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Mechanical Properties of Novel Hybrid Bamboo Fibre/ Aluminium Mesh Reinforced Polymer Composite

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ABSTRACT

Bamboo fibres are one of the sustainable lignocellulosic resources explored for polymer composites in recent years. Research has shown that bamboo fibres have the potential to be used in a variety of critical applications. Nevertheless, bamboo fibres are susceptible to thermal and hygroscopic loads, and their mechanical properties are limited by the unequal interfacial strength and varying fibre dimensions. Implementing hybrid procedures or incorporating alternative materials, such as aluminium metal, is strongly advised to address this issue. Thus, this study investigates the tensile and flexural performances of the hybrid bamboo fibre/aluminium expanded mesh-reinforced polymer composites. The composites were fabricated using epoxy resin reinforced with bamboo fibre, and an aluminium expanded mesh sheet was constructed using a vacuum infusion process utilising various stacking sequences and mesh sizes. The test findings indicated that the composite material exhibited tensile stress values ranging from 27 to 34 MPa

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and a corresponding tensile strain value between 1.1% and 1.6%. The flexural strength and strain values were measured within the range of 44 Mpa to 59 Mpa and 2.2% to 3.2%, respectively. ANOVA analysis showed that both stacking sequences and mesh size significantly affected the tensile performances of the composites, while only stacking sequences affected the flexural performance significantly. Overall, a hybrid composite of bamboo fibre and aluminium mesh is well-suited as a substitute material in industries requiring exceptional mechanical properties.

Keywords: Aluminium mesh sheet, bamboo fibre, hybrid composite, mechanical properties, natural fibre composite

INTRODUCTION

The increasing awareness of green and sustainable materials has attracted more researchers to use natural fibre-reinforced composite (NFRP) in their studies (Lopes et al., 2021; Noori et al., 2021). Natural fibre has been considered as an alternative material to synthetic fibre owing to its benefits of being lightweight, renewable, biodegradable, having high strength and elastic modulus, available at low cost, possessing low energy requirements, and abundant in nature, as reported by many researchers (Adeniyi et al., 2019; Balla et al., 2019; Cavalcanti et al., 2019; Li et al., 2020; Nascimento et al., 2021; Otto et al., 2017; Oushabi, 2019; Todkar & Patil, 2019).

Depending on its source, natural fibre can be divided into three categories: mineral, animal, and plant (Alemayehu et al., 2020; Bahja et al., 2020). Among them, plant fibres have the advantage of being abundant and having higher producibility than animal and mineral fibres. Plant fibre properties can also be classified into their origin: stems, leaves, and seeds. Often, natural fibres have drawbacks and limitations, including inhomogeneity properties, high water absorption, and water regains; nevertheless, studies on the NFRP composites keep updated and improved over the years and have been involving many types of plant fibre, such as bamboo (Wang et al., 2022; Yuan et al., 2022), kenaf (Atiqah et al., 2020; Rozyanty et al., 2020), jute (Dhiman & Sharma, 2020; Reddy et al., 2020), banana (Batu & Lemu, 2020; Girimurugan et al., 2020), and pineapple leaf (Umanath et al., 2019).

Among natural plant fibres mentioned, bamboo fibre has superior fibre properties and can be found easily, especially in China and Southeast Asia. According to the news by the International Bamboo and Rattan Organisation (INBAR), over 70 species have been reported in Malaysia alone, with 16 commercially viable species (Joest, 2017). Bamboo fibre may have higher mechanical strength, lower specific weight ratio, higher tensile strength and a higher modulus of elasticity than other natural fibres. Owing to its strength, bamboo, also known as natural glass fibre (Shireesha & Nandipati, 2019), with the tensile strength of a bamboo fibre bundle, can reach the same heights as jute fibre (Okubo et al., 2004; Sen & Reddy, 2011). Concurrently, other studies claimed that bamboo's strength makes it an appealing alternative to steel in tensile stress applications (Rassiah & Megat Ahmad, 2013).

Nowadays, research on bamboo fibre as a compositional reinforcement has gained popularity among researchers, and most studies have investigated bamboo polymer composites. Although research on the use of natural fibre can overcome problems related to sustainability, there is no denying that natural fibre-reinforced polymer composites have their own problems. For instance, high moisture absorption and low bonding strength between natural fibre and matrix are among the problems reported by previous literature (Yadav & Singh, 2021).

Thus, research introducing an upgraded type of composite, also known as hybrid composite, has been done to overcome these problems. Hybrid composites combine more than one reinforcement material to enhance the composite's mechanical, physical and thermal properties, and one of the reinforced materials used is Aluminium (Al). Aluminium is highly used in the production of composites because of its high strength-to-weight ratio and strong fatigue tolerance (Gonzalez-Canche et al., 2017). Besides, aluminium has the best formability when hybridised with fibre-reinforced polymer composites (Kavitha et al., 2020). Table 1 tabulates the studies on aluminium and bamboo as a reinforcement of hybrid composites in recent years.

