Optimisation of AWJM Process Parameters for Machining Granite using PCA Methodology

Lingaraj N, S K Rajesh Kanna, P Sivasankar, Ilayaperumal K, Akash C

Abstract: In Abrasive water jet machining, abrasive particles along with high pressure water are used to intrude on the work materials ranges from soft to hard materials using high velocity jet. The process parameters considered in this research for machining the granite are pressure, standoff-distance and cut quality. Experimental investigation had been carried out, in order to identify the impact of varying the input machining parameters on the results like kerf angle, material removal rate and roughness of the machined surface. In this study, Taguchi's Multi response technique namely principal component analysis had been used to optimize the input parameters of the abrasive jet machine to obtain the desired outcome on granite work piece and also to foresee the best optimal input machining values of abrasive jet machining such as pressure, standoff-distance and cut quality. For each sequence of Taguchi L9 orthogonal array, sufficient number of experimentations had been carried out. Then with the help of principal component analysis, optimal process parameters that influence the granite machining characteristics have identified and to validate the experimentation, confirmation tests also been carried out with required combinations of array.

Keywords : AWJM, Taguchi's Multi response Method, ANOVA, PCA.

I. INTRODUCTION

The industrial needs on manufacturing sector are transforming rapidly, the demand for a versatile and time considerate manufacturing process is evident with regard to the global economy. The best suitable alternative to conventional machining can be the Abrasive Water Jet Machining(AWJM), which is the advanced unconventional machining process, providing an array of unique characteristics like high resilience, small cutting forces, good machining versatility, and no thermal distortion [1, 2] . AWJM process is renowned to make very fine cuts into hard materials such as granite, titanium, etc. Material removal has occurred due to erosion, mechanical force and abrasive nature of the particles carried by the water jet. The erosion happens due to the repeated compressive failure that occurs on the molecules at the point of contact of the water jet on the work piece, where the local fluid pressure override the ultimate compressive limit of the work piece materials [3].

Erosion mechanism of the AWJM resembles a combination of principles used in abrasive jet and water jet machining. In AWJM, highly pressurized water is used as a medium to carry and accelerate the abrasive particles to the workpiece, where impact force of the abrasive material erodes the work piece material providing a highly dynamic and stochastic machining process. The optimum responses for AWJM have been characterized using Taguchi method, from which it infers that the standoff distance value substantially affects the rate of material removal, similar to the adverse effect on surface roughness corresponding to the abrasive flow rate [1] .It was also inspected that traverse speed was considerably the most significant parameter, followed by the water jet pressure in influencing the surface roughness quality criteria. There were also experimental proofs explored by the researchers that the increase in kinetic energy of water jet brought about the best quality of cuts over the materials [4]. Other parameters such as abrasive grit size do not have a significant influence over the material removal rate or surface roughness. It was noted, compared to non-ferrous materials, ferrous materials are having notable enhancement in flow rate of abrasive jet particles, thereby the desirable output have been obtained. However, moderate abrasive flow rates delivered satisfactory results in hard polymers and metal matrix composites [8].

The calibers of abrasive jet machining process are consequently affected by various other process tuning parameters among which water jet pressure, traverse speed of jet and focusing nozzle diameter displays a significant importance, but are also ideally governable up to an extent [10]. In general, the better quality surface finish obtained controlling more than a input parameters, these parameters are of different units and conflicting with each other, so these parameters need to be normalized and then need to be optimized [7]. Taguchi method has been adapted and implied in several research experiments with the aim to study the influence on AWJM process parameters. By varying the primary parameters, experiments have been carried out using L9 orthogonal array (OA) by various researchers [6] .As a result of these investigations, significant factors were identified as variants with respect to certain process parameters [5, 9]. In prior investigations carried out by applying Taguchi L9-OA and L18-OA, optimum process parameters for AWJM have been identified by considering the water jet pressure, as the water jet pressure having paramount variations over the roughness of the machined surface [10,11].

Revised Manuscript Received on December 15, 2019

***** Correspondence Author

Lingaraj N*, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India. Email:lingarajleelavathy@gmail.com

S K Rajesh Kanna, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India. Email:skrkanna@gmail.com

P Sivasankar, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India. Email:sivasankar.p@ritchennai.edu.in

Ilayaperumal K, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India. Email: ilayaperumal@gmail.com

Akash C, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India.

