Optimization of Abrasive Waterjet Machining Process Parameters on Aluminium AL-6061

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Abstract: ***Abrasive Waterjet Machining (AGWM) is an emerging machining technology alternative for hard material parts, which are extremely difficult-to-machine by conventional machining processes. A narrow stream of high velocity water mixed with friction particles provides a relatively inexpensive and environmentally friendly production with a very high content removal rate. Because of that abrasive waterjet machining, has become one of the leading manufacturing technologies in a relatively short time. This letter reviews the research work from the beginning to the development of AWJM in the beginning of the last decade. It reports related to AWJM processes to optimize process variables, improve performance measures, monitoring and control of the process. A wide range of AZJM industrial applications for various class items are reported with variations. In this paper, the future trend of research work in the same area has also been discussed and found that Transverse Rate has a greater influence on the surface Roughness followed by Standoff Distance. Pressure had the least influence on Roughness. Pressure is the most significant parameter for Material Removal Rate, followed by Transverse rate and Standoff Distance respectively.***

Keywords: Abrasive jet, process parameter, optimization, Taguchi, ANOVA

1. Introduction

However development of newer methods has always been the endeavour of engineering personnel and scientists. The main ideas behind such endeavours have generally been the economic considerations, replacements of existing manufacturing methods by more efficient and quicker ones, achievement of higher accuracies and quality of surface finish, adaptability of cheaper materials in place of costlier ones and developing methods of machining such materials which cannot be easily machined through the conventional methods etc. Of all this reasons, the last one has contributed considerably to the post-war developments in machining methods, particularly because of the use of a large number of ‘hard to machine’ materials in the modern industry. A few of such materials are tungsten, hardened and stainless steel, inconel, uranium, beryllium and some high strength steel alloys. The increasing utility of such materials in the modern industry has forced research engineers to develop newer machining methods, so as to have full advantage of these costly materials.

Abrasive jet machining (AJM) process is one of the non-traditional machining processes that have been used extensively in various industry related applications. The basic principles of abrasive water jet machining (AJM) were reviewed in details by Momber and Kovacevic 1998[1]. This technology is less sensitive to material properties as it does not cause chatter, has no thermal effects, impose minimal stresses on the workpiece, and has high machining versatility and high flexibility. But it has some drawbacks; especially it may generate loud noise and a messy working environment (Wang and Wong 1999) [2]

The use of composite materials becomes prominent in today’s modern technological applications. These materials have better mechanical properties such as low densities, high strength, stiffness and abrasion, impact and corrosion resistances. The creation of aramid fibers called Kevlar has lead to the big breakthrough in the development of modern ballistic armour due to its unique properties of special application in armour which give ballistic protection (Komanduri et al. 1991). It has unique characteristics such as high strength to weight ratio, high chemical resistance; high cut resistance, flame resistance and good corrosive resistance (Komanduri et al. 1991).

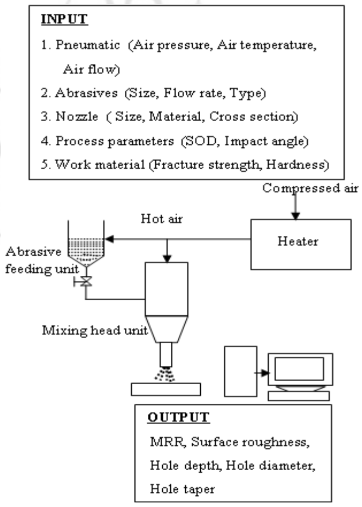

Figure 1.1: Schematic of Abrasive hot air jet process

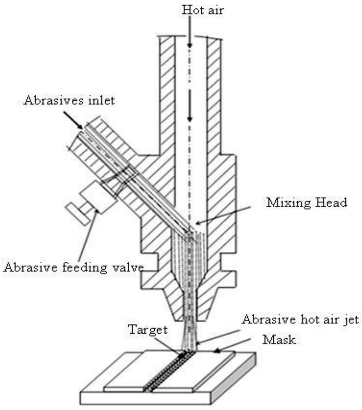

Figure 1.2: Abrasive hot air jet striking on surface of glass plate

2. Literature Review

Ramprasad, Gaurav Upadhyay, Kamal Hassan (2015) [3] accepted effective technology for cutting various material as of its advantages over other non-conventional techniques such as No heat is generated in the cutting process, high machining versatility, minimum stresses on the work piece. Abrasive water jet machine is an industrial machine in which we can cutting of the any types of materials i.e. softer materials and harden materials. In the abrasive water jet machine, the water is supplied at a very high pressure from 20,000-60,000psi and provides the good cutting and surface finishing. In the abrasive water jet machine there is a orifice in which a nozzle fixed and through the nozzle water exit in the cutting stream formation, this nozzle is move in the x-y axis as like in CNC machine.

