

# Mechanical performance of laminated natural fibre bio-composites and hybrids

M. Shukur Zainol Abidin <sup>1,2,\*</sup>, Liang Yeng Fei <sup>1</sup>, Pang Chin Wee <sup>1</sup>, A.Anjang <sup>1,2</sup>, I. Lister Daungkil <sup>1</sup>

<sup>1</sup> School of Aerospace Engineering, Universiti Sains Malaysia, 14300 Penang, Malaysia.

<sup>2</sup> Cluster for Polymer Composites (CPC), Universiti Sains Malaysia, 14300 Penang, Malaysia.

\*Corresponding author: aeshukur@usm.my

**Abstract.** Composite materials are highly utilized in the current era due to their tailored specified properties, such as high strength-to-weight, corrosion resistance, inflammable properties, wear resistance and etc. Bio-composites are materials that consisted of matrix (resin) and reinforcements from natural fibres. The mechanical properties of bio composite materials, such as coir, and palm oil fibre, were analysed and evaluated. Fabrication method via combination of laminating process and compression moulding were developed and utilised to manufacture the specimens. Impact, tensile, compression and bending test were carried to evaluate the mechanical characterisation of the bio-fibre composites. However, the mechanical performance of the natural composite were found to be inferior to that of conventional glass fibre composites. Hybridization of natural fibre with glass fibres composite shows a significant increase in specific strength and specific modulus.

## 1. Introduction

The demand for composite material has been increasing over the years. More industries, especially aerospace related, are searching for cheaper and higher quality material alternatives. Composite consist of two or more material constituents commonly known as reinforcing phase and a matrix. Rayon, nylon, carbon and glass fibres are common synthetic reinforcing phase [1]. Increasing environmental concerns has led to more attention and focus on development of bio-composite. The great potential for using natural fibre reinforced composite lies in their eco-friendliness and wide potential applications for automotive, mobile phone and biomedical industries. Natural fibres such as jute, sisal, coir, hems, as well as banana and pineapple leaves are generally extracted from renewable sources, fully biodegradable, non-toxic, and can be easily recycled to reduce the materials' carbon footprint [2].

In the recent years, there has been a growing interest in the application of natural fibres as reinforcements for polymer matrices [3]. Natural fibre has good potential as reinforcement in thermoplastic and thermoset polymer composites mainly due to low density and high specific properties of fibres [4]. Natural fibres have the properties, composition, structures and features that are suitable to be used as reinforcements or fillers in polymer composites [5]. Additionally, the synergy between plant-based natural fibre with conventional synthetic fibre into polymeric matrices leads to a



new class of fibre-reinforced composite known as hybrid composites. It has been widely reported that hybrid composite materials shows improved mechanical properties like tensile, flexural and impact strength comparable to glass fibre reinforced composites [6-11].

Glass fibre reinforced polymers (GFRPs) are a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass. Fibre glass is a lightweight, strong, and robust material used in different industries due to their excellent properties. GFRP composites are largely used mainly due to a combination of low cost and good mechanical properties. Although strength properties are somewhat lower than carbon fibre and it is less stiff, the material is typically far less brittle[12]. The incorporation of natural fibre with GFRP improves the tensile, flexural and impact strength of the materials [8] and placing the GFRP layers at the ends possess good mechanical strength [13]. The strength properties of natural fibre composites are somewhat lower, because of less stiff and typically less brittle. Reinforcing glass fibre into the natural composites enhanced tensile and flexural properties without any effect on tensile and flexural module. In addition, adding natural fibre with glass fibre improves thermal properties and water resistance of the hybrid composites [14].

## 2. Methodology

### 2.1 Material

Palm oil fibres and coir fibres were used as the natural fibre reinforcement for the composites. The coir fibres and oil palm fibres were supplied by Green Tree Garden & Landscape Nursery and United Palm Oil Industries Sdn. Bhd. respectively. The density of coir fibre is  $1.2 \text{ g/cm}^3$ , whereas for oil palm fibres is  $1.0 \text{ g/cm}^3$ . The fibre glass used throughout this project is chopped strand mat (CSM) with a density of  $2.5 \text{ g/cm}^3$ . CSM is utilized in this project because of its randomly distributed characteristics, which is similar to that of natural fibres. A generic commercially available polyester resin (FRP 101) was used for this study. The polyester resin was mixed with hardener (Luperox DDM-F) at a ratio of 1:100 to obtain the matrix for the composites.

