Experimental investigation into gomuti fibres/polyester composites

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ABSTRACT: In this study, gomuti fibres/polyester composites are examined for tensile and flexural properties. The specimens are produced by hand lay-up method for practicality. Fibre forms are in four variations that are random original layout, chopped random, unidirectional and woven mat. The fibres are not chemically treated for the purpose to initially evaluate and determine the properties of untreated gomuti fibres/polyester composites. Results showed that specimens with unidirectional orientation have the highest average tensile strength. Meanwhile, woven mat specimens have the highest flexural strength. It is noted from the experimental results that gomuti fibres have a potential prospect as fibre reinforcement in composites.

1 INTRODUCTION

Sugar-palm (*Arenga Pinnata* or *Arenga Saccharifera*) trees are found growing productively in many tropical countries such as Indonesia, Malaysia and Papua New Guinea. The trees are native to most of South-East Asia region, India, Sri Lanka and Papua New Guinea (Jones, 2000, Mogea et al., 1991). This plant is particularly known in Indonesia for its product of palm sugar (Smits, n.d.), vinegar, a distilled alcoholic drink and its sweet sap.

This paper takes a particular interest in the hairy black fibres that cover the trunk of the tree. The fibre is known by several different names including Sugar-palm fibre, Ijuk, Gomutu, and Gomuti. The fibres vary from black or dark brown to light brown in colour, appear to be stiff, are layered and are not oriented in any particular direction.

Gomuti fibres may vary in diameter from 50 μm to 800 μm. Suriani et al. (2007) reported that the range of the diameter of the gomuti fibres in their study is 94 – 370 μm while Bacthiar et al. (2010) reported the range of 99 – 311 μm.

Gomuti fibres are conventionally used for multipurpose rope and roofing material. Mogea et al. (1991) outlined some of the conventional forms of utilisation of the fibres such as rope, filters, in road construction, roof, brooms, basement of sport course and as shelters for fish breeding. The fibres are also known to be seawater-resistant (Heyne 1950 cited in Mogea et al. 1991, p. 123).

Figure 1 shows the sugar palm tree where the gomuti fibres cover its trunk. Figure 2 shows the gomuti fibres that have been removed from the tree.

Figure 1. Fibres cover the outer part of sugar palm tree trunk

Figure 2. Gomuti fibres

The idea to study the feasibility of using gomuti fibres as composite material resulted from the observation of the use of the fibres as rope and traditional building material. As rope, the fibres are twisted to a required diameter so to withstand tensile stress. As traditional roofing in rural tropical areas, the fibres are required to withstand wind loads and to provide protection from rain and tropical sun. Therefore, gomuti fibres are reasonably durable.

As with many other natural fibres, utilising gomuti as reinforcement to fibre composites may pose several limitations such as low fire-resistant, higher water content and higher water absorption. Unlike other natural fibres such as hemp or jute that have a developed cultivating and manufacturing process, to date there are only known manual or conventional methods of cultivating and manufacturing gomuti fibres for most applications.

Natural fibres offer environmental benefits such as biodegradable and are attained from renewable resources. In terms of strength, natural fibres are still outweighed by synthetic fibres. Therefore, for gomuti fibres to achieve reasonable results as a potential alternative material to synthetic fibres in composites, the basic mechanical properties need to be examined and possible improvement by processing or chemical treatments need to be investigated.

2 REVIEW OF EXISTING STUDIES

The variations in the properties of natural fibre reinforced composites (NFRC) as those of synthetic composite materials are affected by the type of fibre and resin that are used, the composition of fibre and resin, and the manufacturing methods. Furthermore, NFRC is also affected by the moisture content of the fibres, treatments, cultivation and retting process of the natural fibres. There are many variables affecting the performance of natural fibre reinforced composites.

Table 1 shows the comparative values of the tensile and flexural properties of several fibre reinforced polyester composites. As shown in the table, the properties of the existing natural fibre composites are almost half of the properties of the synthetic fibres. Given an appropriate strength design, natural fibre composite can be a potential substitute to synthetic fibres.