K. S. Jai Aultrin, M Dev Anand (2015) [4] realised a rapid growth in cutting of hard metals and alloys using unconventional machining process. AWJM is recently developed unconventional machining processes in cutting different kinds of hard materials these days. The principle in which this process works is based on the principle water jet mixed with abrasives resulting in very high velocity that when it impacts on the work piece removes the surface of the work piece. Machine economics and quality of machining are determined by the machining parameters. In this study the effect of five process parameters on MRR and SR for the American element named Lead Tin alloy which is cut by abrasive waterjet cutting machine was experimentally done and analyzed. Based on the Response Surface Methodology, different sets of experiments were conducted on this element by varying the water pressure, abrasive flow rate, orifice diameter, focusing nozzle diameter and standoff distance. In this paper a predictive model for MRR and SR is developed for this Lead Tin alloy using regression analysis and the effects of process parameters on MRR and SR has been studied in abrasive waterjet cutting of Lead Tin alloy and found that all parameters and along with their interactions have significant effect on the MRR and SR.

Partek and Vijay Kumar [5] studied that the abrasive jet machining (AJM) is a non-conventional machining process in which an abrasive particles are made to impinge on the work material at a high velocity. This project deals with the fabrication of the Abrasive Jet Machine and machining on tempered glass, calculating the material removal varying various performance parameters like pressure, angle & abrasive grit size so on. Before performing the experiment fabrication done on AJM which are also discussed.. The different problem faced while machining on tempered glass are also discussed. Taguchi method and ANOVA is used for analysis of metal removal rate.

P. P. Badgujar, M. G. Rathi (2014) [6] 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 SS304. The Taguchi design of experiment, the signal-to-noise ratio, and analysis of variance are employed to analyze the effect of the input parameters by adopting L27 Taguchi orthogonal array (OA). In order to achieve the minimum surface roughness (SR), five controllable factors, i.e. the parameters of each at three levels are applied for determining the optimal combination of factors and levels. The results reveal that the SR is greatly influence by the abrasive material grain size. Experimental results affirm the effectiveness of the solving the stated problem within minimum number of experiments as compared to that of full factorial design.

M. Sreenivasa Rao, S.Ravinder and A. Seshu Kumar (2014) [7] investigated to study the effect of parameters, viz water pressure, Traverse speed, and Standoff distance, of Abrasive Waterjet Machine (AWJM) for mild steel (MS) on surface roughness (SR).Further Taguchi's method, analysis of variance and signal to noise ratio (SN Ratio) are used to optimize the considered parameters of abrasive Water Jet Machining. In Taghuchi's design of experimentation, L9 orthogonal array is formulated and it can be concluded that water pressure and transverse speed are the most significant parameters and standoff distance is sub significant parameter.

3. Experimental Set Up

The water jet experiments were conducted in Omax machine using sand as abrasives. The input parameters were Pressure (MPa), Standoff Distance (mm) and Transverse Rate (mm/s). The output measures being the surface roughness of the machined surface of work material (Ra). Values of the controllable factors were chosen based on the literature review. Three controllable factors were used in the experiments and have been split into three different levels. Moreover, this work adopted L9 orthogonal array based on Taguchi method to conduct a series of experiments to optimize the Water Jet parameters. Experimental data were evaluated statistically by analysis of variance (ANOVA) and all other machine parameters were kept constant during the time of experiment.

Figure 1.3: Omax water jet machine

Assumptions of Experimentations

1) Throughout the experimentation input power supply is constant.
2) The vertical travel of ram of the machine is straight.
3) Fluctuation in the input current supply is neglected.
4) Throughout the experimentation uniform flushing pressure and electrode rotation is applied.
5) Setting of work piece and abrasive is same for all experiments.

Material Used

Aluminium alloy 6061 is a medium to high strength heat-treatable alloy with strength higher than 6005A. It has very good corrosion resistance and very good weldability although reduced strength in the weld zone. It has medium fatigue strength.. Not suitable for very complex cross sections. Aluminum AA6061 has very good atmospheric corrosion resistance and workability with high thermal conductivity, reflectivity and weldability. 6061-T6 Aluminum Sheet / Plate are frequently found in aircraft construction. Alloy 6061-T6 is perhaps the most common grade of Aluminum because of its good mechanicability and weldability.