Table 1
Aluminium/bamboo reinforced composites reported in recent years

No	References	Materials	Properties
1	Sheng et al. (2023)	Aluminium plate (3- and 6-mm thickness) and bamboo scrimber (Moso bamboo)	Flexural properties
2	Harikumar and Devaraju (2020)	Aluminium oxide (nanoparticles) and bamboo fibre	Hardness, impact, tensile, and flexural properties
3	Kali et al. (2019)	Aluminium sheet (0.5 mm thickness), bamboo stripe, carbon fibre, and glass fibre	Vibration characteristics

In addition to the hybrid composite studies, fibre metal laminate (FML) is another type of hybrid composite that has been certified to improve the mechanical properties of composites. Furthermore, In their review, He et al. (2021) stated that aluminium is the most commonly used metallic material in fibre metal laminate composite due to its high impact resistance and superior ductility. Gonzalez-Canche et al. (2017) investigated the tensile properties of FML reinforced with low aluminium alloy and aramid fabric. Tensile studies demonstrated that FMLs are more ductile than their constituents, as observed by a 230% increase in strain to failure compared to the composite laminate of aramid fabric and a 400% increase compared to aluminium sheet. Another study by Megeri and Naik (2021) focused on the impact behaviour of hybrid FML reinforced with aluminium, carbon and glass fibre, which discovered the ability of hybrid FML to withstand more impact loading than glass FML. In addition, using high-stiffness carbon fibre increased the impact resistance of hybrid FML.

While studies regarding FML demonstrated a gain in mechanical properties, these composites still have a significant disadvantage: low interface roughness between the aluminium and fibre layers. Due to this difficulty, further research has been conducted to improve the interface bonding of this reinforcement. One method for improving this bonding interface is substituting aluminium wire mesh for the aluminium sheet (Arun Prakash & Julyes Jaisingh, 2018; Megahed et al., 2021). According to a study by Megahed et al. (2021), adding aluminium wire mesh layers improved tensile strain by 54% and flexural strain by 117.5% compared to glass fibre-reinforced polymer composite. In addition, the presence of an Al mesh layer in the first and last layers, where the highest shear and normal stresses occur, allowed for ductile deformation of the Al layers, which increased the failure strain.

Using bamboo fibres and aluminium as reinforcement in the composite has been discussed, highlighting important insights and advantages. Hybridisation research can be done to examine the different qualities of both materials. However, the hybridisation of aluminium wire mesh and natural fibre, especially bamboo fibre, was less in number. There is a scarcity of durable hybrid bamboo fibre/aluminium reinforced polymer composites, essential for critical applications as a replacement for synthetic composite materials currently available. Therefore, this study was conducted to determine the feasibility and the properties of hybridising the bamboo fibre and aluminium mesh sheet in the composites, also known as bamboo fibre/aluminium mesh reinforced polymer composites (BFAMRP).

MATERIALS AND METHOD

Materials Preparation

This study employs two reinforcement materials: bamboo fibre nonwoven preform and aluminium expanded mesh. Bamboo fibres were mechanically extracted from *Schizostachyum grande* or *Buluh Semaliang* among locals. This type of bamboo was chosen for this study because it was widely distributed throughout Malaysia. Furthermore, this bamboo has been classified as one of 13 varieties of bamboo that can be commercialised in Malaysia. According to a study by Siam et al. (2019), this variety of bamboo also has some of the highest modulus of elasticity (MOE) and modulus of rupture (MOR) values, which was advantageous in the production of polymer-based composite materials. The bamboo was harvested in Sungai Petani, Kedah, Malaysia and supplied by Hangterra Bamboo Sdn

Bhd., Kedah, Malaysia. This study used two sizes of aluminium expanded mesh: a small mesh size of 3.5 mm x 2.0 mm and a large mesh size of 4.0 mm x 3.0 mm. Epoxy resin with a 2.7 g/cm^3 density was used for the matrix composite. The properties of materials used in this study are depicted in Table 2.

