INVESTIGATION ON WATER JET ABRASIVE MACHINING DURING CUTTING OF CERAMIC TILE

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ABSTRACT

In this paper, production of ceramic tiles by using waste raw material egg shells and sea shells additives was investigated. The egg shells and sea shells is regarded as a suitable raw material for ceramic tile production because of its physical properties and chemical composition. It's provide high strength to the bonding of ceramic tile. Abrasive water jet cutting is a non-traditional machining method that offers a productive alternative to conventional techniques. It uses a fine jet of ultra-high pressure water and abrasive slurry to cut the target material by means of erosion. This thesis attempts to investigate kerf width and material removal rate in abrasive water jet machining of ceramic composite material tiles which is having wide applications in domestic, commercial and industrial construction work. Three different process parameters were undertaken for this study; water pressure, standoff distance and abrasive flow rate. Experiments were conducted Design of Experiment using Taguchi's design analysis by MiniTab17.

Keyword: - *AWJ, Taguchi, Water pressure, Standoff distance, Abrasive flow rate*

1. INTRODUCTION

Abrasive water jet was selected because it does not have contact with tools, no heat zone and low machining force when cutting is apply. While temperature at the impact zone can be very high, total temperature is low. The presence of a high speed waterjet acts very effective convective coolant as well. Hence, AWJ is most suitable for machining heat-sensitive and hard to machine materials.

Abrasive Jet Machining (AJM) is the removal of material from a work piece by the application of a high speed stream of abrasive particles carried in gas medium from a nozzle. The AJM process is different from conventional sand blasting by the way that the abrasive is much finer and the process parameters and cutting action are both carefully regulated. The various objectives focused in this paper include:

1) To determine the Material Removal Rate (MRR) of ceramic tile using AWJ.
2) To determine the Kerf width of ceramic tile using AWJ.
3) To determine the suitable AWJ cutting parameters to cut ceramic tiles.

2. LITERATURE SURVEY

D. K. Shanmugam, J. Wang, H. Liu (2008), Kerf taper is a special and undesirable geometrical feature inherent to abrasive water jet (AWJ) machining. In this study, an experimental investigation is carried out to minimize or eliminate the kerf taper in AWJ cutting of alumina ceramics by using a kerf-taper compensation technique. Among the cutting parameters studied, kerf-taper compensation angle is found to have the most significant effect on the kerf taper and the kerf taper angle varies almost linearly with this compensation angle. It shows that with this technique, it is possible to achieve a zero kerf taper angle without compromising the nozzle traverse speed or cutting rate. An assessment of the model shows that the model can give adequate predictions with an average percentage deviation of 6.2% and the standard deviation of 13.4% from the corresponding experimental data.[7]

Bhaskar Chandra Kandpal, Naveen Kumar, Rahul Kumar, Rahul Sharma, Sagar Deswal (2011), this paper presents various results of experiments have been conducted by changing pressure, nozzle tip distance on different thickness of glass plates and ceramic plates. The effect of process parameters of AJM on the material removal rate (MRR) was measured and graphs were plotted. These were compared with the theoretical results. It was observed that as nozzle tip distance increases, material removal rate (MRR) increases as it is in the general observation in the abrasive jet machining process. As the pressure increases material removal rate (MRR) is also increased as we found in AJM process. Similarly as abrasive particle size increases MRR increases. [9]

M. Chithirai Pon Selvan, Dr. N. Mohana Sundara Raju (2012), Performed Experimental investigations for the surface roughness in abrasive waterjet cutting of ceramics. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on surface roughness have been investigated. As a result of this study, it is observed that these operational parameters have direct effect on surface roughness. It has been found that water pressure has the most effect on the surface roughness. An increase in water pressure is associated with a decrease in surface roughness. This experimental study has resulted surface smoothness increase as standoff distance decreases. Therefore to achieve an overall cutting performance, low standoff distance should be selected. [10]

Leeladhar Nagdeve, Vedansh Chaturvedi and Jyoti Vimal (2012), In this paper, Taguchi method is applied to find optimum process parameter for Abrasive water jet machining (AWJM). Abrasive water jet machining is a non–traditional process of removal of material by impact erosion of high pressure, high velocity of water and entrained high velocity of grit abrasives on a work piece. For each combination of orthogonal array we have 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. Experimental results are provided to verify this approach. [11]

