INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. 18, ISSUE 4, 9170 – 9178
DOI: https://doi.org/10.15282/ijame.18.4.2021.02.0705

ORIGINAL ARTICLE

Effect of Water Absorption Behaviour on Tensile Properties of Hybrid Jute-Roselle Woven Fibre Reinforced Polyester Composites

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ABSTRACT – Incorporating natural fibre as reinforcement in the polymer matrix has shown a negative effect since the natural fibre is hydrophilic. The natural fibre easily absorbs water which causes an effect on the mechanical properties of the composites. The objective of this paper is to investigate the water absorption behaviour of hybrid jute-roselle woven fibre reinforced unsaturated polyester composite and the effect of water absorption in terms of tensile strength and tensile modulus. The effect of hybrid composite on the thickness swelling will be tested. The fabrication method used in this study is the hand lay-up technique to fabricate 2-layer and 3-layer composites with layering sequences of woven jute (J)/roselle (Ro) fibre. The results of the study showed that pure roselle fibres for 2 and 3-layer composites have the highest water absorption behaviour 3.86% and 5.51%, respectively, in 28 days) as well as thickness swelling effect, whereas hybrid J-Ro and J-J-Ro composites showed the least water absorption (2.65% and 3.76%, respectively) in 28 days) in both the tests. The hybridisation between jute and roselle fibres reduced water absorption behaviour and improved the fibres dimensional stability. The entire composites showed a decreasing trend for both tensile strength and tensile modulus strength after five weeks of water immersion. Jute fibre composite hybridised with roselle fibre can be used to reduce the total reduction of both tensile strength and tensile modulus throughout the whole immersion period. Moreover, the tensile testing showed that jute fibre composite hybridised with roselle fibre have produced the strongest composite with the highest tensile and modulus strength compared to other types of composites. The hybridisation of diverse fibre reinforcements aids in minimising the composite water absorption and thickness swelling, hence reducing the effect of tensile characteristics.

ARTICLE HISTORY
Received: 5th May 2021
Revised: 31st Aug 2021
Accepted: 23rd Nov 2021

KEYWORDS
Jute fibre;
Roselle fibre;
Hybrid composite;
Natural fibre;
Tensile properties

INTRODUCTION

Fully utilising renewable resource, such as natural fibre, to manufacture high performance and low-cost engineering material is always the ultimate goal for scientists and researchers to achieve worldwide [1], [2]. With the rise of environmental awareness and the depletion of petroleum resources, researchers, academicians and scientists have seen the importance of these issues and urgently finding more environmentally friendly and sustainable resources to minimise the reliance on the earth's precious resources. More and more countries have established new environmental regulations to reduce the environmental impact due to the use of non-renewable synthetic fibre [3]. This forced the manufacturing industries to search for more eco-friendly materials to reduce the dependency on synthetic fibre such as carbon and glass fibre [4]. This has resulted in a new trend of utilising natural resources such as natural fibre rather than using conventional petroleum-based synthetic fibre [5]. Besides the environmental benefit, natural fibre has low cost, low density, and considerable mechanical strength properties. Natural fibre is an ideal replacement or substitute for conventional synthetic fibre in various applications, especially in automotive industries with these outstanding properties. Worldwide recognised automotive manufacturer companies such as German carmaker BMW Group utilised many natural fibre composites in their production [6]. The report has shown that BMW Group used a tremendous amount of natural fibre, approximately 10,000 tons to be exact, in 2004 [7]. Most of these natural fibre composites will be utilised to produce vehicle components like door panels, noise insulation panels, headliner panels and many other components [8]. Besides the automotive sector, natural fibre composite also received wide usage in different fields such as construction and many other areas. Hamdan et al. [9] reported that natural fibre composite uses experienced a constant growth rate of 13% for the past ten years.

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However, replacing synthetic fibre with natural fibre has indicated some disadvantages, such as the relatively low mechanical properties because of the incompatibilities between the hydrophilic fibres and hydrophobic thermoplastic, requiring further treatment to improve the compatibility [10]. Apart from that, the natural fibre itself possesses strong water absorption properties due to its hydrophilic nature. This composite's mechanical properties can be significantly affected when the composite is subjected to moisture, limiting its application. Moisture absorption related problems also included micro-cracks in the matrix resulting from the natural fibre [11]. From the chemical reaction point of view, the main reason behind the strong water absorption properties of natural fibres is the presence of hydroxyl groups, which are hydrophilic. Previous research work by Tezara et al. [12] reported that the interface adhesion between the fibre and matrix play an important role in the determination of the mechanical properties of natural fibre reinforced composite. However, the water present in natural fibre reinforced composites can significantly weaken the bonding strength between the fibres and matrix, drastically reducing the composite's mechanical strength. As a result, it is essential to understand the water absorption behaviour for natural fibre as reinforcement in polymer matrix material and identity the effect of water absorption for the composite in terms of their tensile properties, such as tensile strength tensile modulus. Hence, this paper will focus on the investigation of the effect of water absorption behaviour on tensile properties of hybrid roselle/jute woven fibre reinforced unsaturated polyester composites.

