Prasad et al., *Cogent Engineering* (2018), 5: 1497830
https://doi.org/10.1080/23311916.2018.1497830

cogent engineering

Received: 28 March 2018
Accepted: 03 July 2018
First Published: 11 July 2018

*Corresponding author: S. Rajendra Prasad Department of Mechanical Engineering, JNTUA, Ananthapuramu
E-mail: siddagunta.raja@gmail.com

Reviewing editor:
Yuegang Yuegang Tan, Wuhan University of Technology, China

Additional information is available at the end of the article

This article has been republished with minor changes. These changes do not impact the academic content of the article.

PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Experimental investigation and parametric optimization in abrasive jet machining on nickel 233 alloy using WASPAS and MOORA

S. Rajendra Prasad[1]*, K. Ravindranath[2] and M. L. S. Devakumar[1]

Abstract: This article correspond to a multi criterion decision making approach, compared with Multi-Objective Optimization on the Weighted Aggregated Sum Product Assessment (WASPAS) and ratio analysis (MOORA) to optimize different interconnected responses during Abrasive jet machining (AJM) process of Nickel 233 alloy. The response parameters preferred are the average material removal rate (MRR) surface roughness (Ra) and Taper angle (Ta). The entire of them have been calculated in terms of injecting pressure, standoff distance, and abrasive grain size. The proposed technique Weighted Aggregated Product Sum Assessment technique is investigation of parametric optimization on AJM process. The outcome acquired using the WASPAS method demonstrate perfect parallel with those obtained by the ratio analysis (MOORA) method which confirms the applicability and potentiality of these MCDM methods for resolving compound AJM process parameter selection problems.

Subjects: Manufacturing Engineering; Production Engineering; Manufacturing Engineering

Keywords: WASPAS; NICKEL 233 alloy; Pressure; NTD; average grain diameter; Material Removal Rate; Surface Roughness; Taper angle, MOORA.

1. Introduction

In the present manufacturing scenario, there is a large variety of materials like Al, Mg, steel and so on and still increasing day-by-day. To process the component with required properties, it is especially difficult with conventional machining processes. In general, it may be extremely difficult to process the hard materials with conventional machining when compared to soft materials, and

S. Rajendra Prasad

ABOUT THE AUTHORS

S. Rajendra Prasad is a Research Scholar at the mechanical Engineering, JNTUAAnanthapuramu. He received his Bachelors degree and Masters Degree in Mechanical Engineering from JNTU in 2006 and 2012, respectively. His Ph.D research project was in experimental investigation and optimization of abrasive jet machining on aerospace material, under the supervision of Professor K. Ravindranath and Dr M. L. S Devakumar from Jawaharlal Nehru technological University, the co-authors of this manuscript. Professor K. Ravindranath leads the industrial engineering research group in the Department of mechanical Engineering, JNTUA, and Dr M. L. S Devakumar is a leading researcher in the manufacturing.

PUBLIC INTEREST STATEMENT

Among all the unconventional machining processes, Abrasive Jet Machining process has evolved recently and has become very popular as this is used for machining hard metals including glass, where accuracy is not of prime importance.

At present, we have taken up this research work involving AJM process and our objective is to conduct experimental investigation on process parameters and studying the type of responses. It is hoped that this production process would find wide applications in the area of various turbine blades, military hardware's which is very important in defence industries.

also the machining of hard materials is time consuming, high processing cost, less accurate, more chance of tool failure, poor surface finish etc. All these factors lead to development of new machine and techniques to achieve required properties with ease of operations, less time consumption, good surface finish, increasing material removing rate, increased tool life, less power consumption, low cost of production as well as products involving complex designs. Most of the unconventional machining solutions are available to process complex designs, with different material characteristics (physical and mechanical) to suit required applications. They are ultrasonic machining (USM), electrical discharge machining (EDM), electrochemical machining (ECM), laser beam machining (LBM), plasma arc machining (PAM), water jet machining (WJM), abrasive water jet machining (AWJM), abrasive jet machining (AJM), etc.

AJM is relatively a new manufacturing process; however, it is an impact machining method that removes material by directing a high velocity stream of abrasive particles onto a work piece. The process differs from sand blast in three fundamental ways: (i) the main reason of sand blast is to clean work piece surface, while AJM is used to cut material; (ii) the abrasive particle dimension used in sand blast is bigger than that of the abrasive fine particles used in AJM; and (iii) high velocity flow of particles is feasible among AJM.

