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ORIGINAL PAPER

Multi Response Optimization of AWJM Process Parameters on Machining TiB_2 Particles Reinforced Al7075 Composite Using Taguchi-DEAR Methodology

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Abstract
The importance of synthesizing particles reinforced metal matrix composites is increasing owing to their distinct physical properties. The machining of such composites is a tedious process due to its higher strength. In the present study, an endeavor has been made to investigate the influence of process parameters in abrasive water jet machining process while machining TiB_2 particles reinforced Al7075 composite. Water jet pressure, transverse speed and standoff distance have been considered as input parameters to evaluate the performance measures such as material removal rate, surface roughness and taper angle in the machining process using Taguchi-DEAR methodology. From the experimental investigation, it has been found that water jet pressure has higher influence on determining performance measures in AWJM process owing to its importance on determining impact energy. The optimal process parameters combination has been found as water jet pressure (280 MPa), transverse speed (345 mm/min) and standoff distance (4 mm) among the chosen process variables and evaluated using confirmation test with 1.2% of deviation from mean MRPI value.

Keywords AWJM · Composites · Reinforcement · Taguchi-DEAR · Optimization

1 Introduction

Aluminum alloys is mostly utilized in manufacturing industries owing to its distinct physical properties such as light weight, high elastic modulus and high load carrying capacity [1]. The aluminum alloy are reinforced with the ceramic particles to synthesis ceramic reinforced metal matrix composite (MMC) for enhancing the physical properties [2–4]. Such MMC alloys have to be involved forming and machinability process for producing final product [5]. Since it is very tedious process to machine metal matrix composites using conventional machining process, the unconventional machining processes such as Electrical Discharge Machining (EDM), Electro Chemical Machining (ECM), and Abrasive Water Jet Machining (AWJM) are preferred to machining such materials [6]. Owing to its ability of producing heat affected zone (HAZ), recast layer and higher machining time, EDM process may not be suitable for machining the MMC [7]. ECM process may produce corrosive layer over the machined specimen [8]. Hence the AWJM process has been suggested to avoid these draw backs and enhancing the performance measures of machinability [9]. The AWJM process provides a single tool that is suitable for machining a wide range of composite materials [10]. As the ceramic reinforced composites are hard, brittle, and lower electrical conductive in nature, the AWJM process can be easily

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applicable to machine such materials [11]. There are numerous flow associated parameters and factors of AWJM process can influence the performance measures of the machined surfaces [12]. It is very important to optimize the process parameters in the AWJM process due to its nonlinear nature [13]. Since the machining process contains more than one performance measure, conventional Taguchi based single response optimization approach is not accurate one [14]. Hence multi response optimization algorithms such as assignment of weight method, response surface methodology (RSM), Artificial neural network (ANN), taguchi-gray relational analysis (TGRA) can be used for the optimizing the parameter [15]. The data interpretation in the response surface methodology is tedious one [16]. Even though the assignment of weight is very easiest method, the accuracy of the prediction is not favorable one. The selection of the gray distinct co-efficient based on the nature of the process parameters is a complex process [17]. The ANN based optimization approach can provide better accuracy of prediction. However the complexity on computation needs many steps for enhancing the prediction [18]. It has been inferred that Taguchi-DEAR methodology can predict the optimal process parameters combination in an efficient way [19].

While analyzing the literatures, it has been found that only few research attempts have been made to apply multi response optimization techniques for machining TiB_2 particles reinforced aluminum metal matrix composites (MMC). It has observed that only little attention has been given to find the optimal process parameter combination in AWJM process using Taguchi- Data Envelopment Analysis based Ranking Methodology (DEAR) methodology. Hence the present investigation has been carried out.