METHODOLOGY

Materials

The natural fibres of woven jute and roselle were obtained from Impiana Enterprise Kuala Lumpur, Malaysia. The woven natural fibres were washed in mild condition, roughly about ten times with distilled water to ensure the elimination of the natural salinity and dust present in the woven mat [13]. Next, before the laminating process of woven pure jute, roselle, and hybrid composite, the woven fibres were put in the oven for 24 hours at the temperature of 80 ºC in order to remove all the moisture. Lastly, these natural fibres were cut into the desired dimension to shape the mould later, and the fibre was stored a vacuum plastic to make sure the fibre did not absorb humidity from the surrounding. The unsaturated polyester resin Reversol P9509 was purchased from Tazdiq Engineering Kuala Lumpur, Malaysia. Polyester Reversol P9509 is suitable for hand lay-up application due to its favourable characteristics for the study which include non-waxed, low viscosity (450-600 @25 ºC (cps)), low reactivity (25-35 Gel time @25 ºC (min)), and thixotropic in general purpose. The polyester hardener methyl ethyl ketone peroxide (MEKP) was selected as the catalyst (1% total weight of polyester) to pre-promote for ambient temperature gel and cure.

Composite Plate Fabrication

Before the laminated process of woven pure jute, roselle, and hybrid composite, the woven fibres were dried in the oven for 24 hours at the temperature of 80 ºC. The hand lay-up method was carried out for the preparation of composite laminates. The woven natural fibre of jute and roselle, together with unsaturated polyester resin was used during the fabrication process. Firstly, the wax or releasing agent was sprayed to coat the inner mould surface with the purpose of preventing sticking between the composite plate and the mould surface for ease of removal. The different arrangement of jute/roselle composite plates was prepared.

The unsaturated polyester resin was then poured into the mould and each layer of fibre was placed over the top of the resin repeatedly until the desired thickness was obtained, considering the fabric alignment tolerance. Then, the mould with complete layering placement of composite was pressed with 50 bars to ensure full viscidity and placed at the room temperature for 24 hours to remove air trapped during the hand lay-up process. Thereafter, to post-cure the plates, the composite plate was left in the oven under 80 °C for another two hours. Figure 1 shows the picture regarding the different sequence of layer arrangements composite. Table 1 shows the different types of composite plates for the tensile and water absorption test.

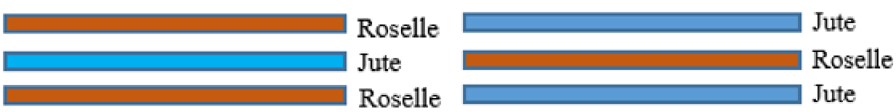


Figure 1. Different fibre arrangements for the composite plate.

Water Absorption Test

A water absorption test was carried out after immersing the specimens into the water for five weeks (following ASTM D570-98) to determine the percentage of weight gain by the specimens. The specimen for the water absorption test in this study has the same geometry as the specimen for the tensile test, which is in accordance with ASTM D 638-type IV. The weight change of the specimens was measured every day using a high precision weighing balance capable of giving accuracy up to 4 decimal places. The weight gain percentage, ΔM(t), was calculated using Eq. (1) [4].

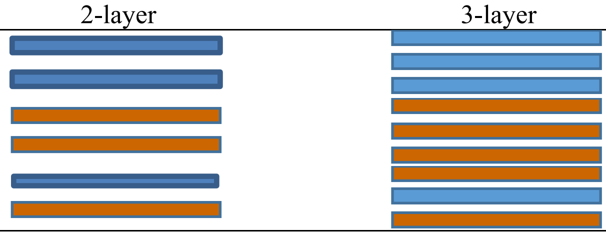
$$\Delta M(t) = \frac{M_t - M_0}{M_0} \times 100 \tag{1}$$

where, M_t is the weight after immersion, M_0 is the original weight of the composite.