II. EXPERIMENTAL WORK

Material: The cutting performance of abrasive water jets have been critically investigated for the diverse group of materials that are preferably machined using this process such as steel, brass, aluminium, inconel. Several literatures indicate the notable results that have been achieved for granite cutting. Granite had a wide range of civil applications, which have led to various investigations to enhance performance and productivity of processing technologies with regard to reduction of cost. In this research Granite of 10mm thickness is selected for parametric investigation of AWJM. The fine prints of the AWJM used for this research are given in the Table-I.

Table-I: AWJM Specifications

PARAMETERS	RANGE
Maximum Pressure	50763 psi
Minimum Pressure	21756 psi
Machining Quality	Q1 - Q5
Maximum Power	30Hp Motor drive
Transverse rate	9m/min
Accuracy	±0.025
Repeatability	0.05
X Y Travel	1.5m X 1.5m
Table Size	2.3m X 2.7m
Orifice Diameter	0.35mm

In AWJM, the cutting factors are transverse direction, transverse speed, stand-off distance(SOD) and impact angle of jet has effect on Surface roughness and kerf angle on work. The hydraulic and abrasive factors namely hydraulic pressure, feed rate, type of abrasive, grit size and orifice diameter plays the impact in the MRR. In this study, three important variables input responses namely hydraulic pressure, cut quality and stand-off distance were selected for analysis with each at three levels as shown in Table-II. Garnet of 100 grit size is used as the abrasive material.

Table-II: Control Parameters

SYMBOL	VARIABLES	LEVEL I	LEVEL II	LEVEL III
A	Pressure (in MPa)	100	120	140
B	Quality of cut	Q3	Q4	Q5
C	Stand off distance (in mm)	01.50	02.50	03.50

A suitable Taguchi Orthogonal array to conduct the set of experiments, degree of freedom is calculated as 7 based on the parameters, levels and interactions. In our experiments, it is assumed that there is no interaction between the parameters, since it is evident from the literature. Hence, a standard L9 OA is used for carrying out present experimental work. Hydraulic pressure of 100MPa, Q3 cut quality and 1.5mm SOD were the initial setting of parameters as per L9 OA.

In granite, the machining outcome responses such as rate of material removal (MRR), machined surface roughness (Ra) and kerf angle (KA) have been analyzed. MRR is one of the most pro-dominant parameter which influencing the rate of production, higher the MRR, higher the production and vice versa. Ra and kerf angle are considered as the machining quality control parameters to assess the quality of production. Experiments are carried as per the L9 OA and the machining outcomes such as MRR, Ra, and Ka are provided in the Table-III. The effects of varying these variables with in a range were critically analyzed and the remaining parameters which are having less influence over the production have kept at fixed values for ease in experimentation and interpretation of the results. The variations in the outcome on Ra and Ka are measured by using the surf coder and vision measuring system respectively.

Table-III: Output Responses for L9-OA

A	B	C	MRR (in grams/sec)	Ra (in µm)	Ka (in degree)
100	Q3	1.5	5.375849	4.711	0.813057
100	Q4	2.5	4.069372	3.818	0.569427
100	Q5	3.5	3.565512	4.799	0.777707
120	Q3	2.5	7.35652	6.315	0.977389
120	Q4	3.5	6.278336	4.625	0.92293
120	Q5	1.5	3.766977	4.682	0.942038
140	Q3	3.5	6.908778	3.888	0.882803
140	Q4	1.5	5.393566	5.529	1.166561
140	Q5	2.5	4.176025	4.108	1.11879

*Signal to Noise ratio(*S/N ratio) curve indicates the quality characteristics scatter plot from the expected values. In Taguchi optimization method, signal is represents the characteristics of the desirable output responses and another parameter, the noise, represents the other undesirable characteristics of the output responses. For experimentation, objective function have to be formulated, in this research, the objective functions is the combination of characteristics such as smaller-the-better, larger-the-better and nominal-the-best. Among these three characteristics, former is to minimize the roughness of machined surface and kerf angle, the second characteristic larger-the-better is used to maximize the MRR. So the objective function is the combination of minimization and maximization functions. S/N ratio for the machining output responses such as the MRR, Ra and KA have been recorded with respect to the quality characteristic and average of those values for the experimented samples are given in the following Table-IV.

