Properties and behaviour of gomuti fibre composites under tensile and compressive load

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ABSTRACT: Gomuti fibre or sugar-palm fibre is a natural fibre that traditionally has been used as roofing and insulation material. This paper presents an experimental investigation into the properties and behaviour of gomuti fibre composites when subjected to axial tensile and compressive load. Composite panels prepared for this study are the combinations of untreated unidirectional gomuti fibre with three different polymer thermoset resins (epoxy, vinylester and polyester). The panels are fabricated manually by hand lay-up. Results show that the average tensile strength of the composite specimens is between 35–46 MPa and the average compressive strength between 82–108 MPa. Specimens of gomuti/vinylester have the highest average tensile and compressive strength. Load vs extension plots of tensile specimens of all three combinations display elastic region before sudden break after peak load while compressive specimens of each combination exhibit different tendency after the elastic region and peak load.

1 INTRODUCTION

Natural fibre composites are becoming an interesting topic in various areas of engineering for many reasons. Being natural resources, natural fibre can be categorised as renewable material. Moreover, the use of natural fibre offers a more environmental sustainable supply of material and promotes less synthetic waste.

Current applications of natural fibre composites range from automotive applications (O'Donnell, 2004), furniture and packaging industries to civil engineering applications such as beams (Alms et al., 2009), roof (Dweib et al., 2006) and pipe repair (Yu et al., 2008). In civil engineering applications, natural fibre composites may find its slots in the development and production of non-structural elements or elements that require lower to moderate strength such as roofing, decking or slats, wall cladding and insulation panel.

The suitability of natural fibre composite in a certain engineering applications is essentially depends on the characteristics and behavior of the composite itself. To obtain the properties and understand the characteristics and behaviour a material, mechanical tests are required. Tensile and compressive tests are two of the mechanical tests that can be performed to obtain important basic mechanical properties of natural fibre composites.

This paper aims to present the study on the tensile and compressive behavior of untreated unidirectional aligned gomuti fibre composites. Tensile and compressive tests are performed to observe the response of the composite specimens to axial loading.

2 REVIEW OF EXISTING STUDIES

Many types of natural fibre are readily available in most countries around the world. Some of them have been subjected to extensive studies as natural fibre composites. Examples are jute, hemp, flax, sisal and coir.

Table 1 shows the tensile properties of several natural fibre composite. Typically, composites with flax fibre exhibit highest tensile strength among other natural fibre composites, while coir composites offer the lowest tensile strength. This characteristic is influenced by the strength of the individual fibre itself.

Table 1. Tensile properties of natural fibre composites

Material	Tensile strength	MoE	Ref.
	MPa	GPa	
Coir/epoxy	13.05	2.06	Biswas et al. 2011
Hemp/polyester	32.90	1.42	Rouison et al. 2006
Flax/polyester	61.00	6.30	Rodríguez et al. 2005
Sugar-palm/epoxy	42.85	3.33	Bachtiar et al. 2008

Other factors that also contribute to the properties and characteristics of natural fibre composites are fibre orientation or fibre form, fibre fraction, fibre condition, treatment to the fibre, composite fabrication method and process, and the selection of matrix to provide bonding to the fibre,.

Gomuti fibre is a natural fibre obtained from *Arenga pinnata* tree (Ticoalu et al., 2011). Other names associated with gomuti fibre are sugar-palm fibre, gomutu, ijuk, arenga fibre, etc. The fibre is used traditionally in Indonesia as roofing material, rope, insulation, water filters and brooms.

A number of studies have been conducted on the mechanical properties of gomuti fibre (sugar-palm fibre) and its composites. Bachtiar et al. (2010) reported that the average single fibre tensile strength of gomuti was 190.29 MPa and the modulus of elasticity was 3.69 GPa. When epoxy resin was used, the composite with 10% weight fraction of untreated long random fibre reached 50.39 MPa of tensile strength and 1.04 GPa of tensile modulus (Suriani et al., 2007). With similar weight fraction, chopped random fibre reached tensile strength of 33.76 MPa and tensile modulus of 1.07 MPa, while woven fibre reached 51.72 MPa and 1.01 of tensile strength and modulus respectively (Suriani et al., 2007). Previous study by the authors (Ticoalu et al., 2011) reported that gomuti/polyester composites reached the tensile strength of 15.40 MPa, 14.52 MPa, 24.49 MPa and 9.24 MPa for 10% fibre weight fraction of random original oriented fibre, chopped fibre, unidirectional fibre and woven fibre, respectively.

From the mentioned studies, it can be observed that gomuti composite with long fibre offer higher strength with the same 10% weight fraction. Contrast results can be noted for woven fibre with epoxy and polyester. The differences in the nature of weaving and resin type were the possible factors to the contrasting results. Furthermore, increasing the fibre weight fraction to 15% and 20% has resulted in lower tensile strengths of gomuti fibre composite specimens (Suriani et al., 2007).

