth and material removal rate was more at higher pressure due to high kinetic energy of jet. It was revealed that the small abrasive size gives quite good surface as compared to large grit size.

Pandu R. Vundavilli et al. [2] reported fuzzy logic-based expert system for prediction of depth of cut in abrasive water jet machining process. It was investigation of depth of cut depends on various process parameters, such as diameter of focusing nozzle, water pressure, abrasive mass flow rate and jet traverse speed. The experiment developed for three approaches to predict the depth of cut in AWJM using FL system. The first Approach deals with the construction of Mamdani-based fuzzy logic system. It is important to note that the performance of the FL depends on its knowledge base. In Approach 2, the data base and rule base of the FL-system are optimized, whereas in the third Approach, the total FL-system is evolved automatically. The developed expert system eliminates the need of extensive experimental work, to select the most influential AWJM parameters on the depth of cut. The performances of the developed FL-systems have been tested to predict the depth of cut in AWJM process with the help of test cases. The prediction accuracy of the automatic FL-system (i.e. Approach 3) is found to be better than the other two approaches.

1V.DESIGN OF EXPERIMENT

The three-level design is written as a 3k factorial design. It means that k factors are considered, each at 3 levels. These are referred to as low, intermediate and high levels. These levels are numerically expressed as 0, 1, and 2. One could have considered the digits -1, 0, and +1, but this may be confusing with respect to the 2-level designs since 0 is reserved for centre points. Therefore, we will use the 0, 1, 2 scheme. Thus standard order (in terms of 0, 1 and 2 for coded test condition of -1, 0 and 1 respectively) 000 and 222 indicates all process parameters are at their low levels and higher levels respectively. Figure shows the geometric representation of the design of experimentations. The set of 27 tests have been performed randomly however some experimental limitation has been considered in randomization. Table shows all possible combination of 33 full factorial design of experiment.

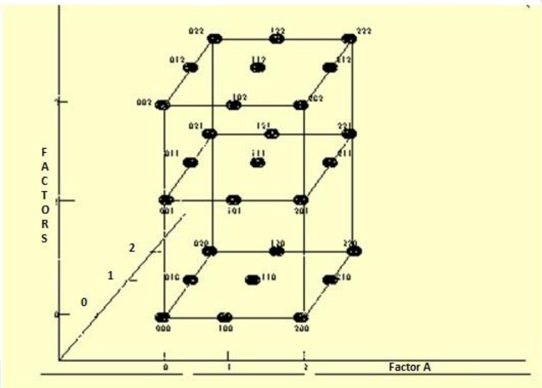


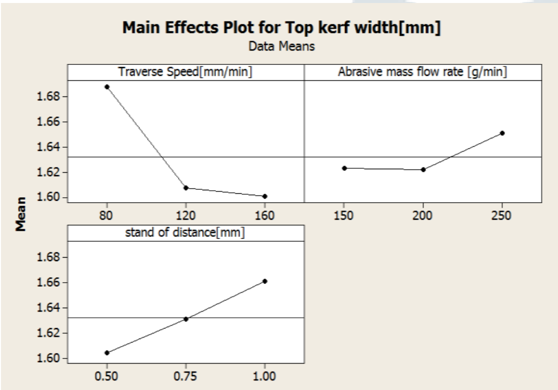
Fig. 4.1 Full Factorial 33 Geometric Representation

V. RESULT AND DISCUSSION

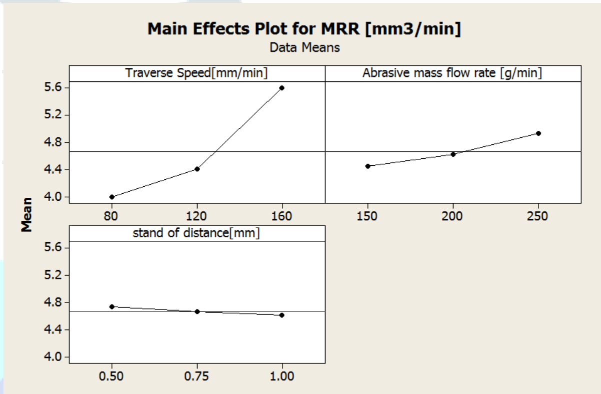
Sr no.	Traverse Speed [mm/min]	Abrasive mass flow rate [g/min]	stand-off distance [mm]	Top kerf width [mm]	MRR [mm3/min]	SR [µm]
1	80	150	0.5	1.65	4.125	2.15
2	80	150	0.75	1.67	3.987	2.27
3	80	150	1	1.68	3.874	2.35
4	80	200	0.5	1.62	4.105	2.25
5	80	200	0.75	1.67	4.055	2.31
6	80	200	1	1.69	3.935	2.38
7	80	250	0.5	1.71	4.055	2.31
8	80	250	0.75	1.72	3.897	2.39
9	80	250	1	1.78	3.982	2.43
10	120	150	0.5	1.54	4.256	2.1
11	120	150	0.75	1.59	4.125	2.16
12	120	150	1	1.65	3.981	2.31
13	120	200	0.5	1.6	4.684	2.18
14	120	200	0.75	1.61	4.472	2.24
15	120	200	1	1.63	4.394	2.31
16	120	250	0.5	1.59	4.875	2.29