AJM devices that are at present commercially available and used by the researchers employ a fundamental structure, through which the abrasive particles are blasted constantly on to the work piece that produces hole with respect to nozzle diameter of specified size.

Broad literature on experimental and optimization models is available (Abdelnasser, 2016; Abbas, Aly, & Hamza, 2016; Borty, Bhattacharyya, Zavadskas, & Antucheviciene, 2015; Jagan Natha, Hire Math, & Shirappa, 2012; Loc, Shiou, & Yu, 2013; Madhu & Balasubramanian, 2017; Nanda, Mishra, & Dhupal, 2017; Nouhia, Sookhak Lari, Spelt, & Papini, 2015; Routara, Nanda, Sahoo, Thatoi, & Nayak, 2011; Sookhak Lari, Ghazavi, & Papini, 2017; Srikanth & Sreenivasa Rao, 2014; Xiao, Shi, Huang, & Wang, 2016).

However, most of the studies are inter-related to machining operation. Some works dealing with parametric analysis in AJM process have been investigated by various authors. Madhu and Balasubramanian (2017) conducted an experiment on modified nozzle shape of internal threading system on parameters such as nozzle Dia, grain size, and stand of distance (SOD) on carbon fiber reinforcement Particle (CFRP) material. The investigational result showed the presence of excellent surface finish on CFRP material from the newly considered nozzle with inside thread. Srikanth and Sreenivasa Rao (2014) fabricated AJM setup and conducting on glass material with different parameters and observed Kerfs characteristics. Sookhak Lari et al. (2017) proposed a novel approach, rotating mask arrangement fixed in abrasive jet micro machining (AJMM) on SOD and time-changing parameters are used to conduct experiments. It improves the footprint shape on the target material using rotary mask. Xiao et al. (2016) demonstrated surface texturing of mechanical seals in machining process consideration of abrasive flow rate (AFR) and SOD on reaction-bonded silicon carbide (RBSC), SU304, and carbon graphite. It analyzed the parameters and hence found that Carbon graphite has great material removal rate, and SUS304 could have low surface irregularity after machining on least AFR and SOD. Nouhia et al. (2015) implemented shadow mask for direct marks on glass material with different parameters and observed that least amounting of frosting decreases SOD and particle size.

Some investigators have attempted to optimize different quality presentation index in Abrasive Jet machining with respect to different process variables and responses.

Routara et al. (2011) conducted experiments on glass material and analyzed different responses such as MRR and Ra in machining parameters pressure, SOD, and abrasive size. The outcome is analyzed by analysis of variance (ANOVA) and grey relational analysis (GRA). It is accomplished with performance characteristics of the AJM development such as MRR and surface roughness. Jagannatha, Hire

Math, & Shirappa (2012) conducted experiments and analyzed the process parameters on SOD, feed, and air temperature using ANOVA. In that they found air is the more dominant parameter among the other parameters to get minimum roughness and maximum MRR. The article presented by Loc et al. (2013) indicated the use of N-BK7 glass material to perform machining operations by considering process parameters such as pressure, angle, and abrasive dimension using copper nozzle on the consequential analyzed by Taguchi. The values obtained are observed that the polishing time, the air pressure, and the impact angle drastically affect the polished Ra. Abbas et al., (2016) in their article demonstrated that multi-objective optimization fuzzy-evolutionary approach is validated on other process. In that they concluded a well-spread Pareto front line for the measured MOOUC problems. Nanda et al. (2017) used a modified experiment and also parametric optimization in multiple regression and particle swarm optimization (PSO) on different parameters. The experimental optimal progression parametric settings are pressure of 5 kgf/cm2, nozzle tip distance of 8 mm, and grain size of 260 μm to achieve the finest responses, and the outcome are experimentally validated finally. Abdelnasser (2016) considered parameters such as pressure, SOD, nozzle dia, grain size, and impact angle on glass material and the results obtained were analyzed using artificial neural network (ANN) and genetic algorithm (GA) and concluded that the process produces to form the MRR more exactly and mostly to find affairs among practical machining parameters and experimentally calculated MRR and achieved a maximum inaccuracy of 5.3%. The result shows that the GA is a successful method to see the optimal solutions for maximum MRR amid an inaccuracy of 8.4%.

