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Effect of IR Radiation on Drilling of Natural Fiber Mesh-reinforced Hybrid Epoxy Composites

Rajesh MOHAN [1] *, Suresh PARAMASIVAM [2], Soundarrajan MADESH [2], Harikaran MADESWARAN [3]

[1] *Department of Mechanical Engineering, Rathinam Technical Campus, Coimbatore, Tamilnadu, India*
[2] *Department of Mechanical Engineering, Muthayammal Engineering College (Autonomous), Rasipuram, Tamilnadu, India*
[3] *Department of Civil Engineering, Muthayammal Engineering College (Autonomous), Rasipuram, Tamilnadu, India*

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Due to anisotropic performance of polymer matrix composites (PMC) drilling is a complex process in traditional drilling. Different type of fiber meshes and their resistance to infrared radiation (IR) on drilling operations are examined in this study. The natural and synthetic meshes are used to fabricate the composites, which are jute fiber mesh composite (JTMC), glass fiber mesh mixed composite (GLMC), nylon fiber mesh mixed composite (NLMC), cotton fiber mesh mixed composite (CTMC), and gunnet fiber mesh mixed composite (GNMC).In order to reveal the addition of heat on the machining characteristics of different composites, the Infrared (IR) radiations are used in the machining zone. The most important process parameters in the drilling process such as drilling speed in rpm, feed rate in mm/min and machining zone temperature in ºC are considered for the experiment. Among the composites, GNMC shows the lowest delimitation Factor (DF) of 1.3 i.e 52.2 % which is less than JTMC for the parameter combination of 60 rpm, 12 mm/min and 40 ºC. Also, the least surface roughness in *R*a (SR) noted with the JTMC, which is 44.6 % lesser than GNMC at the same parameter combination. The infrared radiation heat affects the strands of fibers and its soft nature with the stiffness which contributes major role on surface roughness. The GLMC and CTMC are produces the next lesser DF when compared with the JTMC, which creates 4.95 and 5.68 DF, respectively. Furthermore, scanning electron microscope (SEM) figure studies are carried out on the circumference of drilled workpiece to distinguish the effect of heating and fibers impact on drilling quality.

Keywords: fibers, nylon, glass, gunnet, mesh, cotton, surface roughness, infrared.

1. INTRODUCTION

Polymer matrix composites are owing their unique and highly desirable mechanical, thermal and physical properties to specific design. By strategically combining polymer matrix and fibre reinforcement creates composite material that far outperforms its individual components and makes composites vital for engineering future materials [1 – 3]. Among various fibres employed in polymer matrix composites, mesh shaped fibres create the major mechanical and micro structural possessions relatively than normal stand form fibres. As well, natural fibres are cost-effective, risk-free, ecological and elevated mechanical power in all aspects. There are a number of occurrences of the booming consumption of dissimilar fibres in household life from corner to corner the globe [4 – 6]. On the other hand, use of PMC's in manufactured goods growing enormously owing to their mechanical distinctiveness. In industrialized manufacturing, drilling hole is a necessary and highly desirable operation. In row with that researchers are prepared to disclose the machining uniqueness of fibre reinforced PMC. Mohanavel et al. [7] tried the madar and ramie fibres as reinforcement agent and magnesium oxide particles mixed with the composites to enhance the drilling quality of the hole. They exposed that drilling speed of 1500 rpm, 0.6 mm drill bit size and 0.1 mm/rev are produced the lesser delimitation factors among all other drilling factors. Elanjeitsenni et al. [8] studied the effect of corn fiber reinforcement and bio silica as filler in epoxy composite to reveal the machining and mechanical characteristics. They noted that 160 % more toughness, 2500 % higher energy than pure epoxy. Also, the addition of bio silica 30 % higher fatigue strength than plain epoxy plate. Kumar et al. [9] examined the effect on addition of clam shell fiber, chemosphere filler material with the glass fiber composite on drilling and mechanical characteristics. They considered the process parameters and levels such as drill bit size from 6 to 10 mm, feed rate 0.04 to 0.12 mm/rev and weight 0 to 20 % for conducting experiment. Ozdemir et al. [10] conducted drilling experiments on carbon and glass fibre reinforced composites to optimize the machining characteristics. They used the composites in the freeform shape and noted better surface finish with the carbon fibre reinforced composite. Based on the ANOVA, feed rate and spindle speed contributes 63 % and 13 % respectively on whole machining quality. Gokul Kannan et al. [11] investigated the drilling behavior of banana fiber and fly ash reinforced polymer composites. The study considered key process parameters such as feed rate, spindle speed, and the addition of fillers for optimization. The authors observed that increasing the volume percentage of filler in the composite adversely affects the hole quality. Furthermore, a feed rate of 100 mm/min resulted in nearly twice the

*Corresponding author: R. Mohan.
E-mail: *rajesh.som@rathinam.in*

reduction in delamination compared to the other feed rates employed during the drilling process. Choudhury et al. [12] examined the woven natural fibre reinforced composite under a conventional drilling process. They noticed that drill bit size impacts the machining quality by around 62 % and the delimitation factor reduces by addition of fillers in the composite. Ye et al. [13] investigated the drilling characteristics by developing novel composites. The fibres such flax and glass fibres in laminates forms are used in the composite fabrication. They tried dry drilling, cryogenic treated drill bit employed drilling and hybrid drilling process with a novel composite. Based on the results 64 % lesser delimitation factor was noted with the cryogenic tested tool electrode when compared to the normal dry drilling tool electrode. Mishra et al. [14] investigated the drilling parameters for the fly ash and hemp fibre reinforced polymer composite. They used drill bit shapes, feed rate and spindle speed as process parameters. The fly as mixed composite produces the reduced thrust force around 80 % and 8 face drill bits are contributes for higher drilling rate which increases the torque with the same composite. Also, drilling temperature noted while machining was 90 °C and decreased after completion of the hole to 71 °C for the fly ash mixed composite and normal composite. Hüseyin et al. [15] studied the effect of graphite and boron carbide particle addition on glass fiber reinforced composite while drilling. The filler materials are varied with the concentrations from 5 % to 15 % and the hand layup method. Based on the test results mechanical strengths are decreased with increasing of graphite and boron carbide particle mixing.