R. V. Shah, D. M. Patel (2012), Quality of cutting surface in AWJM is depending on so many process parameters. Process parameter which affect less or more on quality of cutting in AWJM are hydraulic pressure, Stand off distance, types of abrasive, size of abrasives, abrasive flow rate, nozzle diameter, orifice size, and traverse speed. Quality of cutting surface is measured by material removal rate, surface roughness, kerf width, kerf taper ratio. From the literature review compare to above all mentioned parameter traverse speed is most effective parameter for MRR. Abrasive flow rate is also an important parameter for increasing MRR. Traverse speed is directly proportional to productivity and should be selected highest possible without compromising kerf quality and surface roughness. [12]

Vishal Gupta, P.M. Pandey, Mohinder Pal Garg, Rajesh Khanna, N.K.Batra (2014), Abrasive water jet cutting is a non-traditional machining method that offers a productive alternative to conventional techniquesExperiments were conducted according to Taguchi's design of experiments. Analysis of variance (ANOVA) was used to evaluate the data obtained to determine the major significant process factors statistically affecting the kerf characteristics. The results revealed that the nozzle transverse speed was the most significant factor affecting the top kerf width, the kerf taper angle. [17]

Sreekesh. K, Dr. Govindan P (2014), Quality of cutting surface in AWJM is depending on so many process parameters. Process parameter which affect less or more on quality of cutting in AWJM are hydraulic pressure, Standoff distance, types of abrasive, size of abrasives, abrasive flow rate, nozzle diameter, orifice size, and traverse speed. Quality of cutting surface is measured by material removal rate, surface roughness, kerf width, kerf taper ratio. From the literature review compare to above all mentioned parameter traverse speed is most effective parameter for MRR. Abrasive flow rate is also an important parameter for increasing MRR. But beyond some limit with increase in abrasive flow rate and traverse speed the surface roughness decreases. Increasing traverse speed also increase the kerf geometry. So it is required to find optimum condition for process parameter to give better quality of cutting surface. Traverse speed is directly proportional to productivity and should be selected as high as possible without compromising kerf quality and surface roughness. [18]

Debasish Ghosh, Probal K. Das, B. Doloi (2014), Experimental investigations have been carried for the surface roughness in abrasive waterjet cutting of ceramics. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on surface roughness have been investigated. As a result of this study, it is observed that these operational parameters have direct effect on surface roughness. An increase in water pressure is associated with an increase in surface roughness. Machining with 5000 bar pressure is basically a high pressure operation. These results indicate 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. Therefore to achieve an overall cutting performance, low standoff distance should be selected. [19]

Meet R. Vadgama, Kaustubh S. Gaikwad, Harshil K. Upadhyay And Siddharajsinh G. Gohil (2015), The MRR increases with increasing in pressure and decreasing in glass thickness and SOD. MRR is proportional to the pressure. With the increase in pressure the kinetic energy of the abrasive particle is responsible for material removal by erosion process. The MRR increase with the SOD increases for certain limit, beyond the limit with increase in SOD there is decrease of MRR. With the decrease in SOD the work piece and nozzle jet and abrasive mesh size the MRR increase because the abrasive mixture impinge on the work piece more directly without deflecting, with a large force, thus results in greater removal rate. [21]

Senthilkumar. N, Ananthakumar A, Dheepan S, J Jagan Pradeep V, Katam Gnana Ujjwal (2016), This paper attempts to select the significant process parameters by Taguchi methodology while machining of STAINLESS STEEL 410 by AWJM. Different process parameters like pressure, feed rate, and standoff distance in three different levels are selected for optimization with three contravene responses, higher MRR and low machining timing by a single parametric combination. For Design of experiment L9 orthogonal array is prepared to set the input significant parameters for final product is calculated for better optimization purpose also different combinations of the factors are ranked on basis of grey relational grade. [25]

Andrzej Perec (2016), Existing models of predict the abrasive water jet cutting effects, does not give satisfactory results in a wide area of parameter changes, in particular for different, unusual materials. This implies the need to carry out extensive research in order to expand the empirical database. To optimize the process can be used modern methods referred to as Design of Experiment (DoE). One of the methods to determine the effect of parameters on the controlled different technological processes is orthogonal array design, also called the Taguchi approach. The article discusses one method for cutting optimization of aluminum alloy by high pressure abrasive water jet. [26]

