Materials Physics and Mechanics 47 (2021) 830-842
Research article

Received: June 30, 2021
Accepted: November 23, 2021

INVESTIGATION OF THE MACHINING PERFORMANCE OF BASALT FIBER COMPOSITES BY ABRASIVE WATER JET MACHINING

P. Amuthakkannan[1]✉, V. Manikandan[2], M. Uthayakumar[3], K. ArunPrasath[2], S. Sureshkumar[3]

[1]Department of Mechanical Engineering, PSR Engineering College, Sivakasi

[2]Department of Mechanical Engineering, PSN College of Engineering and Technology, Tirunelveli

[3]Department of Mechanical Engineering, Kalasalinagm Academy of Research Education, Krishnankoil

✉ amuthakkannanp@gmail.com

Abstract. The abrasive water jet machining technique is a contemporary approach for cutting the materials without any thermal distortion with small cutting forces. The basalt fiber reinforced polymer composites are material with superior mechanical properties compared to glass fiber composites. The aim of the current study focused on the cutting parameters (travel speed of nozzle, standoff distance, and pressure of water) of abrasive water jet machining (AWJM) for the machining of basalt fiber composites using Grey Relation analysis. The top kerf, bottom kerf, and kerf angle are considered as output parameters and based on the grey relation optimization, the optimum process parameters are water pressure (240 MPa), traverse speed (20 m/s), and standoff distance (1mm). The results revealed that the water pressure is highly influencing machining parameter. When increasing water pressure, the increases of the kerf was observed and Standoff distance increases the delamination of the composites.

Keywords: basalt fiber, polymer composite, AWJM, Grey Relation analysis

Acknowledgements. *No external funding was received for this study.*

Citation: Amuthakkannan P., Arunprasath K., Manikandan V., Sureshkumar M., Sureshkumar S. Investigation of the machining performance of basalt fiber composites by abrasive water jet machining // Materials Physics and Mechanics. 2021, V. 47. N. 6. P. 830-842. DOI: 10.18149/MPM.4762021_3.

1. Introduction

Newer material development is a key factor for manufacturing industries to alter the existing materials thereby increasing the performance of the systems. Composite materials play a major role in automobile, aerospace industries, etc. The machining of composites is an important task for the industries. The non-traditional machining technique is extensively used in many industries for the machining of composites. The researchers are studying the machining of glass fiber composite and polymer-metal laminates composites using abrasive water jet machining. Jagadish and Kapil Gupta [1] studied the abrasive water jet machining of wood dust filler-based reinforced polymer composites with different cutting parameters using Taguchi and MOORA methods. It was concluded that the AWJM is a process for making green machining with high-quality parts and less time. Jun Wang [2] showed that Abrasive

http://dx.doi.org/10.18149/MPM.4762021_3

Water jet cutting is a viable and effective alternative for polymer matrix composite processing with good productivity and kerf quality. Izzet Karakurt et al. [3] studied the effects of the abrasive water jet machining parameters on their kerf angle. Different type of rocks was used and material properties were correlated with kerf angle. It was concluded that the grain size of the rock highly influenced the kerf angles of the rock rested.

Deepak and Ashwin [4] studied the influence of drilling parameters in glass fiber composites through an abrasive water jet. The results revealed that the operating pressure significantly influenced the hole diameter of the composites. Izzet Karakurt et al. [5] studied the kerf angle of granite machined parameters using Taguchi method. The most significant parameters of the study were transverse speed and standoff distance. Jayakumar [6] investigated the machinability of Kenaf/E-glass fibers reinforced hybrid polymer composite through AWJM. The surface roughness has been measured and the optimum value was obtained with water pressure of 255MPa, abrasive flow rate of 0.275Kg/min SOD of 1.9mm, and transverse speed of 0.26mm/min. Deepak et al. [7] investigated that the effect of abrasive water jet machining parameters such as jet operating pressure, feed rate, standoff distance (SOD), and concentration of abrasive on kerf width produced on graphite filled glass fiber reinforced epoxy composite based on the Taguchi L27 orthogonal array. It was found that operating pressure, the SOD, and the feed rate are found to be significantly affecting the top kerf width of the composites.

Syed Altaf et al [8] studied that the machinability of GFRP composite tubes of different fiber orientation angles varies from 300 to 900. They have used different cutting tools namely Carbide (K-20), Cubic Boron Nitride (CBN), and Poly-Crystalline Diamond (PCD), and analyzed that the performances of the cutting tools were evaluated by measuring surface roughness (Ra) and Cutting force (Fz). Chithirai and Mohanasundararaju [9] reviewed the research and development in AWJM. It was concluded that more experimental work is required to fully understand the relationship between the importance of AWJM parameters namely water pressure, nozzle traverse speed, and abrasive mass flow rate. Alberdi et al. [10] studied the behavior of a machinability model in composite materials based on the abrasive water jet machining parameters. It was concluded that the tool selection is a significant one for productivity improvement.

Sreekesh and Govindan [11] reviewed the studies in abrasive water jet machining for machining the composite materials. The machining performance is mainly based on the parameters like traverse speed, hydraulic pressure, abrasive flow rate, standoff distance, and abrasive type, work material. Vishal Gupta et al. [12] investigated kerf characteristics in abrasive water jet machining of marble using Taguchi's design of experiments. It was revealed that the nozzle transverse speed was the most significant factor affecting the top kerf width and the kerf taper angle.