Table 4: S/N ratio for machining Outcome Responses

MRR- Larger the better	Ra- Smaller the better	Ka-Smaller the better
14.6089	-13.4623	1.79758
12.1905	-11.6367	4.89124
11.0424	-13.623	2.18368
17.3334	-16.0075	0.19866
15.9569	-13.3022	0.69663
11.5199	-13.4086	0.51863
16.788	-11.7945	1.08273
14.6375	-14.8529	-1.33815
12.4153	-12.2726	-0.97497

III. PRINCIPAL COMPONENT METHOLODY

In the case of multi-response problems, Taguchi method proved unsuitable to be used as an optimization technique. However, Taguchi's designs can be used to collect the observed data for each response and further be analyzed by alternate methods developed for the same application.

In general, the identification of the optimal levels for the considered factors by considering only one response for a trailwill produces different set of independent optimal values for the each and every set in the multi response problems. But these optimal values might not be used in the real time applications, as the real time applications are involving multiple objectives to be satisfied at a time. Since most literatures which are using Taguchi optimization method were considered only single response for identifying the best values for the parameters, these eventualities have to be avoided for the multi objective optimization functions. In common, multi response optimization problems are combining the responses and the characteristics in a single statistic (response) function and that function have used as the objective function, to identify the optimal levels of the involved variables. So in this research, the conflicting responses such as maximization of the MRR and minimization of the Ra and KA for the machining of the granite have been combined in the single response function, this function have been used to identify the optimum values of the machining input parameters using principal component method.

Principal Component Analysis method (PCA) is a commonly used technique in which the principal components are obtained. The principal components are the set of smaller number of input machining variables which are obtained by transforming a set of considered correlated variables by using underlying mathematical principals and rules. PCA was originated from multivariate data analysis; although its applications are far more diverse, which we will display. Many researchers had used the PCA technique as the vital method for several applications in the initial step of analyzing large sets of data, as it uses the linear algebra concepts for identifying the solutions. Generally, in order to decrease the dimensionality of large data sets PCA utilizes a vector space transform. It has several other applications such as; de-noising signals, data compression and blind source separation. In cases where the original data set may involve many variables, the implementation of mathematical projections can be used to elucidate it to just a few variables (the principal components). Performing the PCA methodology, reasonably reduces the dimension data set, allows the researcher to identify trends procedures, patterns and finally the outliners in the data set. The process is much easier provided PCA is performed.

The obtained sets of experimented data (say S/N ratio) have to be converted into principal component in order to implement the PCA. The transformed experimental data are given as the input the PCA, again in the initial step of PCA, the given data are segregated and the set of quality characteristics have been transformed into equivalent set of correlated and uncorrelated principal components (PC), in order to simplify the computation. As the outcome should be the optimal values within the set of transformed values, in PCA, indexing mechanism have been used with a weighting factor. The PCA index is allotted for each and every set of principal components by calculating the percentage of the contributions with respect to total variance. The calculated total principal component index(TPCI) for each and every trial are utilized to identify the average factor of that concern trail and the same have to be continued for the entire set of principal components at each and every level. Further, the machining parameter levels corresponding to TPCI value are also need to be calculated for the clear interpretation of the solution obtained from the implemented methodology. The calculated TPCI with reference to the experimented set of principal components are provided in the Table V.

Table V: Calculated TCPI with respect to PC

PC1	PC2	PC3	TPCI
-0.3623	0.8626	0.19655	0.6968
-1.1134	0.8814	0.13009	-0.1019
-0.6708	0.4067	0.04309	-0.2211
0.37345	0.9599	-0.0078	1.3255
-0.1689	0.9665	0.37056	1.1682
-0.5034	0.3537	0.26392	0.1142
-0.3495	1.1923	0.60867	1.4515
0.13411	0.5455	0.28426	0.9639
-0.4477	0.4217	0.63483	0.6088

IV. RESULTS AND DISCUSSIONS

In PCA methodology, TPCI value is the major parameter used to identify the better value of the input parameter in accordance with the output responses and the obtained TPCI for the experimented data set are provided in the Table 6 along with the analysis of variances.