Five sample specimens were tested for each type of composite by immersing the sample specimen in the distilled water in a closed box and were conditioned at room temperature [33]. The sample specimen was taken out from the water after a certain period of time and then dried before its weight and thickness were measured. The dimension stability test was then continued and repeated until the required constant weight of the sample was obtained. Eight data were collected for each type of composite to obtain an average value for the data analysing purpose.

Table 1. Different configurations of hybrid jute-roselle composites

Type of fibre	Number of layers	
	2-layer	3-layer
Jute (J)		
Roselle (Ro)		
Jute-Roselle		



= Jute fibre = Roselle fibre

Thickness Swelling

The thickness swelling test is intended to determine the thickness change of the specimens due to the water intake throughout the period of immersion in water. Similar to the water absorption test, the thickness swelling test was carried out after immersing the specimens for five weeks. Both the water absorption and thickness swelling tests run simultaneously to obtain as many accurate results as possible. The thickness change of the specimens was measured every day using a digital Vernier calliper capable of giving accuracy up to 2 decimal places. Besides, the results obtained from the digital Vernier calliper were also verified with the use of conventional Vernier calliper for maximum accuracy. The percentage of thickness swelling ΔT(t) was calculated using Eq. (2) [34]:

$$\Delta \mathrm{T}(t) = \frac{T_t - T_0}{T_0} \times 100 \quad (2)$$

where, T_t is thickness after immersion, and T_0 is the original thickness of the composite.

Tensile Testing

Tensile test of the composites was carried out using Instron 3369 universal testing machine by following the standard of ASTM D 638 - IV. The geometry of the tensile test specimens is shown in Figure 1. Five sample specimens were tested for each category with a cross-head speed of 2 mm/min. Tensile strength and tensile modulus of composites were recorded.

RESULTS AND DISCUSSION

Water Absorption

Water absorption in fibre-reinforced polymer composites is mediated by three major mechanisms; diffusion, capillary, and water molecule transport. The diffusion mechanism takes place between the micro gaps between polymer chains. Certainly, water diffusion at the fibre-matrix interface causes differential swelling of the natural fibre, which is mostly due to its hydrophilic nature. As a result, fibre swelling may induce tension at the interface, resulting in matrix degradation and micro-cracking, which exacerbates water uptake [35]. Capillary transport occured in the gaps at the fibre-matrix interface space if the reinforcement was not completely impregnated with the matrix during the manufacturing process [36]. The transport of water molecules through microcracks that can occur in the matrix as a result of fibre swelling is especially relevant in natural fibre composites [37].

The percentage of weight gain (%) against the immersion days for all of the samples is as illustrated in Figure 2. A clear trend could be seen for the water absorption behaviour for the composites, where for the first four weeks, a significant amount of water is being absorbed by all types of composites. Similar results were also obtained in the work of Hamdan et al. [4], whereby in the first week, the water intake increased exponentially for hybrid jute roselle composite. After the first four weeks, the percentage of weight gain started to slow down and eventually reached its constant. This result revealed that the composite absorbed the maximum amount of water that it can take after four weeks, so-called the saturation point [38]. The greater hemicellulose and cellulose content of the roselle fabric means a greater percentage of hydroxyl and acetyl groups, which are the main contributors to moisture absorption [4].

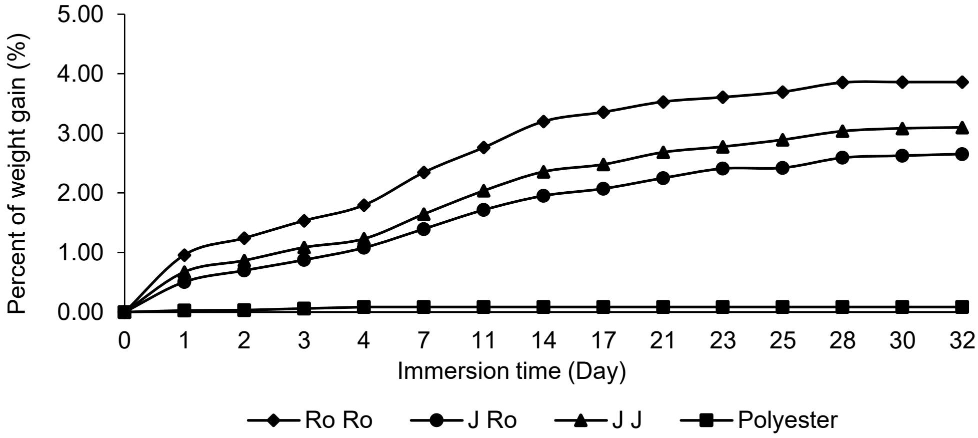


Figure 2. Percentages of weight gain for 2-layer composites.