Sangeetha et al. [16] investigated drilling characteristics with the amine functionalized luffa fibre composite using response surface methodology technique. They considered drill bit sizes from 6 mm to 12 mm on none functionalized and amine functionalized composite. The results noted that amine functionalized composite produces the 45 % lesser delamination and enhanced surface finish than other composite. Srinivasulu et al. [17] studied the drilling quality with kenaf fiber mixed hybrid composite in addition with steel wire mesh. The hardness of composite noted with the steel wire mesh reinforced composite is 2.0040 µm which is 45 % lesser than non-wire mesh reinforced composite. Mishra et al. [18] studied the coated and non-coated drill bits effect on the graphene reinforced composites with drilling characteristics. They noted that non coated drill bits are shows the 78 N thrust force which is 18 % higher than coated drill bit. Ramesh et al. [19] investigated the mechanical and drilling characteristics with sand blasted surface and amino silane treated pineapple fibre reinforced composite for the space applications. They noted that surface and chemical treatment increases the mechanical characteristics around 40 %. Kumar et al. [20] drilled and investigated the composite surface features such as material removal, overcut and heat affected zone with the natural fiber reinforced thermoplastic composite using 2.5 GHz micro wave energy. They exposed that 810 W electric power produced 0.9 mm heat affected zone with 10 % of fiber additions with composite. Also, overcut of the hole increased when rising of input power energy. Moreover, the employment of micro wave energy hinders the fibre pull outs and micro defects on the circumference of hole significantly. Seif et al. [21] investigated the glass fibre and aluminium mesh for the reinforcement on the composite and revealed the hole quality. They employed fibre and mesh in two different techniques and most influencing process parameters feed rate, spindle rotation speed and drill bit angle are optimized using Grey relational analysis technique. Based on the optimized process parameters 83 % and 76 % lesser circularity and delaminating factor respectively are obtained. The parameter combination, point angle 90º, spindle speed 3000 rpm and feed rate 20 mm/min are produces the 17.38 % lesser circularity. The proceedings with the literature material provided above makes it abundantly evident that studies were carried out using variety of fibres and techniques to improve the exterior quality of the hole. There are very few studies are endeavoured by the researchers with fibre mesh reinforced composite [22 – 24]. Although, no evidence found for the heating approach with PMC drilling, yet whereas in other metal machining studies that are most effective with both traditional and non-traditional techniques employs addition of heating to the machining zone [25 – 28]. Since, the heating of machining surface stimulates the materials surface to microstructure elongation and makes softer to the certain extent which significantly increases the machining quality. Hence, with aim of speed and quality micro hole fabrication in the mesh-type fibres including cotton, jute, glass, nylon and gunnet reinforced composites are employed as work material along with the most successful heating technique IR radiation heating is considered in this research for heating machining zone. The experiment takes into account the main affecting process characteristics, including the type of fibre mesh, drilling speed in rpm, feed rate in mm/min and machining zone temperature in degree Celsius. Drilling performance is evaluated by estimating the hole's DF and SR. Additionally, SEM figure analyses are conducted to know fibres impact and temperature on hole quality.

2. MATERIALS AND METHODS

Different plates of epoxy composites are prepared by hand layup method and considered as work material. The hand layup method of different composite preparations and experimental setup presented in Fig. 1. Eco-friendly, sustainable, pollution free, strong natural fibre meshes and synthetic fibre meshes are considered as the reinforcement. Among different fibres gunnet and jute are the natural fibers which are involved in chemical treatment. The fibers meshes such as glass and nylon are the synthetic woven fibers which are not involved in the chemical treatment. Also, the square structured jute and cotton fabrics are natural whereas obtained commercially. Hence, the commercial fibers directly employed in composite fabrications. The gunnet fibres meshes are acquired from the coconut trees, which are naturally grown, like wovened mesh over the coconut trees to prevent the seeds and stems. This mesh is exposes the excellent tensile and impact carrying strength by naturally. Since, the gunnet meshes grown up with uniformed outer mesh layer and its thick stems crossed as supporting block for the meshes. Therefore, gunnet fibre are collected and involved in the chemical treatments which are followed by the literature [14].

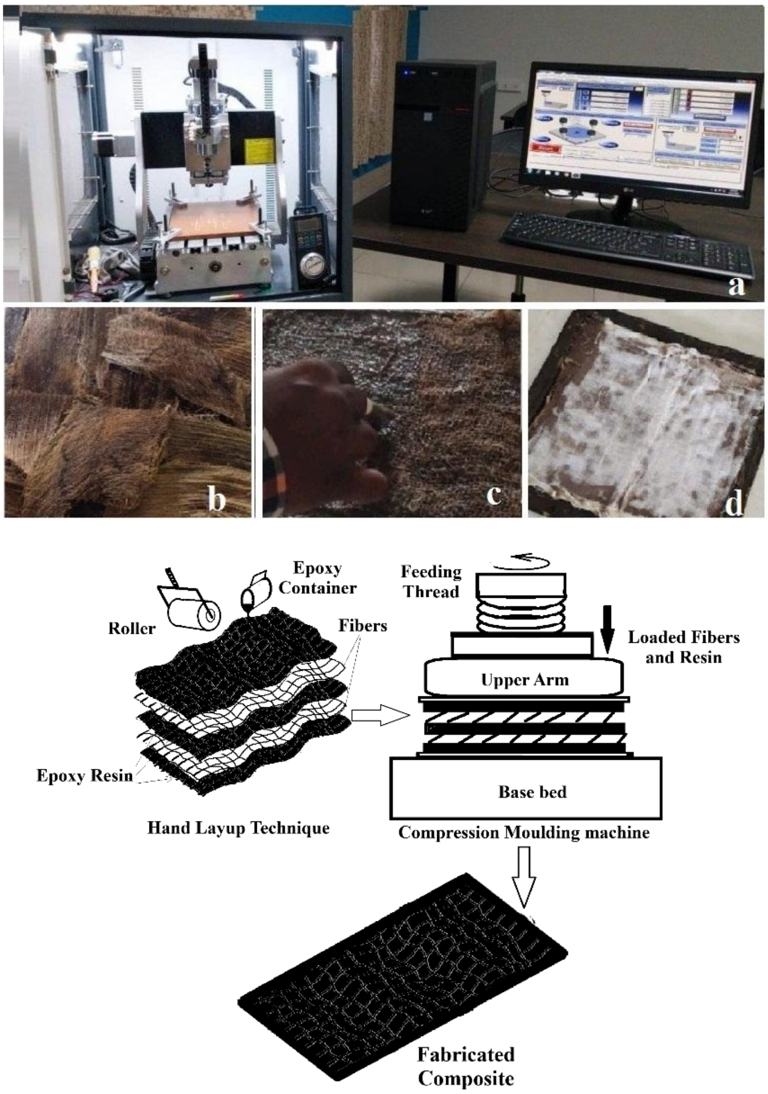

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Fig. 1. Representations of experimental setup and composite preparations: a – CNC drilling machine; b – gunnet; c – jute; d – cotton; e – fabricated composite

With the base of this gunnet fibre GTMC are fabricated. GLMC are prepared with commercially available 300 g/m^2 chopped glass fibre mat (woven) mesh supplied by the Renuka enter prizes, Dombivli East, Mumbai, Maharashtra, India. The CTMC are utilized the Non printed white150 g/m^2 woven cotton fabric mesh procured from Shree Ganesh Knitters, Amritsar, Punjab, India and 500 g/m^2. The JTMC fibres are obtained from Green Jute Implex Pvt Ltd, Kolkatta, India and Nylon fabric mesh purchased from KM Green Vision, Uttam Nagar, New Delhi, Delhi, India to produce the NLMC.