Ahmed A. Hussien et al. [13] investigated the AWJM of CRPF composites with different fiber orientations for their kerf and surface roughness. It was concluded that both output parameters improved by increasing the water pressure and decreasing the cutting rate. Fathi Masoud et al. [14] investigated the input parameters of AWJM of sugar palm fiber composites. The results of the experiments were SOD highly influencing followed by water pressure and a small contribution of traverse speed. Jayprakash Umap et al. [15] studied the AWJM of carbon fiber composites and compared the GRA and Taguchi methods. They concluded that Grey Relational Analysis exhibited a more precise result than the Taguchi method. Adel Abidi et al. [16] investigated the surface roughness and the hole taper of the CFRP composites. The results showed the stand-off distance and the abrasive flow rate were major influencing parameters.

Schwartzentruber [17] examined the parameters that affected piercing operations in borosilicate glass for which stand-off distance (SOD), dwell time and pressure for three nozzles sizes were taken. The experimental results helped to improve the hole circularity. Varun and Nanjundeswaraswamy [20] made a review on the effect of process parameters of AWJM. They concluded that further research is requiredto better understand the machining parameters.

Armagan and Armagan Arici [21] investigated the machining performance of glass fiber reinforced vinyl ester composites. The various AWJ cutting parameters were considered to determine the influence of process parameters like standoff distance, abrasive mass flow rate, traverse speed, pressure, and material thickness. The result obtained based on the optimization of the standoff distance was the most effective parameter. Selvam et al. [22] investigated the performance of abrasive water jet machining of hybrid composites. It was observed that traverse speed, water pressure, and abrasive flow rate are significant parameters for obtaining less surface roughness. Kalirasu et al. [23] studied the AWJM machining performance of jute/polyester composites for various thicknesses. They have implemented the mathematical regression analysis for the study. It was found that these models more suitable for polymer-based composites and limited to 3mm thickness. Fermin Banon et al. [24,26] investigated the carbon fiber thermoplastics composites machining performance in AWJM. The optimized machining parameters were water pressure of 280MPa, an abrasive flow rate of 170g/min and traverse speed of 100mm/min for the smooth and homogeneous surfaces. Vidyapati Kumar et al. [25] investigated the machining characterization of glass fiber composites. It was concluded that the grey-fuzzy method-based approach is an effective method for optimizing the mixed parameters. Based on the literature, it was found that the machining characteristics of the basalt fiber reinforced polymer composites are not available. Hence the machining performance of the basalt fiber composite using abrasive water jet machining was studied.

2. Experimental details

Materials used. Basalt fiber was imported from by ASA.TECH, Austria, and Unsaturated polyester resin, methyl ethyl ketone peroxide (MEKP), and co-naphthenate were purchased from GVR traders, Madurai, India. The properties of the basalt fiber are presentedin Table 1.

Table 1. Properties of basalt fiber

Moisture content (%)	0.15
Density at room temperature (g/cm 3)	2.64
Diameter of fiber (mm)	0.0166
Mean breaking strength (G)	1644.4
Mean elongation (%)	1.15

Fabrication of composites. Basalt fiber reinforced polymer matrix composites were fabricated using the hand layup techniques and the unsaturated polyester resin was used as a matrix. Cobalt naphthenate and methyl ethyl ketone peroxide were used as an accelerator and a catalyst for the curing process of the composites. The twelve layers of basalt fiber mat were used. The equal weighted (1:1) fiber and matrix were taken. The polyester resin was cured by incorporating one weight percent of the catalyst and an accelerator was added. A hand stirrer was used to homogenize the mixture of the matrix. Then, the resin mixture was used to fabricate the composites. The samples were cured for approximately 24 hours at room temperature. Figure 1 shows the fabricated composite specimen after machining.

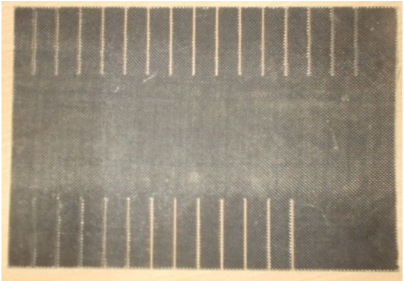

Fig. 1. Fabricated composite after machining

Machining of composites. The machining (cutting) of basalt fiber composites was carried out by DWJ1313-FB water jet cutter equipped with DIPS6-2230 ultrahigh-pressure pump. The thickness of the specimen used for machining operation was 3mm. The impact angle of the water jet is 90° to the surface of the specimen and the diameter of the nozzle is 0.7 mm. The abrasive particle used for this machining was Garnet with a particle size of 80 meshes. The mass flow rate of the abrasive particle was 47.23 gm/min. The typical setup of the abrasive water jet machine is shown in Fig. 2. Table 2 shows the operating variables used for machining.

Fig. 2. Abrasive water jet machining setup

Table 2. Operating variables

Variable	Level 1	Level 2	Level 3
Pressure (MPa)	240	260	280
Travel speed (mm/min.)	20	30	40
Standoff distance (mm)	1	2	3

Measurement of Delamination and kerf. The machined composite delamination and kerf were measured by Trinocular Optical Microscope. Figures 3 and 4 showthe optical microscope and delamination measurements respectively.

