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Comparative Analysis of delamination factor in CNC drilling of novel flax fiber-reinforced aluminum wire mesh sandwich composite and flax fiber laminate with $90^0/0^0/90^0$ply orientation angle

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Abstract

Aim: There has been using natural flax fiber and biodegradable polymers due to their environmental sustainability. The use of natural flax fiber the fabrication is done and the delamination factor is tested in CNC and it is drilled by using Carbide Tipped Drill (8 mm). This study aims to Compare delamination factor in CNC drilling of Novel Flax Fibre-reinforced aluminum wire mesh sandwich composite and Flax Fibre laminate with $90^0/0^0/90^0$ ply orientation angle **Materials and Methods:** The work material is chosen for this study is Aluminum wire mesh of grade 6092 and flax fiber. The type of drill bit selected for drilling operation is Tungsten Carbide Tipped drill bit. Two input parameters considered are cutting speed (m/min) and feed rate (mm/rev). Two groups of experimental study are selected with 20 samples per group and delamination factor is measured for all the samples and the average is utilized for roughness calculation. On the whole 40 samples are collected and measured for 2 groups with g-power 80% used for calculating sample sizes. **Results:** The delamination factor obtained during the study is measured and analyzed. All the results obtained were analyzed for their significance by SPSS software and the graphs were plotted and the level of significance was found to be 0.024 ($p<0.05$). **Conclusion:** Within the limitations of this study, the analysis of flax fiber laminate with ($90^o/0^o/90^o$) ply orientation angle has produced a delamination factor of of 1.1370 for the samples reinforced with Aluminium mesh and the mean delamination factor of 1.2045 for samples reinforced without Aluminium mesh with an improvement of 5.9% in reducing delamination factor comparing base materials.

Keywords

Novel Flax Fiber, Aluminum wire mesh, Delamination, Ply orientation angle, CNC, Epoxy, SPSS Software.

INTRODUCTION

The Flax fiber is extracted from the bast beneath the surface of the stem of the flax plant. According to Liebig's law, weather conditions are the key limiting factor that impacts flax yield in many parts of Europe (precipitation) (Heller and Byczyńska 2015). It is found that flax fiber composites with reinforcement can produce enhanced mechanical properties by the factor of 3 to 4 compared to common Non-woven flax composites and they can compete with manufactured based glass-fiber composites in terms of stiffness. The effects of chemically treating flax fiber mats with acetic anhydride (AA) were examined ((Fathi et al. 2019; Depuydt et al. 2019). Vacuum bagging was used to make unidirectional fiber composites from bio-based epoxy resin and conventional epoxy resin (Loong and Cree 2018). The mechanical properties of flax fiber were measured using a single fiber strength meter, the average fineness of a single fiber, qualitative and quantitative chemical composition analysis using an infrared spectrophotometer, crystallinity, and orientation using an X-ray diffractometer, and physical morphology using a scanning electron microscope (Z. Li et al. 2020). Without stopping fiber reinforcement was introduced in the beget of UD type 5009 flax fibers (Switzerland) for fabrication of Flax Fibre-composites. /Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative as man-made fibers used for the manufacturing of composites (Habibi et al. 2020).

About 2,289 articles were published in Google Scholar and 1,338 articles were published in ScienceDirect from the past 5 years. By using compression after impact (CAI) tests, this research looked into the damage tolerance and damage progression of a non-woven flax composite's compressive failure. The effects of parameters such as impact form, delamination region, and impactor penetration on compressive behavior were investigated (Maroju 2011). In the current years, Commonplace fibers have played a noteworthy role in kipping environmental sustainability with the application of these fibers in polymer composites. During the last decade, there is a growing interest in growing commonplace flax fibers that was reinforced in the environmental awareness, international authority policy, and regulation (X. Li et al. 2006). Natural fibers have been approved as a great alternative to typical polymer composite reinforcements (Fathi et al. 2019). The appeal of Commonplace flax fibers as a choice reinforced sandwich composite comes from its highly narrated to particular properties (strength and stiffness) and excellent eco-friendly performance when compared to old-fashioned fibers for example glass.The delamination behavior and hole quality of flax/epoxy composite laminates are investigated in this research in relation to feeding, spindle speed, and three distinct types of the drill bit (Maleki et al. 2019). From the literature considered, the closely related best study is the analysis of delamination factor during high-speed edge trimming of flax fiber composite (Fathi et al. 2019)).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Venu and Appavu 2021; Gudipaneni et al. 2020; Sivasamy, Venugopal, and Espinoza-González 2020; Sathish et al. 2020; Reddy et al. 2020; Sathish and Karthick 2020; Benin et al. 2020; Nalini, Selvaraj, and Kumar 2020).The unanswered question is: is aluminium mesh included in the fiber matrix composite will decrease the delamination property?. Hence in this research approaches with available research facilities and eminent faculties, the test aimed to compare kenaf fiber reinforced with aluminium wire mesh (flax+aluminium+flax+aluminium+flax) and without aluminium wire mesh ($90^0/0^o/90^o/0^o/90^o$) orientation angle, and find the composite which prompted diminished delamination. Thus the delamination factor to keep up with ideal machining conditions. The drilled samples were utilized for this investigation.