The natural fibres such as jute and gunnet are considered for chemical treatment to remove the impurities. The treatment of natural fibres ensures that their strength and chemical properties are preserved uniformly. Also, chemical reaction due to the microorganisms present in the fibres eradicated by the chemical treatment. The fibres are collected and engrossed in water for three days. The fibres are drenched at ambient temperature subsequent to take out from the branch through metal wire brush. The collected fibre meshes are physically cut into individual sheets, each measuring 100 mm in length. For the alkaline conditioning, 2 % of sodium hydroxide solutions were utilized at ambient temperature. After soaking in the cleaning agent, the fibres are cleaned and allowed to dry in the direct sunlight for four days and then utilized in preparation of composites.

The treatment utilized simple low-viscosity and transparent epoxy resin Bisphenol-A (Epoxy Resin 556) as the matrix. A curative agent HY 951 employed as the hardener. The epoxy resin and hardener were completely mixed at weight ratio of 10:1. The materials were sourced from M/s. Hereinba enterprises Chennai, India

These fibres are considered as reinforcements to the various composites. Along with these, 5 grams fly ash powders are mixed to the epoxy for the purpose of increasing further strength among themselves in all composites. During fabricating composite materials, the reinforcement is selected first to maximize the machining and mechanical properties of the final product. Reinforcements such as woven fabrics or mesh structures made from glass, jute, cotton, nylon, gunnet fibers are cut to the required dimensions and dried to remove moisture. The prepared reinforcement layers are then carefully arranged on the mold surface in controlled sequence to achieve uniform fiber orientation and consistent volume fraction. In laminated composites, successive fiber layers are alternated to ensure even distribution. Next, the polymer matrix typically an epoxy resin combined with a hardener is mixed in the prescribed ratio and stirred thoroughly to achieve consistent viscosity. This liquid matrix is poured over the arranged fibers, ensuring complete wetting and impregnation of the reinforcement. Light pressure is applied to the mold assembly to expel trapped air and ensure close contact between fibers and the matrix. The assembly is then cured at ambient temperature. After full curing, the composite laminate is demolded, trimmed, and post-processed for testing. Following these steps ensures strong fiber-matrix bonding, minimal voids, and enhanced structural integrity of the composite. The composite plates are prepared for the sizes 300 mm, 200 mm and 7.5 mm in length, width and thickness respectively. Note that four types of composites included with fly ash and meshes such as gunnet, glass, Nylon, Cotton and Jute to conduct the drilling experiment. Table 1 presents the experimental planning.

Table 1. Experimental planning

Ex No.	Drilling speed, rpm	Feed rate, mm/min	Temperature, °C
1	20	12	40
2	30	12	40
3	40	12	40
4	50	12	40
5	60	12	40
6	60	4	40
7	60	6	40
8	60	8	40
9	60	10	40
10	60	12	40
11	60	12	32
12	60	12	34
13	60	12	36
14	60	12	38
15	60	12	40

The experiments are planned inclusive with drilling speed, feed rate and temperature and framed based on the vaiying one parameter and keeping others at higher constant level method. The diameter 3 mm and 30° helix angle twist dill bit employed as tool electrode for the experiments. The drilled specimens and experimental setup presented in Fig. 2. Table 2 and Table 3 show the numerical values of calculated DF and SR for the different fibres. The drilling experiments of different work specimens such as GNMC, GLMC, NLMC, CTMC and JTMC plates were performed in a vertical MATAB XL Milling CNC machining centre under different machining parameters and machining temperatures. The multi-layered all composites are drilled based on the most successful trialling strategy that varying one parameter and keeping others constant, method is employed to conduct the experiment.

The CNC machine inbuilt with a force dynamometer which is used to measure force created at the machining zone. The temperature of machining monitored using a thermocouple connected with the CNC setup, ranging from 20 to 50 °C and ± 0.1°C accuracy.

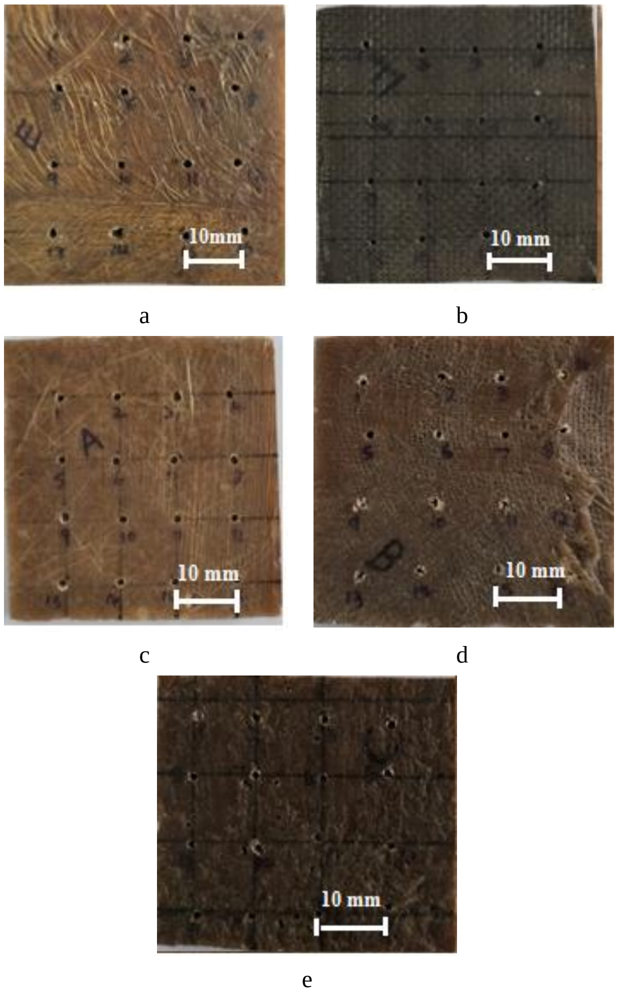


Fig. 2. Macro image of Work specimens: a – GNMC; b – NLMC; c – GLMC; d – CTMC; e – JTMC