Table 2
Materials used in the study

Material	Notes
Bamboo fibre	Type of bamboo: Schizostachyum Grande (Semaliang)
Fine mesh aluminium sheet	Mesh size: 3.5 mm x 2.0 mm, Orientation: 60°, thickness of the wire strand 0.5mm
Medium mesh aluminium sheet	Mesh size: 4.0 mm x 3.0 mm, Orientation: 60°, thickness of the wire strand 0.8mm
Epoxy resin 1006	Epoxy to hardener weight ratio 10:6

The processing of bamboo fibre nonwoven preform entails several stages. The initial stage was fibre extraction. The internode of the bamboo pole was cut into long with a width of 20 to 25 mm. Besides easing the fibre extraction process, a specific strip width size is necessary to ensure the desired physical fibre obtained is fine and homogenous. Next, the bamboo strips were retted by soaking them in normal water at room temperature for two days to allow them to soften. The retted bamboo strips were then inserted into a fibre decorticator. The fibres extracted from the fibre decoticator were collected to remove residuals and impurities before being washed. Previous reports proved that alkaline treatment would increase surface bonding between reinforcement and matrix (Manalo et al., 2015; Sánchez et al., 2020; Vigneshwaran et al., 2020). Thus, the bamboo fibres were treated by soaking them in a solution of 5% NaOH for 24 hours at room temperature, as suggested by Getu et al. (2020). Later, the fibres were washed several times under running water to neutralise them before being dried in an open space for three days. The final stage in making bamboo fibre preform was the needle punching nonwoven method. The fibres were gathered and fed into the nonwoven opening section, followed by blow room and carding, before being fed into the needle punching section. The machine parameter was set following 400 gsm of bamboo fibre nonwoven output. Each layer of bamboo fibre nonwoven mat weighed 12.5 ± 0.5 g. Figure 1 summarises the overall steps of making a nonwoven bamboo fibre preform.

Eight types of BFAMRP composites with four different stacking sequences and two mesh sizes of the aluminium mesh sheet were developed for this study. Each composite was comprised of five layers of reinforcement with a dimension of 300 mm x 300 mm. Table 3 depicts the composition of the specimen, including the code, stacking sequence, and Al mesh type. As adapted from Chokka et al. (2020), the vacuum infusion technique was used for the present study. The composites were left at room temperature for 24 hours to cure.

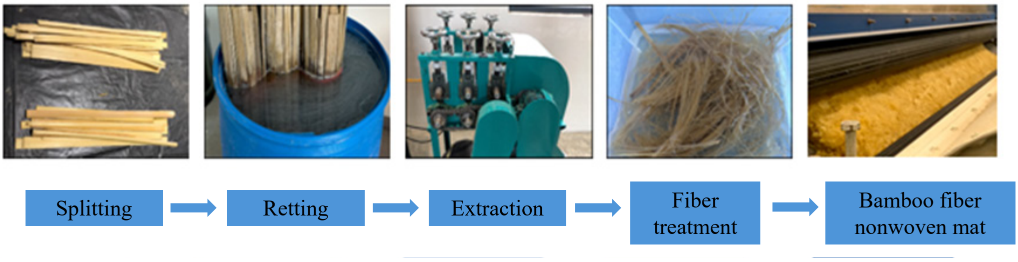


Figure 1. Steps to produce bamboo fibre nonwoven preform

Table 3
BFAMRP composites code, stacking sequence, mesh size, and average thickness

No	*Specimens code	**Stacking sequence	Mesh size	Avg. thickness, cm
1	A1S	A/B/A/B/A	S	0.51
2	A1L		L	0.54
3	S2S	B/A/A/A/B	S	0.51
4	S2L		L	0.56
5	A3S	B/A/B/A/B	S	0.60
6	A3L		L	0.63
7	S4S	A/B/B/B/A	S	0.51
8	S4L		L	0.55

* First letter indicated stacking structure; A*:* alternate structure, and S*:* sandwich structure
* Middle number indicated stacking sequence
* The last letter indicated the size of the mesh: S—small mesh, and L—large mesh
** A: Aluminium expanded mesh, B: Bamboo fibre nonwoven mat

Tensile and Flexural Tests

The tensile test of BFAMRP composites was conducted according to the ASTM D3039 standard using a Shimadzu Servopulser E-Type loading frame in the Machine Testing Laboratory at the Faculty of Mechanical and Manufacturing, UTHM. During the test, the specimens with the dimensions of 250 mm x 25 mm each were put in the machine's grips, while axial tensile loads were applied to the samples at a 2 mm/min loading rate. A repeatability test of three samples for each group of specimens was conducted to ensure the accuracy of the results. Tensile strength, tensile strain, and Young Modulus were obtained and discussed.

A flexural test was performed using the ASTM D790 three-point method. The Shimadzu Universal Testing Machine (UTM) of the Polymer Laboratory, Faculty of Mechanical and Manufacturing Engineering, UTHM, was utilised to perform the test. Specimens with 127 mm x 12.7 mm dimensions were loaded into the three-point bending fixture at 2 mm/min. The span of the supports was set to 80 mm for the flexural test, and the pin diameter of 5 mm was used throughout the test. The load was applied at the specimen's mid-span, and the resulting load and displacement values were recorded. Five tests for each specimen set were repeated to ensure an accurate result.