### 2.2 Fabrication process

Clean natural fibres were handpicked and separated from impurities, such as sand and leaves. These impurities may cause inconsistent density of the specimen, as well as affecting the results of the tests. Separated fibres were then weighted using electronic weighing balance before being allocated on designated plate with area of  $160 \text{ mm} \times 160 \text{ mm}$ . The total mass of the natural fibre was divided by 4 as 4 plies of fibre sheets will be used. To evenly distribute the mass of the fibre, the mass of each ply of fibre was divided by 9, to be allocated on the designated squares as shown Figure 1. For instance, the total mass of coir to be used in CFRP is 27.65 g. This amount will be divided by 4, which makes it 6.92 g per ply, then divided by 9 making it 0.768 g per square grid.



**Figure 1.** Fibre allocated on aluminium plate with area of  $150\text{mm} \times 150\text{mm}$

Upon fibre allocation, the fibres are dried by placing in the oven at approximately 50 °C for at least 5 hours. The purpose of drying the fibre is to extract moisture from the fibre to prevent the water from affecting the results, as well as enhancing the curing process. The fibre sheet was placed on a plastic paper, then being rolled into a much thinner sheet of fibre. Compression moulding method was used to fabricate the composite plates that will be used for testing. Compression moulding provides good surface finish of composite and it is easy to perform. Aluminium plate moulds were used to compress the composite into shape.

The aluminium bases and mould were waxed thoroughly to prevent the composite from attaching onto the surface during curing process. The first layer of the fibre sheet was aligned on the mould after applying the polyester resin. A roller was used to spread the resin evenly. This step is repeated until all fibre sheets were stacked up. Another aluminium base was used to cover the specimen. A heavy metal plate was placed on the aluminium mould to ensure uniform distribution of force during compression. The mould was then being compressed with hydraulic jack. Excessive resins were removed during this process, and then the specimen was left to cure for at least 12 hours. The fibre sheets stacking configuration is summarised in Table 1. After curing, the specimen was demoulded and trimmed in accordance to the specific test standards using a wet diamond cutter.

**Table 1.** Fibre sheets stacking configuration

Type	Ply Configuration	Ply Sequence
GFRC	8 plies of Glass Fibres	G/G/G/G/G/G/G/G
CFRC	8 plies of Coir Fibres	C/C/C/C/C/C/C/C
PFRC	8 plies of Palm Fibres	P/P/P/P/P/P/P/P
HCRC	4 plies of Glass Fibre + 4 plies of Coir Fibres	G/G/C/C/C/C/G/G
HPRC	4 plies of Glass Fibre + 4 plies of Palm Fibres	G/G/P/P/P/P/G/G

### 2.3 Characterisation method

#### 2.3.1 Specimen density measurement

Each sample was cut into a square with both width and length at 20 mm. The length, width, and thickness of the specimens were measured again using a Vernier calliper to obtain a more accurate volume. The mass of each sample was measured using a digital weighing scale. The average volume and mass were obtained from three samples of each specimen type. The mass of each sample was divided by the volume to obtain the density.

#### 2.3.2 Tensile testing

A tensile test was carried out based on ASTM D3039 on the composite samples to determine the tensile strength, elastic modulus, tensile strain and modulus of toughness. The composite plate was cut into five pieces at 160 mm × 25 mm × 3 mm using a cutting machine. The test section length of 100 mm was marked by a permanent marker. The test was conducted using an Instron 3367 Universal Testing Machine. An extensometer was placed on the middle of test section to measure the local strain. The crosshead movement was set at 2 mm/min.