Table 2. Delamination factor (DF) for fibres

Ex No.	Delamination factor (DF)				
	GNMC	NLMC	GLMC	CTMC	JTMC
1	1.787	1.94	2.17	2.35	2.45
2	1.43	1.87	1.82	2.05	2.21
3	1.41	1.76	1.8	1.98	2.15
4	1.38	1.47	1.43	1.78	2.05
5	1.3	1.52	1.4	1.7	1.98
6	3.83	4.09	5.4	6.82	8.5
7	3.48	4.12	5.1	5.945	6.26
8	3.46	4.11	4.93	5.12	7.2
9	3.43	4.22	4.83	4.98	6.1
10	3.35	3.77	4.05	4.35	6.03
11	2.35	3.06	3.22	3.33	3.43
12	2.41	2.5	2.8	3.03	3.19
13	2.488	2.74	2.88	2.96	3.13
14	2.36	2.45	2.41	2.76	3.03
15	2.328	2.5	2.38	2.68	2.96

The drilling operation was conducted without coolant application and the temperature of the machining zone was modified to explore the possibilities of increasing machining quality via holes fabrication.

Table 3. Surface roughness (SR) for fibres

Ex No	Delamination factor (DF)				
	GNMC	NLMC	GLMC	CTMC	JTMC
1	7.45	5.01	5.87	4.02	3.25
2	6.98	4.63	4.92	3.52	2.98
3	5.87	4.16	4.36	3.04	2.67
4	4.5	3.12	3.98	2.98	2.64
5	3.87	3.01	3.4	2.64	2.02
6	9.8	6.06	6.92	5.07	4.3
7	7.03	5.68	5.97	4.57	4.03
8	7.82	5.21	5.41	4.09	3.72
9	6.98	4.17	5.03	4.03	3.69
10	4.92	4.06	4.45	3.69	3.07
11	8.43	5.99	6.85	5	4.23
12	6.96	5.61	5.9	4.5	3.96
13	5.85	5.14	5.34	4.098	3.65
14	5.68	4.1	4.96	3.96	3.62
15	4.85	3.99	4.38	3.62	3.07

The IR lamp was used to varying the machining zone temperature, which is energized separately. Although, the continuous usage of IR lamp leads to produce over heat on the work surface which affects the machining nature intensively. To avoid overheating and maintaining machining zone temperature as per the experimental planning, a digital thermometer is utilized to measure the machining temperature.

The IR lamp fixed 150 mm distance apart from the machining zone to avoid the machining zone disturbances. Commercially available 220 V clinically applicable IR lamp is used to vary temperature. The temperature of IR lamp maintained keenly for the different ranges. The separately energized IR lamp emitting the heat over the work material and machining zone which is illustrated in Fig. 2.

3. RESULT AND DISCUSSION

Fig. 3 a. shows the effect of drilling speed on DF for the different composites such as GNMC, NLMC, GLMC, CTMC and JTMC. In overall, the tendency of the graph for DF decreases with increasing of drilling speed. The increasing of drilling speed decreases the DF with respect to all composites. Among all types of composites, GNMC shows the lowest DF of 1.3 for the parameter combination of 60 rpm, 12 mm/min and 40 °C. Moreover, with decreases in drilling speed, the DF increases less linearly up to 50 rpm and linearly between 20 rpm to 40 rpm. At higher drilling speed, fibres associated with the composite are pulled toward the inside, which resulting in lower DF. Therefore, GNMC produces 52.2 % reduced DF than the JTMC. The fiber mesh pull traction occurs along the circumference of the hole in the direction opposite to the applied force. And the NLMC produces the second least DF for the same parameter combination. In NLMC the strength of nylon mesh provides the major role for lower DF. The NLMC work material DF of hole is measured as 1.94 and 1.52 at the drilling speeds ranges of 60 and 40 rpm respectively. When the applying temperature at the machining zone increases the electrode temperature and passes with NLMC, it persuades the Joule warming owing to the opposition caused by the tool electrode rotation. Also, production of heat while drilling is high which again raises the machining zone temperature [27].

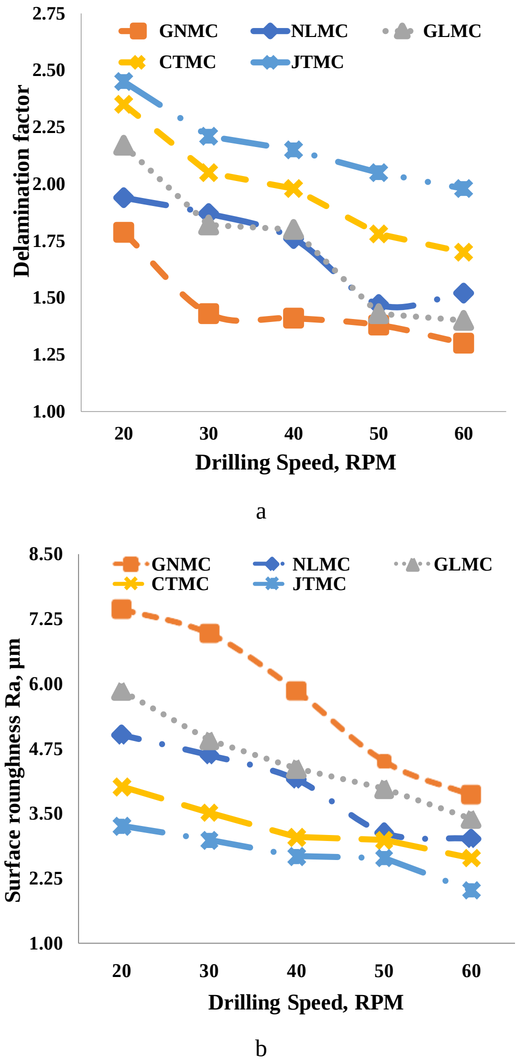


Fig. 3. Effect of drilling speed on: a – DF; b – SR at 12 mm/min and 40 °C constantly

Therefore, higher heat production softens the composite which reduces the residual stress and makes the drill easier.

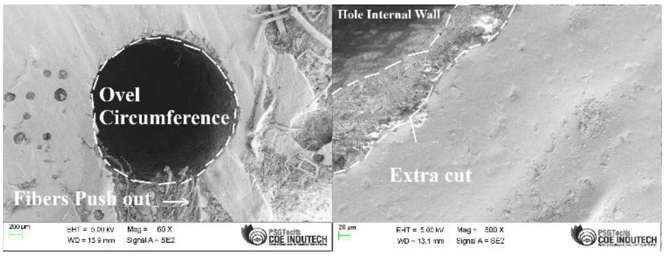
Hence, NLMC produces 43.1 % reduced DF than the JTMC. Furthermore based on the graph, GLMC produces DF of 2.17 for the parametric combination of 60 rpm, 12 mm/min and 40 °C. Also these values are the third least DF value between the conducted investigations. The glass fibres are manufactured using more than 50 % with silica which has high tensile and chemical resistant characteristics. Therefore, both heats such as applied heat and machining zone drilling heat are not penetrated inside to the composite which leads to the third lesser DF value [28]. Also, for the same parameter combinations CTMC work material possess next least DF than JTMC which produces DF of 2.35. CTMC's are generally lesser density fibre when compare to other fibres used in this investigation. Hence, CTMC expresses 36.13 % lesser DF than JTMC.

