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EXPERIMENTAL INVESTIGATION TO DETERMINE EFFECT OF VARIOUS PARAMETERS IN ABRASIVE WATER JET MACHINE BY USING TOPSIS

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Abstract— *Abrasive water jet (AWJ) machining process is non-conventional machining process, which has been used in industrial applications. AWJ machining process operates at relatively high pressure, 200-400 Mpa and focused stream of abrasive particles carried by high pressure water is made to impinge on the work material is removed by erosion by high velocity Abrasive particles. In abrasive water jet machining process pure water is used and for abrasive particles like sand (SiO_2), glass beads, Aluminum oxide, silicon carbide and garnet is generally used. In this paper different experiments will be performed on Al6082 work piece by varying various parameters such as water pressure, traverse rate, abrasive flow rate and abrasive mesh size determine Material Removal rate and Kerf width, Surface roughness. Here, TOPSIS (Technique for order of preference by similarity to ideal solution) method is used for optimizing various parameters to obtain maximum material removal rate and Kerf width, surface roughness.*

Keywords- *AWJM, TOPSIS, MRR, Kw, SR.*

I. INTRODUCTION

Water jet machine uses cold supersonic abrasive erosion to cut almost any materials both metals and nonmetals. The highly pressurized water stream is forced through a tiny area which carries abrasive garnet to erode away the material. Abrasive water jet and pure water jet both start with pressurized water, water is pressurizes up to 4100 bar, then is transported to the cutting head where the pressurized water passes through a tiny hole in jewel orifice. The pressure is exchanged for velocity which is whatever the water jet cuts with, water jet actually erode the material they are cutting. Effect, and accelerated down the mixing tube. The abrasive garnet is mixed into water-stream and is accelerated like a bullet out of a rifle.

Working principle of AWJM is a highly pressurized water jet accelerates the air driven abrasive particles to from a very high energy abrasive water jet which strikes the work-piece and removes the material. The major advantages acclaimed for AWJM may be listed as: practically no dust, low power requirements, no thermal stresses, high cutting speed, no fire hazards, better quality of cutting, reduced striation and effective on a large variety of materials.

Abrasive water jet is widely used in the machining of materials such as titanium, steel, brass, aluminum, stone, inconel, any kind of glass and composites, concrete ceramics and even diamonds the minimal stresses on the work piece. AWJ finds its use for machining operations such as cutting milling drilling, turning, shot-peening etc. Recently, research has been also carried out on polishing with the help of Abrasive water jet machine.

II. EXPERIMENTATION AND OBSERVATION

A. Material selection

The work piece is used to do this experiment AL6082 used to machining the process. Chemical composition of the AL6082, table.1 shows the chemical composition of AL6082.

Table 1. Chemical Composition of Aluminium Alloy-6082

ELEMENT	CONTENT (%)
Silicon	1.13
Magnesium	0.824
Manganese	0.774
Zinc	0.014
Chromium	0.064
Titanium	0.015
Copper	0.05
Iron	0.42
Aluminium	96.555

This alloy has considerably more silicon content than magnesium or other elements. This alloy has low weight, high thermal and electrical conductivity as compared to steel. It has excellent corrosion resistance to air, water and oils so painting of the parts made by this alloy is prevented. Its properties include high bearing capacity, ease of workability weld ability, high toughness, tremendous fabricabilty, low maintenance cost, ease of extrusion.

B.Experimental setup

Experimentation is done on AWJM center (Model: 2626) manufacture by M/s OMAX Corporation, USA is used for this work. The AWJM as shown in fig.1.The equipment details are given in table 2.

Fig.1. Photograph of the AWJM setup

Table 2. AWJM Details

Machine used	OMAX 2626 Precision Jet Machining Center
Power	22Kw, 50Hz
Min Waterjet Pressure	138 Mpa
Max Waterjet Pressure	413Mpa
CNC Work Table Size	1168 mm x 787 mm
Work Envelope	X-Y cutting travel of 737 mm x 660mm
Focusing Nozzle Diameter	0.76 mm
Orifice Diameter	0.35 mm

Machining parameters for experimentation is considering with of three levels of process parameters for the experiment is used given table 3.

Table3.Variable Process Parameters at different levels

S.NO	Variable process parameters	Levels		
		Low	Med	High
A	Water pressure (Mpa)	150	200	250
B	Traverse Rate (mm/min)	60	90	120
C	Abrasive Flow Rate (Kg/min)	0.24	0.34	0.44
D	Abrasive Mesh Size (#)	80	100	120

C.*Design of experiments*

The DOE L_{27} Orthogonal array (OA) design of experiments is used to doing the machining on work piece. As shown in fig2.