MATERIAL AND METHODS

The machining and the drilling process is administered at Saveetha Industries, Saveetha School of Engineering (SSE), Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai. As no human samples involved no ethical approval required. There are 2 groups and sample size was calculated with use of mean 2.23 and 1.35 and SD of 0.1204. Control groups are done using unidirectional Novel flax fiber in different angles without reinforcement of aluminium wire mesh (flax ($90^o/0^o/90^o/0^o/90^o$). Experimental groups are made using reinforcement of aluminium wire mesh. The G power 80% and alpha 0.05 set for calculating sample size of 20 samples per group with a total of 40 samples (Herakovich 1997).

In the last few years, the use of flax fibers as reinforcement in composites was well-liked due to increased provisions for developing sustainable materials. Flax fibers are more costly than other fibers and provide particular mechanical properties comparable to glass fibers. Composites composed of flax fibers with thermoplastic, thermoset, and biodegradable matrices have exhibited excellent mechanical properties and for a few years, the use of flax fibers as reinforcement in composites has gained popularity due to the increasing requirement for developing composite materials.

The raw materials utilized for manufacturing the composite materials are Flax Fiber, aluminum cable mesh reinforcement materials. These are utilized in the Quality Money industry and it's gathered in fiber location Chennai, Bharat for manufacturing the composite materials with flax fiber, Epoxy (LY-556)and Hardener(HY-556)is utilized and it's gathered from hayavel aerospace Bharat Pvt Ltd, Chennai, India.

Drilling was performed on the Drilling machine under the distinctive machining conditions, for example, feed rate (mm/min) and speed (rpm). All the samples are drilled for assessing the surface roughness of the drill hole. The tungsten carbide drill of 8 mm diameter was utilized to drill the holes using a CNC Drilling machine as shown in Fig. 1. Testing setup to execute the damage quality of drilled surface was determined by placing the analyzed sample beneath the Celestron microcapture 2000 stereo microscope to detect the induced entry surface delamination, After the image has been captured, the software's tool measurements function is used to perform the measurement. The drilled specimen is shown in Fig. 2.

Standard of machining process of the material is done as per the ASTM standards. The parameters used in this study are drilling speed, feed rate, drill bit diameter to measure delamination factor. The equation (1) is used to determine the delamination factor of the composite laminate.

$$F_d = D_{max} / D_0 \quad (1)$$

Where, F_d = Delamination Factor
D_{max} = Maximum diameter of the hole at delaminated zone in mm
D_0 = Nominal diameter in mm

Statistical analysis:

Independent sample T-test was used to analyze the significance of with and without addition of aluminium wire mesh in flax fiber reinforced polymer composites. The statistical analysis SPSS V.26 was used to calculate the standard deviation, standard error, mean. In this experiment the independent variables are spindle speed, drill bit diameter, feed rate and the dependent variable is delamination factor (Loong and Cree 2018).

RESULTS

The CNC drilling on (Flax fiber without aluminum wire mesh) is drilled with the consideration of speed, feed rate, and drill diameter respectively. The corresponding delamination factor values of group 1 and group 2 are shown in Table 1. The delaminated zone in flax fiber epoxy composite and flax fiber with aluminium wire mesh strengthened epoxy composite is shown in Fig. 3. Bar chart in Fig. 4 shows the comparison between the mean delamination factor of Novel flax fiber samples reinforced with AA 6092 mesh and Novel flax fiber samples reinforced without AA 6092 mesh drilled using Carbide drill.