Chakraborty et al. (2015) investigated the applicability of weighted aggregated sum product assessment (WASPAS) method to explore the parametric optimization of five nontraditional machining processes. It is accomplished that WASPAS method can be deployed as a helpful tool for both single response and multi-response optimization of the NTM processes. It is also experimental that this method is reasonably strong.

Madić et al. [14] attempted selection of non-conventional machining processes (NCMP) on different criterions are selected at a time by using MOORA method. They are concluded as AWJM is best one to compare other processes and validated inTOPSIS is exactly match.

A number of researchers (Abdelnasser, 2016; Abbas et al., 2016; Jagan Natha et al., 2012; Loc et al., 2013; Madhu & Balasubramanian, 2017; Nanda et al., 2017; Nouhia et al., 2015; Routara et al., 2011; Sookhak Lari et al., 2017; Srikanth & Sreenivasa Rao, 2014; Xiao et al., 2016) experimented on AJM in optimization of process parameters on brittle materials, but investigations on hard materials have been not adequately carried out.

The goal of this article is focused on parametric optimization used as a multi-objective optimization technique by a WASPAS method of hard material as NICKEL 233 alloy. The method has been developed and successfully used by Chakraborty et al. (2015) in the non-traditional machining process. The methodology developed can handle even MCDM approaches efficiently.

2. Methodology

2.1. Design of experiments

Design of experiment (DOE) is a systematic approach to deal among engineering problem-solving. Standard procedures are applied for the information collection and to organize the guarantee generation of substantial, faultless, and supportable designing conclusions.

Also, the greater part of this is done under the requirement of an insignificant use of designing runs, time, and cash. The primary four zones that DOE can be connected are comparative, modeling, screening and characterizing, and optimizing. For the optimal reaction, the last region of DOE, that is optimization, is distinguished. In the optimization, the engineer is occupied with deciding ideal settings of the practice factors, that is to decide the level of every variable that optimizes the process response.

2.2. Box–Behnken designs

Box–Behnken design is an experimental model used for response surface methodology, conceived George E. P. Enclose with Donald Behnken 1960, to accomplish the objectives like estimation variance, factorial design, block design and so forth. For the response optimization of procedure parameters of AJM, the Box–Behnken outlines are utilized.

2.3. WASPAS

The WASPAS method takes the concepts of Box–Behnken design for solving single response as well as multi-response optimization problems.

The procedural steps being involved in solving multi-objective optimization problems is presented below as illustrated by Chakraborty et al. (2015).

Step 1. Set the initial decision matrix

Step 2. Normalization of the decision matrix using the following equations:

$$X_{ij} = \frac{x_{ij}}{\max\limits_{i} x_{ij}} \text{ for beneficial criteria,} \tag{1}$$

$$Xij = \frac{\min\limits_{i} x_{ij}}{x_{ij}}, \text{ for non-beneficial criteria} \tag{2}$$

$_{xij}$ is the normalized value of *xij*. Its application primarily requires expansion of a decision matrix, $X = [x_{ij}]m \times n$ where x_{ij} is the performance of the i^{th} alternative with respect to the j^{th} condition, *m* is the number of candidate alternatives and *n* is the number of appraisal criterion.

Step 3. The first decisive factor of optimality, that is decisive factor of a mean weighted achievement is parallel to WSM method. The total relative importance of the i^{th} alternative, based on weighted sum method (WSM), is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} X_{ij}\ w_j \tag{3}$$

Here *wj* is weight (relative importance or significance) of the j^{th} criterion. The weight of a particular criterion can be determined using analytic hierarchy process or entropy method.

Step 4. The total relative importance of the i^{th} alternative, based on weighted product method (WPM), is calculated as follows:

$$Q_{i=}^{(2)} \prod_{j=1}^{n} X_{ij}{}^{wj} \tag{4}$$

A joint generalized criterion of weighted aggregation of additive and multiplicative methods is then proposed as follows:

$$Q_i = 0.5Q^{(1)} + 0.5Q^{(2)} = 0.5 \sum_{j=1}^{n} X_{ij}\ w_j + 0.5 \prod_{j=1}^{n} X_{ij}{}^{wj} \tag{5}$$

Step 5. To have increased ranking accuracy and effectiveness of the decision-making process, in WASPAS method, a more generalized equation for determining the total relative importance of the i^{th} alternative is developed and further applied as below:

$$Q_i = \lambda Q^{(1)} + (1-\lambda)\ Q^{(2)} = \lambda \sum_{j=1}^{n} X_{ij}\ w_j + (1-\lambda) \prod_{j=1}^{n} X_{ij}{}^{wj},\ \lambda = 0,\ 0.1 \tag{6}$$

This article is arranged to develop the possible parametric combination for a AJM process in the direction of control and its improved machining presentation; numerous experimental trials are frequently conducted based on Box–Behnken design, which is an experimental plan and it is a good parametric setting for the AJM process that is considered to be capable of being carryied on between the presented experimental trials.