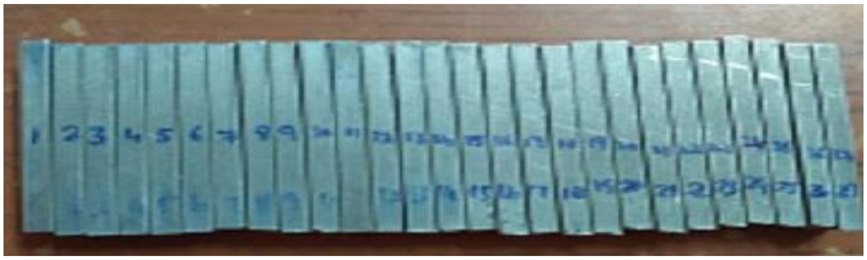

Fig.2. AWJM of AL6082 as per L_{27}

In the present experimental study Water pressure, Traverse rate, Abrasive flow rate and Abrasive mesh size have been considered as process variables**.**

D.Calculation of MRR, Kw and SR:

Material removal rate: MRR is calculated by measuring the time of machining. Material removal rate can be calculated using this formula.

$$MRR = \frac{volume}{time} = \frac{l*b*h}{t} \ mm^3/min$$

Here, l=length of the specimen
b= breadth of the specimen
h=height of the specimen
t=machining time

Kerf width: Kerf is equal width of material that is removed by a cutting process. It can be used for Kw by Video Measuring System (VMS) to measure the width of Kerf at the top, a VMS (make rational precision instrument, Model:2010F) Resolution of 0.5 and 6.5:1 zoom optics offering 12-300x magnification with auxiliary lens and metlogixnM3 metrology software was used. The VMS as shown in fig.3.

Fig.3. Photograph of the VMS

Surface roughness: It is quality of the machining surface related to the geometric irregularities of the surface. Surface roughness R_a arithmetic average height of surface above and below the central line. It is measured by using Mitutoyo SJ-201 Talysurf.

III. INTRODUCTION

A.TAGUCHI METHOD

Taguchi has envisaged a new method of conducting the design of experiments which are based on well defined guideline. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. Design of Experiment (DOE) is scientific approach to study the effect of multiple variables simultaneously. DOE has advantages of less number of experiments required for preciseness in effect estimation improvement quality of a product or process. AWJM is such a process in such a process in which a number of control factors collectively determine the output responses. Hence in the present work one statistical technique called Taguchi method is used to optimize the process parameters leading to the improvement in quality characteristics of the part under study.

The most important step in the DOE lies in the selection of the control factors and their levels. AWJM process has large number of process parameters but based on different literature review four machining parameters namely, water pressure [Mpa], jet traverse rate [mm/min], abrasive flow rate [kg/min] and abrasive mesh size [#] are identified and set at three levels which are shown in table 3. For further experimentation L_{27} Orthogonal array has been selected which is shown it table 4. Considering all four control parameters at different levels total 27 experiments have been performed.Taguchi is single response optimization technique means this method optimize one parameters at a time so this method cannot be applicable under the given circumstances. In order to optimize multiresponses, the process has been first modeled by means of TOPSIS then we will go for Taguchi optimization technique

B.TOPSIS: TOPSIS stands for “Technique for order preference by similarity to ideal solution”. This method was first discovered by Hwang and Yoon in 1981. The basic concept of this method is that the selected alternative must be at the minimum distance from the positive ideal solution and at the maximum distance from negative ideal solution. Positive ideal solution is related is with maximization the profit criteria and minimization the profit criteria and minimization of loss criteria, on the other hand the negative ideal solution related with minimization of the profit criteria and maximization the loss criteria.

IV.RESULTS AND DISCUSSION

The experimental design and corresponding results from the experimental plan for MRR, SR and Kerf width as shown in Table 4. Using Minitab 17 software and finally the process parameters are to be optimized by using TOPSIS.