From the results, it is shown that the composite of pure 2-layer roselle composite (Ro-Ro) has the highest percentage of weight gain with the gain of 3.86% throughout its entire period of water immersion, followed by jute-jute (J-J) and jute-roselle (J-Ro) composites with maximum percentage weight gain of 3.10% and 2.65%, respectively. These results are expected since the roselle fibre contains around 69.38% of cellulose [39] compared to jute fibre that only contains approximately 58.3% of cellulose. Cellulose is the main contributor to water absorption behaviour for natural fibre [16]. Hence, the recorded percentage of weight gain for pure polyester is only 0.08% which is almost zero due to the absence of cellulose contribution from natural fibre.

A similar trend can also be seen in Figure 3, where the percentage of weight gain is increased linearly at the beginning and reaches a constant line roughly after 28 days. From the graph, the highest water absorption by the composite belongs to the 3-layer pure roselle (Ro-Ro-Ro) composite with a maximum weight gain of 5.52% when it reached a saturation point. On the other hand, the lowest weight gain recorded is by the jute-jute-roselle (J-J-Ro) composite, where the maximum recorded percentage of weight gain is only 3.76%.

The recorded maximum weight gains for other composites such as jute-roselle-roselle (J-Ro-Ro), jute-jute-jute (J-J-J), jute-roselle-jute (J-Ro-J) and roselle-jute-roselle (Ro-J-Ro) were 5.49%, 4.74%, 4.50% and 4.15%, respectively, at saturation point. This also showed the water absorption effect of the composite could be reduced through introducing hybridisation. For instance, the percentage of weight gain by 3-layer pure roselle (Ro-Ro-Ro) composite is effectively reduced from 5.51% to 4.15% by using jute fibre as a reinforcing agent to form a Ro-J-Ro hybrid composite. A similar study also showed that using banana fibre hybridised with sisal fibre composite can effectively reduce water uptake [17].

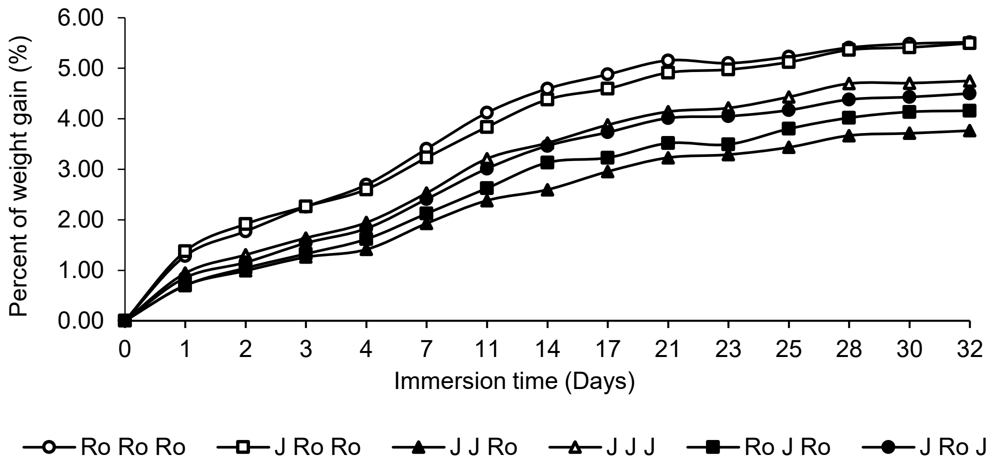


Figure 3. Percentages of weight gain for 3-layer composites.

Figure 4 presents the percentage of weight gain for both 2-layer and 3-layer composites with different immersion times. From the graph, it was observed that the gradient or the slope of the line for the first four weeks for the 3-layer composites is much more inclined compared to the 2-layer composites, which indicated that the water absorption is much more intense for the 3-layer composites for the first four weeks.

This result was reasonable as the 3-layer composites are fibre content contain than 2-layer composites, which resulted in a higher water absorption rate for the composite [18]. The same goes for the maximum percentage of weight gain at the saturation point for the composite. For instance, the recorded percentage weight gains for the 2-layer and 3-layer pure roselle fibre composites increased from 3.86% to 5.51%, respectively, at the saturation point. But, the exceptional result is found where the 2-layer Ro-Ro composites have more than 0.10% water absorption than the 3-layer J-J-Ro composite.

This might be due to the presence of defects such as a hole or void in the composite itself, which can trap excess water and ultimately alter the result [19].