Scanning Electron Microscope (SEM) Analysis

The fracture specimens of BFAMRP composites from both tensile and flexural samples were observed using a high-resolution Scanning Electron Microscopy (SEM) machine, JEOL JSM-6380LA, located at Material Science Laboratory, UTHM. Morphological assessment using SEM was performed to determine the integration between the matrix and reinforcement after applying loads. It was also used to observe the microscopic failure of composites at different stages, including elastic, plastic, local fracture of fibre layer, and delamination stages (He et al., 2021). Before observing the specimens, the specimens underwent a coating process by JEOL Auto Fine Coater.

Analysis of Variance (ANOVA)

Statistical analysis of the measured tensile and flexural performances of BFAMRP composite was performed with the general linear model (GLM) of analysis of variance (ANOVA) using MINITAB 19 Software. The analysis was conducted at a 5% significance level.

RESULTS AND DISCUSSION

Tensile Test

Table 4 shows the ANOVA table for the tensile properties of BFAMRP composites. According to Table 4, the stacking sequence significantly affected the tensile performance with a *P*-value of less than 0.05. However, the mesh size also significantly affected the tensile performance. The contribution percentage also showed that the stacking sequence was the main factor that affected all the tensile strength and tensile strain of the BFAMRP composite.

Figure 2 illustrates the tensile stress-strain curve of BFAMRP composites. Generally, all eight specimens displayed the same stress-strain curve trend, which was linear behaviour along the elastic region curve before the failure point. From observation, specimens with aluminium at the outer layer had better tensile stress than specimens with bamboo at the outer layer. This is a result of the ductility of the aluminium (metal mesh), which prevented the formation of fractures and, consequently, their propagation, thereby increasing the tensile stress (Choudary et al., 2020). Additionally, specimens with smaller aluminium mesh sizes have greater tensile performances compared to those with larger mesh sizes. This finding was substantiated by a study conducted by Tanawade and Modhera (2017), wherein it was observed that the close proximity of the mesh wires resulted in elevated tensile loads on the specimens. The presence of aluminium ductile material might cause slight curvature linear trends. The curve showed a similar trend in hybrid composite material reinforced with carbon and glass fibres with wire mesh, as Hasselbruch et al. (2015) and Prakash and Jaisingh (2018) reported. The failure points for overall specimens had significant differences at different strain levels.

Table 4
ANOVA results for tensile properties

Source	DF	Adj SS	Adj MS	*F*-value	*P*-value	% Contribution
1. Tensile stress						
Stacking sequence (SS)	3	71.93	23.978	10.41	0.000	39.49
Mesh size (MS)	1	49.93	49.931	21.69	**0.000**	27.41
SS * MS	3	23.47	7.824	3.40	**0.044**	12.88
Error	16	36.84	2.302			
Total	23					
2. Tensile strain						
Stacking sequence (SS)	3	0.6461	0.21538	15.57	**0.000**	54.74
Mesh size (MS)	1	0.1190	0.11900	8.60	**0.010**	10.08
SS * MS	3	0.1938	0.06462	4.67	**0.016**	16.42
Error	16	0.2214	0.01384			
Total	23					