Table 4. Results for Experimental design runs by Taguchi L27 method

S.NO	Water pressure (Mpa)	Jet traverse rate (mm/min)	Abrasive flow rate (Kg/min)	Abrasive mesh size (#)	MRR mm^3/min	Kerf width (mm)	Surface Roughness (µm)		
							Ra	Rq	Rz
1	150	60	0.24	80	41.80	0.83	2.67	3.19	15.47
2	150	60	0.34	100	42.31	0.84	2.72	3.42	13.67
3	150	60	0.44	120	41.80	0.87	2.82	3.45	15.45
4	150	90	0.24	100	85.65	0.84	1.29	3.45	9.41
5	150	90	0.34	120	84.42	0.88	2.93	3.65	11.36
6	150	90	0.44	80	80.43	0.87	2.62	3.40	14.40
7	150	120	0.24	120	63.84	0.88	2.35	3.66	11.65
8	150	120	0.34	80	62.70	0.90	2.51	3.30	11.29
9	150	120	0.44	100	63.84	0.92	2.78	3.65	13.64
10	200	60	0.24	80	63.84	0.92	2.22	3.61	15.13
11	200	60	0.34	100	62.70	0.85	2.78	3.69	14.75
12	200	60	0.44	120	62.70	0.86	2.60	4.07	16.44
13	200	90	0.24	100	42.13	0.88	2.78	3.10	11.74
14	200	90	0.34	120	44.23	0.90	2.61	2.63	9.31
15	200	90	0.44	80	42.13	0.91	2.24	3.35	12.49
16	200	120	0.24	120	85.65	0.87	2.69	3.44	11.51
17	200	120	0.34	80	83.16	0.88	2.71	3.32	12.31
18	200	120	0.44	100	84.16	0.89	2.33	3.18	12.88
19	250	60	0.24	80	83.16	0.84	1.41	3.06	11.18
20	250	60	0.34	100	85.65	0.84	2.3	3.11	11.6
21	250	60	0.44	120	85.65	0.87	2.67	3.15	14.4
22	250	90	0.24	100	63.84	0.89	2.19	2.76	11.44
23	250	90	0.34	120	62.70	0.88	2.45	2.88	10.26
24	250	90	0.44	80	42.31	0.90	2.61	3.09	10.39
25	250	120	0.24	120	42.31	0.95	2.12	2.24	9.66
26	250	120	0.34	80	62.70	0.96	2.45	3.15	11.47
27	250	120	0.44	100	41.80	0.97	2.74	3.36	11.67

V.SELECTION OF OPTIMAL PROCESS PARAMETERS COMBINATION USING TOPSIS METHOD

TOPSIS method is used to determine the optimum parameter combination by analyzing the experimental data. TOPSIS method consists of following steps:

Step 1: The first step is to formulate decision matrix with 'm' alternative and 'n' attributes, the decision matrix calculated in table 4.1 by using equation (1).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} - - - (1)$$

Step 2: Take weight ages for each response, after normalization of experimental data, the weighted normalized decision matrix is obtained by using equation (2) calculated in table 4.

$$V_{ij} = \mathrm{Wi} * r_{ij} - - - (2)$$

Step 3: This weighted normalized matrix is formed by integrating the AHP weight age calculated in table 4.3 with TOPSIS normalization matrix

Step 4: After obtaining weighted normalization matrix now Positive separation ideal solution (PIS) and negative separation ideal solution (NIS) are determined using equations 3 and 4. These ideal solutions are follows. From weighted normalized decision making matrix, the positive separation ideal solution a^+ obtained as shown in given table 4.3 weighted normalized decision matrix

Positive ideal (best) solution

$$a^+ = \{(\max V_{ij}, j \in J), (\min V_{ij}, j \in J')\}$$

$$= \{V_1^+, V_2^+, V3^+ \ldots\ldots V_j^+ \ldots. V_n^+\} \text{ ----------- } (3)$$

$$a^+ = \{0.0503, 0.036, 0.019, 0.026, 0.028\}$$

Negative ideal (worst) solution

$$a^- = \{(\min V_{ij}, j \in J), (\max V_{ij}, j \in J')\}$$

$$= \{V_1^-, V_2^-, V3^- \ldots\ldots V_j^- \ldots. V_n^-\} \text{ ---------- } (4)$$

From weighted normalization decision making matrix, the Negative separation ideal solution a^-

a- = {0.024, 0.042, 0.045, 0.047, 0.050

Step (5): Now we need to calculate Euclidean distance of each alternative from Positive ideal and Negative ideal solution by using the equation 5 and 6. These Positive and Negative separation ideal solution from table 4.4

$$s_i^+ = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j^+)^2} - - - (5)$$

$$s_i^- = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_j^-)^2} - - - (6)$$