While the existing studies have provided important information on the variations of properties based on the fibre form and fibre weight fractions, there are limited publications on evaluating the properties and behaviour of gomuti fibre composites with different type of matrix and how it behave under compressive load.

Common thermoset polymer resin matrices such as epoxy, polyester and vinylester have different characteristics and different price. Polyester (thermosetting polyester) generally has lower price and faster curing compared to epoxy. However, it has lower tensile strength and more brittle. Epoxy is more expensive but it offers better bonding characteristic. Vinylester is cured similar to polyester but generally has the properties in between polyester and epoxy. Vinylester is produced by the reaction of an epoxy with an unsaturated acid (Åström, 1997).

It is therefore important to evaluate the properties and behaviour of gomuti fibre composites when combined with different matrices.

3 MATERIALS AND METHODS

Non-chemically treated gomuti fibres were obtained from Minahasa, North Sulawesi, Indonesia. The fibres were rinsed with water, air-dried and brushed to obtain unidirectional aligned fibres. Next, they are trimmed to approximately 300–400 mm long, as shown in Figure 1. Before fabrication, the fibres are washed with hot water to remove dust and impurities, air-dried and oven dried to remove moisture.

Three thermoset polymer resins were used to develop the composite panels; that are polyester, vinylester and epoxy. Resin variation is designed to evaluate the difference in tensile and compression properties. The panels are made with hand lay-up method aiming to use as less resin as possible but with good workability. Fibre fraction of approximately 20% was achievable for all panels. Polyester and vinylester resins were mixed with 1.5% catalyst while epoxy was used with 4:1 ratio.

Figure 1.Unidirectional aligned gomuti fibre

Tensile tests were conducted based on the Australian Standard AS1145. Dimension of tensile specimens was approximately t (thickness) x 25 mm (width) x 250 mm (length). Loading rate for tensile specimens was 2 mm/min. An extensometer was used to obtain strain reading. When the strain reached 0.3%, the extensometer was removed and the testing continued until the specimen failed. Figure 2 shows the set-up for tensile test.

Compressive tests were carried out based on ASTM D695. Compressive specimens were of rectangular prism shape with dimension of t (thickness) x 2t (width) x 2t (height). The loading rate for compressive specimens was 1.3 mm/min. Figure 3 shows the set-up for compressive tests.

Both tensile and compression tests were completed using MTS 100 kN Insight machine at the Centre of Excellence in Engineered Fibre Composites (CEEFC) laboratory, University of Southern Queensland.


Figure 2. Tensile test set-up

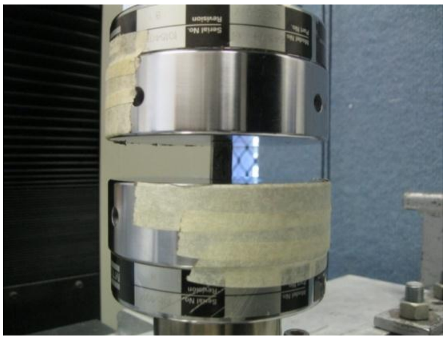
Figure 3. Compression test set-up

4 RESULTS AND DISCUSSIONS

4.1 *Results of tensile test*

The tensile testing machine provides the reading of load and extension of the specimens, and the extensometer provides the reading of strain. Data of stress, strain and modulus of elasticity are then generated by the integrated software. Table 2 presents the tensile strength and tensile modulus of gomuti fibre composites specimens.

Table 2. Tensile properties of gomuti fibre composites

Specimen	Tensile strength	Modulus of elasticity
	MPa	GPa
Gomuti/E*	44.89	4.68
	38.31	4.45
	34.22	4.95
	46.93	5.40
	48.06	5.39
Average	42.48 (SD: 5.97)	4.97 (SD: 0.42)
Gomuti/VE*	47.08	4.18
	47.30	4.96
	51.31	4.32
	41.44	4.05
	43.77	4.08
Average	46.18 (SD: 3.76)	4.32 (SD: 0.37)
Gomuti/PE*	33.52	5.44
	35.41	5.13
	40.45	5.92
	30.47	5.50
	35.92	5.17
Average	35.15 (SD: 3.65)	5.43 (SD: 0.32)

* E: Epoxy, VE: vinylester, PE: polyester, SD: standard deviation

As observed from Table 2, combination of gomuti/vinylester has obtained highest average tensile strength of 46.18 MPa while combination of gomuti/polyester obtained highest modulus of elasticity of 5.43 GPa in average.

Tensile test results show that when untreated unidirectional aligned gomuti fibre is used in combination with epoxy, the average tensile strength is 42.48 MPa. When polyester is used, the average tensile strength is 35.15 MPa, approximately 17% lower. Combination of gomuti/vinylester reached higher tensile strength of 46.18 MPa, which can be attributed to better bonding of fibre and matrix.

