MATERIALE PLASTICE
https://revmaterialeplastice.ro
https://doi.org/10.37358/Mat.Plast.1964

Effect of Abrasive Water Jet Parameters on the Drilling of Aluminum Foam Sandwiched with Glass Fiber Polymer Composites

MADHAN KUMAR SUBRAMANI[1, 2], SIVAKUMAR KRISHNAMURTHY[3], CHANDRADASS JEYASEELAN[4]

[1]Department of Mechanical Engineering, Faculty of Engineering and Technology, Annamalai University, Annamalai Nagar, Tamilnadu, India
[2]Department of Automobile Engineering, SRM Institute of Science and Technology - Kattankulathur Chengalpattu District, Tamil Nadu, India, 603203
[3]Department of Mechanical Engineering, Faculty of Engineering and Technology, Annamalai University, Annamalai Nagar, Tamilnadu, India, 608002
[4]Department of Automobile Engineering, SRM Institute of Science and Technology - Kattankulathur Chengalpattu District, Tamil Nadu, India, 603203

Abstract: *To attain good geometric shape and size, machining of high-strength metal Fiber laminate becomes inevitable in the field of automotive industries. In this research, aluminum foam sandwiched with glass fiber reinforced polymer (GFRP) composites fabricated using a hand layup process. The glass Fiber composite was fabricated using aluminum foam with a thickness of 1 mm. The effect of abrasive water jet parameters such as pressure (P), stand-off distance (L), and nozzle diameter (D) on material removal rate (MRR) and Kerf angle (Ka) and Surface roughness were investigated. The results were compared without aluminum foam composites. Glass fiber composites with aluminum foam reduced the kerf angle by 44.18 %, and surface roughness (Ra) by 41.77 % as compared with glass fiber composites without aluminum foam. From the investigation, it was noticed that maximum pressure (220 Bar) and minimum stand-off distance (1mm) were optimum parameters for reducing the kerf angle and surface roughness. Also, Optical images of the hole were analyzed for surface quality.*

Keywords*: Glass fiber, Aluminum foam, AWJ, MRR, Kerf angle, Surface roughness (Ra)*

1.Introduction

Metal Fiber Laminate (MFL) is one of the functional structural materials made of skin metal thin sheets with internal arrangements of fiber stacking. MFL displays the special features of both metal and polymer-infused fiber, which include high impact absorption, superior wear resistance, and fatigue resistance [1]. MFLs have attracted many advanced industrial components, including aircraft structures, automobile frames, and ship hull structures. High-strength aluminum layers and prepreg layers comprised of glass fiber and epoxy are alternated in glass metal fiber laminates. The epoxy resin acts as the adhesive between the aluminum and the fiber layers [2]. Fiber-reinforced composite material combines the benefits of both metal and fiber [3]. MFL is frequently used in aerospace applications to reduce weight while it has superior physical and mechanical properties of monolithic metal structures [4].

Machining metal Fiber laminates without damage is relatively tough using conventional machining systems due to their intrinsic anisotropy, heterogeneity, and temperature sensitivity. Abrasive Water Jet Machining (AWJM) is a known versatile technique to address the machining of Fiber-reinforced polymer (FRP). Holes made on composite with minimal damage [5]. However, kerf taper and dela-mination are the significant damages usually recorded in AWJM. The present work aims to minimize the above-said damages by applying a hybrid grey relational analysis (GRA)-principal component analysis (PCA) mathematical model [6].

**email: madhanks@srmist.edu.in*

Composite materials are difficult to machine because their manufacturing process differs significantly from metals [7]. The cohesive zone must be alternately faced with reinforcement of hard Fiber in the soft matrix during the operation of the conventional cutting tool used in Fiber composite machining [8]. Surface integrity defects, such as surface roughness, subsurface degradation, and plague, are observed in traditional machining Fiber composites [9]. An attempt was made to avoid the limitations of conventional machining by using abrasive water jet machining to trim the Fiber composite [10]. Abrasive water jet machining is a low-energy, safe, and ecologically friendly technology. Using erodent, the water jet cutting method is used to cut problematic materials such as hard metals, non-ferrous metallic alloys, thin sheets, foils, and wood, as well as honeycomb, plastics, and leather materials [11]. Cutting using an abrasive water jet is ten times faster than cutting with any other traditional approach [12].

Traditional machining causes plastic deformation and chip development, which is eliminated with abrasive water jet machining [13]. When a water jet is utilized on the workpiece's surface, surface flaws such as heat-impacted zones are significantly reduced [14]. Researchers evaluated the machinability of jute/polyester composites with various laminate thicknesses using the abrasive water jet machining process. Hydraulic pressure, feed rate, and standoff distance were all considered while analyzing the quality of the machining process [15]. With the help of Taguchi and ANOVA, the process parameters of water jet machining for the Kevlar Composite and the hybridized Kevlar-Jute fibre Reinforced Epoxy Composite were examined [16]. The abrasive water jet cutting capabilities of produced composite laminates are being investigated concerning nano clay addition, traversal speed, jet pressure, and standoff distance. The ideal abrasive water jet cutting parameters with 1.2 weight % nano clay addition were 316.24 MPa water jet pressure, 2mm standoff distance, and 304.24 mm/s traverse speed [17]. A hybrid composite with and without seaweed fillers was developed using jute and multi-walled nanotubes for machining investigations in this study. According to the research report, abrasive water jet machining is used to manufacture hybrid metal composites, but just a few studies have looked at hybrid fibre composites. The proposed concept's surface characterization study is not available in quantum for studies [18, 19].