17	120	250	0.75	1.62	4.612	2.31
18	120	250	1	1.64	4.321	2.41
19	160	150	0.5	1.59	5.135	1.98
20	160	150	0.75	1.6	5.256	2.11
21	160	150	1	1.64	5.298	2.24
22	160	200	0.5	1.57	5.235	2.11
23	160	200	0.75	1.59	5.365	2.21
24	160	200	1	1.62	5.371	2.27
25	160	250	0.5	1.57	6.125	2.19
26	160	250	0.75	1.61	6.235	2.21
27	160	250	1	1.62	6.324	2.37

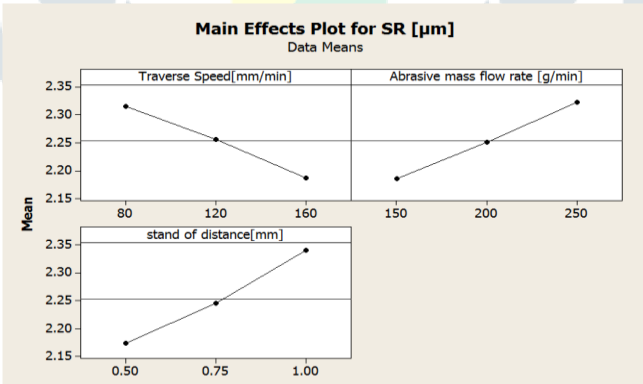
Above table depicts the experimental readings taken with the help of 3*3 full factorial DOE method.



Effect graph for top kerf width



Effect graph for MRR



Effect graph for Surface Roughness

MULTI RESPONSE OPTIMIZATION USING GREY RELATIONAL ANALYSIS

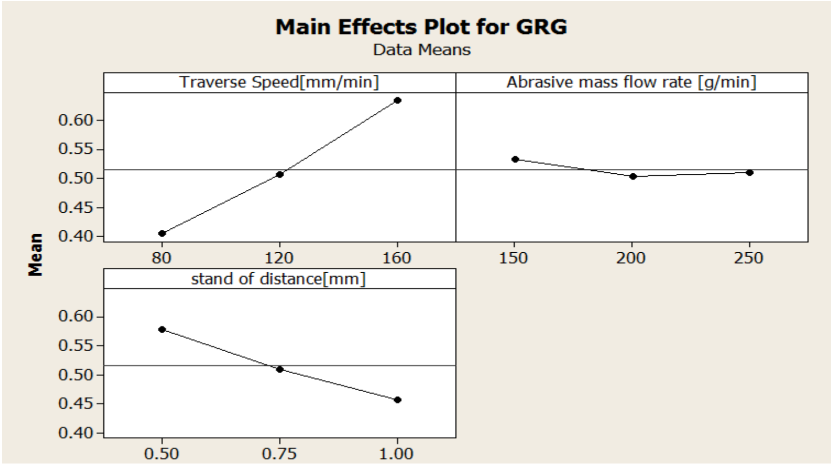
Grey analysis is a new technology, a group of techniques for system analysis and modelling. It is also called grey logic or grey system theory. Grey analysis is useful in situations with incomplete and uncertain information. Grey analysis is particularly applicable in instances with very limited data and in cases with little system knowledge or understanding.

GRA is effective tool for solving the complicated interrelationship among the designated performance characteristics. It also provides an efficient solution to multi-input and discrete data problems. In grey relational analysis the complex multiple response optimization problem can be simplified into optimization of single response grey relational grade.