Independent T-test used to be carried out amongst control and experimental group outcomes of statistical software program SPSS v.26, and the obtained results as shown in Table 2, the place the suggest and trendy deviation of flax fiber epoxy composite is 2.68 µm and 0.35 The flax fiber with aluminium wire mesh strengthened epoxy composite, they imply and general deviation is 1.87µm and 0.65 µm. Table 3 presents Levene's test for equality for variances for the delamination factor obtained for the control and experimental groups.

DISCUSSIONS

In this study, flax fibre reinforced with aluminium wire mesh laminate is drilled and the effect of process parameters on delamination factor are analyzed and presented. The result shows that the flax fiber with metal mesh has lower delamination issues as compared to plain Flax fiber composite. The research also allowed for the display of a few flax fiber internal features, such as the organization of meso- and micro-fibrils (nano-fibrils). The delamination of the flaxy fiber epoxy composite was exhibited with 1.2045 and standard deviation of 0.11 for 20 sample specimens. Flax fiber with aluminum wire mesh exhibited the average delamination of 1.1370, and a standard deviation of 0.32 From the independent t-test, flax fiber with aluminum wire mesh shows greater significance than flax fiber epoxy composite p = 0.024 ($p<0.05$).

Flax fiber reinforced aluminium wire mesh sandwich laminates give better stiffness and strength to the composite laminate compared to flax fiber laminates without aluminium wire mesh (Maroju 2011; Maleki et al. 2019). The extrusion and injection molding were used to create biocomposites from flax fiber with fiber content ranging from 10% to 30% by mass (X. Li et al. 2006). The delaminated zone around the hole on both sides of composites laminates clearly shows the fiber pullouts and aluminium wire mesh damaged part (Z. Li et al. 2020). During each drilling operation the crack propagation around a hole leads to damage initiation in flax/epoxy composites and the damage evolution. At different damage stages, a direct correlation between the percentage of cracks and the mean strain was observed (Sawi et al. 2014). Good bonding between the composite layers will reduce the delamination of the layers. The bonding strength can be achieved by improved interlaminar adhesion ((Z. Li et al. 2020; Heller and Byczyńska 2015).

The limitation of this study is the formation of built in edges during drilling of flax fiber around the periphery of the drilled hole. Hence, the study can be focussed in the future to reduce the built-in edges. The investigation can further be elaborated to analyze process parameters in drilling a variety of natural fiber based sandwich metal laminates is considered to be future scope of present investigations.

CONCLUSION

Within the limitations of this study, the analysis of flax fiber laminate with ($90^o/0^o/90^o$) ply orientation angle has produced a delamination factor of of 1.1370 for the samples reinforced with Aluminium mesh and the mean delamination factor of 1.2045 for samples reinforced without Aluminium mesh with an improvement of 5.9% in reducing delamination factor comparing base materials.

DECLARATION

Conflict of interests

The authors of this research declare no conflict of interest.

Authors' Contribution

Author PA was involved in data collection, data analysis, and manuscript writing. Author GRD was involved in conceptualization, data validation, and critical review of the manuscript.

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TABLES AND FIGURES

Table 1. Value of Delamination Factor

Trial No.	Delamination Factor	
	Novel Flax Fiber Reinforced without Aluminum Wire Mesh Sandwich Composite Laminate with $90^0/0^0/90^0$ ply orientation angle	**Flax Fiber laminate with $90^0/0^0/90^0$ ply orientation angle**
1.	1.2645	1.3265
2.	1.1231	1.2658
3.	1.0212	1.1548
4.	0.7551	1.0135
5.	1.8215	1.2523
6.	1.4642	1.3463
7.	0.2251	1.1058
8.	1.3215	1.3521
9	0.8916	1.0315
10	1.4352	1.4042
11	1.1321	1.2482
12	1.2311	1.2225

13	0.7756	1.2258
14	1.2525	1.3345
15	1.1425	1.1683
16	1.1034	1.0356
17	1.4621	1.2214
18	0.9924	1.1054
19	1.1423	1.1125
20	1.1832	1.2251