The previous work showed that abrasive water jets were utilized for machining synthetic and natural fiber-reinforced polymer composites. Abrasive water jet machining of metal Fiber laminates is scanty. Hence in this work, aluminum foam sandwiched with glass Fiber composites are cut by abrasive water jet machining. Holes were made on GF/Al Foam /GF stack using AWJM. Glass fiber-reinforced polymer composite (GFRP) with and without aluminium foam was used to fabricate the panels in this work. In this work, the effect of aluminium foam thickness on material removal rate, kerf angle and delamination factor were investigated.

2. Materials and methods

2.1. Materials

Glass fibers reinforced polymer composites with and without Aluminium foam were used to fabricate the sandwich panel in this work. In the case of Aluminium foam its thickness was 1 mm. The total thickness of GFRP layers was 3.2mm. A closed-cell aluminium foam material is selected as a core material between glass fibers. S-Glass fiber, Epoxy resin (LY556), and Hardener (HY951) used for this investigation were purchased from Hayal Aerospace Ltd, Chennai. The thickness of the foam panels (purchased from Nanochemazone Inc) used for this investigation is 1 mm, with a glass fiber skin produced during the manufacturing process. In this work, aluminium foam specimens were cut from large panels and used as a sandwich between glass fiber skins. In order to make aluminium foam sandwich samples, epoxy resin was used as an adhesive agent [20]. A hand layup process was used for fabricating the composite samples. Figure 1 shows the fabricated aluminium foam-reinforced GFRP composites of thickness 3.2 mm. Three layers of glass fiber were used to obtain the thickness of 2.2mm. In between the layers of glass fiber, the aluminium foam was inserted with a thickness of 1 mm for fabricating the composite panels with the size of (300 X 300 X 3.2 mm^3). Twenty-seven samples were machined using abrasive jet machining.

Figure 1. Fabricated glass fibre reinforced aluminium foam epoxy composites

2.2. Recognizing the significant abrasive water jet parameters

From the previous research and the investigational works done, the principal abrasive water jet parameters that influence MRR and kerf study have been identified. The study's findings indicated pressure (P), stand-off distance (L), and nozzle diameter (D) as the three main abrasive water jet factors. Abrasive water jet machining is carried out in the fabricated glass Fiber aluminium foam composites. Garnet abrasive particle is used for machining the fabricated composite. The important process parameter influence on the material removal rate and kerf angle were identified based on the experimental work done earlier [21, 22].

2.3. Abrasive water jet machining of aluminum foam sandwiched with glass fiber reinforced composites

Aluminum foam with sandwiched glass Fiber composites was used for experimentation with abrasive water jet machining conditions at different levels of process parameters and according to a central composite design (CCD). A central composite design (CCD) is probably the most widely used for fitting a second-order response surface. It includes a fractional factorial design (FFD) amplified with a set of axial points/subsets that allow assessment of the curvature. Centre point runs were incorporated to reduce model prediction errors, provide process stability measures, and record inherent variability. Table 1 shows the critical abrasive water jet parameters and their limits [23,24].

Table 1. Important AWJ factors and their working range

SNO	Factor	Notation	Unit	Levels		
				(-1)	(0)	(+1)
1	Water pressure	P	Bar	180	200	220
2	Stand-off distance	L	mm	1	2	3
3	Nozzle diameter	D	mm	0.5	1	1.5

Three samples were confirmed for individual investigational conditions in this investigation, and the average output values were considered. For characterization, conventional techniques were used. To measure the top and bottom hole size, an optical microscope with Material Plus 4.5 software was used [14]. Garnet abrasive particles of 110 µm were used for making holes in the fabricated aluminium foam sandwiched glass Fiber composites. Table 2 shows the abrasive water jet machining condition. Figure 2 shows the machined samples using AWJM.

Table 2. Abrasive water jet machining condition

Machine Type	Vortex type mixing chamber
Abrasive Particle	Garnet
Operating angle	90 Degrees

Workpiece Material	(a) Aluminum foam sandwiched with glass fiber reinforced composites. (b) Glass fibre reinforced polymeric composites
Work piece shape	Rectangular

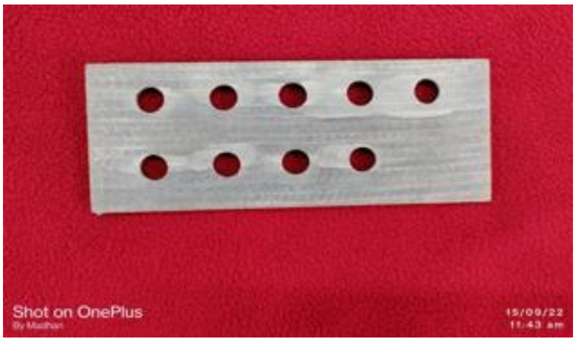


Figure 2. Aluminum foam sandwiched with glass fiber Reinforced composites after machining

An electronic digital stopwatch (Reading: 1/100th of a second with alarm/timer/calendar) is used to observe the machining time for each experiment. For capturing the material removal rate, specimens were measured using analytical balance before and after making holes. An inverted trinocular metallurgical microscope (DE-WINTOR) was used for capturing the top and bottom holes of aluminium foam sandwiched glass Fiber composite [25, 4].

