Parametric optimization of abrasive water jet cutting for AA6063-3 wt. % TiC composites

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Abstract

The present study aims to optimize the abrasive water jet processing parameters as machining aluminum metal matrix composites. Investigations were carried on 3 wt. % of TiC reinforce AA6063 composites produced by stir casting route. Taguchi methodology was used to explore the influence of abrasive water jet parameters and their relations on the output responses. Material removal rate is greatly influenced by standoff distance, feed rate and abrasive flow rate respectively while surface roughness is highly influenced by abrasive flow rate, feed rate and standoff distance. The optimum parameter set in maximizing the material removal rate and minimizing the surface roughness is 100mm/min feed rate, 3mm standoff distance and 200g/min abrasive flow rate. The experimental results and optimization obtained give a technical record for industrial applications.

Key words: AWJM, AA6063, TiC, Optimization.

1. Introduction

Abrasive water jet machining is one of upcoming technology and is kind of non-traditional machining process. It is more efficient and accurate than other machining processes for both ductile and brittle materials [1]. It is used to cut soft materials such as leather, textiles, fiber plastics, card board and thin plates of aluminum. It has provided flexibility and cool cutting characteristics make it suitable for cutting composites materials. The mechanism of material removal in ductile materials seems to be micro-cutting by the free flowing abrasive particles, attend by heavy plastic deformation [2]. The quality of machined parts can be gauged by surface roughness. Taguchi method to find optimum process parameters of AWJM for different materials was carried out [3]. The influence of abrasive water jet cutting process of 6063-T6 aluminium alloy by the process variables are traverse speed, nozzle diameter, work pressure and abrasive flow rate [4]. The regression modeling is used in order to establish the relationships between input and output parameters like depth of cut and surface roughness [5]. The effect of abrasive water jet machining parameters as traverse speed, abrasive flow rate, and standoff distance will be checked on surface roughness of AL6351 materials. The Taguchi method was used to optimize the process parameter of Al-6351 materials are traverse speed 400mm/min, abrasive flow rate 400 gm/min, and standoff distance 2 mm [6]. The influence of jet impact angle on part geometry in abrasive water jet machining of aluminium alloys using Taguchi analysis. It was confirmed that increasing the kinetic energy of AWJM process may produce a better quality of cuts [7]. The characteristics and zones of kerf during the abrasive water jet cutting of hard ceramic materials. Its low cutting speed needs to be increased without compromising the quality of the surface finish. It involves multi-dimensional cutting to examine the effect of jet impact angles on cutting quality [8]. The L9 Taguchi array is used for the design of experimentation material thickness, abrasive mass flow rate and standoff distance on surface roughness while performing abrasive water jet machining. The results show that the most influential parameter at the 95% confidence interval to affecting surface roughness is workpiece thickness [9]. The delamination of composites decreases with increase in abrasive mass flow rate, pressure and decrease in traverse rate, while decrease in stand-off distance decreases the Kerf width of composites [10]. The characteristics of surface roughness during abrasive water jet machining of AA7075. The results are compared with regression analysis results and observed that the parameter values suggested in these approaches are more relevant within the range of values obtained in experimentation [11].

From the literature review, it is evident that little work has not been reported on abrasive water jet machining of AA6063-3 wt. % TiC composites and so the current work has been conducted with garnet #80 as abrasive particles. An attempt was made to study the effect of abrasive water jet machining parameters on metal removal rate and surface roughness of composites and optimal values are obtained.

2. Experimental Work

In this study, AA6063-3 wt. % TiC composite was used as materials. The Taguchi L9 orthogonal array was chosen for AWJ cutting process. This array consists of three control parameters and three levels, as shown in Table1. Abrasive water jet machine (S3015) was equipped KMT ultra-high pressure pump with intensifier system is shown in Figure 1. Garnet was used as the abrasive having an 80 mesh size. All experiments were performed using single pass cutting and the samples are shown in Figure 2. The average surface roughness on the composite was measured by Mitutoyo Surftest SJ-301 roughness tester. The experimental conditions, their levels for each experiment and the observed values of metal removal rate, and surface roughness are shown in Table 2. The S/N ratio was determined using Minitab 17 to rank the parameters according to their effect on the output response and subsequently ANOVA was performed to quantify the significance of parameters with respect to output response parameters.