Currently, the quantity of published studies on the use of gomuti fibres as reinforcing fibres in fibre composites is limited. The following studies have been done with gomuti (sugar-palm) fibres/epoxy composites.

Sastra et al. (2005) studied gomuti fibres/epoxy composites. The study investigated different fibre fractions and fibre orientations. It was found that 10% by weight woven gomuti fibres/epoxy composites have the highest flexural strength (108.15 MPa) and Young’s modulus (4421.8 MPa). In another study, Sastra et al. (2006) reported that tensile strength of 10% woven gomuti fibres/epoxy composites was 51.725 MPa hence the highest of all the specimens.

Bachtiar at al. (2008) investigated the effect of alkali treatment to gomuti fibres while Leman et al. (2008) attempted the freshwater and seawater treatments on the chopped fibres. Results showed that both freshwater and seawater treatment significantly improve the tensile strength of the specimens up to more than 50% (Leman et al., 2008). In Leman et al.

Table 1. Tensile and flexural properties of fibres/polyester composites from several literatures.

Fibre	Tensile stress MPa	Tensile modulus MPa	Flexural stress MPa	Flexural modulus MPa	Reference
Glass	76 - 160	5600 - 12000	140-260	6900-14000	Blaga (1978)
Jute	45.82	3700	61.65	3050	O’Dell (n.d.)
Sisal	47.10	12900	80.43	9370	Bisanda (1991) in Mwaikambo (2006)
Coir	20.40	-	41.54	-	Singh & Gupta, in Mohanty et al. (2005)
Hemp	32.90	1421	54.00	5020	Rouison et al. (2006)
Flax	61.00	6300	91.00	4800	Rodríguez et al. (2005)

Table 2. Summary of sugar-palm fibre/epoxy composites properties from the literatures.

Form of fibres	Tensile stress MPa	Flexural stress MPa	Flexural modulus MPa	Reference
Chopped random 20%wt.	30.49	64.71	3145.8	Sastra et al.(2005), Sastra et al. (2006)
Woven roving 10%wt.	51.73	108.15	4421.8	Sastra et al.(2005), Sastra et al. (2006)
Long random 15%wt.	49.61	92.65	3997.3	Sastra et al. (2005), Sastra et al. (2006)
Chopped 15%wt. untreated	13.78	-	-	Leman et al. (2008)
Chopped 15%wt. 30d freshwater	21.27	-	-	Leman et al. (2008)
Chopped 15%wt. 30d seawater	23.04	-	-	Leman et al. (2008)

(2008), the chopped fibres were soaked for 30 days and the composites were made with the amount of fibres 15% by weight.

Suriani et al. (2007) studied the bonding and interfacial adhesion of gomuti fibres/epoxy composites after tensile test. The study concludes that woven gomuti fibres/epoxy composite showed good interface adhesion between matrix and fibres compared to long random and chopped random composites. Their finding also showed that increasing the weight fraction of fibre (from 10% to 15% and 20%) decreases the tensile strength.

In an experimental study on the effect of accelerated age by Ali et al. (2010), it was found that the average tensile strength of the aged specimens was 32.28 MPa compared to 21.46 MPa of the original specimens. In this study (Ali et al., 2010), specimens for accelerated aged gomuti fibres/epoxy composites were prepared according to standard material age acceleration ASTM F1980, hence were put into an oven for 74 hours and 10 minutes to attain the desired equivalent aging time of 70 days in natural environment.

A summary of the existing results of the studies into gomuti (sugar-palm fibres) composites is presented in Table 2. As shown in the table, regardless the form of gomuti fibres, fibre fraction and treatments, the tensile strength are within the range of approximately 13 – 52 MPa, which means that the tensile strength is comparable to other natural fibre composites. Similar conditions can be observed for flexural properties.

