Optimization of Granite Cutting in Abrasive Water Jet Machining using Taguchi Technique

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Abstract

The paper presents optimization of Granite cutting using Taguchi technique in abrasive water jet machining (AWJM). AWJM is commercially utilized for cutting metals such as steel, brass, bronze, aluminium and non-metals such as plastic, wood. However, very limited study is being done using AWJM in rock industry. The present study aimed to investigate cutting performance of AWJM of granite. The experimental design of L_9 was used for systematic design of experiment. The process parameters considered were travel speed, stand-off distance (SOD), and water pressure and their effect is measured in terms of Material removal rate. Further, analysis of variance (ANOVA) was used to find most effective cutting parameter.

Keywords

Abrasive water jet machining, Material removal rate, Stand-off distance, Granite, ANOVA.

1. Introduction

The use of natural stones such as granite and marble has tremendously increased over the years in whole world. Granite in particular is widely used as building material due to its strength and unique natural patterns with attractive decorative properties. As far as India is concerned, it is one of the largest producers and exporters of granite in the world. At present, India serves a contribution of around 15% of the global production. India has more than 100 varieties of colourful granite produced and explored. At present machining and processing of natural stones are generally carried out by conventional machining processes like diamond multi-wire sawing and blade sawing. With the growing use of natural stones as a construction material, there is an increasing demand on the new machining and processing technologies to improve productivity and reduce costs. As an advance manufacturing technology, a non-conventional technique abrasive water jet machining has been widely used by industries for machining and processing of granite stones. Due to its high advantages such as no thermal damages and highly versatile to cut different materials, small cutting forces it is increasingly accepted by the industries (Aydin et al. 2011). AWJM is an abrasive blasting machining process that uses abrasives propelled by a high velocity water pressure to erode material from the workpiece.

Karakurt et al. (2010) used abrasive water jet machining for studying depth of cut and kerf width in granite cutting by taking into consideration traverse speed, abrasive flow rate, standoff distance, abrasive size and water pressure. They concluded that the traverse speed is the most significant process parameter affecting the cut depth of granite whereas standoff distance and abrasive flow rate are highly effective parameters on kerf width. Riverio et al. (2015) used CO_2 laser using supersonic nozzle for cutting 10 mm Zimbabwe black granite stone. Gupta et al. (2014) studied minimization of kerf taper angle and kerf width using Taguchi's method in abrasive water jet machining of marble and keeping input parameters as water pressure, nozzle traverse speed and abrasive flow rate. They revealed that the nozzle transverse speed was the most significant factor affecting the top kerf width. Abdullah et al. (2016) studied the surface quality of marble machined by abrasive water jet by taking input parameters as standoff distance, nozzle traverse speed, abrasive flow rate and two material types as input. Output parameters considered were surface roughness, surface waviness and kerf taper ratio. Shah and Patel (2012) analysed material removal rate of granite in AWJM by considering hydraulic pressure, standoff distance & traverse speed as input parameters. They concluded that traverse speed is the most significant control factor. Liu and Chen (2004) studied the effect of jet diameter and traverse speed for granite cutting using AWJM. They used acoustic emission signals of the cutting process to analyse surface quality. Padmakar et al. (2017) worked on improving the quality characteristics of abrasive water jet machining of marble material using multi-objective artificial bee colony algorithm for optimizing kerf width, kerf taper, and depth of striation free surface by considering stand of distance, traverse speed, water pressure, and abrasive flow rate as input parameters.

The aim of this research is to provide a systematic and scientific method to the people working in this industry for selecting the best suitable input parameters used for cutting black granite in AWJM. The response under consideration is the material removal rate and control factors consider for optimizing MRR were water pressure, standoff distance and traverse speed.

2. Experimental Study

2.1. Material and Procedure

In this experiments, pre-dimensioned black galaxy granite specimen of 18 mm thickness, 30 mm width cut by a water jet cutter.

Workpiece Material

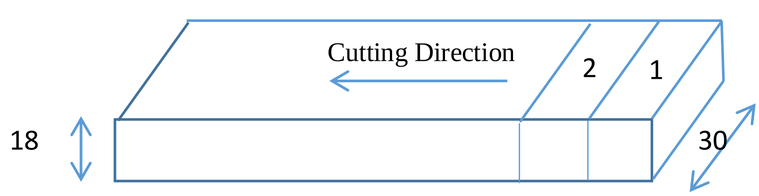

Figure1. A schematic illustration of the granite specimen after cutting.