Fig.1AWJ machining process

Table 1 Details of parameters and levels

Input variable parameters				Output responses
Levels	1	2	3	Metal Removal Rate (MRR) (mm^3/min) Surface Roughness (SR) (µm)
Feed Rate (mm/min)	50	75	100	
Stand off Distance (mm)	1	2	3	
Abrasive Flow Rate (g/min)	200	250	300	

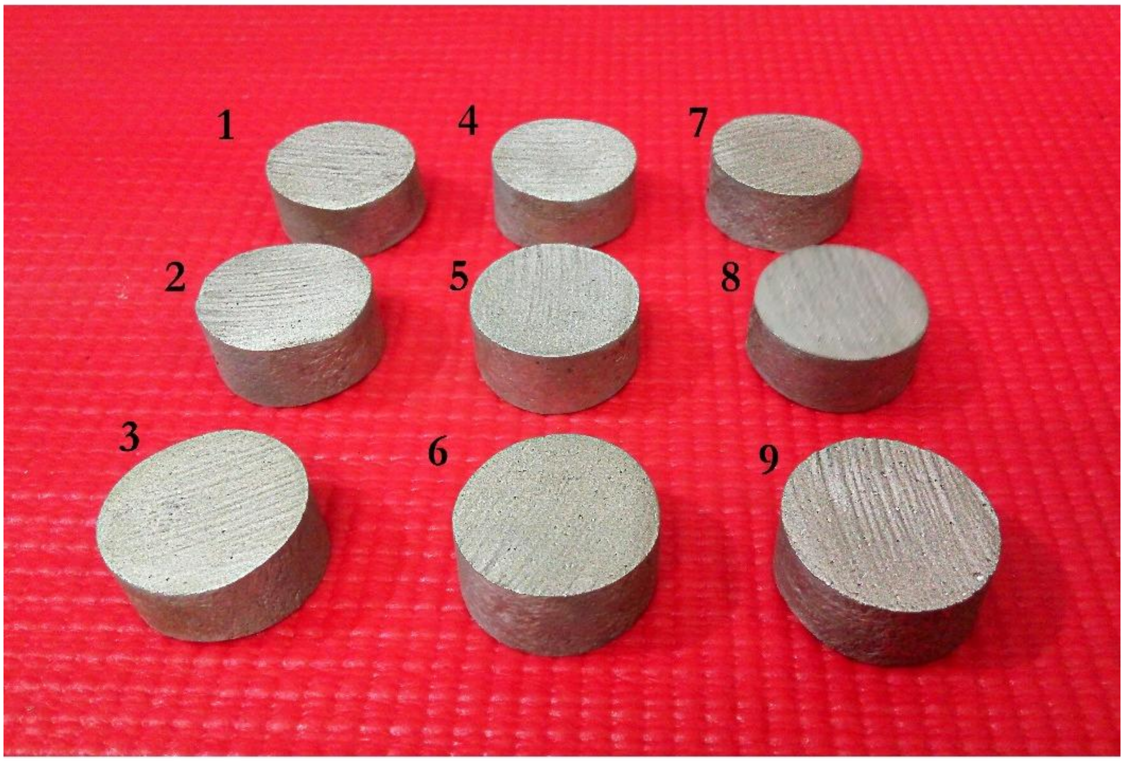

Fig. 2 AWJC samples.