Fig. 3. Optical Microscope

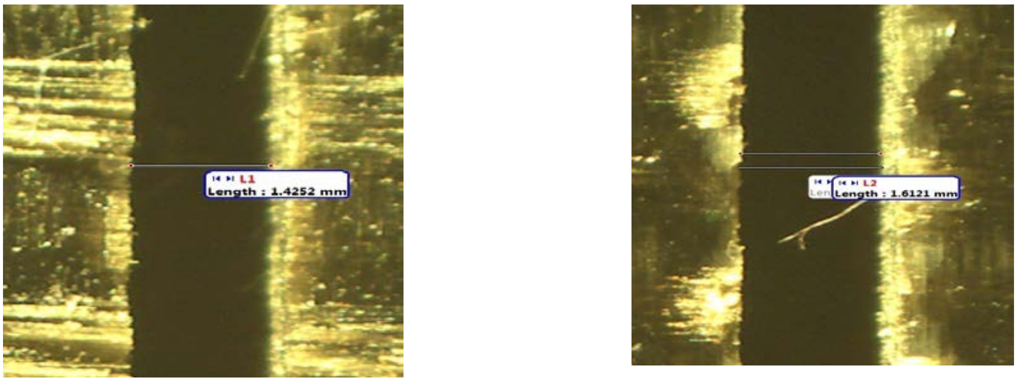

Fig. 4. Measurements of delamination and kerf

Grey Relational Analysis (GRA). The grey relational analysis is a multi-objective optimization technique used to determine the optimum combination of the input parameters and also to determine the influence of each machining parameter on the machining characteristics. The steps of the GRA are presented below.

Step 1: S/N Ratio Calculation

The machining characteristics such as top kerf, bottom kerf, and delamination are to be minimized, and hence, the smaller-the-better characteristic is selected for the analysis. The signal-to-noise ratio (S/N ratio) can be determined using equation 1. This is suitable for a problem where minimization of the response characteristics is anticipated.

$$\frac{s}{n}\ ratio = -10\ log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n} y_{ij}^{2}\ , \qquad (1)$$

where n – number of replications; y_{ij} – observed response, i = 1, 2… n; j =1, 2... k.

Step 2: Normalization

It is necessary to normalize the S/N ratio values before analyzing them using the grey relation concept [14]. Here normalization is done for the experimental result of the responses and rated between 0 and 1. The normalization of the result is determined using equation 2.

$$z_{ij} = \frac{\max(y_{ij,}\ i=1,2\ldots n) - y_{ij}}{\max(y_{ij},\ i=1,2\ldots n) - \min(y_{ij}, i=1,2..n)}\ , \qquad (2)$$

where y_{ij} is the j^{th} performance characteristic in the i^{th} experiment, and max y_{ij} and min y_{ij} are the maximum and minimum values of the j^{th} performance characteristic for an alternative i^{th} experiment.

Step 3: Grey relational coefficient

The Grey Relational Coefficient (GRC) for the response characteristics from the normalized values can be calculated using equation 3.

$$\gamma\left(y_o(k), y_i(k)\right) = \frac{\Delta min + \xi \Delta max}{\Delta_{oj}(k) + \xi \Delta max}\ , \qquad (3)$$

where:

i. j = 1, 2… n; k = 1, 2… m, n is the number of experimental data items and m is the number of responses.

ii. $y_o(k)$ is the reference sequence $y_o(k)$ = 1, k = 1, 2… m); $y_i(k)$ is the specific comparison sequence.

iii. $\Delta_{oj}= \|y_0(k) - y_j(k)\|$ – the absolute value of the difference between $y_0(k)$ and $y_j(k)$.

iv. $\Delta min = min \|y_0(k) - y_j(k)\|$ is the smallest value of $y_j(k)$.

v. $\Delta max = max \|y_0(k) - y_j(k)\|$ is the largest value of $y_j(k)$.

vi. ξ is the distinguishing coefficient, which is defined in the range $0 \le \xi \le 1$.

Step 4: Grey Relational Grade

The Grey Relational Grade (GRG) for the combined objectives of the responses can be calculated from the GRC for all the output responses and it is ranked in the order. The evaluation of the performance characteristics is based on GRG and it is determined using equation 4.

$$\delta_j = \frac{1}{k}\sum_{i=1}^{m} y_{ij} \qquad (4)$$

where δ_j is the grey relational grade for the j^{th} experiment and k is the number of performance characteristics.

Implementation of GRA. The signal-to-noise ratio (S/N ratio) was determined for all the individual responses by considering smaller-the-better characteristics. Further, the normalization was also done to rate the values of each response between 0 and 1. Finally, the Grey Relational Coefficient (GRC) was calculated by assuming the coefficient constant as ξ = 0.5. Table 3 shows the grey relational grade determined from the GRC value. Figure 5 shows the variation of grey relational grade with an experimental run.