#### 2.3.3 Bending testing

A bending test was carried out based on ASTM D790 on the composite samples to determine the flexural strength, flexural modulus, and flexural strain. The composite plate was cut into five pieces at

160 mm × 25 mm × 3 mm using a cutting machine similarly to tensile test specimen. The test section length of 100 mm was marked by a permanent marker. The crosshead movement was set at 2 mm/min

#### 2.3.4 Compression testing

The compression test was carried out based on ASTM D695 on the composite samples to obtain the compressive strength, average value and standard deviation. The composite plate was cut into 10 specimens. 5 longer specimens were cut to be at dimensions of 150 mm × 12.7 mm × 3 mm while another 5 shorter specimens were cut to be at dimensions of 122mm × 12.7 mm × 3 mm using a cutting machine. The gauge length of longer specimen is 38 mm while the gauge length for shorter specimen is 10 mm. The crosshead movement was set at 1.2 mm/min.

#### 2.3.5 Impact testing

Impact testing was carried out in accordance with ASTM D256 on the composite samples to obtain the impact energy and specific impact energy. The composite plate was cut into 5 specimens with the dimension of 64 mm × 12.7 mm × 3.2 mm. The impact resistance of the specimen involves flexural shock using standardized pendulum-type hammer when breaking specimens under one swing. A 15 Joule hammer was selected as the energy required to break the specimen. After impact, the energy required to break the specimen was indicated at the impact gauge.

### 3. Result and Discussion

Compression moulding method would give a good surface finish and easier to obtain many specimens with fixed dimensions depending on the mold used. The thickness of the mold was at 3 mm. However, composite specimens that contains natural fibre has irregular thicknesses of 3-6 mm. The pure natural fibre (CFRP and PFRP) composite plate was the thickest followed by hybrid (CGFRP and PGFRP) and pure glass fibres (GFRP) specimens. This is because the natural fibre sheets expands more during the layup process with polyester resin. The car jack used to compress the mold also does not provide sufficient force to control the thickness. As a result, the CFRP, PFRP, CGFRP, and PGFRP may contain lower fibre content per unit volume due to increased thickness. Hence, the mechanical testing results for each fabrication batch of the same type of fibres used may be different due to the variations of thickness.

#### 3.1 Density Measurement

As expected, the density of the GFRC were higher than that of both natural fibre composites and hybrid composites. The density of the composites are tabulated in Table 2. Furthermore, the densities measured are in agreement with the expected densities as estimated via Rule of Mixture. Therefore the voids in these samples should be sufficiently low and does not degrade the mechanical performance of the composites.

**Table 2.** Measured density of the composites.

	Density, kg/m <sup>3</sup>
GFRC	1656.38 ± 13.02
CFRC	1260.26 ± 6.43
PFRP	1217.88 ± 10.11
HCRC	1466.27 ± 9.82
HPRC	1420.69 ± 9.06

#### 3.2 Tensile properties

GFRC (pure glass composite) has the highest ultimate strength, strain-to-failure and elastic modulus followed by HPRC (hybrid palm), HCRC (hybrid-coir), CFRC (pure coir), and PFRP (pure palm) as tabulated in Table 3. It was expected and shown that pure glass composite would give the highest

tensile properties. Hybrid composite were superior in terms of tensile properties in comparison to pure natural fibre composite. This shows that the added glass fibre on the hybrid composite greatly improves the tensile property of natural fibre reinforced composites.