Black galaxy granite is one of the world's famous granite varieties. It is found in Chimmakurthi village in Ongole district in the State of Andhra Pradesh in India. It is also known as star Galaxy and Ongole Galaxy. It is dark black base granite and contains golden specks on the surface. Its gold specks are due to the presence of ferrous rich enstatine (bronzite). After polishing it appears very shiny and glassy. It is medium hard granite. This variety comes in dark black, dark with a greenish/black tinge, dark with whitish/black background variations. Physical Properties of black galaxy material are as in Table 1.

2.2. Experimental Setup

The experiments were performed using international YONGDA abrasive water jet machine (YP-3020) (as shown in Figure 2) at Malviya Crafts Pvt. Ltd., Mount Abu Road, Rajasthan. It is driven by a tecsis hydraulic pressure system with an operating pressure of upto 380Mpa. The nozzle diameter and length were 0.76 mm and 100 mm respectively. The abrasive size was kept constant at 80 mesh.

Table 1. Physical properties of black galaxy material.

Compressive Strength	2777 Kg/cm^2
Ultimate Tensile Strength	274 Kg/cm^2
Water Absorption	0.04%
Specific Gravity	2.960 Kg/m^3
Coefficient of Thermal expansion	0.0065 mm/m°C
Hardness	6.5 MPa

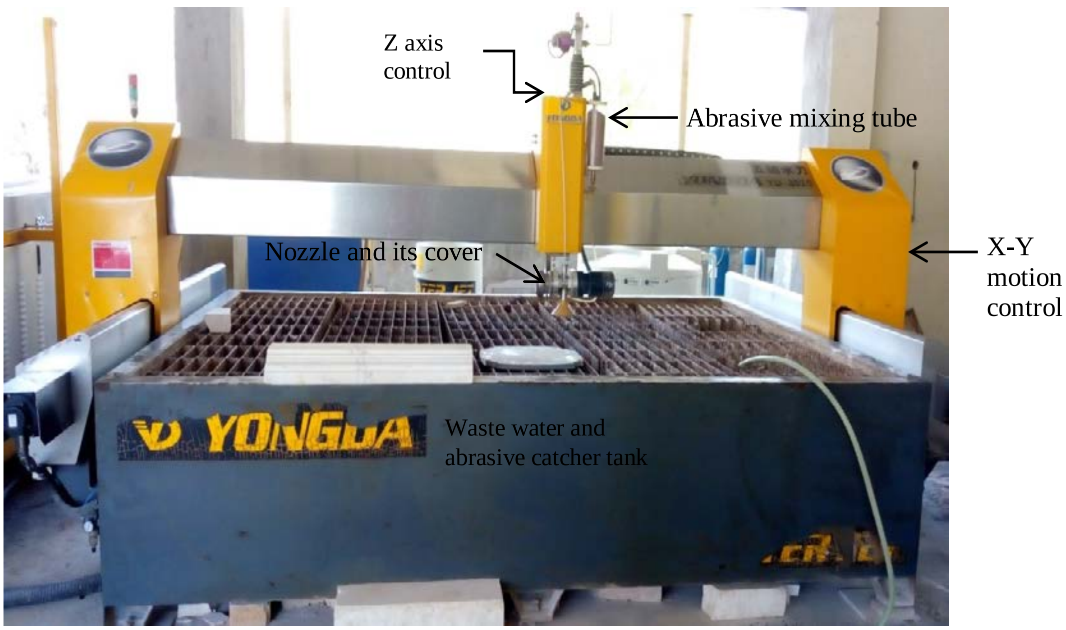

Figure 2. YOGNDA (AWJM) experimental Setup.

The main properties of abrasive water jet machining which kept constant for all the experiments are as given in Table 2.

Table 2. Main properties which kept constant during the abrasive water jet machining.

Machine Model	YONGDA YD- 3020
Orifice Diameter	0.36 mm
Energy Consumption	40 KWH
Water Consumption	3.87 (lt/m)

Nozzle Diameter	0.76 mm
Nozzle Length	100 mm
Abrasive Size	80 mesh
Abrasive Type	Garnet
Carrier Medium	Water
Depth of Cut	18 mm
Length of cut	30mm

2.3. Design of Experiments (DOE)

Design of Experiments is the systematic method which helps in planning the process of the experiments based on the process parameters at different level. It helps to determine relationship between control factors affecting the process and the output of that process. Experimental design using Taguchi's method provides systematic and efficient approach for conducting the experiment. In this work three factors varied at three different levels as shown in Table 3. An L_9 orthogonal array was used to perform the experiments. The response of experiments was measured in terms of time taken to cut the sample and MRR and is as shown in Table 4. The MRR is calculated using equation (1).

$$MRR = \frac{width \times depth \times Dia\ of\ \ Nozzle}{Time\ Taken} \tag{1}$$

Table 3. Process parameters and their levels considered for the experiments.