Table 2 Observed values of MRR and SR

Feed Rate (mm/min)	Stand off Distance (mm)	Abrasive Flow Rate (g/min)	MRR (mm^3/min)	SR (µm)	S/N ratios MRR	S/N ratios SR
50	1	200	28	3.28	28.94	10.32
50	2	250	30	4.23	29.54	12.53
50	3	300	32	6.25	30.10	15.92
75	1	250	29	3.22	29.25	10.16
75	2	300	30	5.45	29.83	14.73
75	3	200	31	3.22	29.94	10.16
100	1	300	30	3.47	29.54	10.81
100	2	200	31	2.28	29.83	7.16
100	3	250	35	4.34	30.88	12.75

3. Results and Discussion

In the investigations, the quality characteristic such as MRR and SR are chosen as the objective function. The higher characteristic value represents better machining performance, such as MRR is ‘Larger is better’. Inversely, the lower characteristic value represents better machining performance, such as SR is ‘Smaller is better’. The optimum condition is identified by studying the main effects of each of the factors. The main effects indicate the general trends of the influence of the factors.

3.1 Main Effects Plot

The effect of feed rate during AWJ Machining of the composites, it found from the analysis plot that when the feed rate increases the MRR of composites increases, an increase in abrasive flow rate leads to a small reduce in the MRR, and increase in standoff distance increase MRR linearly as shown in Figure 3. The influence of abrasive flow is not significant as that of other process parameters.

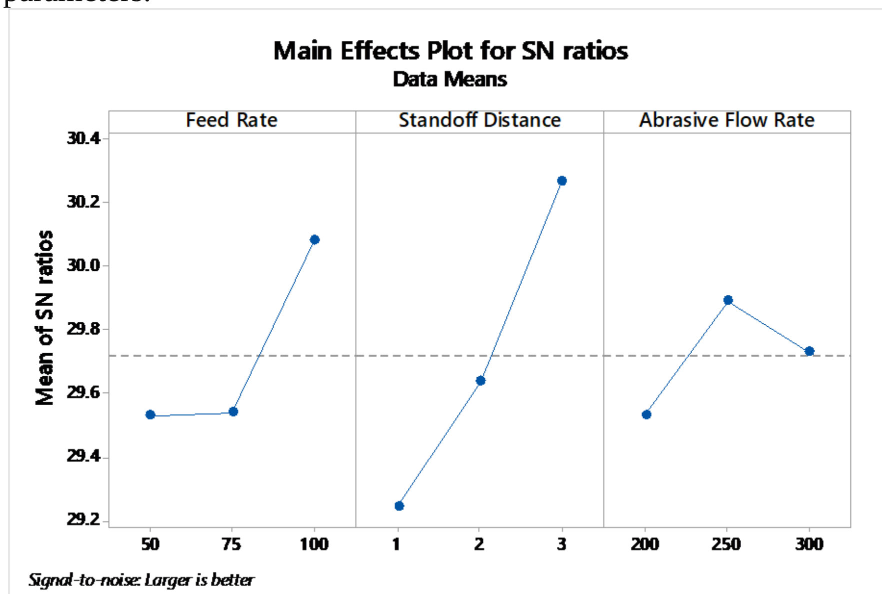

Fig. 3 Main effects plot of MRR

The effect of feed rate during AWJ Machining of composites, it found from the analysis plot that when the feed rate increases the SR of composite material increases, an increase in abrasive flow rate leads to slightly decrease in the SR, and increase in standoff distance increase SR decrease as shown in Figure 4. The influence of standoff distance is not significant as that of other process parameters.