3. Result and discussions

After making holes on the fabricated glass Fiber polymer composited sandwiched with and without aluminium foam with different settings of input parameters such as water jet pressure, stand-off distance, and diameter of the nozzle, the values of output parameters such as machining time, MRR, and kerf angle was noted. Table 3 shows the machined samples' material removal rate, kerf angle, and surface roughness (Ra).

Table 3. Experimental results of glass fibre polymeric composites with and without aluminium foam

	Coded values			MRR	Kerf angle	Ra	MRR	Kerf Angle	Ra
1	-1	-1	-1	8.9	5.8	9.56	11.54	7.4	12.45
2	-1	-1	-1	8.7	5.6	8.94	11.76	7.3	11.98
3	-1	-1	-1	8.4	5.4	9.35	11.34	7.7	12.34
4	-1	0	0	9.7	6.4	7.54	12.45	8.2	11.45
5	-1	0	0	9.5	6.1	7.62	12.76	8.4	11.34
6	-1	0	0	9.4	6.5	7.59	12.21	8.5	11.67
7	-1	1	1	7.7	8.9	6.78	10.32	10.2	10.45
8	-1	1	1	7.5	8.5	6.56	10.54	10.4	10.21
9	-1	1	1	7.9	8.3	6.81	11.01	10.5	10.34
10	0	-1	0	11.3	3.7	5.61	14.45	5.7	9.45
11	0	-1	0	11.2	3.8	5.72	14.76	5.4	9.34
12	0	-1	0	11.5	3.6	5.60	14.67	5.1	9.45
13	0	0	1	12.4	9.4	7.98	15.67	11.4	9.21
14	0	0	1	12.3	9.3	7.45	15.43	11.7	9.45
15	0	0	1	12.6	9.5	7.34	15.65	11.3	9.56
16	0	1	-1	14.6	4.6	8.71	17.87	6.7	10.11
17	0	1	-1	14.3	4.7	8.31	17.09	6.4	10.24
18	0	1	-1	14.5	4.5	8.45	17.54	6.9	10.23
19	1	-1	1	15.7	2.4	4.21	18.67	4.3	7.45
20	1	-1	1	15.3	2.5	4.27	18.05	4.6	7.87
21	1	-1	1	15.4	2.7	4.32	18.45	4.5	7.23
22	1	0	-1	16.7	3.9	5.67	20.54	5.76	7.35

23	1	0	-1	16.5	3.87	5.78	20.45	3.12	7.45
24	1	0	-1	16.4	3.78	5.45	20.32	5.16	7.89
25	1	1	0	13.5	3.13	8.74	16.95	5.23	11.45
26	1	1	0	13.6	3.19	8.54	16.54	5.42	11.67
27	1	1	0	13.3	3.42	8.45	16.76	5.66	11.56

3.1. Effect of abrasive water jet process parameters on MRR

Table 3 explains the materials removal rate (MRR) obtained using AWJM in glass Fiber composites with and without aluminium foam. Figure 3a shows that when the pressure is 220 Bar, the maximum material removal rate is obtained in both glass Fiber composites with and without aluminium foam. Figure 3b shows the effect of stand-off distance on the material removal rate [26]. Figure 3b shows that when the stand-off distance is minimum material removal rate increased in both the composite samples. Figure 3c explains the nozzle diameter on material removal rate. The testing results demonstrated that increasing the nozzle diameter above 0.5 mm significantly decreased the material removal rate. A maximum of 16.7 g/s material removal rate was obtained in the glass Fiber composites with aluminium foam by using abrasive water jet machining with the pressure 220 Bar, Stand-off distance 1 mm, and nozzle diameter 0.5 mm, while a maximum of 20.54 g/s material removal rate obtained in the machining of glass Fiber composites without aluminium foam. Figure 3 compares the material removal rate obtained in the abrasive water jet machining of glass Fiber composites with and without aluminium foam. From this work, it was noticed an average increase in the material removal rate by 23% without aluminium foam, when compared to the machining of glass Fiber composites with aluminium foam. Aluminum foam with a 1 mm thickness between the glass Fiber laminates increased the machining time, decreasing the material removal rate. The garnet abrasive particles take much time to reach the bottom surface of the samples as compared with glass Fiber without aluminium foam [16, 8].