Process Parameter	Unit	Level 1	Level 2	Level 3
Water Pressure	MPa	200	250	280
Standoff Distance	mm	3	4	5
Traverse Speed	mm/min	50	100	150

Table 4. Results in form of time taken and MRR of the experiments performed

Sr. No.	Water Pressure (MPa)	Traverse Speed (mm/min)	Standoff Distance (mm)	Time Taken (min)	MRR (mm^3/min)
1	200	50	3	0.79	519.49
2	200	100	4	0.36	1140.0

3	200	150	5	0.4	1026.0
4	250	50	4	0.76	540.0
5	250	100	5	0.45	912.0
6	250	150	3	0.35	1172.57
7	280	50	5	0.73	562.19
8	280	100	3	0.42	977.14
9	280	150	4	0.32	1282.5

3. Results and Discussion

3.1. Analysis of Variance

Analysis of variance was used to find the most significant control factors. It is a technique conducted to learn about the impact and influence of various design parameters and identify which are the most significant factors. ANOVA was performed using Minitab 18 software. This analysis was carried out at 95% confidence level. ANOVA results of MRR are as shown in Table 5. The F-value corresponded to a continuous probability distribution. If this probability (Prob > f) value for the considered factor was less than 0.05, this indicated that the control factor was significant (i.e., at a 95% confidence level). If Values of Prob > f higher than 0.05 indicated that a control factor was non-significant. ANOVA analysis revealed that, traverse speed was the most significant control factor affecting the MRR of granite material. The model summery results are as shown in table 6. R^2 of 97.34% and R^2(adj) of 89.35% are indicative of good model fitting for the obtained regression equation of MRR as shown in equation (1).

Table 5. Results of Analysis of Variance (ANOVA) for the MRR.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Water Pressure (MPa)	2	6801	3401	0.37	0.729	Non-significant
Traverse Speed (mm/min)	2	626946	313473	34.20	0.028	Significant
Standoff Distance (mm)	2	36480	18240	1.99	0.334	Non-significant
Error	2	18334	9167			
Total	8	688562				

Table 6. Model Summary

S	R-sq	R-sq(adj)
95.7452	97.34%	89.35%

Regression Equation of MRR:

MRR = 903.5 - 8.4 Water Pressure_200 - 28.7 Water Pressure_250+37.1 Water Pressure_280
- 363.0 Standoff Distance_3 + 106.2 Standoff Distance_4 + 256.8 Standoff Distance_5 - 13.8 Traverse Speed_50
+ 84.0 Traverse Speed_100 - 70.1 Traverse Speed_150

3.2 Finding Optimum Process Parameter Setting

The higher values of S/N ratio for the control factor settings are considered for finding optimized process parameter settings. The higher S/N ratio is indicative of minimization of effects of noise factors. From the Figure 3 which is main effects plot for S/N ratio of MRR, optimum process parameters for cutting granite are water pressure 280 MPa, SOD 5 mm, and traverse speed 100 mm/min. This is also confirmed from the main effects plot for means of MRR as shown in Figure 4.