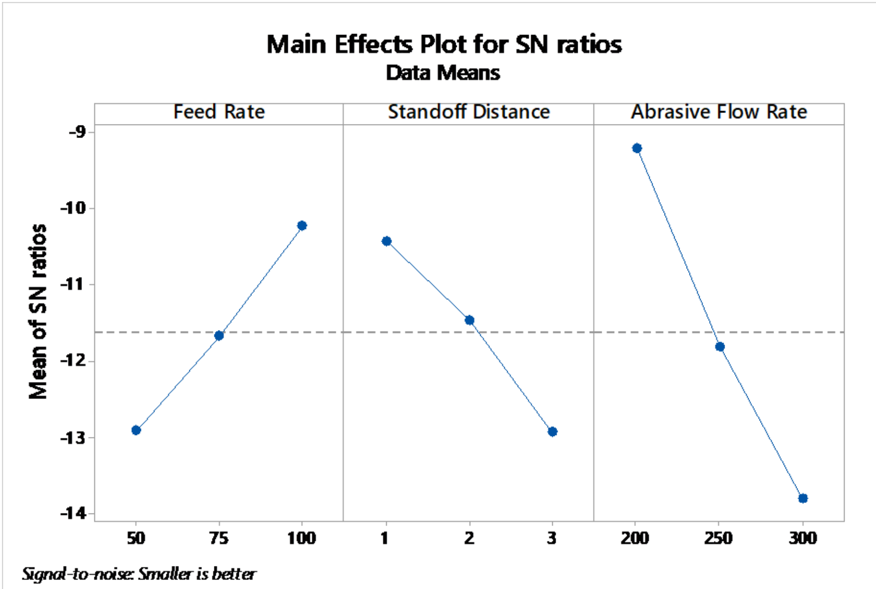

Fig. 4 Main effects plot of SR

3.2 Response Table

Table 3 shows the Signal to Noise Ratio values for MRR and SR. The standoff distance and abrasive flow rate was ranked the mainly significant parameters between the three input parameters with the highest delta value for MRR and SR respectively.

Table 3 Response Table for S/N ratio of MRR and SR

S/N ratio of MRR				S/N ratio of SR		
Level	Feed rate	Standoff distance	Abrasive flow rate	Feed Rate	Standoff distance	Abrasive flow rate
1	29.53	29.24	29.53	-12.921	-10.427	-9.211
2	29.54	29.64	29.89	-11.681	-11.471	-11.811
3	30.08	30.27	29.73	-10.238	-12.942	-13.817
Delta	0.55	1.03	0.36	2.682	2.514	4.606
Rank	2	1	3	2	3	1

3.3 ANOVA Studies

Analysis of variance tables for the effect of parameter on MRR as shown in Table 4. Standoff distance has p-value very minimum, hence it is significant parameter. Standoff distance affect for response of MRR. Feed rate has little effect over the MRR. Abrasive flow rate is also significant parameter but not as much as Feed rate. Rank order as per the significance level is that standoff distance, feed rate and abrasive flow rate. The requirement of the MRR optimum level can be fixing on by SN ratio plot.

Table 4 Analysis of variance for S/N ratio of MRR

Source	DF[a]	AdjSS[b]	AdjMS[c]	F	P[d]	Remarks
Feed rate	2	8.0000	4.0000	12.00	0.077	Significant
Standoff distance	2	20.6667	10.3333	31.00	0.031	Significant
Abrasive flow rate	2	2.6667	1.3333	4.00	0.200	Insignificant
Error	2	0.6667	0.3333	-	-	Insignificant
Total	8	32.0000	-	-	-	-
S =0.577350; R^2 = 97.92%;[a] Degrees of freedom, [b] Adjusted sums of squares, [c] Adjusted mean squares, [d] Probability.						

Analysis of variance tables for the effect of parameter on SR as shown in Table 5. Abrasive flow rate is significant parameter in AWJ machining of the composites. Abrasive flow rate affect for response of SR. Feed rate has little effect over the SR. Rank order as per the significance level is that Abrasive flow rate, Feed rate and Standoff distance. The requirement of the SR optimum level can be fixing on by SN ratio plot

Table 5 Analysis of variance for S/N ratio of SR

Source	DF[a]	AdjSS[b]	AdjMS[c]	F	P[d]	Remarks
Feed rate	2	8.2451	1.1225	2.86	0.242	Significant
Standoff distance	2	2.4587	1.2293	3.14	0.259	Insignificant
Abrasive flow rate	2	6.8130	3.4065	8.69	0.103	Significant
Error	2	0.7838	0.3919	-	-	Insignificant
Total	8	12.3005	-	-	-	-
S =0.626001; R^2 = 93.63%;[a] Degrees of freedom, [b] Adjusted sums of squares, [c] Adjusted mean squares, [d] Probability.						