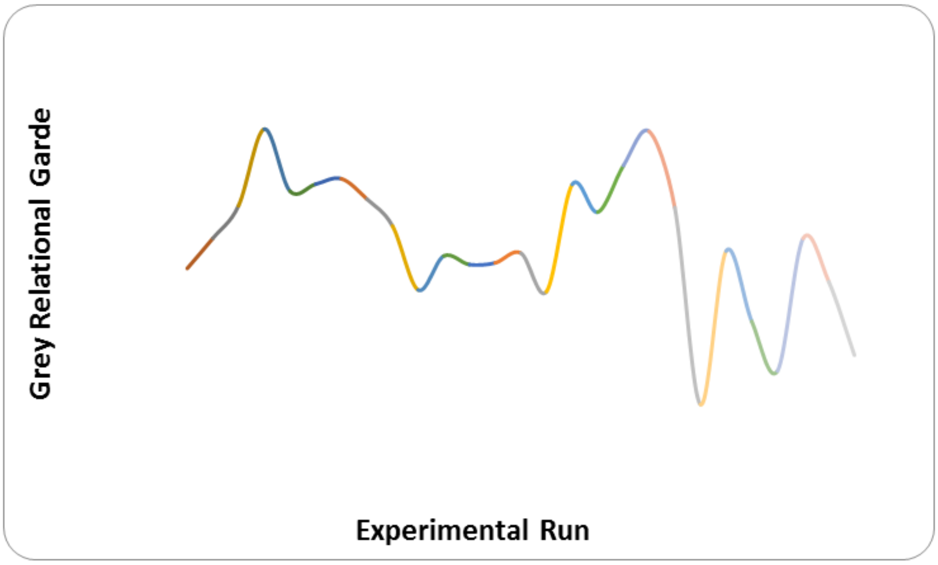

Fig. 5. Experimental Run vs. Grey Relational Grade

3. Result and discussion

The machining of polymer composites was done using abrasive water jet machining and the influencing parameters such as water pressure, SOD, and travel speed of nozzle are studied. In this study, the same parameters are considered for machining the basalt fiber reinforced polymer composites using AWJM. Initially, GRA was used for optimizing the parameters based on the L_{27} array. The experimental data are presented in Table 3. The Grey Relational analysis was used to analyze the parameters considering the output parameters of top kerf, bottom kerf, and delamination.

Table 3. Response table for Grey Relational Grade

SI NO	Pressure	Travel speed	SOD	Top kerf	Bottom kerf	Delamination	Grey Relational Grade
1	240	20	1	1.4836	1.5304	0.7836	0.6043
2	240	20	2	1.472	1.472	0.772	0.6644
3	240	20	3	1.4136	1.507	0.7136	0.7293
4	240	30	1	1.3902	1.4136	0.6902	0.8821
5	240	30	2	1.4136	1.472	0.7136	0.7586
6	240	30	3	1.4019	1.4836	0.7019	0.7722
7	240	40	1	1.4136	1.4486	0.7136	0.7833
8	240	40	2	1.4836	1.4019	0.7836	0.7427
9	240	40	3	1.472	1.4486	0.772	0.6891
10	260	20	1	1.5304	1.5187	0.8304	0.5615
11	260	20	2	1.4836	1.4953	0.7836	0.6293
12	260	20	3	1.4836	1.5187	0.7836	0.6120
13	260	30	1	1.4953	1.4953	0.7953	0.6154
14	260	30	2	1.472	1.507	0.772	0.6351
15	260	30	3	1.5187	1.5421	0.8187	0.5582
16	260	40	1	1.3902	1.5187	0.6902	0.7716
17	260	40	2	1.4369	1.472	0.7369	0.7165
18	260	40	3	1.3902	1.472	0.6902	0.8093
19	280	20	1	1.3551	1.5071	0.6551	0.8775
20	280	20	2	1.4252	1.4836	0.7252	0.7261
21	280	20	3	1.764	1.764	1.064	0.3333
22	280	30	1	1.4836	1.4837	0.7836	0.6390
23	280	30	2	1.5888	1.5421	0.8888	0.4989
24	280	30	3	1.7056	1.6121	1.0056	0.3999
25	280	40	1	1.4369	1.5421	0.7369	0.6640
26	280	40	2	1.5421	1.4836	0.8421	0.5779
27	280	40	3	1.6822	1.5655	0.9822	0.4315

From the above calculation of grey relational grade, it was found that the water pressure (MPa) is 240, Traverse speed (m/s) is 20 and Standoff distance (mm) have the highest value of 0.8821 and next to this, the water pressure (MPa) is 280, Traverse speed (m/s) is 20 and Standoff distance (mm) is 1 was found to be higher.

The response of each level of the three parameters is calculated and presented in Table 4. It reveals that the optimum combinations of process parameters for minimizing the combined objectives are water pressure, traverse speed, and standoff distance are 280 MPa, 30 mm/min, and 3 mm respectively.

Table 4. Calculation of response value

Factors	Level 1	Level 2	Level 3	MAX-MIN
Pressure	0.7362	06565	0.5720	0.1642
Traverse speed	0.6375	06399	0.6873	0.0498
SOD	0.7109	0.6610	0.5927	0.1182
Error	0.6456	0.6762	0.6429	0.0333

Analysis of Variance (ANOVA) is a statistical tool applied to determine the influence of each parameter on the combined responses. A single objective method cannot be used to find the contribution of input parameters and hence, the ANOVA is applied to identify the contribution of each input on the combined objectives which is shown in Table 5.