Patel Divyakumar , Vikrambhai Patel (2016), Abrasive Water Jet Machining AWJM is non-conventional mechanical process. AWJM is useful to cut complex shape parts which is difficult with conventional machining process. Here AISI 52100 steel used for die application, after applying heat treatment to AISI 52100, its mechanical properties are improved and it's hard to machining. In this case AWJM is used for machining process. Quality and Productivity is performance indicator of any machining method, performance of AWJM is influenced by various input parameters. Selection of right improve parameter value improve output performance of machining and makes less difficult. For this aim to achieved high performance on AWJM, series of experiment is carried out to find effect of input parameter on output performance parameter. Three different process parameters were undertaken for this study; water pressure, nozzle transverse speed and abrasive flow rate. Experiments were conducted according to Taguchi's design of experiments. [27]

3. DESIGN OF EXPERIMENT

3.1 General factorial designs

In statistics, a full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable.

If the number of combinations in a full factorial design is too high to be logistically feasible, a fractional factorial design may be done, in which some of the possible combinations (usually at least half) are omitted.

3.2 Taguchi method

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much-reduced variance for the experiment with optimum setting of process control parameters. Thus the integration of design of experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi method. Orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which is logarithmic functions of desired output serve as objective functions for optimization. You can also add a signal factor to the Taguchi design in order to create a dynamic response experiment. A dynamic response experiment is used to improve the functional relationship between a signal and an output response.

Table 1: Parameters considered for ceramic tile

Factors	Level 1	Level 2	Level 3
Abrasive feed rate (lb/min)	2.5	2.80	3
Water jet pressure (MPa)	206	275	345
Standoff distance (mm)	2	3	4

4. METHODOLOGY

4.1 Raw Materials

1. **Seashell**

A seashell or sea shell, also known simply as a shell, is a hard, protective outer layer created by an animal that lives in the sea. The shell is part of the body of the animal. Empty seashells are often found washed up on beaches by beachcombers. The shells are empty because the animal has died and the soft parts have been eaten by another animal or have rotted out.

Figure 1: Sea Shell

Table 2: Chemical composition of Seashell

Oxide	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	**LOI**
%	1.60	0.92	51.56	1.43	0.08	0.06	0.31	41.84

2. Egg Shell

The chicken eggshell is used as fine aggregate in this research at 100% replacement for fine sand. The main ingredient in eggshells is calcium carbonate (the same brittle white stuff that chalk, limestone, cave stalactites, sea shells, coral, and pearls are made of). The shell itself is about 95% CaCO3 (which is also the main ingredient in sea shells). The remaining 5% includes Magnesium, Aluminum, Phosphorous, Sodium, Potassium, Zinc, Iron, Copper, Ironic acid and Silica acid. Next, clay, mica and feldspars – the standard raw material are mixed.

Figure 2: Egg Shell

Figure 3: Egg Shells crushed using Rolling Pin

Table 3: Chemical composition of eggshell

Oxide	Al_2O_3	SiO_2	S	Cl	CaO	Cr_2O_3	MnO	CuO	**LOI**
%	0.001	0.001	0.001	0.009	99.83	0.003	0.001	0.001	0.153

4.2 Machine specification

With kind permission at **Asian Granito India Ltd.**, this research could able to work on identified machine model "**DWJ1313**" which is abrasive water jet cutting machine shown in figure

Figure 4: DWJ1313-FBI Machine

Table 4: Specifications of DWJ1313 CNC X-Y

Cutting table	Dardi water jet CNC X-Y cutting table
Structure	Flying Arm
Cutting table Size (X*Y)	1400 * 1400 mm
Cutting Range	X-axis = 1300mm Y-axis = 1300mm Z-axis = 1300mm
Traversing Speed	0-15 m/min max
Maximum Operating Pressure	400 Mpa
Nozzle Diameter	0.76 mm
Nozzle Length	76.2 mm

Table 5: Performance parameters standard values

Sr. No.	**Parameters**	**General Values**
1	Abrasive material	Al2O3 / SiC / Granite
2	Abrasive shapes	irregular / spherical
3	Abrasive size	10-50µm