3.4 Regression Analysis

The following second order regression equation was fitted to the MRR and SR with R^2 value by using regression analysis.

MRR = 22.33 + 0.0400 Feed rate + 1.833 Standoff distance + 0.00667 Abrasive flow rate
SR = -0.80 - 0.02447 Feed rate + 0.640 Standoff distance + 0.02130 Abrasive flow rate

The parameter R^2 describes the amount of variation observed in cutting force is explained by the input parameters. R^2 is 97.92 % and 93.56% of MRR and SR indicates that the model is able to predict the response with high accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model. The standard deviation of errors in the modeling, S_{MRR}= 0.577350 and S_{SR}=0.626001. Comparing the p-value to commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant. So it can be said that except MRR and SR, all parameters are significant.

The residuals are found to be normally distributed along the straight line in the normal probability plot for MRR and SR is shown in Figure 5 and Figure 6 respectively. It is evident from these figures, the plotted points form a reasonably straight line and within the confidence intervals lines. The points follow the fitted distribution line fairly close. Hence the data fit relatively well.

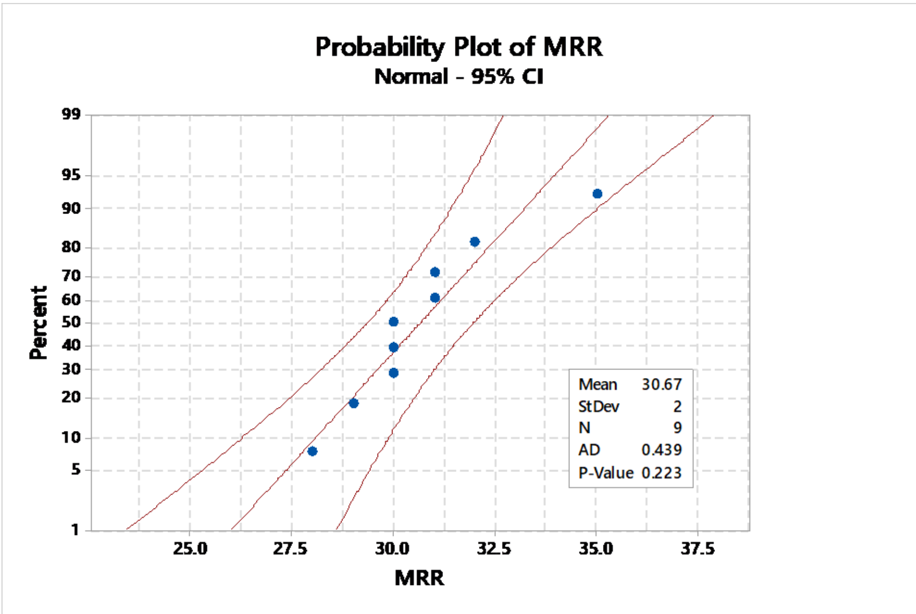

Fig. 5 Probability of MRR