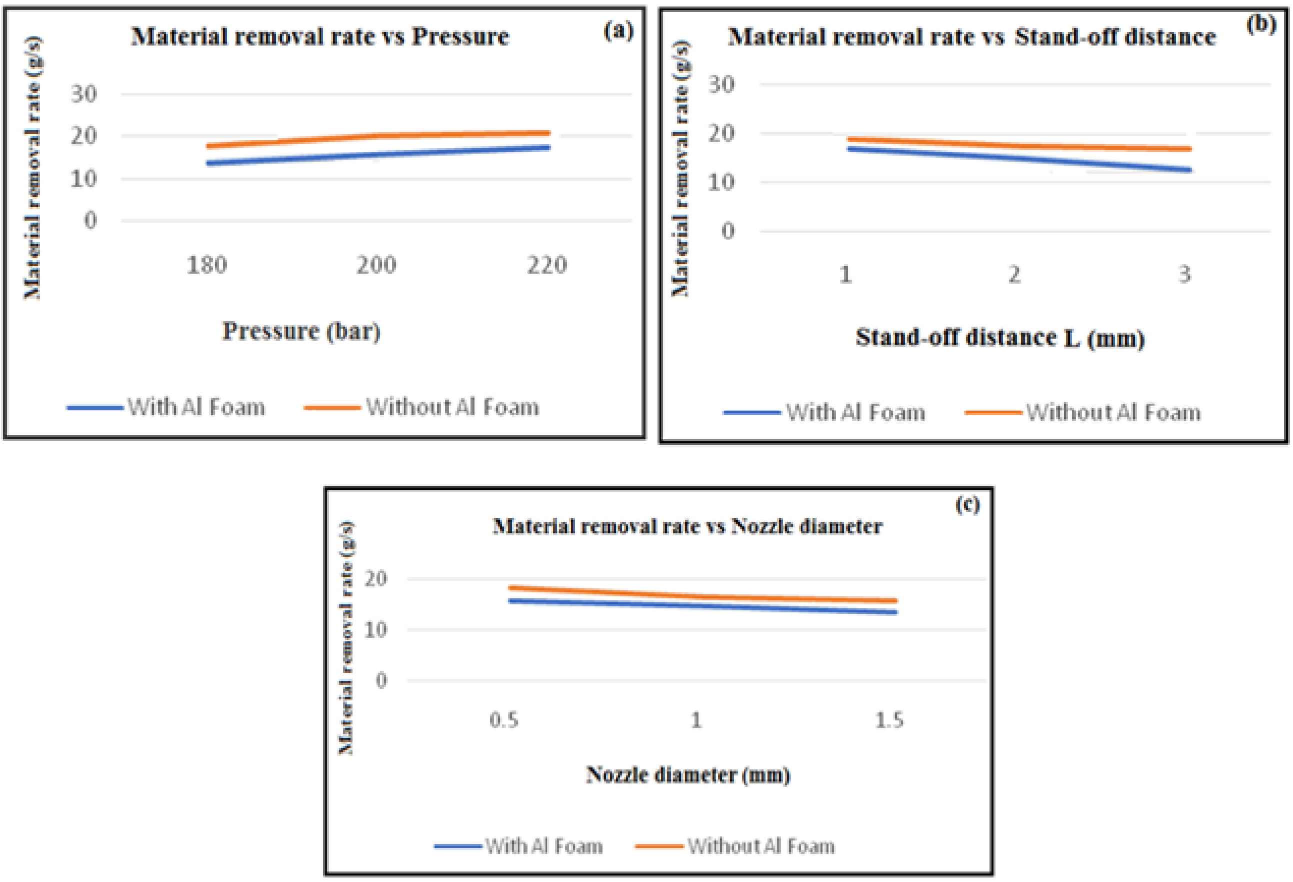


Figure 3. Effect of abrasive water jet parameters (Pressure, Stand-off distance, and Nozzle diameter) on MRR in glass Fiber composites with and without aluminium foam

3.2. Effect of abrasive water jet process parameters on kerf angle

Figure 4 explains the kerf angle obtained using AWJM in glass Fiber composites with and without aluminium foam. From Figure 4a it was observed that the obtained kerf angle is minimum at maximum pressure (220 Bar) in both cases: glass Fiber composites with and without aluminium foam. Figure 4b shows the effect of stand-off distance on kerf angle. It was observed that the kerf angle is minimum at a stand-off distance of 1 mm for both composite samples. Figure 4c explains the effect of the nozzle diameter on the kerf angle. The experimental results showed that the minimum nozzle diameter (0.5 mm) reduced the kerf angle. A minimum of 2.8 ϴ kerf angle was obtained in the glass Fiber composites with aluminium foam by using abrasive water jet machining with the pressure 220 Bar, Stand-off distance of 1 mm, and nozzle diameter of 0.5 mm, while a minimum of 4.7 ϴ kerf angle obtained in the machining of glass Fiber composites without aluminium foam [23, 8]. Figure 4 shows the comparison of kerf angle obtained in the abrasive water jet machining of glass Fiber composites with and without aluminium foam. From this work, it was observed an average reduction of kerf angle of 44.18% in the machining of glass fiber composites with aluminium foam. Aluminium foam with 1 mm thickness between the glass Fiber laminates decreases the jet deviation from top to bottom surface [16, 4]. Hence the garnet abrasive particles reach the bottom surface of the samples without any deviation.