Compared to the typical tensile strength of neat resins (as in Table 3), the strength of gomuti/epoxy composites is approximately 30-70% lower than neat epoxy, the strength of gomuti/vinylester composites is approximately 40% lower compared to neat vinylester, and the strength of gomuti/polyester composites is approximately 40% lower compared to neat polyester.

Table 3. Tensile properties of typical thermoset resins

Material	Strength	Modulus	Ref.
	MPa	GPa	
Epoxies	55-130	2.7-4.1	Aranguren&Reboredo, 2007
Vinylester	72.17	2.74	current study
Polyester	55.20	3.40	Barbero, 1999

Results of tensile modulus, however, show different tendency, in which the moduli are slightly higher (approximately 20-45% higher) compared to the modulus of neat resins.

Tensile test results suggest that the use of gomuti fibre with epoxy, vinylester and polyester do not increase the strength of the resin, however the fibre contributes in increased value of tensile modulus.

The use of natural fibre as composite ingredients in polymer thermoset resins may not necessarily increase the tensile strength of the resin but it reduces the amount of resin used with acceptable properties.

4.2 *Results of compression test*

Compression test results as presented in Table 4 show that gomuti/vinylester combination has the highest average value compared to the other two combinations. In the case of compressive moduli, however, gomuti/polyester has the highest value.

Overall, based on the compressive test results, compressive strength of gomuti fibre composites with thermoset resins (epoxy, vinylester and polyester), is in the range of approximately 82–108 MPa, while the compressive modulus is in the range of 1.9–2.05 GPa.

Comparing the results of compressive test to the typical properties of the neat resin (Table 5), it can be observed that the compressive strengths of the composites are lower than the neat resin (approximately 8–47% lower). Compressive moduli are also lower by 30–40% than the compressive moduli of neat resins. The results suggest that the inclusion of gomuti fibre do not increase the compressive strength as well as the compressive modulus of the resins.

Table 4. Compressive properties of gomuti fibre composites

Specimen	Compressive strength	Compressive modulus
	MPa	GPa
Gomuti/E*	86.23	1.99
	86.57	1.97
	79.14	1.65
	78.42	1.72
	79.56	1.99
Average	82.08 (SD: 4.02)	1.93 (SD: 0.18)
Gomuti/VE*	109.54	2.03
	107.58	2.17
	102.46	1.71
	111.84	2.25
	108.92	1.87
Average	108.07 (SD: 3.49)	2.01 (SD: 0.22)
Gomuti/PE*	95.24	2.05
	108.21	2.06
	107.89	1.75
	108.67	2.23
	100.34	2.14
Average	104.07 (SD: 6.02)	2.05 (SD: 0.18)

*E:Epoxy, VE:vinylester, PE:polyester, SD:standard deviation

Table 5. Compressive properties of typical thermoset resins

Material	Strength	Modulus	Ref.
	MPa	GPa	
Epoxy	102.00	3.40	CEEFC internal report
Vinylester	117.10	-	Barbero, 1999
Polyester	195.00	2.90	CEEFC internal report

4.3 *Behaviour of the composite specimens under tensile load and compressive load*

Test results show that compressive strength of gomuti fibre composite specimens are approximately 2–3 times higher than the tensile strength, while the compressive moduli are 2–3 times lower than the tensile moduli.

Load vs extension plots of tensile and compressive specimens are presented in Figure 4 and 5 respectively. It can be observed that the results of the specimens in every combination are reasonably close to each other, which show uniformity of the specimens.

Figure 4 shows that under tensile load, all three combinations exhibit sudden brittle failure after linear elastic region, with extensions up to approximately 3-5 mm. Under compressive load, however, the specimens sustained increases in compressive extension after linear elastic region and peak load (Figure 5).