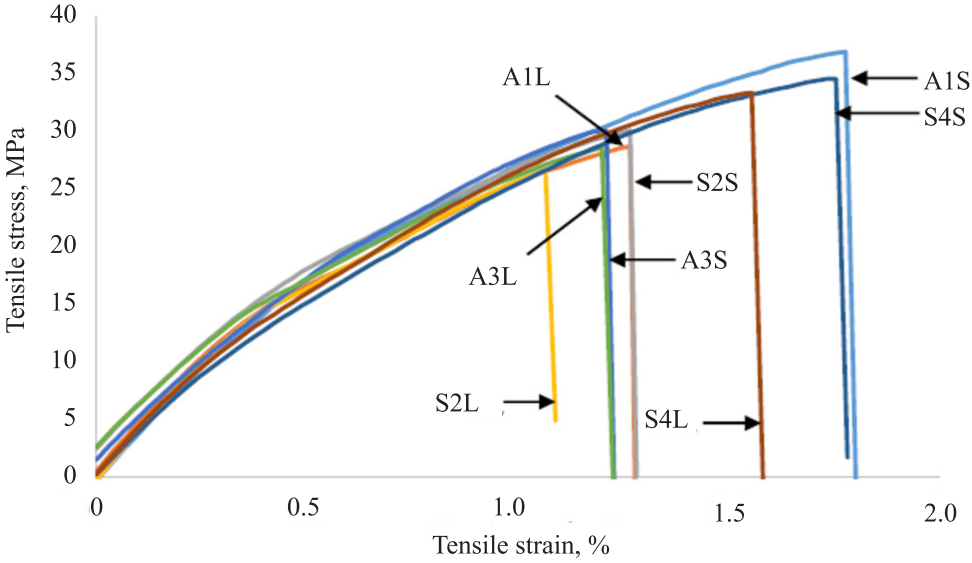


Figure 2. The tensile stress-strain curve of BFAMRP composites

Table 5 tabulates the tensile stress and tensile strain results. Among those with considerable maximum stress and strain values were specimens A1S, with a stress value of 34.22 MPa and a percentage strain value of 1.6%, respectively. This result was influenced by the aluminium mesh position on the exterior of the composite, which served to safeguard the bamboo fibre nonwoven mat layer, which was more delicate. Furthermore, the stress and strain values of this specimen were also enhanced by using a small mesh aluminium mesh sheet. These results were also supported by a study conducted by Tanawade and Modhera (2017), in which it was noted that the mesh wires being positioned closely together led to increased tensile loads on the specimens. In comparing the specimen S2L's lowest value of 27.28 MPa for tensile stress and 1.1% for tensile strain, the data showed an increase of 25.4% for tensile stress and 45.45% for tensile strain percentage.

Table 5
Tensile properties of BFAMRP composites

Specimens code	Tensile stress, MPa		Tensile strain, %	
	Mean	Std Dev	Mean	Std Dev
A1S	34.22	2.45	1.61	0.19
A1L	28.11	0.58	1.21	0.11
S2S	29.97	0.55	1.30	0.05
S2L	27.28	0.77	1.10	0.09
A3S	29.99	1.16	1.10	0.10
A3L	29.17	1.86	1.17	0.02
S4S	34.15	0.83	1.56	0.17
S4L	32.25	2.39	1.53	0.09

Regarding the failure behaviour, the specimens could be divided into two groups: (1) specimens with the aluminium mesh as the outer layer and (2) specimens with bamboo fibres as the outer layer. Group 1, which consisted of specimens A1S, A1L, S4S and S4L, indicated the same failure behaviour. The ductility of the aluminium mesh sheet at the external layer could have functioned as the shield to protect the bamboo fibre layer in the middle structure of the composites. The inclusion of the aluminium mesh with the fibre may have resulted in less void formation and an increase in the fracture strength of this composite. This improvement may result in less microcrack propagation on the composite (Singh & Rajamurugan, 2021). The aluminium mesh elongated until it broke and peeled away from the matrix due to the constant pressure on the specimens. Once the aluminium mesh was broken, the load caused the matrix and the fibre to break. Due to the fragility of the fibre and matrix, the crack spread, and the specimen broke. Moreover, the mesh geometry of the aluminium sheet was followed by the matrix crack.

Meanwhile, the specimens with bamboo in the external stacking sequence had a different trend. The specimens were obtained from composites S2S, S2L, A3S, and A3L. The load applied to the composite caused the matrix to fracture and the fibre to break, as these materials (bamboo fibre-reinforced polymer composites) are known for their brittle properties (Chin et al., 2020). Cracks soon reached the layer of aluminium mesh. The core of the composite's aluminium mesh was designed to withstand abrupt increases in pressure by stretching out until the wire broke and pulled away from the matrix, ultimately collapsing the specimen and explaining its low strength and strain.

Flexural Test

Table 6 displays the ANOVA for the flexural characteristics of BFAMRP composites. A *P*-value of less than 0.05 indicated that the stacking sequence significantly affected flexural strength and strain. In contrast to its tensile properties, the flexural properties of this composite material were not considerably impacted by the mesh size. The percentage contribution further demonstrated that the stacking sequence was the primary factor influencing the flexural strength and strain of the BFAMRP composite.

Table 6
ANOVA results for flexural properties

Source	DF	Adj SS	Adj MS	*F*-value	*P*-value	% Contribution
1. Flexural stress						
Stacking sequence (SS)	3	507.2	169.06	5.63	**0.003**	28.21
Mesh size (MS)	1	113.6	113.63	3.78	0.061	6.32
SS * MS	3	215.7	71.89	2.39	0.087	12.00
Error	32	961.4	30.05			
Total	39					
2. Flexural strain						
Stacking sequence (SS)	3	3.36883	1.12294	47.16	**0.000**	69.93
Mesh size (MS)	1	0.01170	0.01170	0.49	0.488	0.24
SS * MS	3	0.67503	0.22501	9.45	**0.000**	14.01
Error	32	0.76204	0.02381			
Total	39					