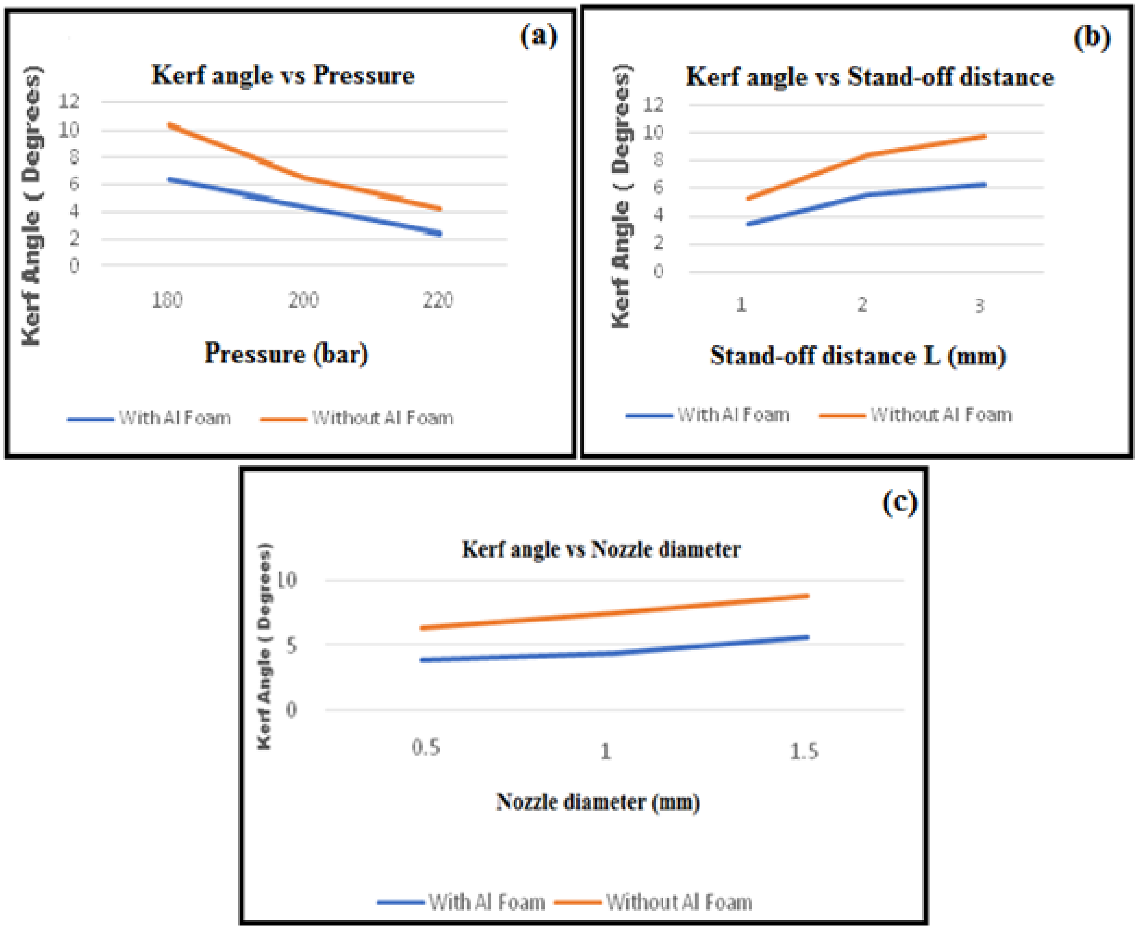


Figure 4. Effect of abrasive water jet parameters (Pressure, Stand-off distance and Nozzle diameter) on kerf angle in glass Fiber composites with and without aluminium foam

3.3. Effect of abrasive water jet process parameters on surface roughness (Ra)

Figure 5 shows the effect of abrasive water jet parameters on surface roughness (Ra) obtained using AWJM in glass Fiber composites with and without aluminium foam. Figure 5a shows that surface roughness is reduced in the glass Fiber composites with and without aluminium foam when the pressure is maximum (220 Bar). Figure 5b shows the effect of stand-off distance on surface roughness (Ra). The results showed that when the stand-off distance is minimum, surface roughness also decreased in both the composite samples. Figure 5c explains the effect of the nozzle diameter on surface roughness. The experimental results concluded that the maximum pressure (220 Bar) and maximum nozzle diameter (1.5 mm) reduced the surface roughness. A minimum of 4.21 µm surface roughness was obtained in the glass Fiber composites with aluminium foam by using abrasive water jet machining with the pressure 220 Bar, Stand-off distance of 1 mm and nozzle diameter of 1.5 mm, while a minimum of 7.23µm surface roughness obtained in the machining of glass Fiber composites without aluminium foam. Figure 5 shows the comparison of surface roughness obtained in the abrasive water jet machining of glass Fiber composites with and without aluminium foam. From this work it was observed an average reduction of the surface roughness of 41.77 % for the machining of glass Fiber composites with aluminium foam [15,11]. When the pressure is maximum (220 bar), abrasive particles impinge the composite samples with high velocity, which in turn increases the kinetic energy of the jet. Aluminium foam placed between the glass Fiber laminates decreases the jet deviation. Hence the surface roughness of glass fiber composite with aluminium foam reduced as compared without aluminium foam [4,11].