2 Materials and Methods

2.1 Development of TiB_2 Particles Reinforced Al7075 Composite

In the present study, TiB_2 particles reinforced Al7075 composite has been used as work piece specimen owing to its importance in manufacturing and automobile fields. In the stir casting approach, Al 7075 placed in a graphite crucible and then heated to 800 °C using electrical furnace. The micron size powder particles have been heated to 850 °C. TiB_2 particles with the average size of 5 μm have been added as the reinforcement particles. Then preheated TiB_2 particles have been gradually added to molten Al7075 with 2% of weight percentage [4]. In this preparation process stirring has been carried out in the graphite crucible for ensuring homogeneous distribution of the mixture of composite. The stirring has been performed with the help of a drilling machine for about 30 min at the stirring speed 350 rpm. Then the mixture has been poured into the mold cavity and allowed to cool by keeping the mold room temperature. Figure 1 SEM image of synthesized Al7075 composite with TiB_2 particles as reinforcement. The mechanical properties of synthesized composites are shown in Table 1. The homogenous distribution of TiB_2 particles in aluminum matrix has been observed in the Fig. 1, owing to the proper stirring process.

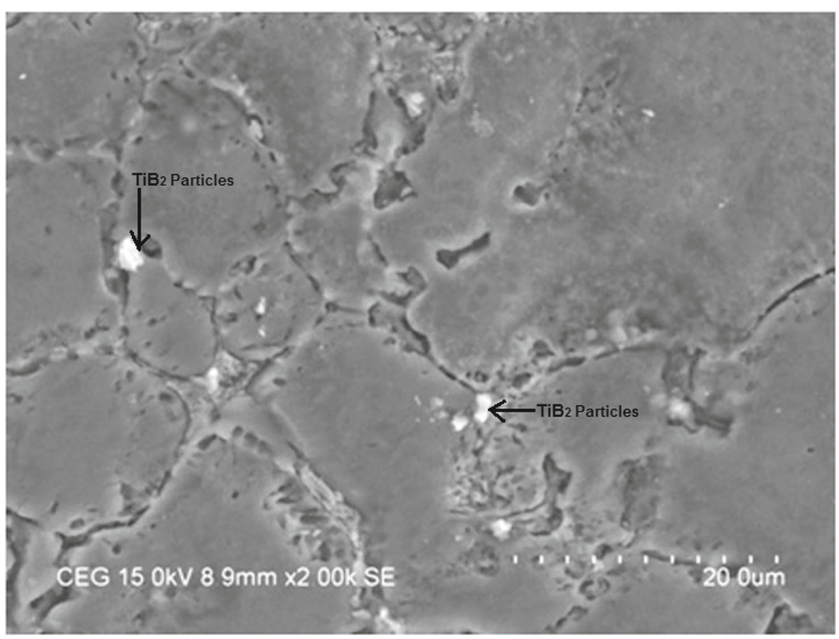

Fig. 1 SEM image of TiB_2 reinforced Al7075 composite

Table 1 Mechanical properties of Al7075 - 2% TiB_2 composites

Property	Unit	Value
Tensile strength	MPa	174
Elongation	%	6
Hardness	BHN	95.26

2.2 Selection of Process Parameters of AWJM Process

The cutting of specimens has been performed using OMAX MAXIEM 1515 abrasive water jet machining arrangement with the nozzle diameter of 0.76 mm and speed of 12,700 mm/min. The X-Y axis travel of the machine is 1,575 mm × 1,575 mm with Z axis travel of 305 mm and tank capacity of 3,000 lb. The abrasive flow rate has been determined as 0.432 Kg/min. The depth of cut has been selected as 10 mm. Garnet has been used as abrasive powder with mess size of 40. Water jet pressure, transverse speed and standoff distance have been chosen as input process parameters owing to their importance on determining impact energy in AWJM [9]. Since the present study deals with three input levels through three different process parameters, L_9 orthogonal array (OA) design has been selected based on Taguchi design of experiments [15]. Water jet pressure, transverse speed and standoff distance have been taken as input parameters due to their importance of these process parameters in AWJM process. The process variables have been chosen in the higher, medium and lower ranges of process parameters as shown in Table 2.