Table 4.1: Decision Matrix

S.N. O	MRR (mm^3/min)	Kerf width (mm)	Surface Roughness(μm)		
			Ra	Rq	Rz
1	41.80	0.83	2.67	3.19	15.47
2	42.31	0.84	2.72	3.42	13.67
3	41.80	0.87	2.82	3.45	15.45
4	85.65	0.84	1.29	3.45	9.41
5	84.42	0.88	2.93	3.65	11.36
6	80.43	0.87	2.62	3.40	14.40
7	63.84	0.88	2.35	3.66	11.65
8	62.70	0.90	2.51	3.30	11.29
9	63.84	0.92	2.78	3.65	13.64
10	63.84	0.92	2.22	3.61	15.13
11	62.70	0.85	2.78	3.69	14.75
12	62.70	0.86	2.60	4.07	16.44
13	42.13	0.88	2.78	3.10	11.74
14	44.23	0.90	2.61	2.63	9.31
15	42.13	0.91	2.24	3.35	12.49
16	85.65	0.87	2.69	3.44	11.51
17	83.16	0.88	2.71	3.32	12.31
18	84.16	0.89	2.33	3.18	12.88
19	83.16	0.84	1.41	3.06	11.18
20	85.65	0.84	2.3	3.11	11.6
21	85.65	0.87	2.67	3.15	14.4
22	63.84	0.89	2.19	2.76	11.44
23	62.70	0.88	2.45	2.88	10.26
24	42.31	0.90	2.61	3.09	10.39
25	42.31	0.95	2.12	2.24	9.66
26	62.70	0.96	2.45	3.15	11.47
27	41.80	0.97	2.74	3.36	11.67

Table 4.2: Normalization Decision Matrix

S.N. O	N-MRR (mm^3/ min)	N-KW (mm)	Surface Roughness(μm		
			N-Ra	N-Rq	N-Rz
1	0.1227	0.1803	0.2059	0.1864	0.2370
2	0.1242	0.1825	0.2097	0.1998	0.2094
3	0.1227	0.1890	0.2174	0.2016	0.2367
4	0.2515	0.1825	0.0994	0.2016	0.1442
5	0.2479	0.1912	0.2259	0.2133	0.1740
6	0.2362	0.1890	0.2020	0.1987	0.2206
7	0.1874	0.1912	0.1812	0.2139	0.1785
8	0.1841	0.1955	0.1935	0.1928	0.1730
9	0.1874	0.1999	0.2143	0.2133	0.2090
10	0.1874	0.1999	0.1712	0.2109	0.2318
11	0.1841	0.1847	0.2143	0.2156	0.2260
12	0.1841	0.1868	0.2005	0.2378	0.2519
13	0.1237	0.1912	0.2143	0.1811	0.1799
14	0.1299	0.1955	0.2012	0.1537	0.1426
15	0.1237	0.1977	0.1727	0.1957	0.1914
16	0.2515	0.1890	0.2074	0.2010	0.1763
17	0.2442	0.1912	0.2089	0.1940	0.1886
18	0.2471	0.1934	0.1796	0.1858	0.1973
19	0.2442	0.1825	0.1087	0.1788	0.1713
20	0.2515	0.1825	0.1773	0.1817	0.1777
21	0.2515	0.1890	0.2059	0.1841	0.2206
22	0.1874	0.1934	0.1688	0.1613	0.1753
23	0.1841	0.1912	0.1889	0.1683	0.1572
24	0.1242	0.1955	0.2012	0.1805	0.1592
25	0.1242	0.2064	0.1634	0.1309	0.1480
26	0.1841	0.2086	0.1889	0.1841	0.1757
27	0.1227	0.2108	0.2113	0.1963	0.1788

Table 4.3: Weighted Normalized Decision Matrix

S.N.O	W-MRR (mm³/min)	W-Kw (mm)	Surface Roughness(µm		
			W-Ra	W-Rq	W-Rz
1	0.024	0.036	0.041	0.037	0.047
2	0.024	0.036	0.041	0.039	0.041
3	0.032	0.037	0.043	0.040	0.047
4	0.050	0.036	0.019	0.040	0.028
5	0.049	0.038	0.045	0.042	0.034
6	0.047	0.037	0.040	0.039	0.044
7	0.037	0.038	0.036	0.042	0.035
8	0.036	0.039	0.038	0.038	0.034
9	0.037	0.039	0.042	0.042	0.041
10	0.034	0.039	0.034	0.042	0.046
11	0.036	0.036	0.042	0.043	0.045
12	0.036	0.037	0.040	0.047	0.050
13	0.024	0.038	0.042	0.036	0.035
14	0.025	0.039	0.040	0.030	0.028
15	0.024	0.039	0.034	0.039	0.038
16	0.050	0.037	0.041	0.040	0.035
17	0.048	0.038	0.041	0.038	0.037
18	0.049	0.038	0.035	0.037	0.039
19	0.048	0.036	0.021	0.035	0.034
20	0.050	0.036	0.035	0.036	0.035
21	0.050	0.037	0.041	0.036	0.044
22	0.037	0.038	0.033	0.032	0.035
23	0.036	0.038	0.037	0.033	0.031
24	0.024	0.039	0.040	0.036	0.031
25	0.024	0.041	0.032	0.026	0.029
26	0.036	0.041	0.037	0.036	0.035
27	0.024	0.042	0.042	0.039	0.035