4	Mass flow rate	2 ~ 20 gm/min
5	Carrier gas composition	Air, CO2, N2
6	Air jet velocity	500 ~ 700 m/s
7	Pressure	10 to 55 ksi
8	Flow rate	5-30lpm
9	Mixing ratio-mass flow ratio of abrasive to gas	Mabr/Mgas
10	Stand-off distance	0.5 ~ 5 mm
11	Impingement angle	600 ~ 900
12	Nozzle-Material	WC / sapphire
13	Diameter	0.2 ~ 0.8 mm
14	Life	10 ~ 300 hours

5. RESULT MEASUREMENT

Table 6: Observation Table

Sr. No.	Input Parameters			Output Parameters	
	Abrasive feed rate	Water jet pressure	Standoff distance	Kerf Width (mm)	MRR (mm^3/min)
1	2.5	206	2	**2.03**	**779.14**
2	2.5	206	3	**2.15**	**810.11**
3	2.5	206	4	**2.17**	**825.40**
4	2.5	275	2	**1.80**	**993.59**
5	2.5	275	3	**1.70**	**939.58**
6	2.5	275	4	**1.60**	**880.25**
7	2.5	345	2	**1.52**	**1053.21**
8	2.5	345	3	**1.42**	**978.75**
9	2.5	345	4	**1.36**	**958.52**
10	2.8	206	2	**2.11**	**808.12**
11	2.8	206	3	**2.17**	**770.86**
12	2.8	206	4	**2.22**	**804.40**
13	2.8	275	2	**1.80**	**955.70**
14	2.8	275	3	**1.83**	**955.70**
15	2.8	275	4	**1.85**	**982.80**
16	2.8	345	2	**1.60**	**1012.51**
17	2.8	345	3	**1.57**	**985.52**
18	2.8	345	4	**1.52**	**985.52**
19	3	206	2	**2.11**	**763.45**
20	3	206	3	**2.05**	**782.07**
21	3	206	4	**2.05**	**782.07**
22	3	275	2	**1.63**	**912.60**
23	3	275	3	**1.81**	**977.40**
24	3	275	4	**1.83**	**972**
25	3	345	2	**1.43**	**924.71**
26	3	345	3	**1.46**	**951.71**
27	3	345	4	**1.40**	**924.73**

6. ANALYSIS OF RESULTS

Experimental Result Taguchi Analysis: kerf width versus Abrasive feed rate, standoff distance, Water jet pressure.

Main effect plot: Minitab 17 is used for graphical representation of the analysis results obtained by experimental work.

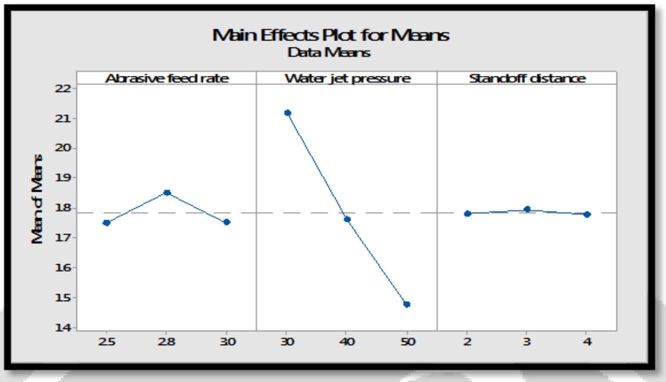

Figure 5: Main effects plot for means kerf width vs AWJ, SOD, WJP

Main effects plot for kerf width is shown in figure 5. The first plot displays effect of abrasive feed rate on kerf width using data means. The graph shows that the kerf width decreases rapidly as abrasive feed rate from 2.5 lb/min to 3 lb/min (pound per minute).

Second plot for kerf width displays effect of water jet pressure on kerf width using data means. The graph shows that the kerf width increases rapidly as water jet pressure increases from 30 ksi to 50 ksi (kilopound per unit).

The third plot displays effect of standoff distance on kerf width using data means. The plot shows that as the standoff distance increases from 2 mm to 4 mm then the kerf width is static.

Table 7: Response Table for Means

Level	Abrasive feed rate	Water jet pressure	Standoff distance
1	1.750	2.118	1.781
2	1.852	1.761	1.796
3	1.752	1.476	1.778
Delta	0.102	0.642	0.018
Rank	**2**	**1**	**3**

Table 7 shows response table for signal to noise ratio for kerf width. This response table represents the effects of various input factors on kerf width. Here according to ranks, the effects of various input factors on kerf width.