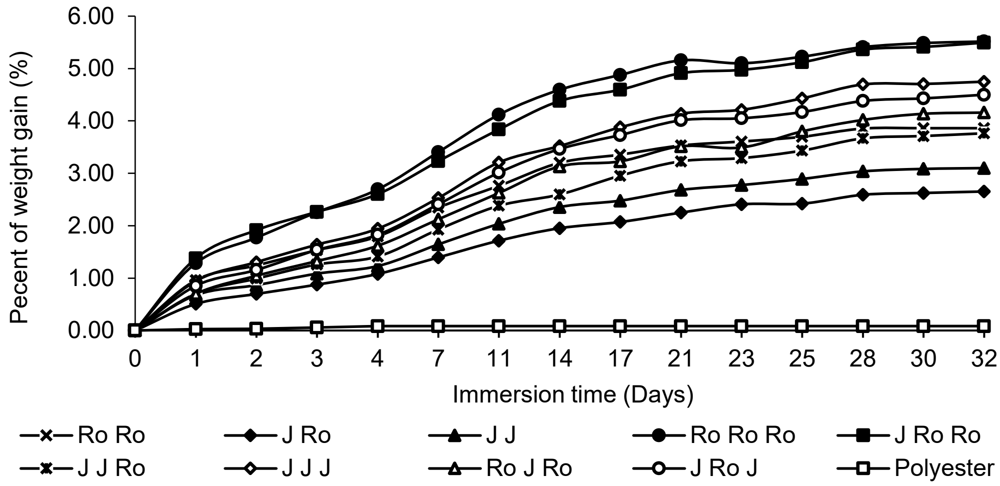


Figure 4. Comparison of weight gain for 2-layer and 3-layer composites.

Thickness Swelling

Figure 5 shows variations of the percentage change in the thickness swelling of the composite specimens at various immersion times. As can be seen from the graph, the thickness swelling shows an increasing trend until three to four days of the immersion time, and the thickness gain reaches its equilibrium state afterwards. The thickness swelling of the specimens was mainly due to the high water attraction nature of the hemicellulose part and the presence of the hydroxyl group in the cellulose structure of the natural fibres. The aforementioned factors and the capillary action might have caused the composite specimens to absorb more moisture when immersed in water, hence increasing thickness [20].

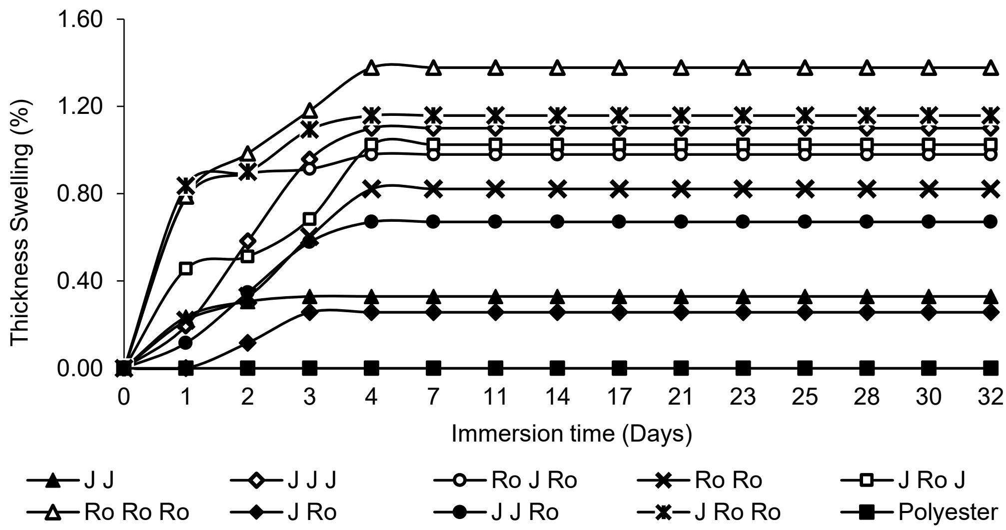


Figure 5. Thickness swelling for various types of composite.

A similar observation was reported by Jawaid et al. [21].. However, thickness swelling does not affect pure polyester composite as it contains no fibres and possesses a strong water resistance matrix. The composites have reached their maximum thickness in such a short period (maximum of four days), and the thickness swelling percentage is insignificant after four days of soaking time [22]. This might be related to the fibre content of the composites and the weight gain percentage. From Figure 4 and Figure 5, the maximum fibre content and the weight gain percentage are only 18.30% and 5.52%, respectively, which are relatively small compared to other researchers' results for the water absorption behaviour of recycled fibre composite with 46% fibre content [23].