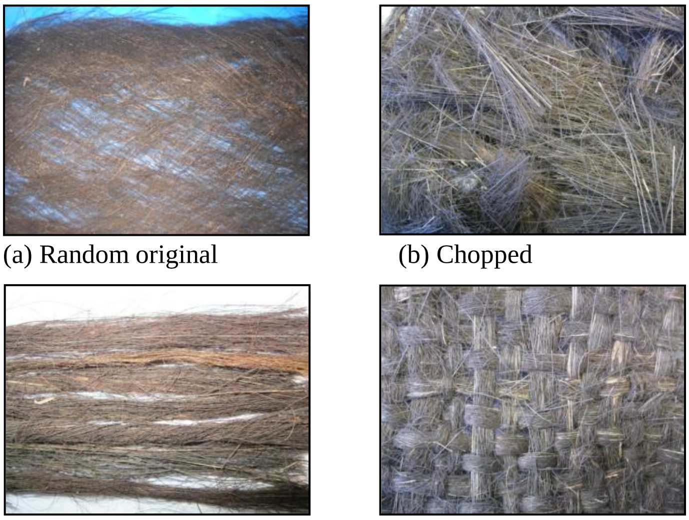
From the above mentioned investigations, several conclusions can be drawn into attention. Firstly, woven and long random gomuti fibres are the stronger form of gomuti fibres in terms of tensile and flexural strength. Secondly, alkaline treatments to the fibres only slightly contribute to the improvement of the tensile strength. Thirdly, 30 days freshwater and seawater treatments to chopped gomuti improved the tensile strength of gomuti fibres/epoxy composites specimens almost up to 50%. Lastly, while the strength of gomuti fibres/epoxy composites showed the need of improvement, it is feasible to do further study into this kind of fibres due to its environmental and cost benefit.

Gomuti fibres can be purchased with relatively low price, approximately 10% of the price of glass fibres. They are easily attained especially in their native countries. The fibres are non-toxic and are biodegradable. As with most natural fibres, one of the challenges in working with gomuti fibres is the broad variability in the properties.

This study looks at the opportunity to utilise gomuti fibres as reinforcement in natural fibre composites. The aims are to investigate the tensile and flexural properties of gomuti fibres/polyester composites and to explore the suitability to use the fibres as reinforcement in composites.

3 SPECIMEN MANUFACTURING AND PREPARATION

Gomuti fibres were taken from *A. Pinnata* (sugar palm) trees and air-dried. They are sourced from Minahasa, North Sulawesi, Indonesia. No chemical treatment or surface cleaning has been made to the fibres in an attempt to simulate the original strength of the fibres. Four forms of fibre orientations were used that are random original orientation, chopped, unidirectional and woven mat. Figure 3 shows the fibre orientations. Fibres in random original orientation mean that they are in their original layered shape straight from the tree trunk. Commonly, the layer consists of two orientations of fibres as can be seen in Figure 2 and Figure 3a. Chopped fibres consist of approximately 0.5 – 5 cm fibres in length.



(a) Random original (b) Chopped

(c) Unidirectional (d) Woven mat

Figure 3. Orientation of the fibres

The specimens were manufactured by hand lay-up method, the commonly used method for small scale composite manufacturing. All composite panels were prepared with ten percent fibres by weight. Polyester resin is used as matrix with 1.5 percent catalyst (methyl ethyl ketone peroxide).

Specimens for tensile were prepared and tested according to AS 1145/ISO 527 while specimens for flexural were prepared according to ISO 14125. For flexural testing of neat resin, ISO 178 was used.

Tensile and flexure tests of the specimens were done in the Centre of Excellence in Engineered Fibre Composites (CEEFC) laboratory. MTS 10kN Alliance machine was used for flexure testing and MTS Insight 100kN machine was used for tensile testing.

4 RESULTS AND DISCUSSIONS

Table 3 and 4 show the results of tensile and flexural tests, respectively. Tensile test results showed that unidirectional specimens have the highest average tensile stress which is 24.5 MPa. The value is slightly over the tensile stress of coir/polyester composites (20.40 MPa – see Table 1).

The lowest average tensile stress value is for the woven mat that is 9.2 MPa with a standard deviation of 1.86. The standard deviation value (1.86) shows that the result of each specimen is in close range to the average value. The results of the random original orientation specimens are more varied than the other three variations as shown by the standard deviation of 8.64.

Woven mat specimens have the highest average value of flexural stress (48.4 MPa) with lowest standard deviation (Table 4). However, results of individual specimens show that one of the unidirectional specimens has the highest flexural stress that is 68 MPa. The average flexural stress of the unidirectional specimens was lower than the woven mat specimens because one unidirectional specimen has lowest flexural stress that is 25.9 MPa. Therefore, results of unidirectional specimens are more varied.