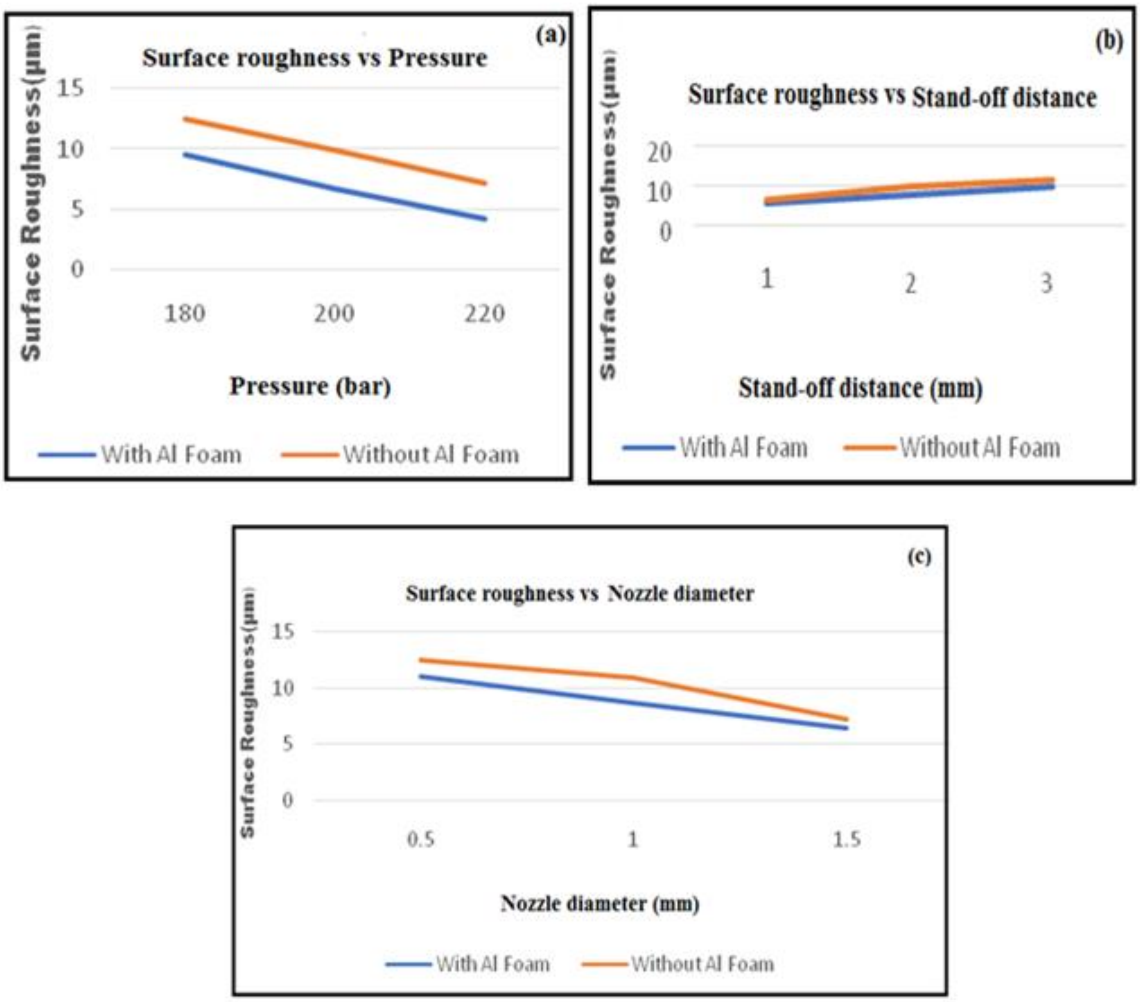


Figure 5. Effect of abrasive water jet parameters (Pressure, Stand-off distance and Nozzle diameter) on Surface Roughness (Ra) in glass Fiber composites with and without aluminium foam

Surface quality of the hole made by AWJ

Figure 6 explains the optical image analysis of the hole made by AWJM in glass Fiber polymer composite with and without aluminium foam. This investigation showed that maximum pressure and minimum stand-off distance produced better surface quality holes. Figure 6a shows the top and bottom kerf of the hole made by AWJM in glass Fiber composites with aluminium foam. When the pressure is at the maximum level, the kerf angle is reduced, and the maximum roundness of the hole is obtained [4, 14], whereas in the glass fiber composite without Aluminium foam uncut region in the bottom hole produced bottom kerf angle is minimum at maximum pressure as shown in Figure 6b. When the pressure is minimum, more delamination and increased kerf angle are produced in both the composites, as shown in Figure 6c and d. From Figure 6e, it was seen that uncut region (less delamination) obtained in minimum stand-off distance (1 mm) level in the glass fiber composite in aluminium foam surface but in contrast without aluminium produced irregularities in the hole and more delamination as shown in figure 6f. At maximum stand-off distance, less uncut region and delamination are produced in the hole [5, 16]. The roundness of the hole produced in glass fiber composite with Aluminium foam is good, as shown in Figure 6g. In the glass Fiber without aluminium foam, when the stand-off distance is maximum more delamination, and some uncut regions were found, as shown in Figure 6h.