Fig. 3 b depicts the effect of drilling speed on SR for different work material such as GNMC, NLMC, GLMC, CTMC and JTMC. The SR is found to be increase with the decreasing of drilling speed. Since, fibres used in the composite triggered to pullout by applying rotation force against to the stably fixed fibres irrespective of all composites. However, the pullouts of fibres are controlled based on their mechanical properties. Based on the graph, JTMC produces the lowest SR among all PMC's. The strands jute fibre are plays vital role in the lesser SR. Since, of jute fibre cellulose and lignin are generally a soft nature which can withstand their stiffness up to 80 ºC. But, the machining zone temperature exits 90 ºC which affects the composite flexibility [29]. This phenomenon contributes to hinder the SR significantly with the JTMC and hole machined with JTMC are presented in Fig. 4 a. The JTMC, SR is found to be 44.6 % lesser than the GNMC at the parameter combination of 60 rpm, 12 mm/min and 40 º. additionally for the similar parameter solution, CTMC shows the next least SR associated to the GNMC Stiffer by naturally. The strands of gunnet fibres are meshup with additional fiber using thick and thick sticks in uniform distance within its structure. Therefore, while applying rotational force on the work material fiber are removed properly from the hole. This phenomenon reduces the DF with GNMC. For the case of NLMC, it possesses high tensile strength due bonding of hydrogen and carbonyl oxygen's which provides long chain and causes for high load barrying capacity [31]. Therefore, GNMC and NLMC are produces 32.1 % and 18.26 % lesser DF than JTMC. At the parametric combination of 6 mm/min, 60 rpm, and 40 °C, the GNMC and NLMC exhibit the lowest DF of 4.12 (38 % reduction) and 4.53 (14.23 % reduction) respectively when compared to the JTMC. Under the condition of 4 mm/min, 60 rpm, and 40 ºC, the GLMC and CTMC yield DF values of 4.95 and 5.68 ranking third and fourth lowest, respectively. Since, the glass fiber mesh and cotton meshes possess higher tensile strength and stiffness compared to jute mesh but lower than gunnet and nylon meshes. Consequently, the composites exhibit deformation DF that are 28.1 % and 12.26 % lower than the JTMC, respectively. Furthermore, at the parametric combination 6 mm/min, 60 rpm, and 40 ºC, the GLMC and CTMC produces lesser DF of 4.35 (i.e 29.5 %) and 5.12 (i.e20.63 %) respectively when related to the JTMC.

Fig. 5 b shows the effect of feed rate on SR for different work material such as GNMC, NLMC, GLMC, CTMC and JTMC. The SR is found to be increase gradually with the decreasing of feed rate.

Generally, an increase in feed rate leads to rapid material removal, which often results in the formation of uneven surfaces during machining. However, in this case an increase in feed rate produced lower SR. This behavior can be attributed to the influence of IR radiation, which form of long-wavelength electromagnetic energy, rapidly heats the machining zone. The localized heating softens the composite material, thereby facilitating smoother material removal and reducing SR.

Also, while increasing the feed rate on machining causes to build-up the additional machining temperature rather than normal machining. Therefore, the IR rays heat and feed rate developed heat are mutually affect the fibres and polymers softness which leads to the lesser SR irrespective of all composites [29].



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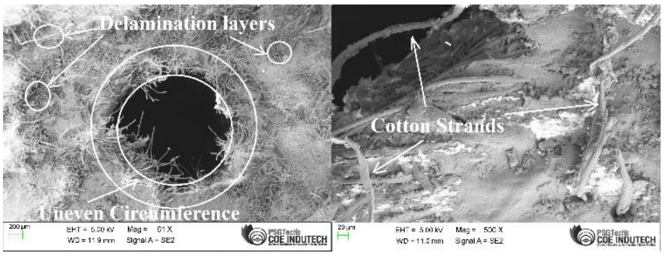

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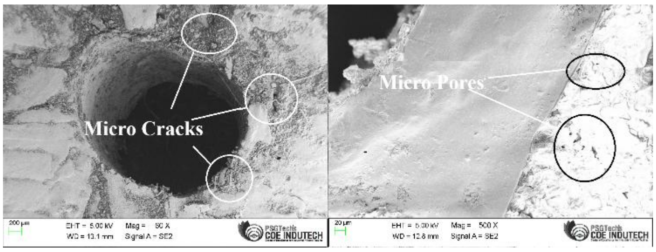

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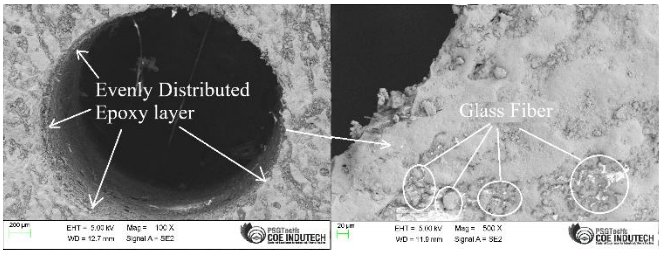

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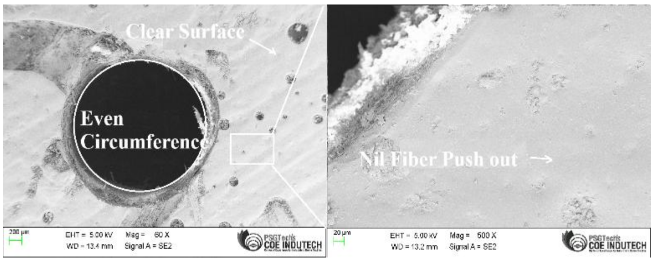