Figure 1.4: Al 6061 Workpiece

Based on the literature review and machine control levels of input factors are finalized. These levels of input parameters and General Linear model for Surface roughness R_a are as per table below:

Table 1.1: Levels of input control factors with units

Factors	Water Jet Machining Parameters	Levels				Observed Values
		L1	L2	L3	L4	1) Material Removal Rate (mm^3/min) 2) Surface Roughness (R_a)
A	Pressure (MPa)	300	350	400	450	
B	Standoff Distance (mm)	1	2	3	4	
C	Transverse Rate (mm/s)	4	5	6	7	

4. Taguchi Design

MINITAB 16 calculates response tables and generates main effects and interaction plots for:-

a) Signal-to-noise ratios (S/N ratios) vs. the control factors.
b) Means (static design) vs. the control factors

A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of nine numbers of experiments to be conducted and hence the OA L16 was chosen. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L16 setup, which in turn would reduce the number of experiments at the later stage.

ANOVA - A statistical method for testing whether two or more dependent variable means are equal (i.e., the probability that any differences in means across several groups are due solely to sampling error).If we have data measured at the interval level, we can compare two or more population groups in terms of their population means using a technique called analysis of variance, or ANOVA.

Table 1.2: Taguchi's L16 orthogonal array with values of levels

Experiment No.	*Pressure (MPa)*	*Standoff Distance (mm)*	*Transverse Rate (mm/s)*
1	300	1	4
2	300	2	5
3	300	3	6
4	300	4	7
5	350	1	5
6	350	2	4
7	350	3	7
8	350	4	6
9	400	1	6
10	400	2	7
11	400	3	4
12	400	4	5
13	450	1	7
14	450	2	6
15	450	3	5
16	450	4	4

Analysis of Material Removal Rate

Table 1.3: L16 Orthogonal Array with Performance

Exp No.	Pressure (MPa)	Standoff Distance (mm)	Transverse Rate (mm/s)	MRR mm^3/min	S/N Ratio
1	300	1	4	8.99	19.0752
2	300	2	5	6.55	16.3248
3	300	3	6	8.04	18.1051
4	300	4	7	8.85	18.9389
5	350	1	5	6.95	16.8397
6	350	2	4	8.15	18.2232
7	350	3	7	7.35	17.3257
8	350	4	6	8.67	18.7604
9	400	1	6	9.88	19.8951
10	400	2	7	8.57	18.6596
11	400	3	4	8.00	18.0618
12	400	4	5	7.98	18.0401

13	450	1	7	8.05	18.1159
14	450	2	6	7.74	17.7748
15	450	3	5	6.04	15.6207
16	450	4	4	8.10	18.1697

Table 1.4: Analysis of variance (ANOVA) for S/N Ratio w.r.t MRR

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Pressure	3	2.7868	2.7868	0.9289	12.10	0.006
Standoff Distance	3	3.4100	3.4100	1.1367	14.81	0.004
Transverse Rate	3	6.9268	6.9268	2.3089	30.09	0.001
Error	6	0.4604	0.4604	0.0767		
Total	15	13.5840				

Table 1.5: Response Table for Signal to Noise Ratio Larger is better

Level	*Pressure (MPa)*	*Standoff Distance (mm)*	*Transverse Rate (mm/s)*
1	18.11	18.48	18.38
2	17.79	17.75	16.71
3	18.66	17.28	18.63
4	17.42	18.48	18.26
Delta	1.24	1.20	1.93
Rank	2	3	1

Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. To obtain the optimal machining performance the higher the better quality characteristics for MRR.As can be seen from Table (above), the MRR is most significantly influenced by the Transverse Rate followed by Pressure. The respective values of these parameters are 1.93 and 1.24.

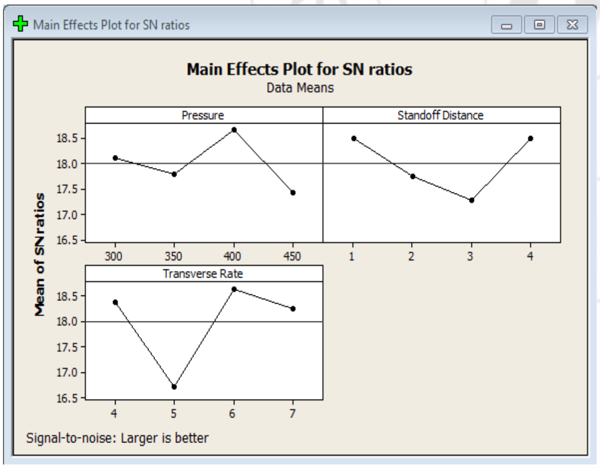

Fig.1.5 S/N Ratio for MRR

Analysis of Surface Roughness

Table 1.6: TheL16 Orthogonal Array with Performance

Exp No.	*Pressure (MPa)*	*Standoff Distance (mm)*	*Transverse Rate (mm/s)*	*R_a (μm)*	*S/N Ratio*
1	300	1	4	6.05	-15.6351
2	300	2	5	6.07	-15.6638
3	300	3	6	6.94	-16.8272
4	300	4	7	6.40	-16.1236
5	350	1	5	6.30	-15.9868
6	350	2	4	8.44	-18.5268
7	350	3	7	7.09	-17.0129
8	350	4	6	7.81	-17.8530
9	400	1	6	7.30	-17.2665
10	400	2	7	8.31	-18.3920
11	400	3	4	9.89	-19.9039
12	400	4	5	8.27	-18.3501
13	450	1	7	6.84	-16.7011
14	450	2	6	9.11	-19.1904
15	450	3	5	9.18	-19.2569
16	450	4	4	9.34	-19.4069