Symbol	Control Factor	Level-1	Level-2	Level-3
A	Traverse speed	0.405269	0.506361	**0.634338**
B	Abrasive mass flow rate	**0.533275**	0.503549	0.509143
C	Stand-off distance	**0.578355**	0.51231	0.457382

Table – Effects of Factors on Grey Relational Grade

No.	Normalized responses			GRC			GRG
	MRR	SR	Top Kw	MRR	SR	Top Kw	
1	0.8976	1.7037	1.9078	0.3578	0.5696	0.5217	0.483
2	0.9539	1.6547	1.8996	0.3439	0.4369	0.48	0.4203
3	1	1.622	1.8955	0.3333	0.3782	0.4615	0.391
4	0.9057	1.6629	1.92	0.3557	0.4545	0.6	0.4701
5	0.9261	1.6384	1.8996	0.3506	0.4054	0.48	0.412
6	0.9751	1.6098	1.8914	0.339	0.36	0.4444	0.3811
7	0.9261	1.6384	1.8833	0.3506	0.4054	0.4138	0.3899
8	0.9906	1.6057	1.8792	0.3354	0.3543	0.4	0.3633
9	0.9559	1.5894	1.8547	0.3434	0.3333	0.3333	0.3367
10	0.8441	1.7241	1.9527	0.372	0.6522	1	0.6747
11	0.8976	1.6996	1.9322	0.3578	0.5556	0.7059	0.5397
12	0.9563	1.6384	1.9078	0.3433	0.4054	0.5217	0.4235
13	0.6694	1.6914	1.9282	0.4276	0.5294	0.6667	0.5412
14	0.7559	1.6669	1.9241	0.3981	0.4639	0.6316	0.4979
15	0.7878	1.6384	1.9159	0.3883	0.4054	0.5714	0.455
16	0.5914	1.6465	1.9322	0.4581	0.4206	0.7059	0.5282
17	0.6988	1.6384	1.92	0.4171	0.4054	0.6	0.4742
18	0.8176	1.5976	1.9118	0.3795	0.3435	0.5455	0.4228
19	0.4853	1.7731	1.9322	0.5075	1	0.7059	0.7378
20	0.4359	1.72	1.9282	0.5342	0.6338	0.6667	0.6116
21	0.4188	1.6669	1.9118	0.5442	0.4639	0.5455	0.5179
22	0.4445	1.72	1.9404	0.5294	0.6338	0.8	0.6544
23	0.3914	1.6792	1.9322	0.5609	0.4945	0.7059	0.5871
24	0.389	1.6547	1.92	0.5624	0.4369	0.6	0.5331
25	0.0812	1.6873	1.9404	0.8603	0.5172	0.8	0.7258
26	0.0363	1.6792	1.9241	0.9323	0.4945	0.6316	0.6861
27	0	1.6139	1.92	1	0.3659	0.6	0.6553



Main effect plot for GRG

VI. CONCLUSION

The AISI1018 has been cut by abrasive water jet cutting machine. The conclusions relevant to this investigation are outlined below:

- The surface roughness increase with increase traverse speed from 100 to 300 mm/min, when the other two parameter are kept constant as well as surface roughness decrease with increase abrasive mass flow rate and water pressure 150 to 350 gm/min and 250 to 350 MPa.
- While studying the effect of the cutting parameters on the top kerf width, it was observed that both the traverse speed and abrasive mass flow rate play equally important roles in the effect on the top kerf width. The role of the water pressure given is not crucial to the same extent. The optimum condition for machining to reduce kerf width would be A3 B1 C3. The traverse speed kept at 160 mm/min, the laser power kept at 750 watt and the gas pressure kept at 3 bar.
- From These study, it has been seen that the kerf width play very important role in qualities of water jet cutting object.
- The optimum condition for machining to reduce surface roughness would be A1 B3 C3. The cutting speed kept at 300 mm/min, the abrasive mass flow rate kept at 150 gm/min and the water pressure 450 MPa.
- While studying the effect of the cutting parameters on the surface roughness, it was observed that both the traverse speed and abrasive mass flow rate play equally important roles in the effect on the surface roughness. The role of the water pressure given is less crucial to the same extent.
- The optimal parameter values are at traverse speed 100 mm/min, abrasive mass flow rate 350 gm/min and 250 MPa water pressure. At these parameters the values of top and bottom kerf, surface roughness and MRR are 1.28 mm, 0.754 mm, 2.44 µm and 5.03 mm3/min respectively.

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