Table 6: TPCI and ANOVA

Factors	DF	Adj. MS	Adj. SS	P test Index	F test Index	PC (in %)
Pressure	2	0.6771	1.3542	0.113	7.86	44.00
Cut Quality	2	0.7362	1.4724	0.105	8.55	47.84
SOD	2	0.0396	0.0791	0.685	0.46	2.57
Error	2	0.0861	0.1722	-	-	5.59
Total	8	-	3.0780	-	-	100

Figure 1 is describing the effects on the output responses with respect to the variations in the input parameter values i.e. the TPCI.As the increase in the water jet pressure index, the quality of the machining surface also increases, so it is clear that the water pressure of the AWJM should be high enough to get the betters surface finish. On the other side, the cut quality is decreases with increase in the index values. So it is clear that, lower the index value, higher the quality, i.e. the minimization function. For SOD, higher the index value, proportionally higher the output. As the outcome of the PCA, the obtained optimal response values for the considered characteristics such as MRR (to be maximized to increase the production rate), Ra (to be minimized to get better quality surface) and Kerf angle (to be minimized for the better quality machining output) is A3B1C3respectively.

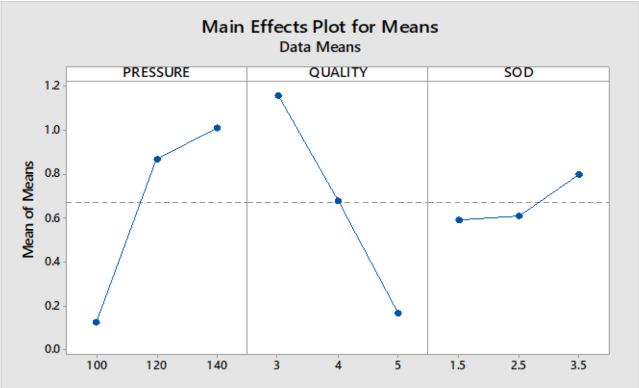

Fig 1: TPCI Vs AWJM process parameters

V. CONCLUSION

In this research, the experimentations have been carried out in the abrasive water jet machining for machining the granite, which is the harder material. In order to identify the optimal input machining parameter for obtaining the best machining surface with higher production rate, in this research, Taguchi multi response method analysis had been used with using principal component technique. Based on the results obtained, analysis of variance, T-test, F-test were also carried out. Also the plots were obtained for the interoperations on the variations and to identify the optimal values for the input process parameters. The following observations were made on AWJM process optimization,

1) In AWJM, Quality of cut and the water jet pressure are found to be the most influencing parameter on Total Principal Component Index optimization. Standoff distance has no much reasonable effect over the TPCI. Hence as the result, the best feasible optimal combination of input machining parameters such as MRR, Ra and KA for machining the granite with the better surface quality is identified as A3B1C3 respectively.
2) In AWJM, MRR proportionally decreases with increase in quality of cut. Since increase in the MRR value in turn increases the transverse feed of the jet, as the transverse feed increase, the surface might have the machining markings and as the result, quality of cut decreases and vice versa. So the optimum value for MRR, Ra and Ka need to be identified and in this research, multi response method have been used to identify the normalized optimal value for those parameters.
3) In order to validate the experimentation, confirmation test have also been carried out for obtained optimum combination of A3B1C3 and the result obtained are found satisfactory and are as desired. The obtained output responses for the identified optimal combination of input machining parameters are given in the Table 7.

Table 7: A3B1C3 **Confirmation test**

	MRR(in g/s)	R_a(in µm)	K_a(in degree)
Initial settings	5.37585	4.711	0.813057
PCA	6.90878	3.888	0.882803

4) It is found that MRR has been improved by 28.52% by PCA. It is also found that SR is reduced by 17.46% by PCA.