The material removal rate (MRR), surface roughness (R_a) and taper angle (θ_t) has been selected as response parameters. Since the present investigation has been performed with more than one performance measure, it is needed to implement multi response optimization in the process. Material removal rate can be computed by finding the weight difference of the specimens before and after the machining process. It is denoted by mm^3 per minute. The average surface roughness has been computed using surfcorder surface roughness tester with cutoff length of 0.8 mm. The surface roughness have been computed in center line average approach and denoted in μm. The taperness is an unavoidable effect in AWJM process. Since it can affect the dimensional accuracy of the cutting, it has to be eliminated as much as possible. The schematic representation of the taperness is as shown in Fig. 2. The taperness can be represented by the taper angle and computed as per Eq. 1.

Table 2 Range of process parameters

Process parameters	Symbol	Unit	Variables
Water jet pressure	WP	MPa	240,260,280
Transverse speed	TE	mm/min	305,345,386
Standoff distance	SD	mm	2,3,4

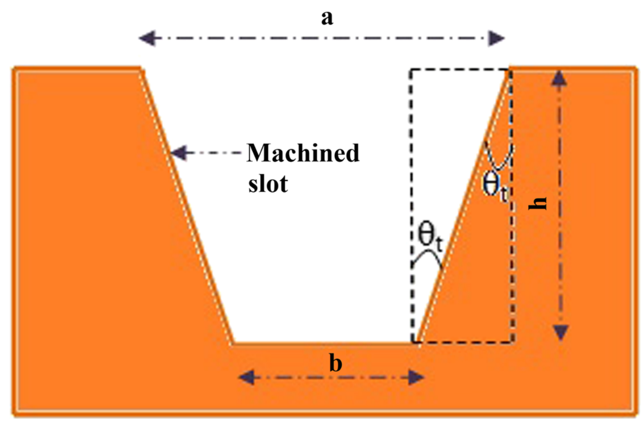

Fig. 2 Schematic representation of taper angle computation

$$\tan\theta_t = \frac{\frac{a-b}{2}}{h} \quad (1)$$

Where a is the entry slot distance; b is the exit slot distance; h is the cutting distance. Table 3 shows the selection of process variables for L_9 orthogonal table.

2.3 Data Envelopment Analysis Based Ranking Methodology

In this method, a set of original responses are mapped into a ratio so that the optimal levels can be found based on this ratio. This value can be treated as MRPI value to find the optimal combination of the process parameters. The following steps are involved in Data Envelopment Analysis based Ranking Methodology (DEAR):

1. Determine the weights(w) for each response for all experiments. Weight of response is the ratio between response at any trial to the summation of all responses.

Table 3 Taguchi L_9 based OA design

Trial	A	B	C
1.	1	1	3
2.	1	2	2
3.	1	3	1
4.	2	1	2
5.	2	2	1
6.	2	3	3
7.	3	1	1
8.	3	2	3
9.	3	3	2

2. Transform the data of response into weighted data by multiplying the observed data with its own weight.
3. Divide the data as larger the better with smaller the better.
4. Treat this value as multi response performance index (MRPI).

MRPI is the ratio between the summation of larger the better data to the summation of smaller the better data. In the present study, the following equations has been used to find the MRPI for the present study where P, Q and R are just variables denotations.

$$\mathrm{MRPI} = \frac{\mathrm{P}}{\mathrm{Q} + \mathrm{R}} \tag{2}$$

$$\mathrm{P} = \mathrm{MRR} * \mathrm{W_{MRR}} \tag{3}$$

$$\mathrm{Q} = \mathrm{R_a} * \mathrm{W_{R_a}} \tag{4}$$

$$\mathrm{R} = \theta_t * \mathrm{W}_{\theta_t} \tag{5}$$

The weights for all the response variables have been computed as the following equations