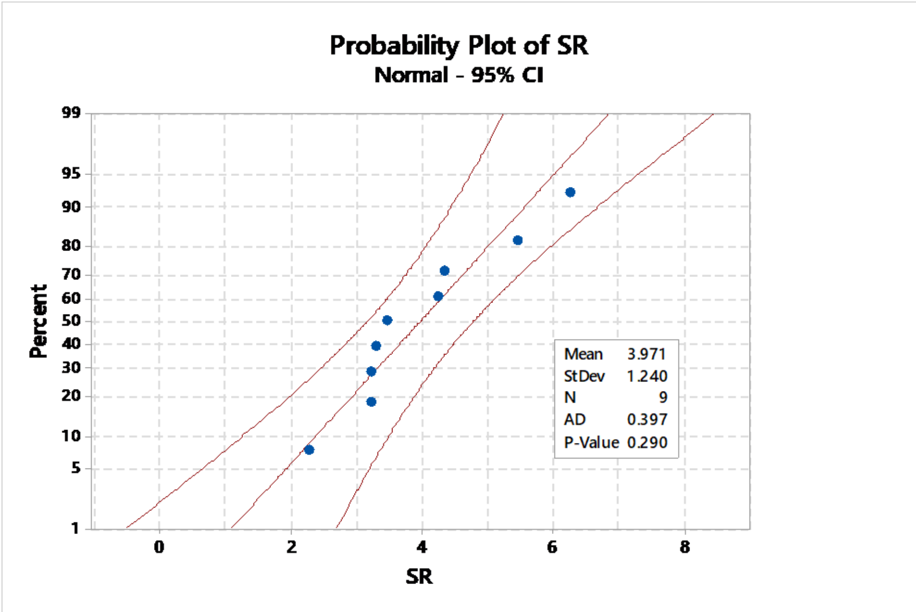

Fig. 6 Probability of SR

The optimization plot for composite is shown in Figure 7, and then the optimal design is verified. The experimental result which is having the high grade value using the initial arrangement of the cutting parameters is compared with the optimal one which has got from the mean effects plot.

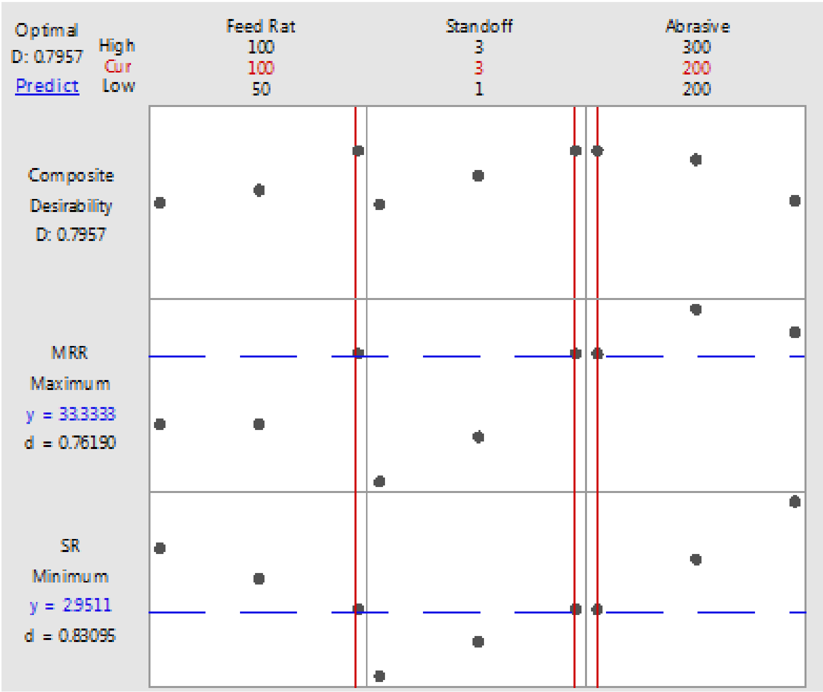

Fig. 7.Optimization Plot

4. Conclusion

The AA6063- 3 wt. % TiC composite produced through stir-casting successfully. In the present study a parametric analysis carried out for MRR and SR for the AA6063- 3 wt. % TiC composites. The L9 orthogonal array based on Taguchi design was performed. Minitab 17 software was used for analyze the result and theses responses were partially validated experimentally. Following conclusion drawn after analysis.

- Standoff distance has the most significant effect on MRR at the 95% confidence interval. Increasing the feed rate decreases the MRR. The Abrasive flow rate has been found to be statistically insignificant for MRR.
- Abrasive flow rate has the most significant effect on SR at the 95% confidence interval. Increasing the feed rate decreases the SR. The standoff distance has been found to be statistically insignificant for SR.

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