Table 5. Calculation of ANOVA value

Design Parameters	Degree of freedom	Sum of Square (SS)	Mean Square	Contribution (Q) (%)	F-Value
Water Pressure	2	0.0404	0.0202	59.23	202
Traverse speed	2	0.0047	0.00235	6.89	23.5
SOD	2	0.0211	0.01055	30.93	105.5
Error	20	0.0020	0.0001	2.93	
Total	26	0.0682	-	-	-

Analysis of Variance (ANOVA). The Analysis of variance used to investigate the design parameters significantly affects the machinability of composites. From Table 5 we predict that the contribution of each parameter like pressure, traverse speed, and standoff distance are 59.23%, 6.89%, and 30.93% respectively. And also, the contribution of error is 2.93% [14]. It is a very much low value when compared to the other three parameters. And also, we considered the F-value as 90%. The F-test was calculated at 95% confidence level. It is understood that all the F-test values are greater than $F_{0.05,\,2,\,26}$ = 3.37 which represents the statistical and physical influence of all the three process parameters affecting the response characteristics simultaneously.

4. Effect of process parameters on delamination

Effect of water pressure on delamination. The effect of water pressure on the delamination of composites is presented in Fig. 6. The percentage of contribution of water pressure is 59.23% which has maximum significant parameters based on the GRA. At SOD of 1 mm as the water pressure increases the delamination also increases. But at the travel speed of 20 mm/min, the delamination increased due to the number of abrasive particle participation to cut the composites. In all the cases the water pressure increases the delamination which also increased due to the higher pressure that produced higher kinetic energy impact onto the material and hence higher delamination of the materials [18].

At SOD of 2 mm, the same results have arrived similar to SOD of 1 mm which is presented in Fig. 6(i). When increasing pressure, the delamination was increased for the travel speed of 30 mm/min and 40 mm/min. But for the 20 mm/min the delamination of the composites decreased due to the slow speed of the nozzle even though the increase in standoff distance [14].

For the standoff distance of 3mm, the water pressure increases the delamination and also increased for all the cases. This was consistent with the earlier finding of Wang, Jun [2]. The increase of delamination may be due to the increasing standoff distance. When increasing the SOD, there is an expansion of the water which hits more surfaces of the composites.

Effect of SOD on delamination. The effect of delamination on SOD is presented in Fig. 7. At a travel speed of 20 mm/min, with an increase in standoff distance, there are no appreciable changes in the delamination of the composites. For water pressure of 240 MPa and 260 MPa, there was so much difference in delamination, which means that at lower water pressure the delamination is not much affected. It is due to the higher kinetic energy of the water [19]. But at 280 MPa with increases the SOD, the delamination also increased due to the downstream of the water jet. It starts to diverge losing its coherence [18]. At the travel speed of 30 mm/min, the same trends were observed. With an increase in the SOD the delamination is not much affected for 240 MPa and 260 MPa water pressure. For 280 MPa water pressure delamination is increased with an increase in the SOD. For a travel speed of 40 mm/min, an increase in the SOD delamination also increased for 240 MPa and 260 MPa of water pressure. But SOD at 3 mm decreased compared to 2 mm. with increases in SOD, the delamination also increased due to higher water pressure [14].