The 3-layer of pure roselle fibre (Ro-Ro-Ro) composite has the highest percentage of thickness swelling. The thickness is increased by 1.38 % from its original thickness compared to the increment of only 0.82 % for the 2-layer pure roselle fibre (Ro-Ro) composite. In contrast, the lowest percentage of thickness gain belongs to the 2-layers hybrid (J-Ro) composites, where the total percentage of thickness gain is 0.26% compared to 0.67 % for the 3-layers J-J-Ro composite. The result is considered reasonable as more layers of fibres can increase the composite's thickness swelling effect due to the increment of the fibre content. A similar result was also obtained from the works of Rozman et al. [24], who investigated the thickness swelling of coconut fibre composite. On the other hand, the average percentage of thickness swelling recorded for other composites such as (J-Ro-Ro), (J-J-J), (J-Ro-J), (Ro-J-Ro), (J-J) showed moderate thickness gain which are 1.16 %, 1.10 %, 1.03 %, 0.98 % and 0.33 % respectively. Interestingly, composite like (Ro-Ro-Ro) has the highest thickness and weight gains, which are 1.37 % and 5.52 %, respectively. Hence, it can be concluded that the percentage of thickness swelling for the composite has a direct relationship with its weight gain [25].

Tensile Test

It was observed that there was a decreasing trend for both tensile strength and tensile modulus for the composite after several weeks of water immersionas can be seen from Figure 6 and Figure 7, respectively. The reduction of the mechanical strength of the natural fibre composite after water immersion is due to the water weakening the adhesion strength between the fibre and the matrix [6]. The pure 2-layer Ro-Ro composite experienced the most significant drop where the tensile strength is decreased from 26.22 MPa to 19.39 MPa or 26.04% of depletion after five weeks of immersion. By comparison, the tensile strength for the J-Ro composite decreased roughly by about 13.41% (from 28.14 MPa to 24 MPa), whereas the tensile strength for the J-J composite dropped by about 12.77% (from 28.11 MPa to 24.52 MPa). This has highlighted that the more vital water absorption ability of the roselle fibre has resulted in the highest reduction of tensile strength compared to other types of composites. Further research conducted also stated the strong water absorption behaviour of the roselle fibre, which often required chemical treatment [26].

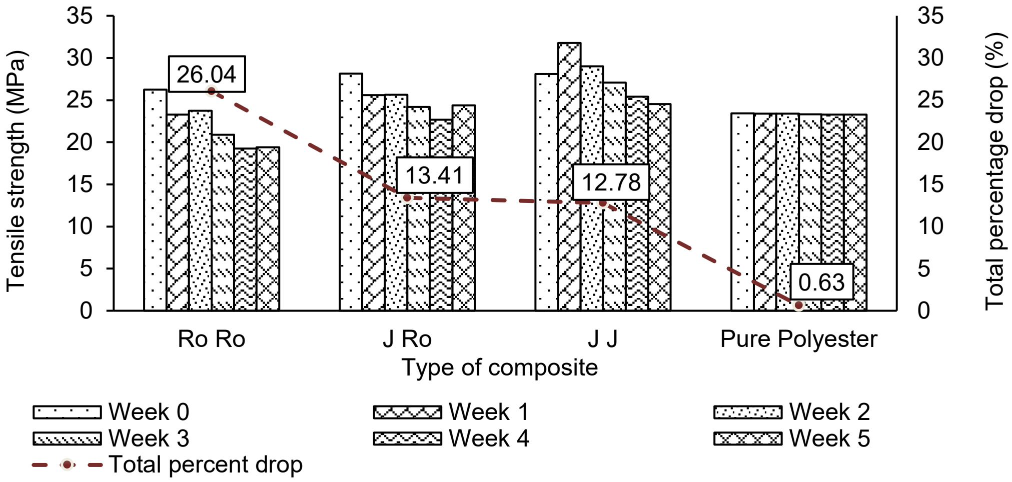


Figure 6. The tensile strength for 2-layer composites.

Similar results could also be seen from tensile modulus displayed in Figure 7, where the Ro-Ro composites also experienced the highest depletion for tensile modulus among other types of the composite where the total drop is calculated to be 18.40% from 979.52 MPa to 799.27 MPa. In contrast, the depletion of the tensile modulus for J-J composite is the lowest due to the relatively low cellulose contained for jute fibre. The recorded tensile modulus dropped from 1060.43 MPa to 951.89 MPa or equivalent to 10.32% of reduction. Through hybridisation, the hybrid J-Ro composite experienced a total drop of only 16.82% from 1033.61 MPa to 859.70 MPa, which is slightly better than pure 2-layer Ro-Ro composite.