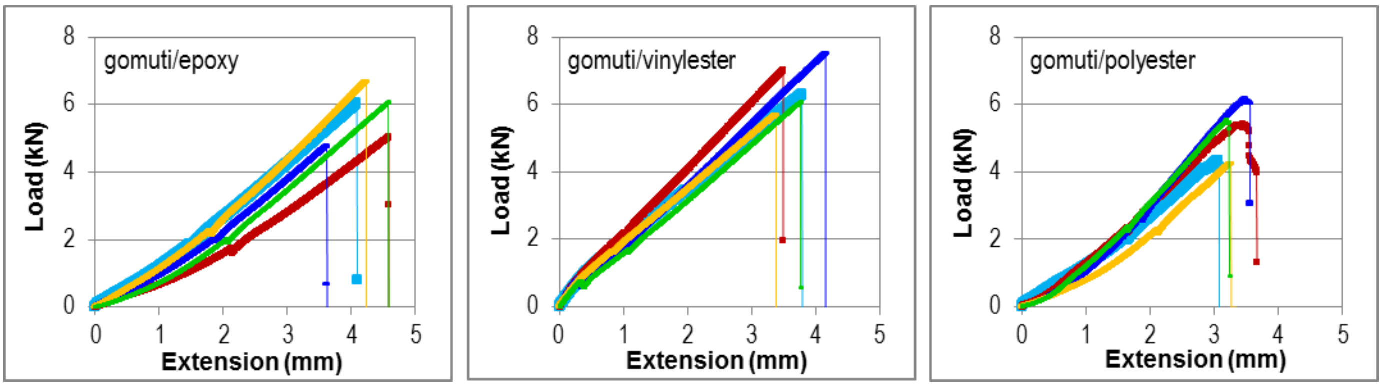

Figure 4. Load vs extension plots of tensile specimens

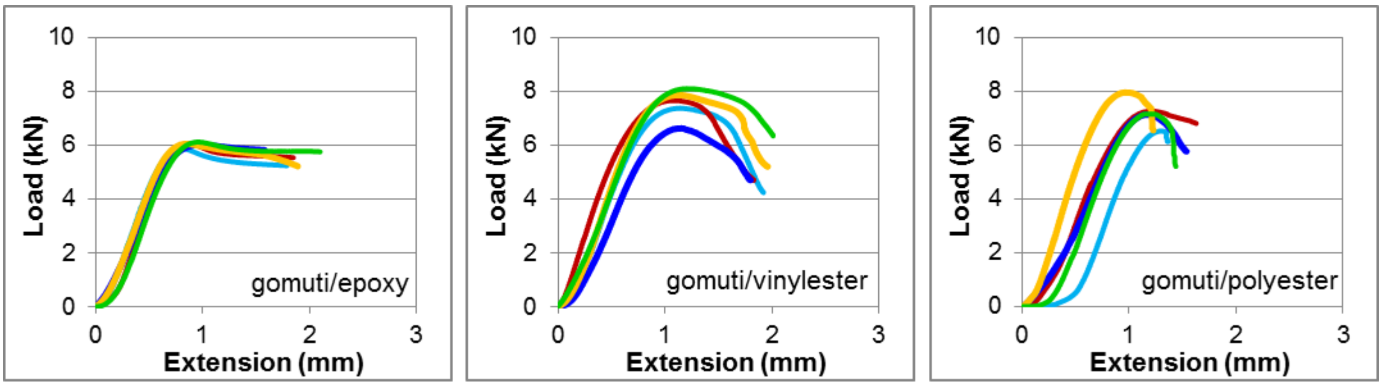

Figure 5. Load vs extension plots of compressive specimens

Furthermore from Figure 5, the curves of gomuti/epoxy specimens show increase in extension after peak load with slightly lower but nearly constant load. Gomuti/polyester specimens sustained higher compressive load compared to gomuti/epoxy but were broken soon after peak load without significant increase in extension. Specimens of gomuti/vinylester exhibit higher strength as well, with load vs extension plots similar to that of gomuti/polyester but with larger extension from peak load to break. From curves of compressive test results, it can be observed that the characteristics of each resin are imparted to the composites.

For tensile specimens, ruptures are noticed by matrix cracking, fibre-matrix debonding then fibre breakage. Failures of compressive specimens are generally combinations of matrix cracking, fibre-matrix debonding and shear cracking without the specimens being completely separated.

In general, tensile and compressive behaviour of gomuti fibre composites are more influenced by the behaviour of the type of matrix than of the behaviour of the fibre.

5 CONCLUSIONS

Although the properties of natural fibre composites are influenced by various aspects, it can be concluded from this study that untreated unidirectional gomuti fibre composites have an average tensile strength of 42.48 MPa when epoxy resin is used, 35.15 MPa when polyester is used and 46.18 MPa when vinylester is used. Average tensile moduli are 4.97 GPa, 5.43 GPa and 4.32 GPa for specimens with epoxy, polyester and vinylester respectively. Average compression strength and modulus for gomuti/epoxy specimens are 82.08 MPa and 1.93 GPa, for gomuti/vinylester are 108.07 MPa and 2.01 GPa, and for gomuti/polyester are 104.07 MPa and 2.05 GPa. In general, compression strength of the composite specimens are higher compared to their tensile strength, however the compressive moduli are lower.

Based on the result of tensile and compressive tests, gomuti/vinylester composites is the best combination compared to gomuti/epoxy and gomuti/polyester because the composites exhibit less brittle failure and better bonding compared to the specimen with polyester. Furthermore, the use of vinylester provides faster curing compared to epoxy, and better workability compared to polyester.

A more thorough investigation which includes the testing of the actually used resin is required to provide better understanding of the behaviour of gomuti fibre composites.

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