$$\mathrm{W_{MRR}} = \frac{\mathrm{MRR}}{\sum \mathrm{MRR}} \tag{6}$$

$$\mathrm{W_{R_a}} = \frac{1/\mathrm{R_a}}{\sum {}^{1}/\mathrm{R_a}} \tag{7}$$

$$\mathrm{W}_{\theta_t} = \frac{1/\theta_t}{\sum {}^{1}/\theta_t} \tag{8}$$

Table 4 Experimental results in AWJM

Factors			MRR (mm^3/ min)	R_a (μm)	θ_t (θ)
WP	TE	SD			
240	305	2	8.4185	2.105	1.34
240	345	3	14.7905	2.865	1.231
240	386	4	16.2164	3.012	1.231
260	305	3	15.1494	2.902	1.632
260	345	4	16.6174	3.042	1.632
260	386	2	19.3555	3.315	1.5446
280	305	4	15.9836	2.988	1.6038
280	345	2	22.5365	3.645	1.6611
280	386	3	18.7005	3.165	1.6611

Table 5 MRPI values of experiments

Trial No.	Weights			MRPI
	MRR	R_a	θ_T	
1.	0.0896	0.155448	0.122915	0.974967
2.	0.097066	0.114212	0.133799	3.009445
3.	0.110933	0.108638	0.133799	3.617674
4.	0.105891	0.112756	0.100923	3.157267
5.	0.110933	0.107567	0.100923	3.798795
6.	0.12261	0.098708	0.106634	5.153824
7.	0.110933	0.109511	0.102698	3.514538
8.	0.12261	0.089772	0.099155	6.987028
9.	0.129422	0.103387	0.099155	4.810887

3 Results and Discussions

3.1 Identification of Optimal Parameters Combination Using DEAR Methodology

In the present study, Taguchi based experiments have been conducted for investigating the effects of AWJM parameters on machinability of Al7075 TiB_2 composite in AWJM process. Table 4 shows the experimental results of all the experiments have been conducted. The weights of the individual performance measures under different process parameters combinations has been calculated based on DEAR methodology as shown in Table 5.

Table 6 shows the consolidated MRPI of all the input factors with all the levels. The Values have been computed by the adding the all MRPI values for corresponding level of each process parameters.

The maximum level value of each process parameters indicates the optimal level of input parameters on determining the machining characteristics. The maximum value of MRPI in each process parameters can be considered as the optimal value of the process variables. From the Table 6, it has been found that water jet pressure (280 MPa), transverse speed (345 mm/min) and standoff distance (4 mm) as the input process parameters in AWJM process. The experimental investigation has been performed with only nine trials in the present study even though there has been possibility

Table 6 Total MRPI values of all trials

Factors	Levels			Max - Min
	1	2	3	
Water jet pressure	7.602086	12.10989	15.31245	7.710367
Transverse speed	7.646772	13.79527	13.58239	6.148496
Standoff distance	10.93101	10.9776	13.11582	2.184812