REFERENCES

1. Badgujar .P, Rathi .M.G ,Taguchi Method Implementation In Abrasive Water jet Machining Process Optimization International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, June2014, Volume-3, Issue-5,.
2. Chirag M Parmar, Mr. Pratik K Yogi, Mr. Trilok D Parmar, Optimization Of Abrasive Water Jet Machine Process Parameter For Al-6351 Using Taguchi Method International Journal of Advance Engineering and Research Development (IJAERD) May 2014, Volume 1,Issue 5, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406.
3. ChithiraiPonSelvan M and MohanaSundara Raju N, Assessment Of Process Parameters In Abrasive Waterjet Cutting Of Stainless Steel International Journal of Advances in Engineering & Technology July 2011.
4. LeeladharNagdeve, VedanshChaturvedi&JyotiVimal, Parametric Optimization Of Abrasive Water Jet Machining Using Taguchi Methodology International Journal of Research in Engineering & Applied Sciences.
5. Nagdeve, VedanshChaturvedi&JyotiVimal,Implementation Of Taguchi Approach For Optimization Of Abrasive Water Jet Machining Process Parameters LeeladharInternational Journal of Instrumentation, Control and Automation (IJICA) ISSN: 2231-1890, 2012,Vol-1 Iss-3,4.
6. Rajesh Kanna S K, Sethuramalaingam P, Stainless Steel 316 Wire EDM Process Parameter Optimization By Using Taguchi Method, International Journal of Emerging Research in Management and Technology , 2017, vol 6, issue, 2, p.p. 69-73.
7. S K Rajesh Kanna, Optimization Of Machining Parameters To Improve The Surface Finish In The Tialcn Nano-Coated Turning Tool Using Ant Colony Algorithm, International Journal of Advanced Research Management Engineering technology, 2017, Vol. 2, issue 3, p.p. 569-576.
8. Sidda Reddy D, Seshu Kumar A, Sreenivasa Rao M,Parametric Optimization of Abrasive Water Jet Machining of Inconel 800H Using Taguchi Methodology Universal Journal of Mechanical Engineering 2(5): 158-162, 2014.
9. Sreenivasa Rao M, Ravinder S and Seshu Kumar S, Parametric Optimization of Abrasive Waterjet Machining for Mild Steel: Taguchi Approach, International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
10. Vinod B. Patel, Prof. V. A., Patel Parametric Analysis Of Abrasive Water Jet Machining Of En8 Material International Journal of Engineering Research and Applications (IJERA)ISSN: May-June 2012, 2248-9622 Vol. 2, Issue 3, , pp.3029-3032.
11. Zoran Jurkovic, MladenPerinic, Sven Maricic, , Application Of Modelling And Optimization Methods In Abrasive Water Jet Machining Journal of Trends in the Development of Machinery and Associated Technology 2012, Vol. 16, No. 1, ISSN 2303-4009 (online), p.p. 59-62.

AUTHORS PROFILE

Lingaraj N is working as Assistant professor at the Department of Mechanical Engineering at the Rajalakshmi institute of Technology, Chennai from 2015. He completed is masters in Manufacturing Engineering from Madras institute of Technology. He is a member in the professional bodies like Institute of Engineers India, Society of Automotive Engineers. His research areas are Material characterisation, composites and optimization. He presented papers in various international and national conferences.

Dr S.K. Rajesh Kanna is working as professor in Rajalakshmi Institute of Technology, Chennai. He completed his research in Anna University. He published more than 50 papers in various journals. He completed many funding projects. He had published a patent. He has got the best teacher award and best researcher award in the academic year 2018-19.

ILAYAPERUMAL K is working as Associate professor at the Department of Mechanical Engineering at the Rajalakshmi institute of Technology. He completed is masters in Computer Aided Design from Madras University. He has 21 years of teaching experience and pursuing Ph.D in Hindustan Institute of Science and Technology, Chennai.

Sivasankar P is working as Assistant professor at the Department of Mechanical Engineering at the Rajalakshmi institute of Technology, Chennai from 2016. He completed is masters in Manufacturing Engineering. He is a member in the professional bodies like ISTE and Society of Automotive Engineers. His research areas are Bio-medical materials and composites. He presented papers in various international and national conferences.

Akash C is a UG student pursuing Mechanical Engineering at the Rajalakshmi institute of Technology, Chennai.