The flexural stress-strain curve of BFAMRP composites is shown in Figure 3. The image of the stress-strain curve illustrated that all specimens have identical curve lines since flexural stress linearly increased until it reached the maximum stress point before failure. From observation, the trend of the flexural stress-strain curve of BFAMRP composites differed from tensile properties. Specimens with bamboo fibre as the outer layer mostly had greater flexural properties, especially those with small aluminium mesh sizes. The observed high flexural stress value was presumably attributed to the surface treatment procedure conducted on bamboo fibre, as documented by Batista and Drzal (2020). The observed phenomenon also can be attributed to the inherent structural characteristics of bamboo fibres, specifically in the configuration of a nonwoven mat. This particular form of reinforcement offers numerous advantages when incorporated into polymer composites. Notably, the bamboo fibres' commendable z-directional strength played a pivotal role in mitigating delamination issues, thereby enhancing the overall performance of the composite material (Patnaik et al., 2019). This phenomenon may indirectly impact the flexural properties of the composite. According to their stacking order, the composites' failure behaviour can be divided into two types. The first group included the specimens A1S, A1L, S4S, and S4L, composites with an exterior layer of aluminium mesh sheet.

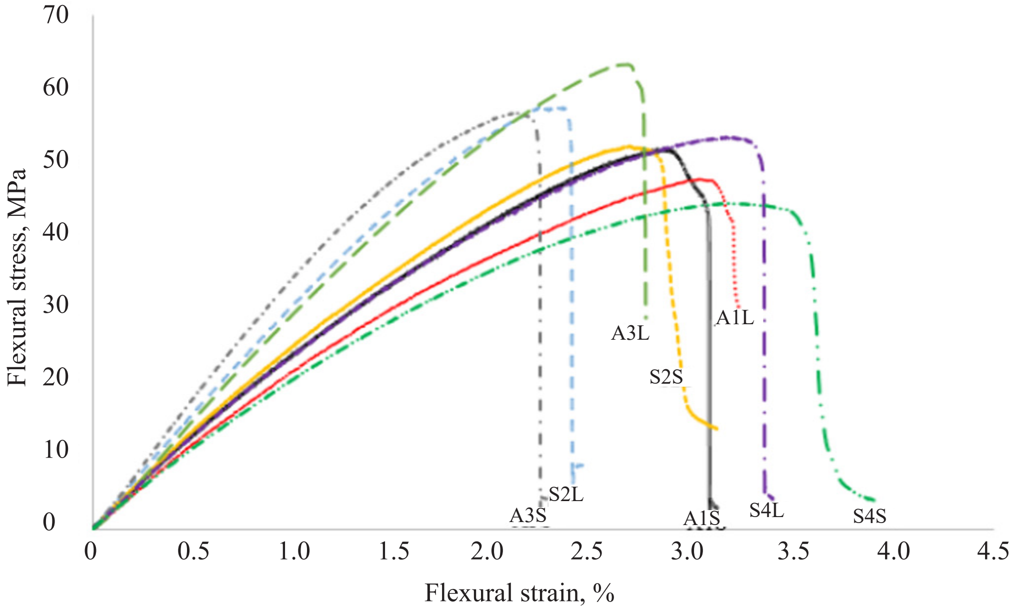


Figure 3. The flexural stress-strain curve of BFAMRP composites

The flexural stress and strain values for all specimens are shown in Table 7. Specimen A3L had the highest stress of all specimens, measuring 59.06 MPa. This specimen was expected to be made up of three layers of bamboo fibre and two layers of aluminium mesh, which is necessary since bamboo fibre had a higher tensile stress than aluminium mesh. Furthermore, using bamboo fibre nonwoven mat as the composites' outer layer improved the specimens' flexural stress since the fibre had a better bonding with the epoxy, which increased the load-sharing ability of the material, resulting in higher flexural stress of the specimens (Sadoun et al., 2021). In contrast, specimen S2L had the lowest flexural stress of 44.63 MPa, a 24.4% decrease over A3L. Although both A3L and S2L had a layer of bamboo fibre nonwoven mat on the outside of the composite, their flexural stress values differed due to the number of bamboo fibre layers and stacking sequences. The aluminium wire mesh in the alternative lay-up of specimen A3L ensured sufficient toughness and exhibited plastic deformation that increased the flexural stress of this specimen (Hu et al., 2022). Meanwhile, specimens S4S and S4L had the largest flexural strain, with 3.16%, a 40.44% increase from the lowest percentage strain, 2.25%, for composite A3S.