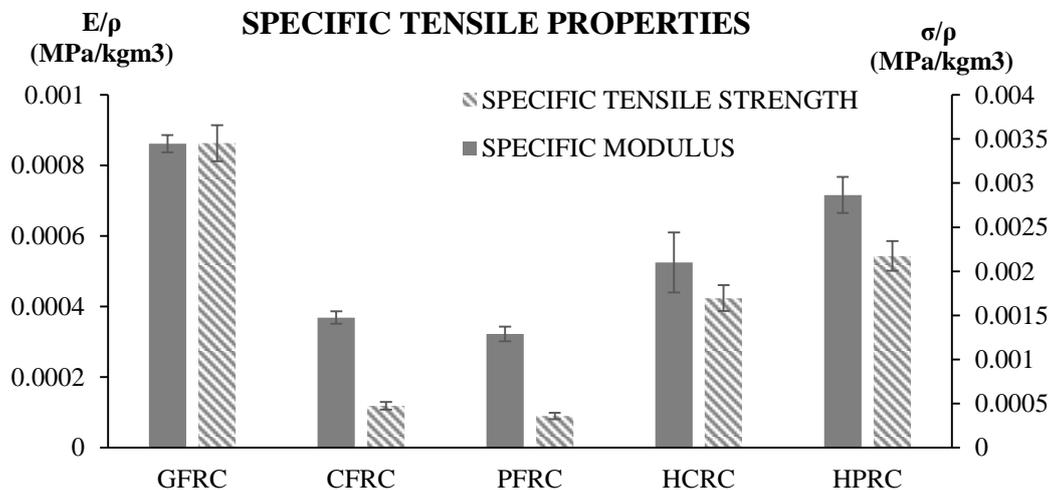


Figure 2. Specific tensile properties of the composites.

### 3.3 Bending properties

GFRC has the highest flexural strength followed by HCRC, HPRC, CFRC, and PFRC. Although the hybrid composite can withstand higher maximum load than pure glass composite, the actual flexural strength of hybrid composite is still inferior compared to pure glass composite. Table 3 also clearly shows that the hybridization causes the flexural strength of NFCs to increase significantly, in this case is nearly 5 times the strength of pure NFCs. The elastic modulus of HCRC is lower than HPRC and GFRC but higher than CFRC and PFRC. This result shows that hybrid composites are nearly as good as pure glass composite in terms of flexural stiffness. Pure NFCs were still far inferior in flexural stiffness.

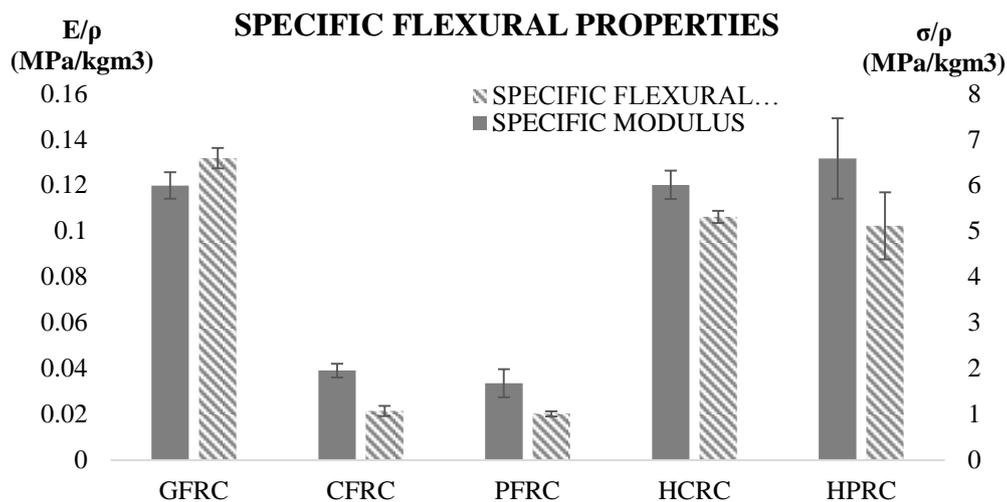


Figure 3. Specific flexural properties of the composites.

### 3.4 Compression properties

GFRC has the highest modulus while there is not much difference between CFRC and PFRC as well as between HCRC and HPRC. Glass composite has the highest modulus here while hybrid composite comes in second.