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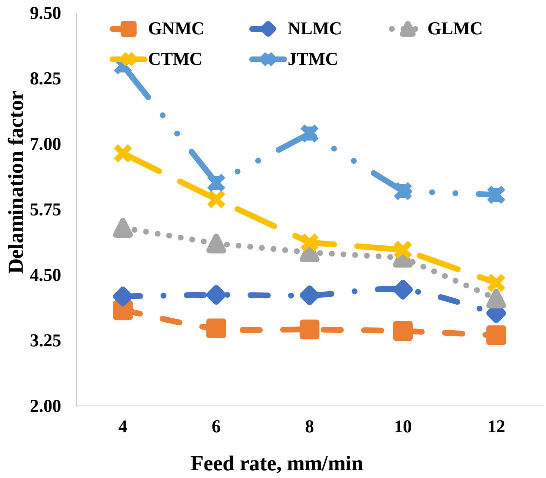
Fig. 4. SEM images of Hole machined on work materials: a – JTMC; b – CTMC; c – NLMC; d – GLMC; e – GNMC at the conditions of 60 rpm, 12 mm/min and 40 ºC

According to the graph, JTMC produces lowermost SR amid of all PMC's. In JTMC, SR is noted to be 34.6 % lesser than that of the GNMC with the parameter combination of 4 mm/min, 60 rpm, 12 mm/min and 40 ºC. For the similar parameter combination, CTMC produces subsequent lesser SR than GTMC. The arrangement of fibres in composite contributes for 29.2 % lesser SR than the GTMC. The SR for NLMC and GLMC is found to be 15.6 % and 12.35 % lesser respectively when compared to GNMC.



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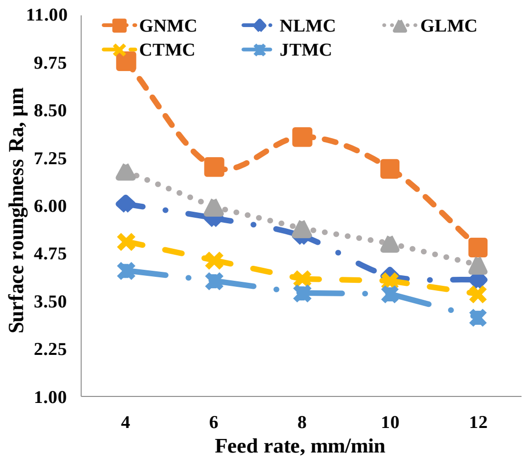
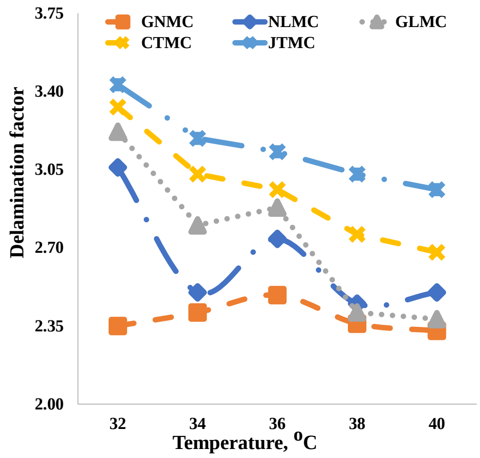


b

Fig. 5. Effect of feed rate on: a – DF; b – SR at 60 rpm and 40 °C constantly

Fig. 6 a reveals the effect of temperature on DF for different composites. It's noted from the graph that GNMC creates 2.42 DF for the parameter combination of 32 °C, 12 mm/min and 60 rpm. This is the very least DF value in this experiment. The NLMC produces the next least DF i.e 3.12 comparing with other JTMC for the same parameter combination.

The JTMC fibres are naturally lighter compared to NLMC and GNMC. Consequently, the GNMC and NLMC composites produce 48.1 % and 30.26 % lower DF, respectively, than JTMC. Furthermore, at the parametric combination of 34 °C, 12 mm/min feed rate, and 60 rpm drilling speed, the GNMC and NLMC exhibit the next lowest DF values of 3.31 (a 39.21 % reduction) and 3.65 (a 26.13 % reduction), respectively, when compared to JTMC. Similarly, GLMC and CTMC are produces another least DF when compared with the JTMC. The GLMC and CTMC create 3.25 and 3.43 DF respectively for the parameter combination of 32 °C, 12 mm/min, and 60 rpm.



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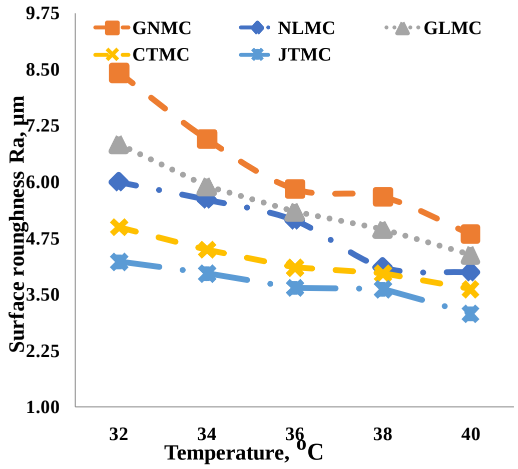

b

Fig. 6. Effect of IR Temperature on: a – DF; b – SR at 12 mm/min and 60 rpm constantly

Moreover, the composites produce the 25.3 % and 19.13 % lesser DF than JTMC. Furthermore with the parametric combination 34 °C, 12 mm/min, and 60 rpm, the GLMC and CTMC generates lesser DF of 3.35 (i.e 23.5 %) and 3.12 (i.e 19.63 %) respectively when compared to the JTMC.

Fig. 6 b demonstrates the influence of machining zone temperature on SR for different composite materials. It was observed that SR increases uniformly with a decrease in machining zone temperature. The rise in temperature enhances the malleability of the composite due to the elongation of its microstructure. This elongation process reduces the stiffness of the composite, leading to higher SR values [32]. Based on the analysis, JTMC exhibited the lowest SR among all composites. Specifically, the SR of JTMC was reduced by 43.6 % compared to GNMC under the parameter combination of 32 °C, 12 mm/min feed rate, and 60 rpm spindle speed. Under the same conditions, CTMC showed a 33.21 % reduction in SR compared to GNMC, while NLMC and GLMC recorded 21.6 % and 18.35 % lower SR values, respectively, relative to GNMC.