Table 7
Flexural properties of BFAMRP composites

Specimens code	Flexural stress, MPa		Flexural strain, %	
	Mean	Std Dev	Mean	Std Dev
A1S	50.65	2.60	2.89	0.20
A1L	51.19	5.34	2.94	0.14
S2S	52.17	3.53	2.69	0.17
S2L	44.63	4.23	2.36	0.14
A3S	57.12	4.83	2.25	0.19
A3L	59.06	4.12	2.65	0.08
S4S	56.23	2.01	3.16	0.09
S4L	47.81	2.60	3.16	0.17

Four specimens, A1S, A1L, S4S and S4L, exhibited the same failure behaviour. At the layer of aluminium on the bottom of the composites, earlier damage initiation can be noticed. The mesh's wire elongated under constant pressure until it broke. The first ductile failure delayed the other laminate's total failure due to the aluminium's ductility, increasing the specimen's flexural strain (Sadoun et al., 2021). The specimen's bottom view revealed that the damage or crack closely resembled the mesh pattern of the aluminium mesh sheet. The matrix and the fibre laminate in the centre of the composite were still under pressure from damage propagation. The cracks grew until they reached the top layer and ultimately failed.

The specimens S2S, S2L, A3S, and A3L exhibited different types of failure. In their stacking structure of composites, all these specimens featured an exterior layer of bamboo nonwoven mat. The damage initially manifested as a matrix crack at the specimen's base. Flexural strength for this specimen was higher than that of other groups since fibre can withstand a significantly higher load than aluminium. This finding was consistent with that obtained by (Xie et al., 2019). The break, however, rapidly spread until it reached the layer of aluminium mesh in the centre of the composites due to the brittle nature of the matrix and bamboo fibre.

Surface Morphology

Scanning electron micrographs of the tensile and flexural fractured surfaces were carried out to observe the interaction between the reinforcements and the matrix and the fracture behaviour. Previous researchers have stated that the bad adhesion of each component in the composites usually causes an issue such as delamination (Hasselbruch et al., 2015; Truong et al., 2019) and can cause catastrophic failure of the composites.

Figure 4 shows the fractured surfaces of the tensile test specimens. All specimens showed a similar failure mechanism: fibre breaks, aluminium strain pulled out from the matrix and matrix crack. The fractured specimen images indicate that aluminium wire was pulled out from the matrix, which might have caused the pull-out mechanism. However, the pull-out case happened in a particular area and might not have caused delamination between the aluminium mesh and the matrix. Almost all images showed the failure of the Al wire mesh in a stretched form (plastic deformation) when subjected to tensile loading. The ductile nature of the Al wire mesh caused the specimen to fail by pulling the Al out of the matrix and tearing it off in a cone fracture. Furthermore, the effect of the matrix around the Al wire mesh indicated a strong bond between the Al wire mesh and the matrix (Singh & Rajamurugan, 2021).