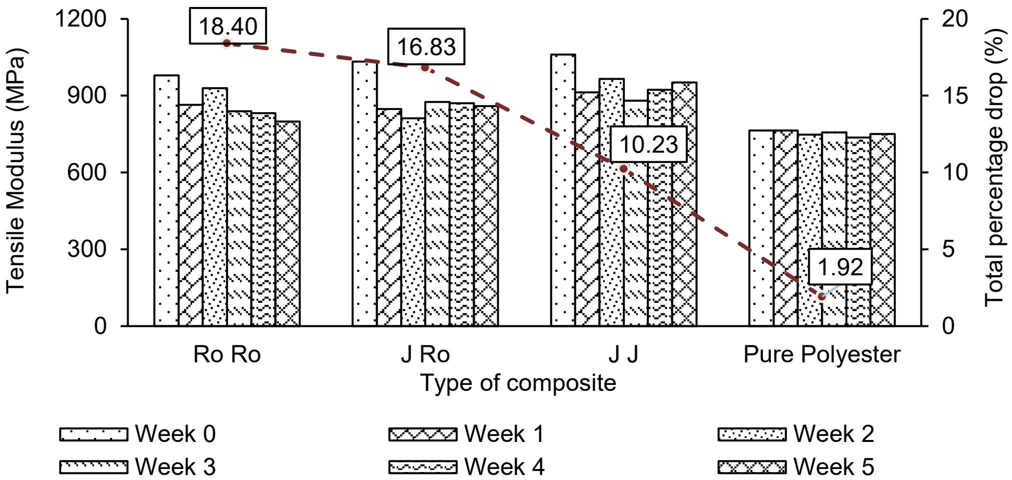


Figure 7. The tensile modulus for 2-layer composites.

Pure polyester composite almost did not experience any drop in both tensile strength and tensile modulus, where the total percentage of decline was only 0.63% and 1.91%, respectively. This result is expected, as pure polyester composite possessed excellent water resistance [27]. Furthermore, Figure 6 indicated that unexpected results could be found, such as the tensile strength after one week of immersion for the J-J was 31.77 MPa higher than its original tensile strength with the value of 28.11 MPa. A similar result was also obtained by other researchers [28], which explained that the gaps between the fibre and matrix was full due to the swelling effect of fibre and resulted in the increase of tensile strength.

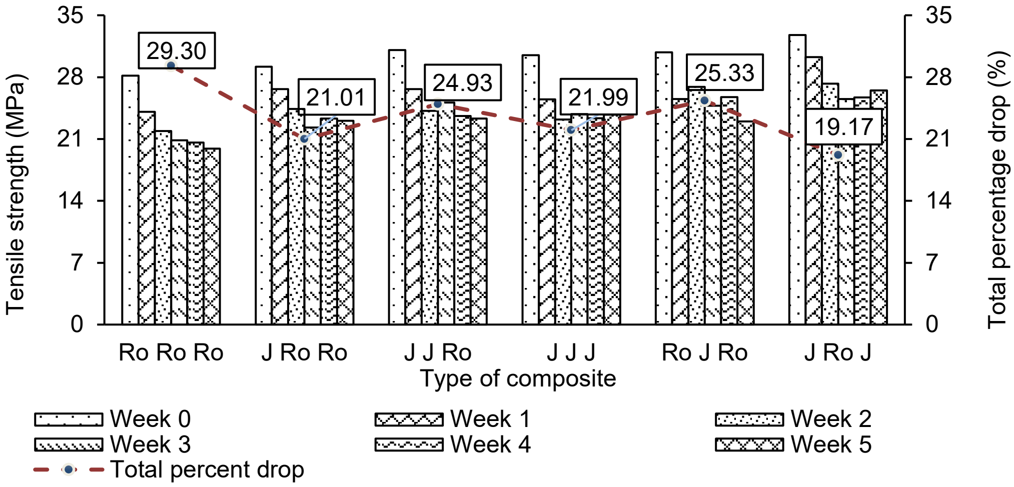


Figure 8. The tensile strength for 3-layer composites.