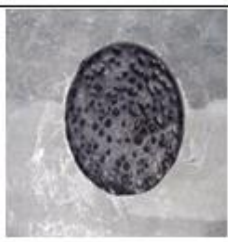
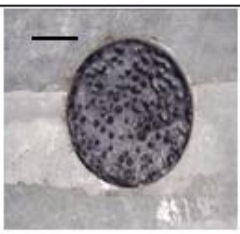
AWJM parameter	Glass Fiber composites with aluminium foam		Glass Fiber composites without aluminium foam	
	Top Kerf	Bottom Kerf	Top Kerf	Bottom Kerf
Pressure at Maximum (220 Bar) Level				
	(a) Kerf angle reduced, Maximum top kerf obtained		(b) Some uncut region in the bottom hole and minimum bottom kerf	
Pressure at Minimum (180 Bar) Level				
	(c) More delamination in the bottom hole surface		(d) Kerf angle increased, causing More delamination in the bottom hole	
Minimum stand-off distance (1 mm) Level				
	(e) Uncut region in aluminium foam surface		(f) More delamination, maximum kerf angle and bell shape	
Maximum stand-off distance (3 mm) Level				
	(g) Roundness and minimum kerf angle		(h) More uncut region in aluminium foam, Irregularities in hole surface	

Figure 6. Optical image analysis

4. Conclusions

Abrasive water jet is performed in the fabricated Glass Fiber polymer composites with and without aluminium foam. Holes were made on the composite samples. The effect of AWJM parameters such as Pressure, Stand-off distance and Nozzle diameter on MRR, Kerf angle and Surface roughness (Ra) was investigated. Based on the experimentations conducted on composite samples, the following conclusions are drawn:

-the material removal rate obtained in the glass Fiber composite without aluminium foam was 20.54 g/s for the pressure of 220 Bar, stand-off distance of 1 mm and Nozzle diameter of 0.5 mm;

-the machining of glass Fiber composites with aluminium foam produced less kerf angle (2.8 degrees) as compared without aluminium foam (4.7 degrees), meaning 44.18 % less than the composite with aluminium foam;

-the surface roughness in the glass Fiber composite with aluminium presented an average reduction of 41.77 % in comparison with the hole made by AWJ in the glass Fiber composite without aluminium foam.

References

1.L. BVOGELESANG, A. VLOT, (2000), Development of fibre metal laminates for advanced aerospace structures, Journal of Materials Processing Technology, Volume 103, Issue 1, 1 June 2000, Pages 1-5. https://doi.org/10.1016/S0924-0136(00)00411-8
2.S. PAUL, A. M. HOOGSTRATE, R. VAN PRAAG, (2002), Abrasive water jet machining of glass fibre metal laminates, Proc Instn Mech Engrs Vol 216 Part B: J Engineering Manufacture
3.NOORDIANA MOHD ISHAK, SIVAKUMAR DHAR MALINGAM, MUHD RIDZUAN MANSOR, NADLENE RAZALI, ZALEHA MUSTAFA, AHMAD FUAD AB GHAN, (2021), Investigation of natural fibre metal laminate as car front hood, Mater. Res. Express 8 025303.
4.MADHU S., BALASUBRAMANIAN, M., Effect of swirling abrasives induced by a novel threaded nozzle in machining of CFRP composites. Int J Adv Manuf Technol 95, 4175-4189 (2018). https://doi.org/10.1007/s00170-017-1488-2
5.ANU KUTTAN, A., RAJESH, R., DEV ANAND, M., Abrasive water jet machining techniques and parameters: a state of the art, open issue challenges and research directions. J Braz. Soc. Mech. Sci. Eng. 43, 220 (2021). https://doi.org/10.1007/s40430-021-02898-6
6.YUVARAJ N, PRADEEP KUMAR M., (2016), Cutting of aluminium alloy with abrasive water jet and cryogenic assisted abrasive water jet: A comparative study of the surface integrity approach. Wear 362:18–32
7.SELVAM R, KARUNAMOORTHY L, ARUNKUMAR N., (2017), Investigation on performance of abrasive water jet in machining hybrid composites. Mater Manuf Process 32(6):700-706
8.NATARAJAN Y., MURUGASEN P.K., SUNDARAJAN L.R., ARUNACHALAM R., (2019), Experimental investigation on cryogenic assisted abrasive water jet machining of aluminium alloy. Int J Precis Eng Manuf Green Technol 6(3):415-432
9.KUMAR P., KANT R., (2019), Experimental study of abrasive water jet machining of Kevlar epoxy composite. J Manuf Eng 14(1):026-032
10.BAÑON, F., SAMBRUNO, A., GONZÁLEZ-ROVIRA, L., VAZQUEZ-MARTINEZ, J.M., SALGUERO, J., A Review on the Abrasive Water-Jet Machining of Metal–Carbon Fiber Hybrid Materials. Metals 2021, 11, 164. https://doi.org/10.3390/ met11010164
11.FERNANDEZ-VIDAL, S.R., FERNANDEZ-VIDAL, S., BATISTA, M., SALGUERO, J., Tool Wear Mechanism in Cutting of Stack CFRP/UNS A97075. Materials 2018, 11, 1276
12.BAÑON, F., SAMBRUNO, A., BATISTA, M., FERNANDEZ-VIDAL, S.R., SALGUERO, J., Study of the one-shot drilling of CFRP/Ti6Al4V stacks with a double tip angle cutting-tool geometry. In AIP Conference Proceedings; AIP Publishing LLC: Melville, NY, USA, 2019; p. 080010