AJM processes have a few responses based on which its machining performance is assessed. Some of these responses (material removal rate) are beneficial in nature requiring higher values. On the further tender, a number of responses (surface roughness and taper cut) are non-beneficial wherever lower values are favored all the time. Depending upon the finish necessities and type of the products manufactured, the method engineer must assign for right way or relative importance to each of the measured responses. Sometimes, the help of analytic hierarchy process is sorted for determining the priority weights of the responses. For a multi-objective optimization problem, the apply engineer should allocate importance to all the measured response and can afterward be valid WASPAS method for a given **λ** value whereas all together optimizing every one the responses.

The measured responses are optimized at all the points and a single parametric arrangement is found in which the direction is set to achieve the best show of the AJM process. Going further on the one hand, in single response optimization, all the responses are optimized independently and diverse personality parametric setting is attained for all of the responses. In this case, the method engineer must assign maximum meaning of one to a demanding response which wants to maximize/minimize and assign minimum importance of zero to the continuing responses. Then, by applying WASPAS technique, the most favorable parametric settings can be attained for an exacting value of ***Q***.

3. Experimental procedure

3.1. Material

A NICKEL 233 (www.azom.com/article.aspx?ArticleID=9301) alloy is selected as the work material. It is commercially available in clean form and exhibits outstanding oxidization resistance and high electrical as well as thermal conductivity. On the other hand, the alloy is subjected to bury coarse embrittlement by means of sulfur compound above 315°C.

In this material, chemical and mechanical properties are given Tables 1 and 2.

3.1.1. Chemical composition

The chemical composition NICKEL 233 alloy is outlined inside the following Table 1.

3.1.2. Mechanical properties

The following Table 2 shows the physical properties of NICKEL 233.

Table 1. Chemical properties

Element	Content (%)
Manganese, Mn	≤ 0.2–0.3
Silicon, Si	≤ 0.05–0.1
Iron. Fe	≤ 0.75–0.1
Copper, Cu	≤ 0.5–0.1
Carbon, C	≤ 0.5–0.1
Magnesium, Mg	≤ 0.01–0.1
Sulfur, S	≤ 0.008
Titanium, Ti	≤ 0.005
Nickel, Ni	Balance

Table 2. Mechanical properties

Properties	Metric	Units
Density	8.89	g/cm3
Melting point	1443	°C
Tensile strength (annealed)	650–880	Mpa
Yield strength (annealed)	350–550	Mpa
Elongation at break (annealed prior to test)	8–25	%
Thermal expansion co-efficient	10	μm/m°C
Thermal conductivity	25	W/mK

3.2. Machining procedure

Machining was performed on a fabricated AJM as shown in Figure 1, which is having a carbide-coated nozzle with diameter of 3 mm as shown in Figure 2. SiC is selected as abrasive particles material with three different size in figure 3 [Ref. Table 3] and the striking rate of work material is controlled by on/off valve.

This total variation of parameters in this process was carried out according to the design of experiments (DOE) by considering the Box–Behnken design. The test specimen was drilled as per requirement of experimental work on AJM setup.

In this article, mainly on three controllable parameters (air pressure, stand-off distance, and average grain diameter) and three response variables (MRR, Ra, and Ta), each factor has three levels shown in Table 3 and also designed as, Table 4, Box–Behnken RSM-coded values.

3.3. Measuring instruments

3.3.1. Surface roughness measuring tester

Mitutoyo make surface roughness tester SJ 401 of measure collection/motion: 80μm/0.001μm was used to calculate surface roughness in expressions of Ra. The Ra significance was considered in

Figure 1. Fabricated AJM setup.

Figure 2. Carbide-coated nozzle in three different sizes.

Figure 3. *SiC* Abrasive particles.