Table 2. GroupStatistics from the Independent T-test Analysis

Group Statistics					
	Groups	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Delamination Factor	**Novel Flax Fiber Reinforced without Aluminum Wire Mesh Sandwich Composite Laminate with $90^0/0^0/90^0$ ply orientation angle**	20	1.1370	.32557	.07280
	Flax Fiber laminate with $90^0/0^0/90^0$ ply orientation angle	20	1.2045	.11492	.02570

Table 3. Levene's test for equality for variances

Independent Samples Test										
		Levene's Test for Equality of Variances		**t-test for Equality of Means**						
		F	**ig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
Delamination Factor	**Equal variances assumed**	5.522	0.024	-.874	38	388	-.06748	.07720	-.2237	.8881
	Equal variances not assumed			-.874	23.662	391	-.06748	.07720	-.2269	.09198

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Fig. 1 CNC drilling machine


Fig. 2 Flax Fibre laminate after drilling

Fig. 3 Image of Delamination factor

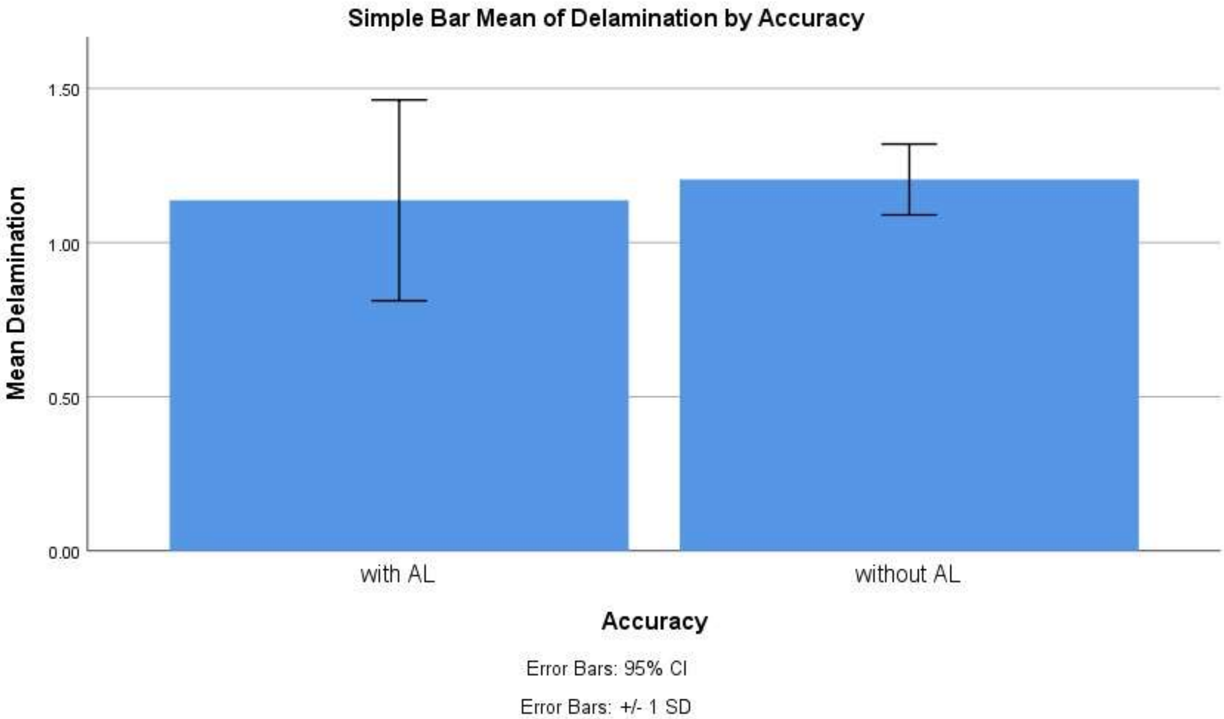

Fig. 4 Bar chart shows the comparison between the mean delamination factor of Novel flax fiber samples reinforced with AA 6092 mesh and Novel flax fiber samples reinforced without AA 6092 mesh drilled using Carbide drill. The obtained mean values show that the samples of Novel flax fiber without AA 6092 mesh have lower delamination factor than the samples of Novel flax fiber with AA 6092 mesh for 90°/0°/90° ply orientation angle. X-axis: Mean delamination factor of Novel flax fiber without AA 6092 mesh vs Novel flax fiber with AA 6092 mesh. Y-axis: Mean of groups ± 1 SD and error bars of 95% CI.