Table 3. Tensile test result of gomuti fibres/polyester composites

Form of fibres	Average tensile stress MPa	Standard deviation
Random original	15.40	8.64
Chopped	14.52	1.20
Unidirectional	24.49	6.30
Woven mat	9.24	1.86

Table 4. Flexure stress result of gomuti fibres/polyester composites

Form of fibres	Range of flexural stress MPa	Average flexural stress MPa	Standard deviation
Random original	34.92–56.35	43.67	9.00
Chopped	36.61–49.19	42.82	4.67
Unidirectional	25.99–68.02	47.82	15.22
Woven mat	45.00–54.29	48.43	3.65

Table 5. Flexure modulus, deflection and strain result of gomuti fibres/polyester composites

Form of fibres	Flexural modulus MPa	Deflection at peak mm	Strain at peak %
Random original	2912	2.57	1.40
Chopped	3538	2.88	1.20
Unidirectional	3396	3.56	1.46
Woven mat	3098	2.07	1.45

Table 5 shows that the value of flexural modulus of gomuti fibres/polyester composites ranged from 2912–3538 MPa, which are close to the value of flexural modulus of neat resin (Table 6). Also shown in Table 5 are the average deflection at peak and average strain at peak.

Table 6. Properties of neat polyester resin

Properties	Value MPa
Tensile strength (O'Dell, n.d.)	68.95
Tensile modulus (O'Dell, n.d.)	3930
Flexural strength	118.00
Flexural modulus	3333

The graph in Figure 4 shows that the flexural strength of all the specimens is lower than the flexural strength of neat resin. This indicates a poor adhesion between the fibres and the resin. However, the flexural modulus of all specimens is similar (Figure 5). This implies that achieving a similar modulus or stiffness for design purpose is feasible.

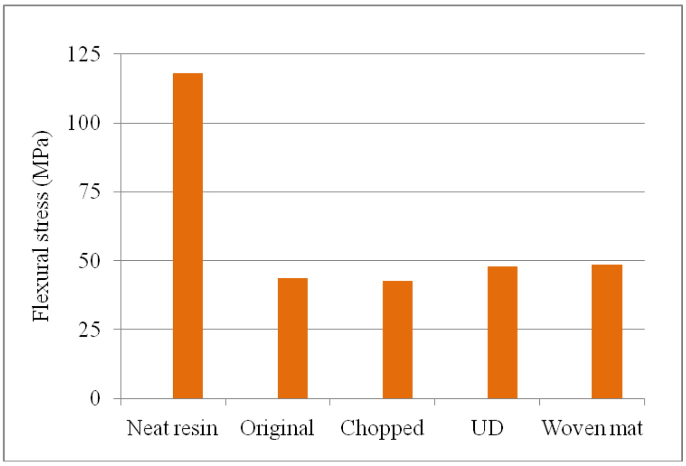


Figure 4. Tensile and flexural stress comparison

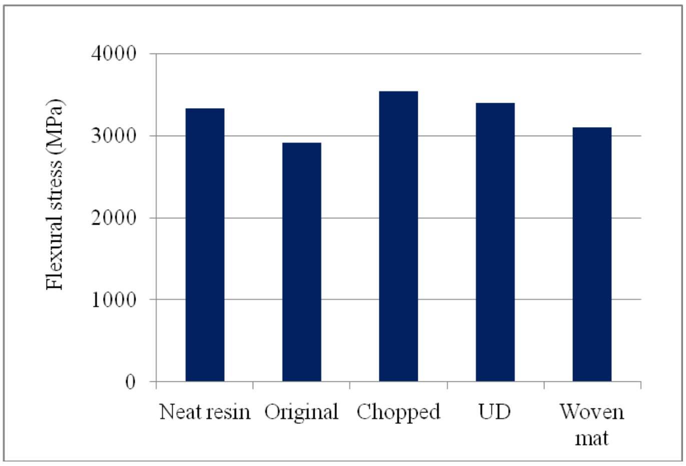


Figure 5. Flexural modulus comparison

Figures 6, 7, 8 and 9 show the stress-strain plot of the flexural test for random-original original orientation, chopped, unidirectional and woven mat respectively. As shown in the stress versus strain curves in the figures, after reaching peak stress, most of the specimens did not suddenly fail to zero stress but indicated a minor strengthening. Only three specimens of chopped fibres failed to zero.