Table 3. Input parameters with their coded value at different levels

S. No	Input parameter	Units	Level1	Level2	Level3
1	Pressure	Kgf/cm^2	5	6	7
2	Stand-off distance	mm	5	7	9
3	Avg Grain diameter	µm	300	400	500

Table 4. Box–Behnken RSM-based-coded experimental design matrix

S. No	Pressure	Standoff distance	Average grain diameter
1	−1	−1	0
2	1	0	1
3	0	1	1
4	0	1	−1
5	1	0	−1
6	1	1	0
7	−1	1	0
8	0	0	0
9	1	−1	0
10	0	−1	−1
11	−1	0	1
12	0	−1	1
13	−1	0	−1
14	0	0	0
15	0	0	0

three epochs at unlike locations chosen randomly, and the standard value was directly measured for investigation. The surface roughness measuring tester is shown in Figure 4.

3.3.2. Digital weighing scale

Venus make, digital weighing scale, has range of 0–1530 kg and precision of 1 g was used to quantify the mass of each work piece. The primary and end weight of work piece and overall series time are used to determine the MRR.

Figure 4. Mitutoyo make, surface roughness tester.

3.3.3. *Taper angle measurement*

Figure 5 shows Opton vision 60, which is used to measure taper angle. The above measuring instruments provide the required parameters like bigger radius (r1), smaller radius (r2), and hole depth (h).by using the following empirical relation taper angle(α) is measured.

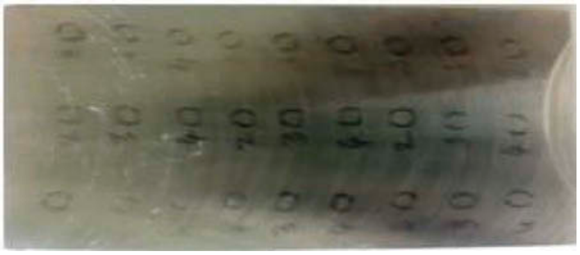
$\alpha = \tan^{-1}(r1\text{-}r2)/h$

Figure 6a&b shows that before & after machining of NICKEL 233 alloy material in AJM

4. Results and discussion

In the developed AJM setup the effects of Pressure (in kpa), Stand-off distance (mm) and average grain diameter (in μm) on three process characteristics (responses), i.e. MRR (in mg/min), Ra (in

Figure 5. *Opton* 60 Vision taper measurement.



(a)

(b)

Figure 6. *NICKEL* 233 alloy material (a) Before (b) After machining.

μm) and taper angle(rad) were investigated while generating holes on 50 × 50 mm and 1 mm thick NICKEL 233 alloy material. During experimentations, each of the process parameters was set at three different levels, i.e. pressure at 5, 6 and7; Stand—off distance at 5, 7, and 9; and average grain diameter at 300,400 and 500. Among the three responses, MRR needs to be maximized, where, minimum values of surface roughness and taper angle. Experimentally Maximum MRR achieved is 0.0046, and minimization of Surface Roughness and Taper angle are 0.921 and 7.47 respectively. These values obtained in different levels as shown in Table 5.

WASPAS method was implemented using same set of variables, constraints and boundary conditions. Table 6 shows the results of WASPAS implementation on the designed problem (goal functions). Using WASPAS method, the maximum MRR is 1mg/min minimum surface finish is 0.5679 μm and **Taper angle is 0.2977 at different levels**. For the purpose of validation, the same AJM process parameter selection problem is solved by using the MOORA method as one of the new MCDM technique. The computational details and step-by-step procedure of the MOORA method is explained in details in [14]. *Yi*is the assessment value (composite score) are rankings are given in Table 7.

Table 8 provides a comparative analysis between the optimal parametric combinations observed experimentally and those attained using WASPAS and MOORA method for single response optimization of the AJM process. In that the WASPAS and MOORA the MRR are getting same ranges at pressure 6, stand-off distance 9, and Avg mesh size 300.surface roughness and taper angle ranges are varied in experimentally are pressure 6, stand-off distance 9, and Avg mesh size300 and taper angle are pressure7, stand-off distance 7, and Avg mesh size is 300. In WASPAS method the SR and Ta optimal ranges are pressure 7, stand-off distance 9, and Avg mesh size 400, and taper angle value ranges are pressure 6, stand-off distance 9, and Avg mesh size 500 are optimal values.