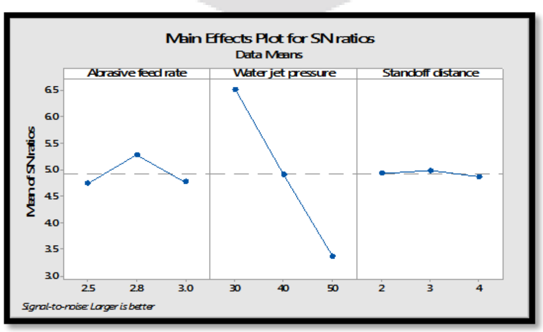

Figure 6: Main effects plot for S/N ratio vs AWJ, SOD, WJP

Fig. 6 shows the similar effects plot in the first and second plot as shown in fig. . The third plot displays effect of wire speed on kerf width using data means for S/N ratio. The plot shows that as the stand of distance increases from 2 mm to 4 mm then the kerf width is static.

Table 8: Response Table for S/N Ratio

Level	Abrasive feed rate	Water jet pressure	Standoff distance
1	4.742	6.514	4.934
2	5.275	4.905	4.986
3	4.769	3.367	4.866
Delta	0.533	3.147	0.120
Rank	**2**	**1**	**3**

Experimental Result Taguchi Analysis: MRR versus Abrasive feed rate, standoff distance, Water jet pressure:-

Main effect plot: Minitab 17 is used for graphical representation of the analysis results obtained by experimental work.

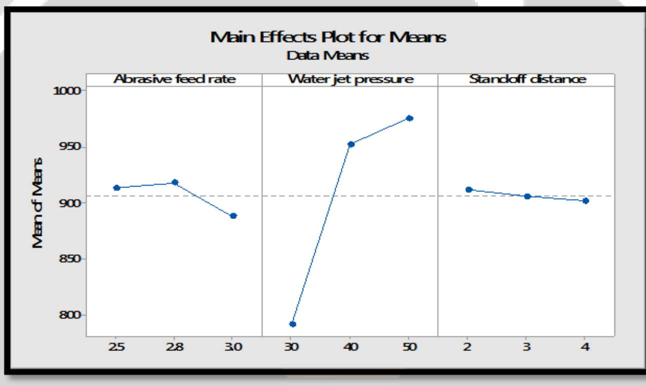

Figure 7: Main effects plot for means MRR vs. AWJ, SOD, WJP

Main effects plot for MRR (Material Removal Rate) is shown in Fig.7. The first plot displays effect of abrasive feed rate on MRR using data means. The graph shows that the MRR decreases rapidly as abrasive feed rate from 2.5lb/min to 3 lb/min (pound per minute).

Second plot for MRR (Material Removal Rate) displays effect of water jet pressure on kerf width using data means. The graph shows that the MRR increases rapidly as water jet pressure increases from 30 ksi to 50 ksi (kilopound per unit).

The third plot displays effect of standoff distance on MRR (Material Removal Rate) using data means. The plot shows that as the standoff distance increases from 2 mm to 4 mm then the MRR is static.

Table 9: Response Table for S/N Ratio

Level	Abrasive feed rate	Water jet pressure	Standoff distance
1	913.2	791.7	911.4
2	917.9	952.2	905.7
3	887.9	975.0	901.7
Delta	30.0	183.3	9.7
Rank	**2**	**1**	**3**

Table 9 shows response table for signal to noise ratio for MRR (Material Removal Rate). This response table represents the effects of various input factors on MRR. Here according to ranks, the effects of various input factors on MRR.

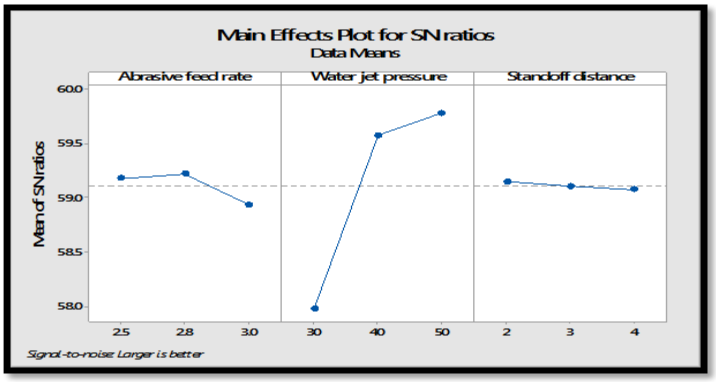

Figure 8: Main effects plot for S/N ratio Vs. AWJ, SOD, WJP

Figure 8 shows the similar effects plot in the first and second plot as shown in fig.7. The third plot displays effect of wire speed on MRR using data means for S/N ratio. The plot shows that as the stand of distance increases from 2 mm to 4 mm then the MRR is static.