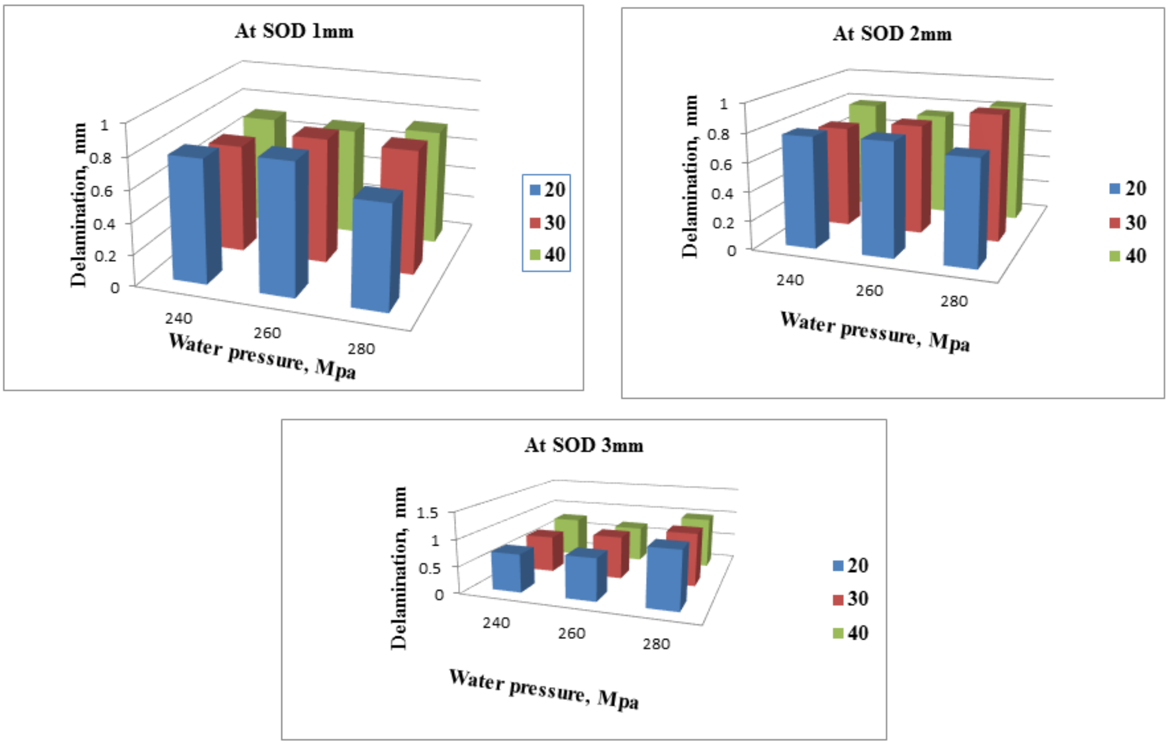

Fig. 6. Delamination of basalt fiber composites at SOD i) 1mm ii) 2mm and iii) 3mm

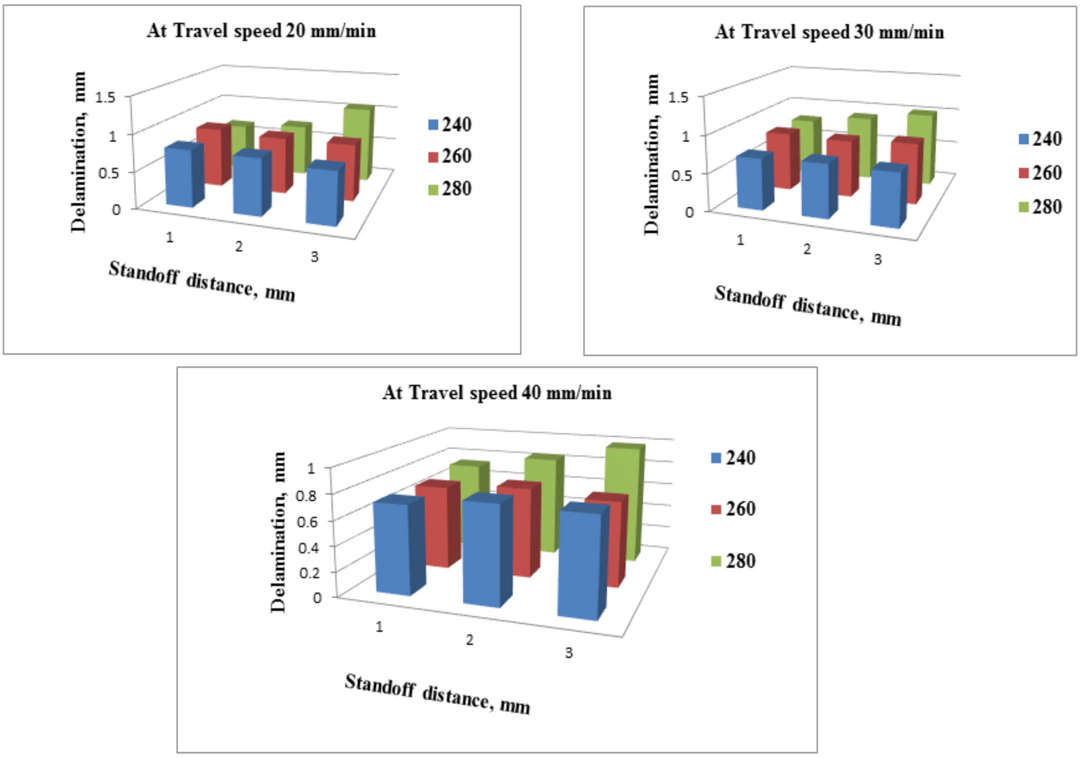

Fig. 7. Delamination of basalt fiber composites at Travel speed (i) 20 mm/min (ii) 30 mm/min and (iii) 40 mm/min

Effect of travel speed on delamination. The effect of travel speed on delamination is presented in Fig. 8. The travel speed of the nozzle is varied from 20 mm/min to 40 mm/min to cut the basalt fiber-reinforced composites. When increasing the travel speed the contact time and a number of abrasive particles hitting the work material are less. At higher travel speed the delamination would be less. By changing the travel speed of the nozzle for the 1 mm SOD, the delamination decreased due to the minimum value of SOD immediately cutting the specimen [14]. For the SOD 2 mm also, the same trend was observed. For SOD 3 mm with increases the travel speed, the delamination was increased because of the water losing its coherence. At 260 MPa water pressure, with increases in the travel speed, the delamination also decreased. Decreasing of the delamination was due to fast-moving nozzle reducing the number of abrasive particles hitting the surface was less. A decrease in travel speed increased the production but achieved the minimum delamination [19]. At 280 MPa water pressure, there is a uniform trend observed. When increasing the travel speed the delamination also increased similarly by increasing the SOD delamination also increased [22]. This was due to the divergence of the water pressure. But for the SOD 3 mm, there is not much difference in delamination. This was due to the higher water pressure (280MPa) and maximum SOD (3mm) which produced less impact on abrasive particles and diverged water flow.