5. Conclusions

The experimental results in Table 5, indicate the AJM Process to machine Ni-233 alloy work piece involves high cost machining as well as increased time consumption. Therefore it is decided to

Table 5. Experimental data

S. no	Hole no	Pr(Kgf/ cm2)	SOD (mm)	GS (μm)	MRR (mg/ min)	Ra(μm)	Ta(rad)
1	1	5	5	400	0.0017	1.23	15.92
2	3	7	7	500	0.0042	1.53	12.82
3	2	6	9	500	0.0038	1.14	25.09
4	5	6	9	300	0.0046	0.92	8.83
5	7	7	7	300	0.0041	0.93	7.47
6	9	7	9	400	0.0036	1.62	10.12
7	10	5	9	400	0.0015	1.43	21.05
8	12	6	7	400	0.0032	1.43	11.60
9	6	7	5	400	0.0028	1.52	9.29
10	8	6	5	300	0.0036	1.01	16.54
11	16	5	7	500	0.0031	0.95	24.64
12	18	6	5	500	0.0036	1.02	16.37
13	4	5	7	300	0.0021	1.06	10.35
14	11	6	7	400	0.0034	1.26	11.75
15	14	6	7	400	0.0031	1.24	10.60

Table 6. Normalized data using WASPAS

S. No	MRR	Ra	Ta	Q1	Q2	Q	Rank
1	0.369	0.747	0.469	0.528	0.506	0.517	14
2	0.913	0.601	0.582	0.698	0.684	0.691	8
3	0.826	0.807	0.297	0.643	0.583	0.613	12
4	1	1	0.845	0.948	0.945	0.947	2
5	0.891	0.989	1	0.960	0.958	0.959	1
6	0.782	0.567	0.738	0.696	0.689	0.693	7
7	0.326	0.643	0.354	0.441	0.420	0.431	15
8	0.695	0.643	0.643	0.660	0.660	0.660	11
9	0.608	0.605	0.804	0.672	0.666	0.669	10
10	0.782	0.910	0.451	0.715	0.685	0.704	5
11	0.673	0.968	0.303	0.648	0.572	0.610	13
12	0.782	0.901	0.456	0.713	0.685	0.699	6
13	0.456	0.867	0.721	0.682	0.659	0.670	9
14	0.739	0.730	0.635	0.701	0.700	0.706	4
15	0.673	0.741	0.704	0.706	0.693	0.708	3

Table 7. Normalized values and rankings of AJM in MOORA

S no	MRR	Ra	Ta	Yi	Rank
1	0.1314	0.2559	0.2709	-0.1359	14
2	0.3248	0.3183	0.2181	-0.0764	8
3	0.2938	0.2371	0.4269	-0.1256	12
4	0.3557	0.1914	0.1502	-0.0046	2
5	0.317	0.1934	0.1271	-0.0011	1
6	0.2784	0.337	0.1722	-0.0709	7
7	0.116	0.2975	0.3582	-0.1797	15
8	0.2474	0.2975	0.1974	-0.1239	11
9	0.2165	0.3162	0.1581	-0.0858	10
10	0.2784	0.2101	0.2814	-0.0704	5
11	0.2397	0.1976	0.4193	-0.1316	13
12	0.2784	0.2122	0.2785	-0.0706	6
13	0.1624	0.2205	0.1761	-0.0779	9
14	0.2629	0.2621	0.1999	-0.0663	3
15	0.2397	0.2579	0.1803	-0.0661	4

make use of optimization off process parameters that the help improved manufacturing process and hence for minimizing the machining time and expenditure.

In this paper, an attempt has been made to validate the applicability and use of WASPAS method while a successful optimization tool as solving Abrasive Jet machining process parameter range problems. It is moderately attractive to watch so as the WASPAS method determines the best likely parametric combination of the AJM processes for mutually single response as well as multi-response optimization problems. As it is an aggregated method based on the concept of WSM and WPM approaches, results in

Table 8. comparison of single response optimization results

Process parameter	Optimal experimental setting			Optimal WASPAS and MOORA methods-based parametric setting		
	MRR	Ra	Ta	MRR	Ra	Ta
Pressure	6	6	7	6	7	5
Stand-off Distance	9	9	7	9	7	7
Avg Grain diameter	300	300	300	300	500	500

precision as expected to be better than the single methods. Determining the optimal values of λ can further increase exactness and efficiency of this method in the decision-making process in further steps. Thus, its appropriateness as an easy and strong optimization tool confirmed to be effectively adopted for parametric optimization of other machining processes.