The curves in Figure 6 and 8 show that random-original and unidirectional specimens have more varied results of strength and strain compared to chopped and woven mat specimens.

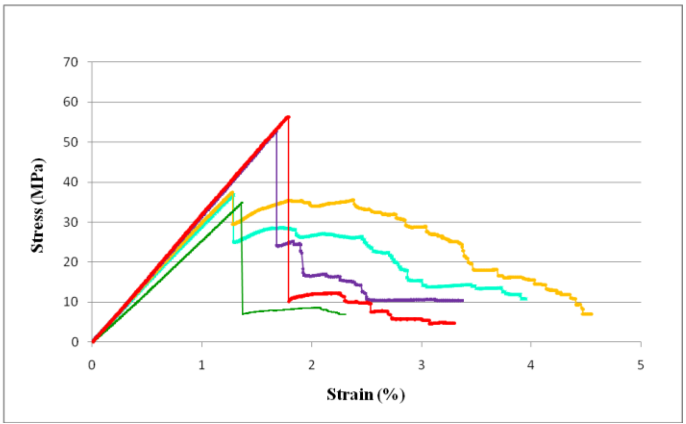


Figure 6. Stress-strain plot of flexural specimens of gomuti fibres/polyester composites: random-original

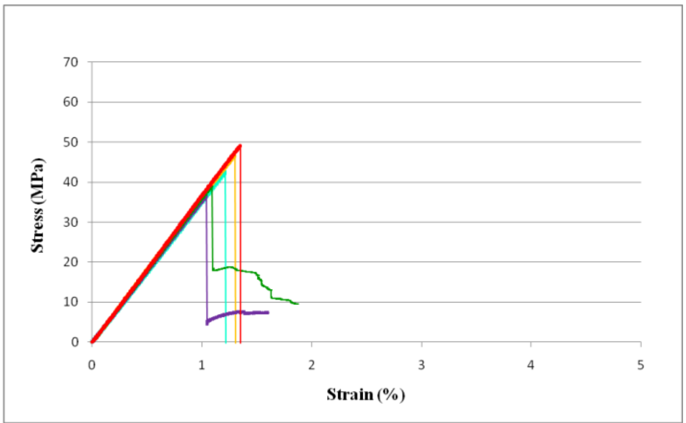


Figure 7. Stress-strain plot of flexural specimens of gomuti fibres/polyester composites: chopped

One unidirectional specimen (Figure 8) has reached the flexural strain of slightly over 2% while the other specimens have reached the strain of less than 2%. The neat resin specimen reached the flexural strain of slightly over 5% (Figure 10). The results suggest that compared to neat resin, the composites of gomuti/polyester were more brittle. However, the minor strengthening observed from the figures (Figures 6, 7, 8, and 9) infer that there is a possibility to improve the flexural properties.

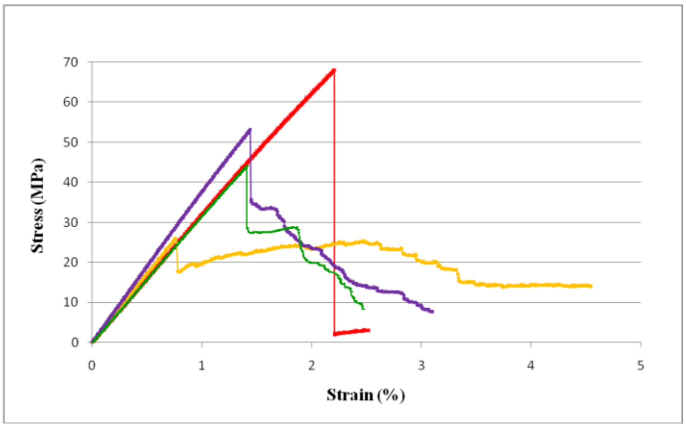


Figure 8. Stress-strain plot of flexural specimens of gomuti fibres/polyester composites: unidirectional