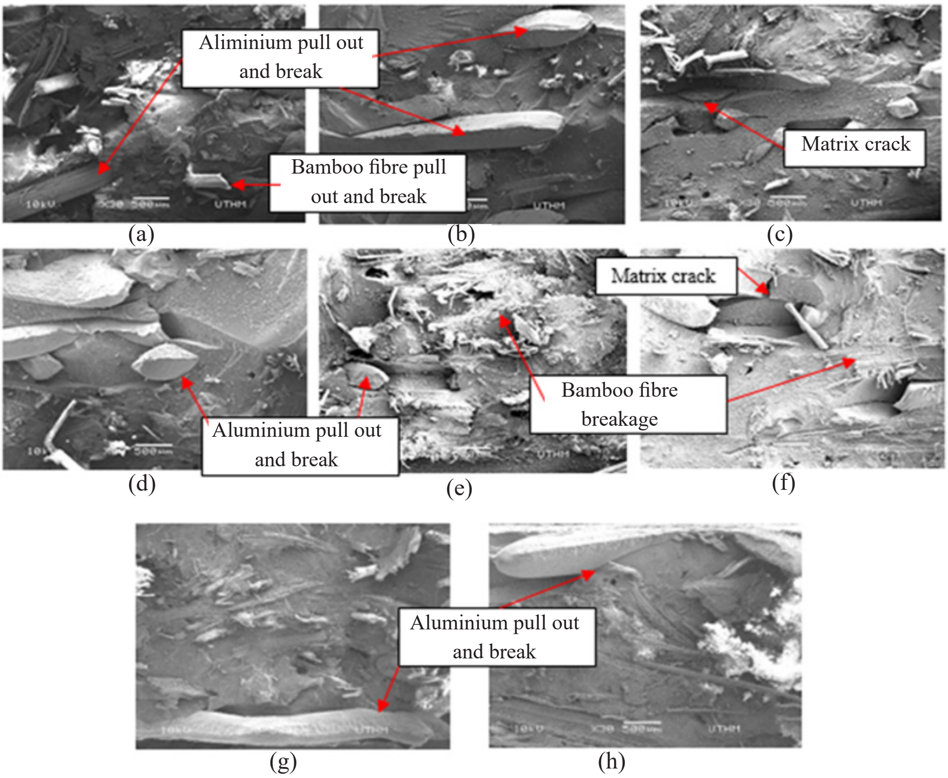
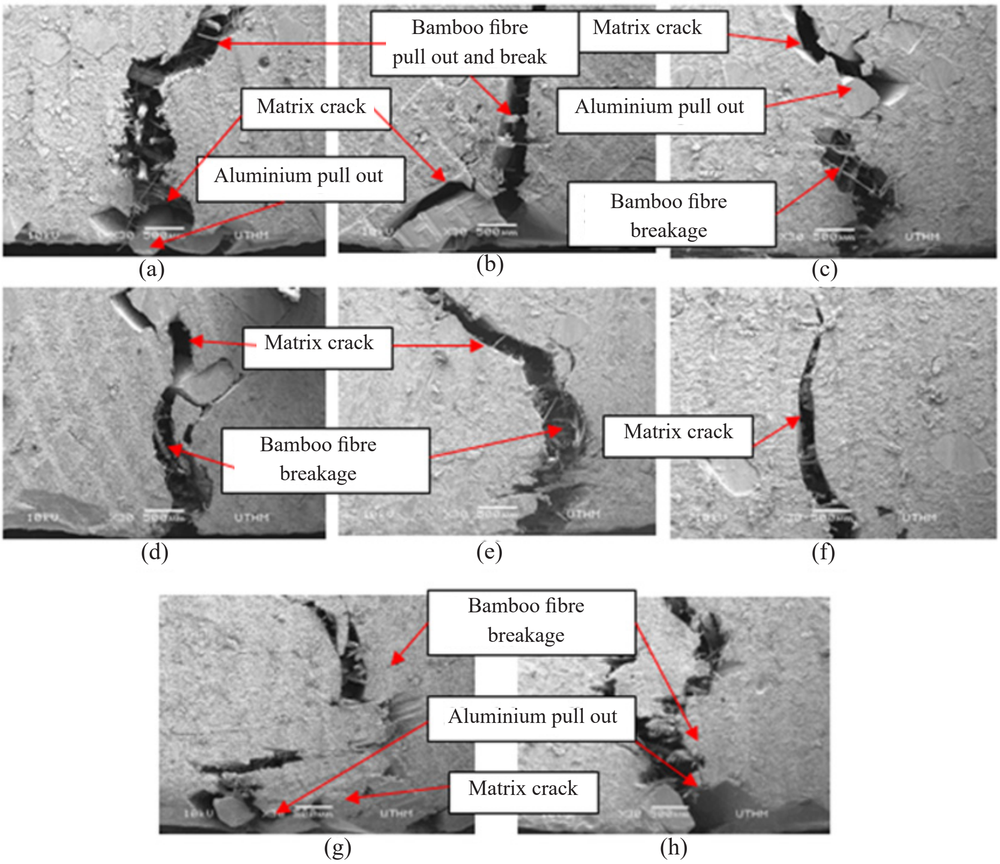


Figure 4. Cross-sectional SEM images of the tensile test specimens: (a) A1S, (b) A1L, (c) S2S, (d) S2L, (e) A3S, (f) A3L, (g) S4S, and (h) S4L

The same phenomenon was observed in the SEM image from flexural specimens in Figure 5. Most failures came from the fibre breakage, aluminium, and fibre pulled out from the matrix and matrix crack. The flexural strength of the composites was affected by the pull-out length, whether the matrix still adhered to the fibre and aluminium surface after pull-out, and whether there was fibre breakage on or near the matrix fracture surface, similar to the findings of (Cavalcanti et al., 2019).



(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 5. SEM images of the surface of the flexural test specimens: (a) A1S, (b) A1L, (c) S2S, (d) S2L, (e) A3S, (f) A3L, (g) S4S, and (h) S4L.

CONCLUSION

Eight BFAMRP composites were created and assessed for their tensile and flexural properties in this experiment. Subsequently, the specimens underwent SEM analysis. The ANOVA analysis demonstrated that the stacking sequence substantially impacted tensile and flexural performance, whereas the mesh size solely affected tensile performance. Specimens using an external layer composed of aluminium mesh demonstrated superior tensile capabilities in comparison to specimens incorporating bamboo fibre nonwoven mats. The tensile and flexural strengths were influenced by the size of the aluminium mesh, with smaller mesh sizes resulting in greater strengths. The stacking structure also affected the flexural properties, with alternating structures exhibiting superior performance when using larger mesh sizes. In comparison, sandwich structures showed better results with smaller mesh sizes. The scanning electron microscopy (SEM) images revealed that the failure of the composite material was mainly caused by the breakage and pull-out of the fibres and aluminium, suggesting a strong adhesion between the reinforcement and the matrix.

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