13. D.K. JESTHI, R.K. NAYAK, B.K. NANDA, DIPTIKANTA, Das Assessment of Abrasive Jet Machining of Carbon and Glass Fiber Reinforced Polymer Hybrid Composites Materials Today: Proceedings Volume 18, Part 7, 2019, Pages 3116-3121 https://doi.org/10.1016/j.matpr.2019.07.185
14.BALASUBRAMANIAN M, MADHU S., Evaluation of delamination damage in carbon epoxy composites under swirling abrasives made by modified internal threaded nozzle. Journal of Composite Materials. 2019;53(6):819-833. doi:10.1177/0021998318791340
15.***An experimental and empirical assessment of machining damage of hybrid glass-carbon FRP composite during abrasive water jet machining, Journal of Materials Research and Technology, Volume 19, 2022
16.S. MADHU, M. BALASUBRAMANIAN, (2018), Impact of Nozzle Design on Surface Roughness of Abrasive Jet Machined Glass Fibre Reinforced Polymer Composites, Silicon (Springer) 10 (6), 2453–2462
17. KAVIMANI V., GOPAL P M., STALIN B., BALASUBRAMANI V., DHINAKARAN V., NAGAPRASAD N., Leta Tesfaye Jule, Krishnaraj Ramaswamy Influence of reduced graphene oxide addition on kerf width in abrasive water jet machining of nanofiller added epoxy-glass Fiber composite. PLoS ONE 17(8): e0270505. https://doi.org/10.1371/journal.pone.0270505
18.HARPREET SINGH, NEERAJ KUMAR BHOI, PRAMOD KUMAR JAIN, Chapter 6 - Developments in abrasive water jet machining process-from 1980 to 2020, Editor(s): Kapil Gupta, Alokesh Pramanik, In Handbooks in Advanced Manufacturing, Advanced Machining and Finishing, 2021, Pages 217-252
19.SHIVAJIRAO, M., SATYANARAYANA, S., Abrasive water jet drilling of float glass and characterization of hole profile. Glass Struct Eng 5, 155–169 (2020). https://doi.org/10.1007/s40940-019-00112-7
20.S MADHU, M. BALASUBRAMANIAN, (2017), Influence of nozzle design and process parameters on surface roughness of CFRP machined by abrasive jet, - Materials and Manufacturing Processes, 2017.
21.D.K. SHANMUGAM, S.H. MASOOD, An investigation on kerf characteristics in abrasive waterjet cutting of layered composites, Journal of Materials Processing Technology, Volume 209, Issue 8, 2009, Pages 3887-3893, https://doi.org/10.1016/j.jmatprotec.2008.09.001.
22.YOUSSEF H, EL-HOFY H, ABDELAZIZ A, EL-HOFY M., Accuracy and surface quality of abrasive waterjet machined CFRP composites. *Journal of Composite Materials*. 2021;55(12):1693-1703. doi:10.1177/0021998320974428
23.KUMAR D, GURURAJA S., Abrasive waterjet machining of Ti/CFRP/Ti laminate and multi-objective optimization of the process parameters using response surface methodology. *Journal of Composite Materials*. 2020;54(13):1741-1759. doi:10.1177/0021998319884611
24.DHANAWADE A, KUMAR S., Experimental study of delamination and kerf geometry of carbon epoxy composite machined by abrasive water jet. *Journal of Composite Materials*. 2017;51(24):3373-3390. doi:10.1177/0021998316688950
25.N PRASANAA IYER, N. ARUNKUMAR, (2022), Investigation of abrasive water jet machining parameters of bismaleimide composites, materials and manufacturing processes, 37 (14), Pages 1642-1651
26.DHARMAGNA R. TRIPATHI, KRUPANG H. VACHHANI, DIN BANDHU, SONI KUMARI, V. RAKESH KUMAR, KUMAR ABHISHEK, (2021), Experimental investigation and optimization of abrasive waterjet machining parameters for GFRP composites using metaphor-less algorithms, Materials and Manufacturing Processes, 36 (14)

Manuscript received: 9.11.2022