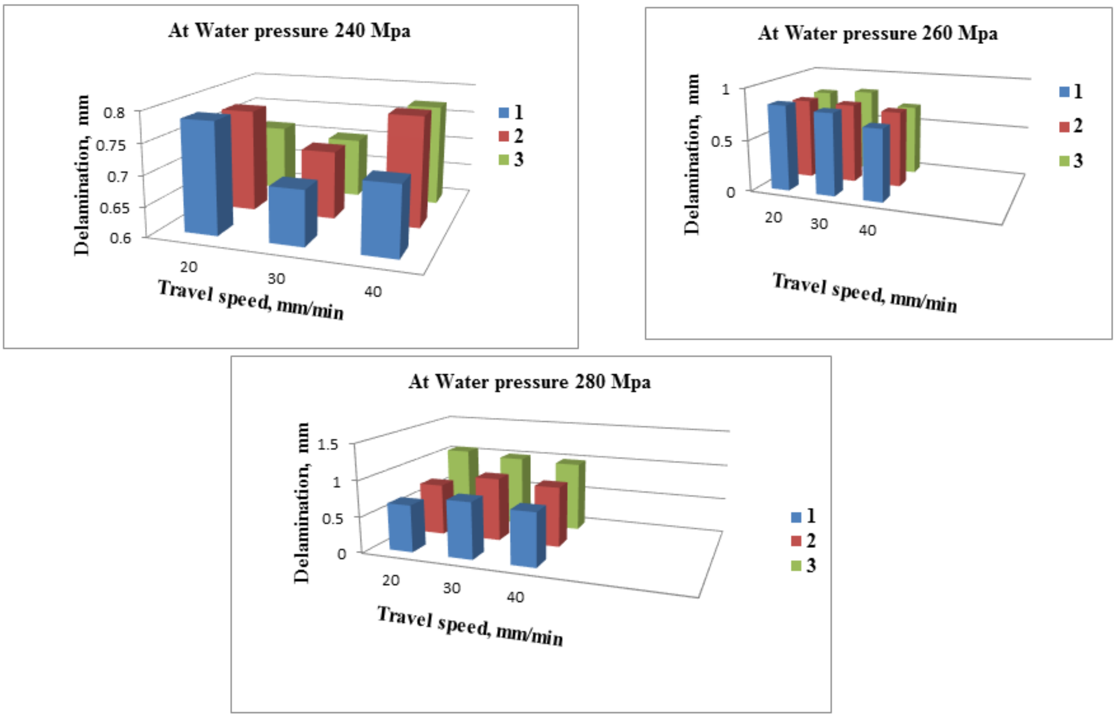

Fig. 8. Delamination of basalt fiber composites at Water pressure (i) 240 Mpa (ii) 260 MPa and (iii) 280 MPa

5. Conclusion

The investigation on the machining parameters of abrasive water jet cutting of basalt fiber polymer composite has been presented using GRA techniques. The following conclusions were drawn,

- Based on optimization techniques, the significant process parameters are water pressure (contribution: 59.23%), SOD (contribution: 30.93%), and travel speed (contribution: 6.89%).
- It was observed that the water pressure is the significant parameter; at higher pressure, the delamination and kerf also increased.

- SOD is mainly involved in the machining performance of the composites, when increasing the SOD, increasing the delamination and kerf were observed.
- The travel speed of the nozzle did not significantly affect the machining of the composites.

References

[1] Jagadish and Kapil Gupta. Abrasive Water Jet Machining of Polymer Composites. *Springer Briefs in Applied Sciences and Technology*. 2019: 33-49.

[2] Jun Wang. A machinability study of polymer matrix composites using abrasive water jet cutting technology. *Journal of Materials Processing Technology.* 1999;94(1): 30-35.

[3] Izzet Karakurt, GokhanAydin and KerimAydiner. A study on the prediction of kerf angle in abrasive waterjet machining of rocks. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture.* 2012;226(9): 1489-1499.

[4] Deepak D and Ashwin Pai K. Study on abrasive water jet drilling for graphite filled glass/epoxy laminates. *Journal of mechanical engineering and sciences*. 2019;13(2): 5126-5136.

[5] Izzetkaracurt, GokhanAydin and Kerim Aydiner. Analysis of kerf angle of the granite machined by abrasive water jet. *Indian journal of engineering and materials sciences.* 2011;18(6): 435-445.

[6] Jayakumar K. Abrasive Water Jet Machining Studies on Kenaf/E-Glass Fiber Polymer Composite. *Proceeding of 10th International conference on Precision, meso, micro and nano engineering (COPEN 10)*. 2017: 396-399.

[7] Deepak Doreswamy, Basavanna Shivamurthy, Devineni Anjaiah, and N. Yagnesh Sharma. An Investigation of Abrasive Water Jet Machining on Graphite/Glass/Epoxy Composite. *International Journal of Manufacturing Engineering.* 2015;2015: 627218.

[8] Syed Altaf Hussain, V. Pandurangadu, K. Palani Kumar. Machinability of glass fiber reinforced plastic (GFRP) composite materials. *International Journal of Engineering, Science and Technology.* 2011;3(4): 103-118.