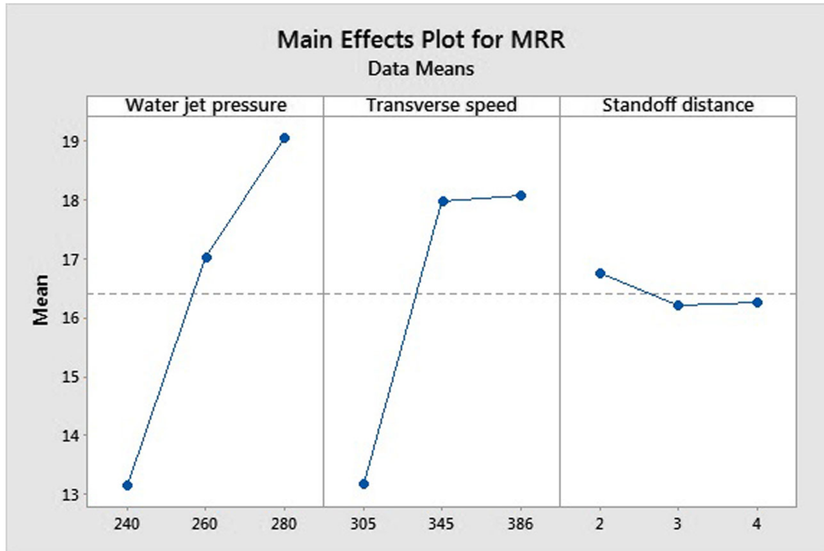

Fig. 3 Effects of process parameters on material removal rate

of conducting 27 trials. The process parameter combination may be derived from any combination of process parameters combinations. Nevertheless the obtained optimal process parameters combination has been exactly matched with eighth trial of the L_9 design in the present study. The larger max-min value indicates higher influence of process parameters on surface performance measures. Hence it has been inferred that water jet pressure strongly influences on determining performance measures owing its importance on determining impact energy in AWJM process [9]. Hence it has been observed that the optimal selection of the water jet pressure can enhance the performance measures of the AWJM process while machining TiB_2 reinforced Al7075 composites.

3.2 Confirmation Experiment

The purpose of confirmation experiment is to validate the optimal process parameters combination derived from the methodology. In the present study, a confirmation experiment has been conducted using the optimal levels of significant factors. At the optimal process parameters setting, the response values from the confirmation experiments have been found as 13.45 mm^3/min (MRR), 1.876 μm (R_a) and 1.202 degree (θ_T). The value of MRPI for the confirmation experiment has been deviated by 1.2% from the average MRPI value. Hence the optimal combination of process parameters has been validated as satisfactory in the present study.