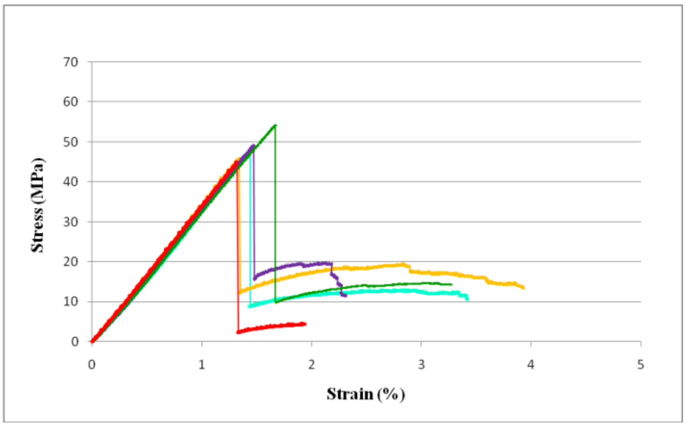


Figure 9. Stress-strain plot of flexural specimens of gomuti fibres/polyester composites: woven mat

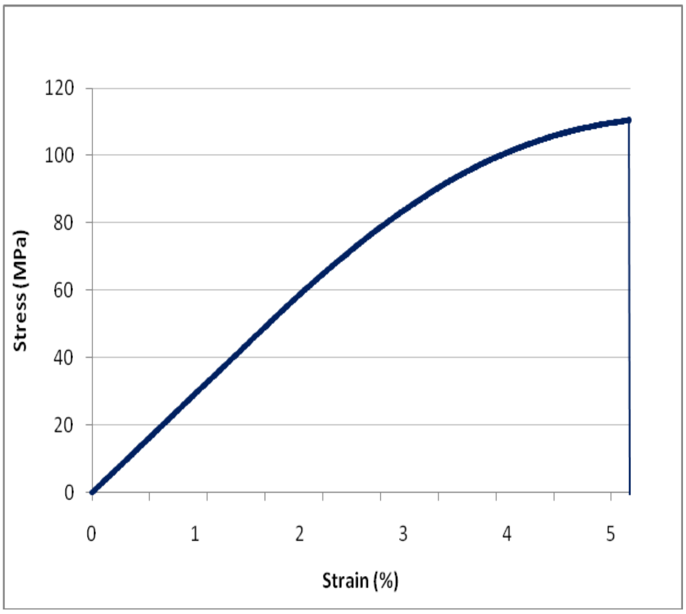


Figure 10. Stress-strain plot of neat polyester resin

For comparison purposes, the stress-strain graph of neat polyester resin is presented in Figure 10. The stress-strain graph of gomuti fibres/polyester (Figure 6, 7, 8 and 9) show lesser value of peak stress and strain. Therefore, in terms of tensile and flexural strength, the results of gomuti fibres/polyester composites are lower than that of neat resin. This suggests that the untreated fibres do not have proper bonding with the matrix.

5 CONCLUSIONS

Tensile and flexural properties of gomuti fibres/polyester composites were investigated and presented. The fact that the strength of the composites specimens are not as strong as glass fibres/polyester composites do not necessarily exclude the potential use of gomuti fibres as reinforcement in composites.

The results confirmed that more studies are needed to determine the beneficial and cost effective applications of the fibres in composites. This study has also confirmed that unidirectional gomuti fibres/polyester composites have the highest tensile strength and the woven mat gomuti fibres/polyester composites have the highest flexural strength. It is expected that with proper treatments, the mechanical properties of the gomuti fibres and the adhesion of gomuti fibres-polyester resin can be improved. Therefore, more studies on unidirectional and woven mat gomuti fibres are required.

6 ACKNOWLEDGEMENT

The authors wish to thank Dr. Julius Pontoh of Sam Ratulangi University, Manado, Indonesia and Mr. Arthur Ticoalu for their help in providing the gomuti fibres.

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