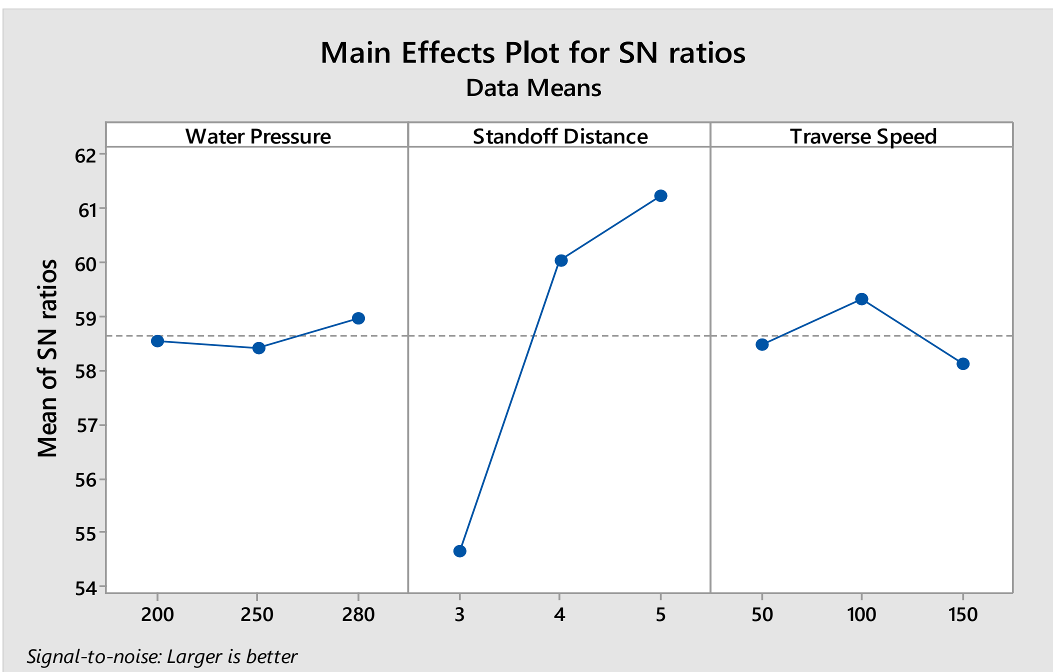

Figure 3: Main effects plot for S/N ratio of MRR

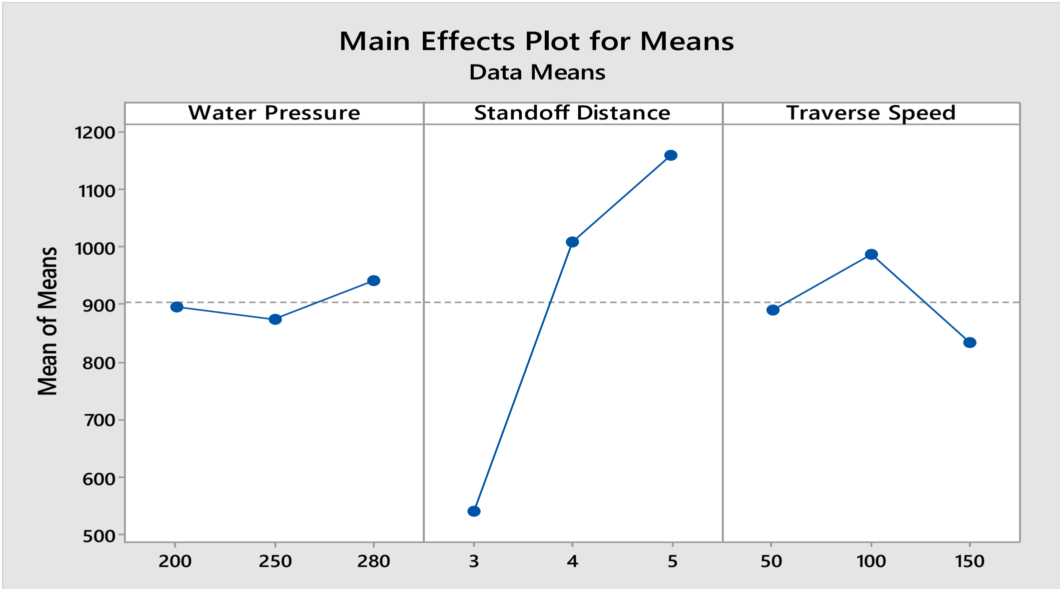

Figure 4: Main effects plot for means of MRR

4. Conclusions

The present work attempted to find optimum process parameters for granite cutting using AWJM method. Taguchi's L9 orthogonal array was used to design the experiments. Following conclusion was withdrawn from the work:

1. ANOVA analysis results revealed that the traverse speed was the most significant process parameter affecting MRR during granite cutting.

2. Further, S/N ratio analysis revealed optimum process parameters as water pressure 280 MPa, SOD 5 mm, and traverse speed 100 mm/min.

5.Acknowledgements

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Biographies

Vaibhav Jain is a student of Industrial Engineering at Pandit Deendayal Petroleum University. He has successfully worked as marketing manager under AIESEC Ahmedabad which is world's largest youth run organisation. He has done technical internships from Pacific Industries Pvt. Ltd. He has also done a Rural Internship & Civic and Social Internship at Bharuch Jilla Yuvak Mandal Sangh.

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