Table 1.7: Analysis of variance (ANOVA) for S/N Ratio w.r.t Ra

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Pressure	3	13.0365	13.0365	4.3455	40.24	0.000
Standoff Distance	3	6.5446	6.5446	2.1815	20.20	0.002
Transverse Rate	3	3.5693	3.5693	1.1898	11.02	0.007
Error	6	0.6480	0.6480	0.1080		
Total	15	23.7984				

Table 1.8: Response Table for Signal to Noise Ratio Smaller is better

Level	*Pressure (MPa)*	*Standoff Distance (mm)*	*Transverse Rate (mm/s)*
1	-16.06	-16.40	-18.37
2	-17.34	-17.94	-17.31
3	-18.48	-18.25	-17.78
4	-18.64	-17.93	-17.06
Delta	2.58	1.85	1.31
Rank	1	2	3

Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio will be determined to know the level of importance of the machining parameters. To obtain the optimal machining performance the smaller the better quality characteristics for SR.As can be seen from Table (above), the SR is most significantly influenced by the Pressure followed by the transverse Rate. The respective values of these parameters are 2.58 and 1.85.

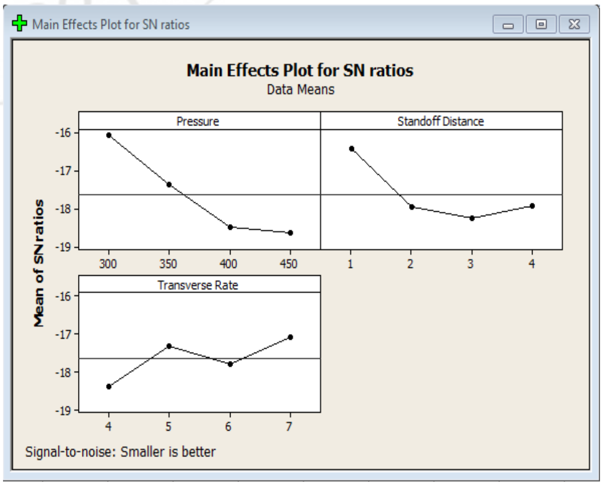

Figure 1.6: Shows the S/N ratio for Surface Roughness

5. Conclusion

From the experimental results, S/N ratio and ANOVA analysis and predicted optimum machining parameters, the following conclusions are drawn:-

In this paper has been presented application optimization technique (Taguchi approach) to obtain optimal parameters of AWJM process. The optimization technique presented here has great potentiality to improve initial process parameters or in study case the achievement of the desired surface roughness at AWJM process.

1) Transverse Rate has a greater influence on the surface Roughness followed by Standoff Distance. Pressure had the least influence on Roughness.
2) Pressure is the most significant parameter for Material Removal Rate, followed by Transverse rate and Standoff Distance respectively.
3) The optimum parameters for Surface Roughness are Pressure (300 MPa), Satndoff Distance (3mm) and Transverse Rate (6mm/s).
4) The ideal parameters for material removal rate are Pressure (300 MPa), Standoff Distance (2mm), and Transverse Rate (6mm/s).

6. Future Scope

The major research areas in AWJM are discussed in previous sections. Researchers have contributed in different directions but due to complex nature of the process a lot of works are still required to be done. The AWJM process is a suitable machining option in meeting the demands of today's modern applications. The AWJM of the modern composite, glass and advanced ceramic materials, which is showing a growing trend in many engineering applications, has also been experimented. It has replaced the conventional means of machining hard and difficult to cut material, namely the ultrasonic machining, laser beam machining and electro discharge machining, which are not only slow to machining but damage the surface integrity of the material. In addition, the AWJM process has sought the benefits of combining with other material removal methods to further expand its applications and improve the machining characteristics. The optimization of process variables is a major area of research in AWJM. Researchers have excluded many important factors such as nozzle size and orifice diameter during study which otherwise would affect the performance characteristics differently. Most of the literature available in this area shows that researchers have concentrated on a single quality characteristic as objective during optimization of AWJM. Optimum value of process parameters for one quality characteristic may deteriorate other quality characteristics and hence the overall quality.

Very little literature available so far shows the standoff distance at the optimal value during the AWJ cutting process using the generated sound monitoring and not for any other parameters. So, more work is required to be done in this area.

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