4. CONCLUSIONS

In this research, the most prominent and novel fiber meshes such gunnet, nylon, glass, cotton and jute are considered for epoxy composite fabrications and studied it's drilling characteristics. Infrared rays are employed to heat the machining zone and its temperature varied for 32 ºC to 40 ºC. The behaviour of composites on drilling operations were studied with major influencing process parameters such as drilling speed in rpm, feed rate in mm/min and temperature ºC. Among different fibre meshes reinforced composite gunnet fiber reinforced composite produces the lowest DF of 1.3 i.e 52.2 % lesser than the jute fiber reinforced composite with for the parameter combination of 60 rpm, 12 mm/min and 40 ºC. The least SR noted with the jute fibre reinforced composite which is found to be 44.6 % lesser than gunnet fibre reinforced composite for the same parameter combination. The study findings reveal that composites reinforced with both gunnet and jute fibres perform exceptionally well during drilling. The research highlights the composites' ability to maintain clean well-preserved structure with very little fiber damage. This property is vital for products where the drilled hole dimensional accuracy and structural integrity are critical. Consequently, these materials are recommended for applications in structural components like panels and brackets, as well as in demanding fields such as sporting goods, including bicycle frames and helmets. The strands of jute fibre and its cellulose, lignin's softness nature with the stiffness are affected by the machining and IR temperature on SR. The strands of jute fiber, along with the inherent softness of its cellulose and lignin components, are influenced by both machining and IR temperature, which in turn affects the SR. Furthermore, the glass fiber-reinforced composite and cotton fiber-reinforced composite exhibited higher DF compared to the jute fiber-reinforced composite, recording values of 4.95 and 5.68, respectively, under the parameter combination of 4 mm/min feed rate, 60 rpm spindle speed, and 40 °C temperature. The strands of jute fiber, along with the inherent softness of its cellulose and lignin components, are influenced by both machining and IR temperature, which in turn affects the SR. Furthermore, the glass fiber-reinforced composite and cotton fiber-reinforced composite exhibited higher DF compared to the jute fiber-reinforced composite, recording values of 4.95 and 5.68, respectively, under the parameter combination of 4 mm/min feed rate, 60 rpm spindle speed, and 40 °C temperature. SEM image studies are carried out on the circumference of drilled work piece to distinguish the effect of heating and fibers impact on drilling quality. Based on the conducted experiment, gunnet fiber reinforced composite shows the better DF which is suggested to the place where need of more accuracy and lesser surface finish. Further experiment can be planned with the same specimens using different coated drilling tools to enhance the surface roughness of hole wall.

REFERENCES

1. **Deepanraj, B., Saravanan, A.M., Senthilkumar, N., Afzal, A.A., Afzal, A.R.** Drilling Characteristics Optimization of Polymer Composite Fortified with Eggshells using Box-Behnken Design and Zebra Optimization Algorithm *Results in Engineering* 2025: pp. 104102. https://doi.org/10.1016/j.rineng.2025.104102
2. **Akter, M., Uddin, M.H., Anik, H.R.** Plant Fiber-reinforced Polymer Composites: A Review on Modification, Fabrication, Properties, and Applications *Polymer Bulletin* 81 (1) 2024: pp. 1 – 85. https://doi.org/10.1007/s00289-023-04733-5
3. **Pokhriyal, M., Rakesh, P.K., Rangappa, S.M., Siengchin, S.** Effect of Alkali Treatment on Novel Natural Fiber Extracted From Himalayacalamus Falconeri Culms For Polymer Composite Applications *Biomass Conversion and Biorefinery* 14 (16) 2024: pp. 18481 – 18497. https://doi.org/10.1007/s13399-023-03843-4
4. **Pankaj Kant, S., Jawalkar, C.S., Khatkar, S.K., Singh, M., Jindal, M.K.** Experimental Investigation on Mechanical Performance And Drilling Behavior of Hybrid Polymer Composites Through Statistical and Machine Learning Approach *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering* 2024: pp. 3350 – 3361. https://doi.org/10.1177/09544089231223022
5. **Sen, M., Eryilmaz, O., Bakir, B.** Micro Drilling Characterization of the Carbon and Carbon–Aramid (hybrid) Composites *Polymer Composites* 45 (6) 2024: pp. 5449 – 5459. https://doi.org/10.1002/pc.28138
6. **Khashaba, U.A.** Analysis of Surface Roughness, Temperature, Short Aging, and Residual Notched And Bearing Strengths In Supported Drilling of Thin Gfrp Composites *Alexandria Engineering Journal* 86 2024: pp. 157 – 173. https://doi.org/10.1016/j.aej.2023.11.057
7. **Mohanavel, V., Thanikasalam, A., Raja, T., Ravichandran, M., Ayyar, M., Lakshmanan, R., Soudagar, M.E.M.** Study on the Process Parameters of Delamination on Novel Madar/Ramie Fibers Reinforced Mgo Nanoparticles Blended Epoxy Matrix Composite *Results in Engineering* 2024: pp. 103738. https://doi.org/10.1016/j.rineng.2024.103738
8. **Manigandan, P., Senthil Vadivu, K., Veera Prabakaran, E., Arul Jothi, G.** Valorisation of Corn Waste As Fiber, Biosilica, and Their Epoxy Composites: Fatigue, Fracture Toughness, Water Absorption, and Drilling Properties *Biomass Conversion and Biorefinery* 15 2024: pp. 16891 – 16903. https://doi.org/10.1007/s13399-024-06306-6
9. **Kumar, G., Gupta, P., Naik, T.P., Sharma, A.K., Singh, I.** Drilling of Natural Fiber Reinforced Thermoplastic Composite Laminates Using Microwave Energy At 2.45 Ghz *Materials Today Communications* 38 2024: pp. 108419. https://doi.org/10.1016/j.mtcomm.2024.108419
10. **Ozdemir, B., Kilickap, E., Bahce, E., Yardimeden, A., Emir, E.** Optimization of Parameters For Drilling Composite Materials With Freeform Surfaces *Materials and Manufacturing Processes* 39 (1) 2024: pp. 55 – 68. https://doi.org/10.1080/10426914.2023.2187826
11. **Kannan, G., Thangaraju, R.** Effect of Industrial Waste Fly Ash On The Drilling Characteristics of Banana Fiber Residue Reinforced Polymer Composites *Journal of Industrial Textiles* 5 2024: pp. 2665S – 2687S. https://doi.org/10.1177/152808372211026
12. **Choudhury, M.R., Dutta, H., Srinivas, M.S., Debnath, K., Arunkumar, T., Upadhyay, V.** Optimizing Drilling Parameters For Fly Ash-Filled Hemp/Epoxy Composites: Investigating Drill Bit Geometries, Feed Rates And Spindle

Speeds *Materials Research Express* 11 (6) 2024: pp. 065302.
https://doi.org/10.1088/2053-1591/ad5816