[9] Chithiraiponselvan. M and Mohanasundararaju. N. Review of the current state of research and development in Abrasive cutting technology. *International Journal of Advanced Engineering Sciences and Technologies.* 2011;11(2): 267-275.

[10] Alberdi A, Suárez A, Artaza T, Escobar-Palafox GA, Ridgway K. Composite cutting with Abrasive Water Jet. *Proceedings of the 5th Manufacturing Engineering Society International Conference*, Zaragoza, 2013.

[11] Sreekesh. K and Govindan P. A review on abrasive water jet cutting. *International Journal of Recent advances in mechanical engineering.* 2014;3(3): 153-158.

[12] Gupta Vishal, Pandey PM, Garg MP, Khanna Rajesh, Batra NK. Minimization of kerf taper angle and kerf width using Taguchi's method in abrasive water jet machining of marble. *Procedia Materials Science.* 2014;6: 140-149.

[13] Hussien Ahmed A, Qasem Isam, Kataraki Pramodkumar S, Al-Kouz Wael, Janvekar Ayub Ahmed. Studying the Performance of Cutting Carbon Fibre-Reinforced Plastic Using an Abrasive Water Jet Technique. *Journal of Mechanical Engineering*. 2021;67(4): 135-141.

[14] Fathi Masoud, Sapuan SM, Mohd Khairol Anuar Mohd Ariffin, Nukman Y and Emin Bayraktar. Experimental Analysis of Kerf Taper Angle in Cutting Process of Sugar Palm Fiber Reinforced Unsaturated Polyester Composites with Laser Beam and Abrasive Water Jet Cutting Technologies. *Polymers.* 2021;13: 2543.

[15] Jayprakash Umap, Shantanu Shelke, Satyam Tripathi, Omkar Karande, Abhimanyu Chandgude. Manufacturing and Optimization of Process Parameters by using Abrasive Water Jet Machining of Carbon Fibre Reinforced Polymer Composites. *International Journal of Recent Technology and Engineering*. 2020;9(2): 955-961.

[16] Adel ABIDI, Sahbi Ben SALEM, Mohamed Athman Yallese. Experimental and Analysis in Abrasive Water jet cutting of carbon fiber reinforced plastics. *Conference: 24ème Congrès Français de Mécanique Brest*, 2019.
[17] Schwartzentruber J and Papini M. Abrasive water jet micro-piercing of borosilicate glass. *Journal of Materials Processing Technology*. 2015;219: 143-154.
[18] Rajesh S, Manivannan J, Chokkalingam R. Machinability Examination on Nylon-6 GFRP Composite with Abrasive Water Jet Machining. *International Journal of Innovative Technology and Exploring Engineering*. 2019;9(2): 346-349.
[19] Premkumar T, Siva I, Sandro C Amico. Abrasive Jet Machining Performance of Vegetable Fiber Polyester Composite and its Modelling. *International Journal of Recent Technology and Engineering*. 2019;8(4): 260-263.
[20] Varun R and Nanjundeswaraswamy TS. A Literature Review on Parameters Influencing Abrasive Jet Machining and Abrasive Water Jet Machining. *Journal of Engineering Research and Application.* 2019;9(1): 24-29.
[21] Mustafa Armagan and Armagan Arici. Cutting performance of glass-vinyl ester composite by abrasive water jet. *Materials and manufacturing processes.* 2016;32(17): 1715-1722.
[22] Selvam R, Karunamoorthy L and Arunkumar N. Investigation on performance of abrasive water jet in machining hybrid composites. *Materials and Manufacturing Processes*. 2016;32(6): 700-706.
[23] Kalirasu SN, Rajini N, Rajesh S, Winowlin Jappes JT and Karuppasamy K. AWJM Performance of jute/polyester composite using MOORA and analytical models. *Materials and Manufacturing Processes.* 2017;32(15): 1730-1739.
[24] Fermin Bañon, Alejandro Sambruno, Moises Batista, Bartolome Simonet & Jorge Salguero. Study of the surface quality of carbon fiber–reinforced thermoplastic matrix composite (CFRTP) machined by abrasive water jet (AWJM). *The International Journal of Advanced Manufacturing Technology*. 2020;107: 3299-3313.
[25] Vidyapati Kumar, Partha Protim Das and Shankar Chakraborty. Grey-fuzzy method-based parametric analysis of abrasive water jet machining on GFRP composites. *Sadhana*. 2020;45: 106.
[26] Pedro F, Mayuet Ares, Franck Girot Mata, Moisés Batista Ponce, and Jorge Salguero Gómez. Defect Analysis and Detection of Cutting Regions in CFRP Machining Using AWJM. *Materials.* 2019;12(24): 4055.

THE AUTHORS

Amuthakkannan P.
e-mail: amuthakkannanp@gmail.com
ORCID: 0000-0001-8329-2341

Arunprasath K.
e-mail: aruncmr12@gmail.com
ORCID: 0000-0002-9078-3808

Manikandan V.
e-mail: vaimanikandan@yahoo.com
ORCID: 0000-0002-8822-7511

Uthayakumar M.
e-mail: uthaykumar@gmail.com
ORCID: 0000-0002-7943-1190

Sureshkumar S.
e-mail: sureshme48@gmail.com
ORCID: 0000-0002-9789-3049