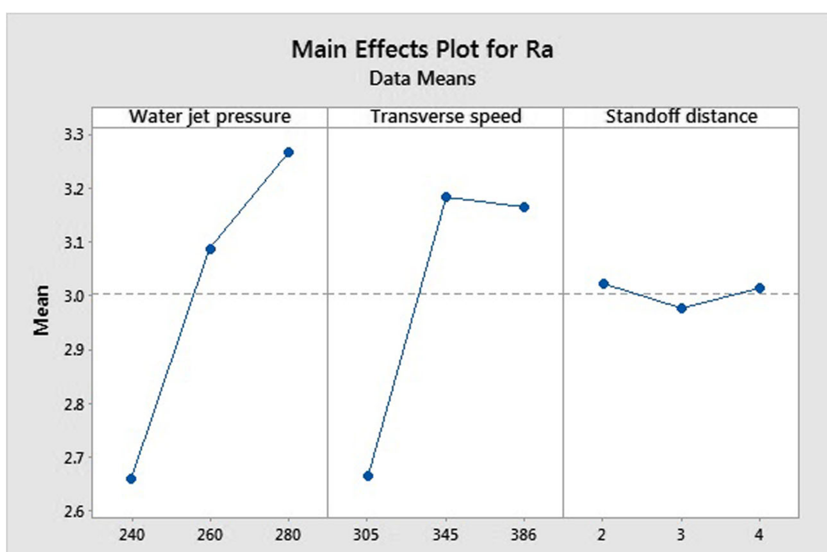

Fig. 4 Effects of process parameters on surface roughness

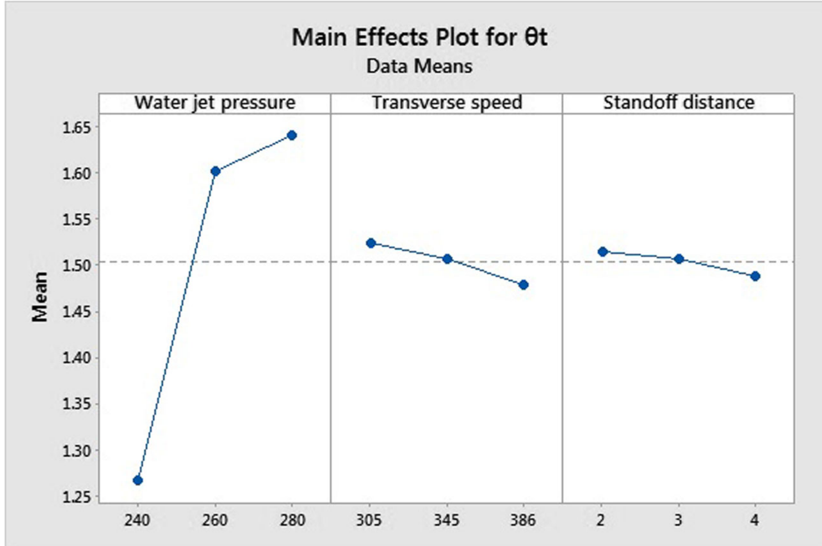

Fig. 5 Effects of process parameters on taper angle

3.3 Main Effect Analysis of Process Parameters

Figure 3, 4, 5 and 6 shows the main effects plots of process parameters on material removal rate, surface roughness, taper angle and MRPI respectively with the help of minitab software package. The deviation of response curve from the horizontal line indicates the most significance nature on machinability of TiB_2 reinforced Al7075 composite. The material removal rate in AWJM process is mainly determined by the energy transferred to the specimens in the machining zone. The higher pressure leads to import more energy on abrasive particles and the water medium. Hence the water jet pressure has higher influent on determining material removal rate. The surface roughness is mainly determined by the crater size in any machining process. Since the energy from the abrasive particles are primarily decided the crater size, the water jet pressure has dominant nature on surface roughness considerably. Taper angle is characterized by the entry and exit hole thickness of machined surface. Owing the importance of material removal on deciding entry and exit thickness, it has also heavily influenced by the water jet pressure. Hence it has been inferred that water jet pressure influence highly on determining performance measures in AWJM process.

4 Conclusions

In the present study, Taguchi- DEAR multiple response optimization methodology has been utilized to obtain optimal combination process parameters on machining TiB_2 reinforced Al7075 composite in AWJM process. From the

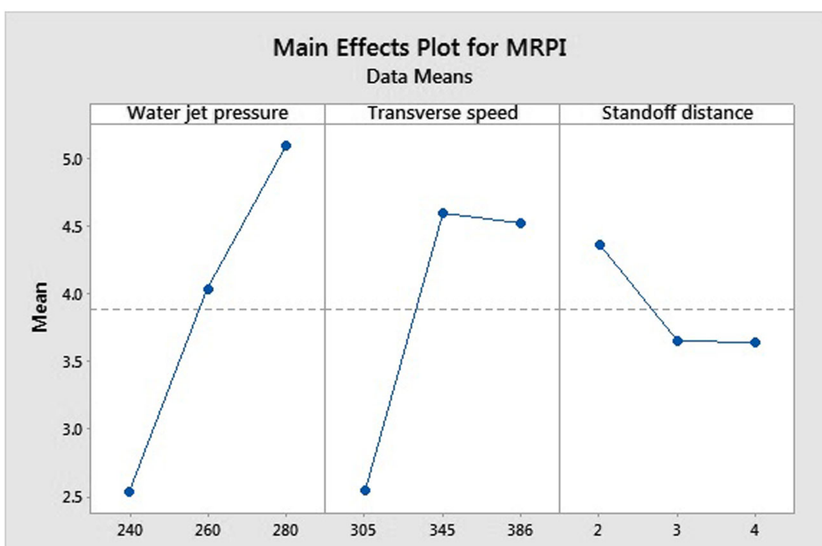

Fig. 6 Effects of process parameters on MRPI

experimental investigations, the following conclusions have been made.

- The optimal process parameters combination among the chosen process variables is water jet pressure (280 MPa), transverse speed (345 mm/min) and standoff distance (4 mm).
- It has also been verified by the confirmation test with deviation of 1.2% from the average MRPI value.
- Water jet pressure significantly influences on determining performance measures in AWJM process.

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