Table 10: Response Table for S/N Ratio

Level	Abrasive feed rate	Water jet pressure	Standoff distance
1	59.17	57.97	59.14
2	59.21	59.57	59.10
3	58.93	59.77	59.07
Delta	0.28	1.80	0.07
Rank	**2**	**1**	**3**

7. CALCULATIONS

Table 11: S/N Calculations in Minitab

Minitab - jay Minitab.MPJ - [Worksheet 1 ***]

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Abrasive feed rate	Water jet pressure	Standoff distance	kerf width	MRR	MEAN1	SNRA2	MEAN3	SNRA4
1	2.5	30	2	2.03	779.14	2.03	6.14992	779.14	57.8323
2	2.5	30	3	2.15	810.11	2.15	6.64877	810.11	58.1709
3	2.5	30	4	2.17	825.40	2.17	6.72919	825.40	58.3333
4	2.5	40	2	1.80	993.59	1.80	5.10545	993.59	59.9441
5	2.5	40	3	1.70	939.58	1.70	4.60898	939.58	59.4587
6	2.5	40	4	1.60	880.25	1.60	4.08240	880.25	58.8921
7	2.5	50	2	1.52	1053.21	1.52	3.63687	1053.21	60.4503
8	2.5	50	3	1.42	978.75	1.42	3.04577	978.75	59.8134
9	2.5	50	4	1.36	958.52	1.36	2.67078	958.52	59.6320
10	2.8	30	2	2.11	808.12	2.11	6.48565	808.12	58.1495
11	2.8	30	3	2.17	770.86	2.17	6.72919	770.86	57.7395
12	2.8	30	4	2.22	804.40	2.22	6.92706	804.40	58.1094
13	2.8	40	2	1.80	955.70	1.80	5.10545	955.70	59.6064
14	2.8	40	3	1.83	955.70	1.83	5.24902	955.70	59.6064
15	2.8	40	4	1.85	982.80	1.85	5.34343	982.80	59.8493
16	2.8	50	2	1.60	1012.51	1.60	4.08240	1012.51	60.1080
17	2.8	50	3	1.57	985.52	1.57	3.91799	985.52	59.8733
18	2.8	50	4	1.52	985.52	1.52	3.63687	985.52	59.8733
19	3.0	30	2	2.11	763.45	2.11	6.48565	763.45	57.6556
20	3.0	30	3	2.05	782.07	2.05	6.23508	782.07	57.8649
21	3.0	30	4	2.05	782.07	2.05	6.23508	782.07	57.8649
22	3.0	40	2	1.63	912.60	1.63	4.24375	912.60	59.2056
23	3.0	40	3	1.81	977.40	1.81	5.15357	977.40	59.8014
24	3.0	40	4	1.83	972.00	1.83	5.24902	972.00	59.7533
25	3.0	50	2	1.43	924.71	1.43	3.10672	924.71	59.3201
26	3.0	50	3	1.46	951.71	1.46	3.28706	951.71	59.5701
27	3.0	50	4	1.40	924.73	1.40	2.92256	924.73	59.3203
28									

8. CONCLUSIONS

The following conclusion can be drawn from the results of the present work:

1. The optimal parameter values are abrasive flow rate at 2.5 gm/sec, pressure at 345 Mpa and stand of distance 3 mm. At this parameters the values of MRR and kerf width are 1053.21 mm3/min and 1.52 mm.
2. It is shown that the performance characteristics of the AWJM process, namely water jet pressure, abrasive flow rate and standoff distance are improved together by using Taguchi Analysis method.
3. From Taguchi it is found that water jet pressure has more significant effect on kerf width and MMR rather than abrasive flow rate and standoff distance.
4. The predicted S/N ratio is nearest to the conformation test S/N ratio; this explains that the Taguchi Analysis method adopted for optimization of parameters is accurate.

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