In order to validate the obtained rankings of AJM obtained by the application of the WASPAS method, the considered AJM process selection problem was solved by using the MOORA method. It was observed that ranking of competitive AJM process parameters exactly match.

The above experimental data which is carried out for the first time will be very much useful for specific industries like; aerospace, where NICKEL 233 alloy is used broadly.

Funding
The authors received no direct funding for this research.

Competing Interest
The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Author details
S. Rajendra Prasad[1]
E-mail: siddagunta.raja@gmail.com
K. Ravindranath[2]
E-mail: kravi1949@yahoo.com
M. L. S. Devakumar[1]
E-mail: devakumar.mech@jntua.ac.in
[1] Department of Mechanical Engineering, JNTUA, Ananthapuramu, India.
[2] Department of Mechanical Engineering, SVCET, CHITTOOR, India.

Citation information
Cite this article as: Experimental investigation and parametric optimization in abrasive jet machining on nickel 233 alloy using WASPAS and MOORA, S. Rajendra Prasad, K. Ravindranath & M. L. S. Devakumar, *Cogent Engineering* (2018), 5: 1497830.

Correction
This article has been republished with minor changes. These changes do not impact the academic content of the article.

References

Srikanth, D. V., & Sreenivasa Rao, M. (2014). Metal removal and kerfs analysis in abrasive jet drilling of glass sheets. *Procedia Materials Science*, *6*, 1303–1311.

Abbas, A. T., Aly, M., & Hamza, K. (2016). Multiobjective optimization under uncertainty in advanced abrasive machining processes via a fuzzy-evolutionary approach. *ASME*, *138*, 071003–1.

Abdelnasser, A. (2016). Elkaseer abrasive jet machining of glass: “Experimental investigation with ANN modelling and genetic algorithm optimization” Taylor & Francis Abdelnasser et al. *Cogent Engineering*, *3*, 1276513.

Chakraborty, S., Bhattacharyya, O., Zavadskas, E. K., & Antucheviciene, J. (2015). *Application of WASPAS method as an optimization tool in non-traditional machining processes*. ISSN 1392–124X (print), ISSN 2335–884X (online) INFORMATION TECHNOLOGY AND CONTROL, T. 44, Nr. 1.

Jagannatha, N., Hire Math, S., & Shirappa, K. (2012). Analysis and parametric optimization of Abrasive hot air jet machining for glass using taguchi method and utility concept. *International Journal of Mechanical and Materials Engineering (IJMME)*, *7*(1), 9–15.

Loc, P. H., Shiou, F.-J., & Yu, Z.-R. (2013). Investigation of optimal air-driving fluid jet polishing parameters for the surface finish of N-BK7 optical glass. *ASME*, *135*, 011015–1.

Madhu, S., & Balasubramanian, M. (2017). Influence of nozzle design and process parameters on surface roughness of CFRP machined by abrasive *jet*. Materials and Manufacturing Processes 32 (9), 1011-1018.

Nanda, B. K., Mishra, A., & Dhupal, D. (2017). Fluidized bed abrasive jet machining (FB-AJM) of K-99 alumina ceramic using SiC abrasives. *The International Journal of Advanced Manufacturing Technology*, *90*, 3655–3672.

Nouhia, A., Sookhak Lari, M. R., Spelt, J. K., & Papini, M. (2015). Implementation of a shadow mask for direct writing in abrasive jet micro-machining. *Elsevier Journal of Materials Processing Technology, 223* (September), 232–239.

Routara, B. C., Nanda, B. K., Sahoo, A. K., Thatoi, D. N., & Nayak, B. B. (2011). Optimisation of multiple performance characteristics in abrasive jet machining using grey relational analysis. *International Journal of Manufacturing Technology and Management*, *24*(1–4), 4–22.

Sookhak Lari, M. R., Ghazavi, A., & Papini, M. (2017). A rotating mask system for sculpting of three-dimensional features using abrasive jet micro-machining. *Elsevier Journal of Materials Processing Technology*, *243*, 62–74.

Xiao, S., Shi, L., Huang, W., & Wang, X. (2016). A multiphase micro-abrasive jet machining technique for the surface texturing of mechanical seals. *International Journal Advancement Manuf Technological*, *86*, 2047–2054.

cogent • oa

© 2018 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:
Share — copy and redistribute the material in any medium or format.
Adapt — remix, transform, and build upon the material for any purpose, even commercially.
The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:
Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.
You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

***Cogent Engineering* (ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com