Table4.4: Positive and Negative separation ideal solution

S.N.O	S_i^+	S_i^-
1	0.039	0.012
2	0.038	0.013
3	0.042	0.009
4	0.014	0.043
5	0.030	0.030
6	0.029	0.025
7	0.027	0.022
8	0.027	0.023
9	0.033	0.016
10	0.030	0.018
11	0.035	0.015
12	0.039	0.014
13	0.036	0.018
14	0.032	0.028
15	0.033	0.018
16	0.026	0.031
17	0.027	0.029
18	0.022	0.030
19	0.011	0.039
20	0.019	0.033
21	0.028	0.029
22	0.021	0.027
23	0.023	0.027
24	0.028	0.032
25	0.028	0.034
26	0.026	0.023
27	0.037	0.017

Table 4.5: Closeness coefficient

S.N.O	CCI	RANK
1	0.244	26
2	0.252	25
3	0.178	27
4	0.752	2
5	0.493	12
6	0.466	14
7	0.447	17
8	0.459	16
9	0.328	21
10	0.372	18
11	0.297	23
12	0.265	24
13	0.340	20
14	0.467	15
15	0.352	19
16	0.539	7
17	0.519	10
18	0.577	4
19	0.776	1
20	0.628	3
21	0.506	11
22	0.570	5
23	0.537	8
24	0.527	9
25	0.544	6
26	0.472	13
27	0.311	22

Step 7: Rank the preference order based on their largest relative closeness co-efficient. It is observed from the Table 4.5, for the higher closeness coefficient is obtained for 19^{th} experimental run.

V. REGRESSION EQUATION FOR MRR, KW AND SR

The single objective optimization for the responses was conducted. A computer code has been developed using MATLAB R2015b for the parametric optimization of Abrasive water jet machining process by considering the following parameters. The regression equation for MRR, SR and KW are shown below.

Y_{MRR}=61.2+0.0037A+0.038B-15.2C+0.031D

Y_{KW}=0.7251+0.0003A+0.000926B+0.0889C-0.000139D

Y_{RA}=1.577-0.00194A+0.00091B+2.050C+0.005D

Y_{RQ}=4.155-0.00486A-0.00269B+1.217C-0.00083D

Y_{RZ}=17.63-0.01582A-0.0408B+8.09C-0.0114D

A.MULTI-OBJECTIVE OPTIMIZATION

Multi-objective optimization is used to find the decision variables while optimizing multi-objectives simultaneously under a set of constraints.

Table 4.6: Multi-objective Optimization results

Optimi Zation method	Response	Value	Wp	Tr	Afr	Ams
GA algorithm	MRR	64.55	245.6	107.5	0.256	109.5
	SR (Ra)	2.19				
	SR (Rq)	3.15				
	SR (Rz)	12.15				
	Kw	0.87				
TOPSIS method	MRR	83	250	60	0.24	80
	SR(Ra)	1.41				
	SR(Rq)	3.06				
	SR(Rz)	11.8				
	Kw	0.84				

The present work is considered for maximizing MRR and minimizing Ra, Rq , Rz and Kw and respectively.

Initially the multi-objective optimization problem is solved by using GA algorithm and these results are compared with the TOPSIS results. The multi-objective optimization results for GA and TOPSIS as shown in table 4.6.

It is suggested that the optimal combination of parameters for maximize MRR and minimize SR, KW are where as in TOPSIS the optimal parameters

are Water pressure=250 Mpa, Traverse rate=60 mm/min, Abrasive flow rate=0.24 kg/min and Abrasive mesh size=80#.. Comparing the results of GA with TOPSIS the MRR increase from 64.55 mm^3/min to 83mm^3/min, SR (Ra) decreased from 2.19 µm to 1.41µm and SR (Rq) decreased from 3.15µm to 3.06µm and Kw was reduced from 0.87 to 0.84 mm. Finally it was clearly observed that the multi-objective function using TOPSIS gives a better result than that of the GA.

VI. CONCLUSION

In the present study TOPSIS is used to determine the optimal process parameters by using multi-objective function for achieving better output responses.

The TOPSIS results are compared with the GA results and it is observed the TOPSIS gives better results. Hence the TOPSIS method is suggested per optimizing process parameters in AWJM for better machining responses

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