13. **Ye, H., Zhang, J., Shang, Y., Xu, G., Zhan, J., Marguet, S., Wang, H.** Investigation of Hole Quality Enhancement In New Glass/Flax Laminates Via Hybrid Drilling Techniques *Composites Part A: Applied Science and Manufacturing* 190 2024: pp. 108651.
https://doi.org/10.1016/j.compositesa.2024.108651
14. **Rezghi Maleki, H., Hamedi, M., Kubouchi, M., Arao, Y.** Experimental Study on Drilling of Jute Fiber Reinforced Polymer Composites *Journal of Composite Materials* 53 (3) 2019: pp. 283 – 295.
https://doi.org/10.1177/0021998318782376
15. **Gürbüz, H., Akcan, İ.H., Baday, Ş, Demir, M.** Investigation of Drilling Performances, Tribological and Mechanical Behaviors of GFRC Filled with B4C and Gr *Arabian Journal of Engineering Science* 50 2024: pp. 9167 – 9184.
https://doi.org/10.1007/s13369-024-09392-w
16. **Dharmalingam, S., Meenakshisundaram, O. Victor, F.S.** Optimization of Drilling parameters for reduced Delamination Factor in Non-functionalized and Amine-Functionalized Luffa/Epoxy Composites *Journal of Polymer Research* 29 2022: pp. 344.
https://doi.org/10.1007/s10965-022-03197-x
17. **Srinivasulu, D., Devi, G.R.** Hole Surface Quality Analysis of novel Kenaffiber Epoxy Composite Laminate With and Without the Reinforcement of Stainless Steel Wire Mesh *AIP Conference Proceedings* 3193 2024: pp. 020162.
https://doi.org/10.1063/5.0233209
18. **Mishra, B.P., Mishra, D., Panda, P., Senapati, P., Mahapatra, T.R.** Experimental Investigation and FEA Implementation on Drilling of Graphene Reinforced GF/Epoxy Polymer Nano Composite Laminate Using Coated and Uncoated carbide Drills *International Journal of Machining and Machinability of Materials* 26 (3) 2024: pp. 193 – 222.
https://doi.org/10.1504/IJMMM.2024.141484
19. **Ramesh, G., Gokilakrishnan, G., Jayaraja, B.G., Patil, P.P.** High-content Al-T6/pineapple Fiber/brass Mesh Reinforcements on Nanosilica-Toughened Epoxy Hybrid Natural fiber Metal Laminate Composite for Aircraft Applications *Biomass Conversion and Biorefinery* 14 (13) 2024: pp. 14017 – 14025.
https://doi.org/10.1007/s13399-022-03354-8
20. **Kumar, M., Jena, H.** Impact of Process Parameters in Drilling of Glass Epoxy Composite with Clam Shell and Cenosphere Filler: A comparative analysis *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 238 (16) 2024: pp. 8258 – 8273
https://doi.org/10.1177/09544062241235090
21. **Seif, A., Sadoun, A.M., Fathy, A., Megahed, A.A.** Evaluation of hole Quality in Drilling Process of GF/Aluminum Wire Mesh Reinforced Epoxy Composites *Alexandria Engineering Journal* 94 2024: pp. 257 – 273.
https://doi.org/10.1016/j.aej.2024.03.013
22. **Shi, J., Zhang, W., Gu, S., Yuan, S., Zhang, J.** Physical and Mechanical Properties of Bamboo Fiber/Glass Fiber Mesh Reinforced Epoxy resin Hybrid Composites: Effect of Fiber Stacking Sequence *Journal of Natural Fibers 20* (1) 2023:pp. 2167145.
https://doi.org/10.1080/15440478.2023.2167145
23. **Seif, A., Fathy, A., Megahed, A.A.** Effect of Drilling Process Parameters on Bearing Strength of Glass Fiber/Aluminum Mesh Reinforced Epoxy Composites *Scientific Reports* 13 (1) 2023: pp. 12143.
https://doi.org/10.1038/s41598-023-39097-3
24. **Krishnasamy, P., Rajamurugan, G., Muralidharan, B., Arbat, A.P., Kishorkumar, B.P.** Effect of S-2304 Wire-Mesh Angle in Hemp/Flax Composite on Mechanical and Twist Drilling Surface Response Analysis *Journal of Industrial Textiles* 51 (2) 2022: pp. 2774S – 2798S.
https://doi.org/10.1177/1528083720988477
25. **Soundarrajan, M., Thanigaivelan, R.** Investigation on electrochemical micromachining (ECMM) of copper inorganic material using UV heated electrolyte *Russian Journal of Applied Chemistry* 91 (11) 2018: pp. 1805 – 1813.
https://doi.org/10.1134/S1070427218110101
26. **Soundarrajan, M., Thanigaivelan, R.** Electrochemical Micromachining of Copper Alloy through Hot Air Assisted Electrolyte Approach *Russian Journal of Electrochemistry* 57 (2) 2021: pp. 172 – 182.
https://doi.org/10.1134/S1023193521020117
27. **Saravanan, K.G., Rajasekaran, T., Soundarrajan, M.** Comparison of Electrochemical Micromachining Performance Using TOPSIS, VIKOR AND GRA For Magnetic Field and UV Rays Heated Electrolyte *Bulletin of the Polish Academy of Sciences: Technical Sciences* 69 (5) 2021: pp. 1 – 11.
https://doi.org/10.24425/bpasts.2021.138816
28. **Kumar, D.S., Thanigaivelan, R., Natarajan, N.** Performance Optimisation of the Turning Process Along With Multi-Surface Heating Process *Materials Science-Poland* 40 (4) 2022: pp. 1 – 13.
https://doi.org/10.2478/msp-2022-0041
29. **Malik, K., Ahmad, F., Keong, W.T., Gunister, E.** The Effects of Drilling Parameters on Thrust Force, Temperature And Hole Quality of Glass Fiber Reinforced Polymer Composites *Polymers and Polymer Composites* 30 2022: pp. 1 – 19.
https://doi.org/10.1177/09673911221131113
30. **Kamath, G., Mishra, B., Tiwari, S., Bhardwaj, A., Marar, S.S., Soni, S., Anjappa, S.B.** Experimental and Statistical Evaluation of Drilling Induced Damages in Glass Fiber Reinforced Polymer Composites–Taguchi Integrated Supervised Machine Learning Approach *Engineered Science* 19 2022: pp. 312 – 318.
https://doi.org/10.30919/es8d733
31. **Thangaraj, R.P., Shanmugam, B.** Performance of RC beams Developed with ECC layer and AR Glass Fiber Mesh under Flexural Loading *Matéria (Rio de Janeiro)* 29 (3) 2024: pp. e20240125.
https://doi.org/10.1590/1517-7076-RMAT-2024-0125
32. **Goutham, E.R.S., Hussain, S.S., Muthukumar, C., Krishnasamy, S., Kumar, T.S.M., Santulli, C., Jesuarockiam, N.** Drilling Parameters and Post-drilling Residual Tensile Properties of Natural-Fiber-Reinforced Composites: A review *Journal of Composites Science* 7 (4) 2023: pp. 136.
https://doi.org/10.3390/jcs7040136