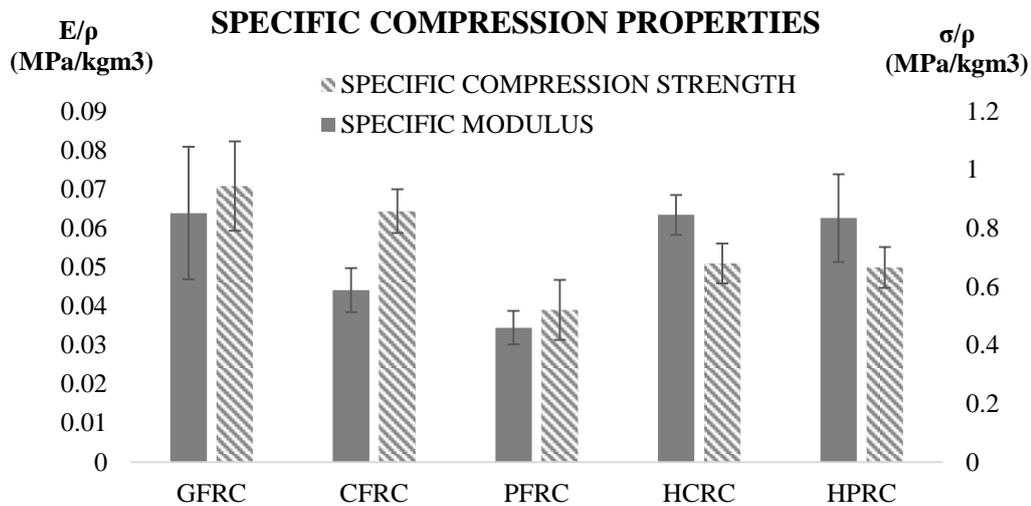


Figure 4. Specific compression properties of the composites.

### 3.5 Impact properties

GFRC has the highest impact energy and specific impact energy compared to the other hybrid composite with about 50% difference in impact resistance. Pure coconut and pure oil palm recorded the lowest impact resistance with 10% and 20% respectively less than the GFRC. On the other hand, the hybrid composites of HCRC and HPRC indicated an increase in impact properties as much as 12.8% and 34.8% respectively. These results shows that hybridization of the composite contribute to the improved mechanical properties of the natural fibre composites.

Table 3. Mechanical properties of the composites.

COMPOSITE SYSTEMS		GFRC	CFRC	PFRC	HCRC	HPRC	
MATERIAL PROPERTIES	Tensile	$\sigma_{max}$ (MPa)	1.430 ± 0.085	0.150 ± 0.014	0.109 ± 0.011	0.622 ± 0.054	0.772 ± 0.060
		E (MPa)	5.71 ± 0.16	1.86 ± 0.09	1.57 ± 0.10	3.08 ± 0.50	4.07 ± 0.29
		Strain to Failure (mm/mm)	0.053 ± 0.005	0.011 ± 0.002	0.011 ± 0.003	0.045 ± 0.007	0.049 ± 0.005
		Compression	$\sigma_{max}$ (MPa)	117.3 ± 19	81.15 ± 7.1	47.56 ± 9.38	74.75 ± 7.49
	E (MPa)		1410.82 ± 375.04	741.44 ± 95.06	560.08 ± 69.86	1240.01 ± 99.78	1185.96 ± 213.29
	Strain to Failure (mm/mm)		0.075 ± 0.045	0.16 ± 0.032	0.092 ± 0.052	0.075 ± 0.01	0.077 ± 0.01
	Bending	$\sigma_{fm}$ (MPa)	218.42 ± 7.39	26.95 ± 2.80	24.53 ± 1.34	155.64 ± 3.93	145.35 ± 20.79
		E (MPa)	9928 ± 477	2464 ± 189	2039 ± 374	8808 ± 452	9355 ± 1248
	Impact	Impact Energy, (kJ/m <sup>2</sup> )	103 ± 7	8.45 ± 1.71	17.57 ± 1.62	43.60 ± 3.89	44.8 ± 6.37
		Specific Impact Energy, (kJ/m <sup>2</sup> )	0.063 ± 0.004	0.0067 ± 0.0014	0.014 ± 0.0013	0.030 ± 0.0026	0.032 ± 0.0045

## 4. Conclusion

From fibre alignment, composite fabrication, and mechanical testing to wind turbine blade fabrication, natural fibres has been used as a one of the reinforcement material. The better way to produce natural fibre sheet is through rolling as the procedure were simpler than hydraulic press which also provides less uniform flattening. It is known that NFCs have poor mechanical properties. However, through hybridization of natural fibre with glass fibre, the tensile and flexural properties had been improved significantly. In flexural test, the specific strength and specific modulus of hybrid bio-composite are higher than that of pure glass composite. In compression test, the effects of hybridization on compressive properties were negligible and only offer slight differences. The idea of hybridization has widened the possible applications of natural fibre in mechanical structures. Due to the abundance of natural fibres, the cost of making strong and reliable structures such and the wind turbine blade can be reduced significantly.

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