Based on Figure 8, all types of composites have shown a decreasing trend in tensile strength despite some fluctuation. For instance, the Ro-Ro-Ro composite encountered the most significant reduction of tensile strength which dropped from 28.18 MPa to 19.92 MPa or equivalent to a 29.29% of decline throughout the five weeks immersion period. In contrast, the hybrid composite J-Ro-J recorded the lowest depletion in tensile strength with only 19.16% of reduction which was reduced from 32.77 MPa to 26.49 MPa. Other composites such as Ro-J-Ro, J-J-Ro, J-J-J and J-J-Ro experienced moderate reduction where the total percentage drop was 25.32%, 24.92%, 21.99% and 21.01%, respectively, in terms of their tensile strength. It is also worth pointing out that the hybrid Ro-J-Ro composite exhibited higher tensile strength with the value of 30.79 MPa compared to J-Ro-Ro which is only 29.17 MPa. Based on the previous study by Venkateshwaran et al. [17], it was stated that the layering sequence could have a great impact on the mechanical strength of jute and banana fibre composites.

All types of composites have shown a decreasing trend in tensile modulus despite some fluctuations, as presented in Figure 9. Supposedly, the tensile strength and tensile modulus strength should decrease with the increased immersion time. The tensile modulus for the J-Ro-J composite at the 1st week of immersion is exceptionally lower than after three weeks of immersion with the value of 918.07 MPa and 990.87 MPa, respectively. This might be due to the defect of the composite.

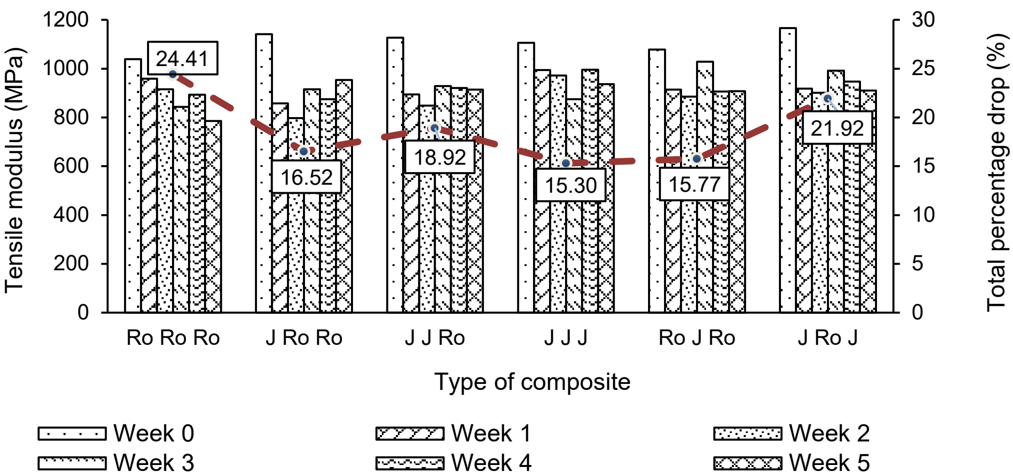


Figure 9. The tensile modulus for 3-layer composites.

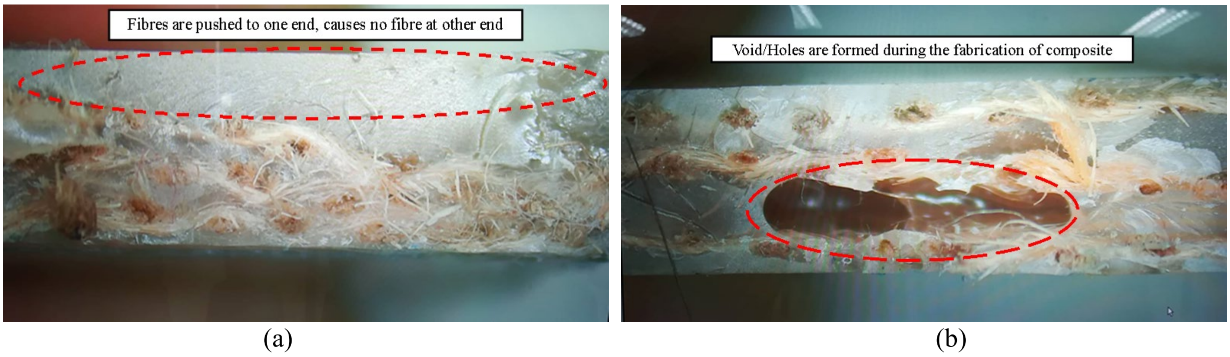


Figure 10. Presence of (a) uneven distribution of fibre and (b) void inside the composites.

Defects like the uneven distribution of fibre and the void are presented in Figure 10 and Figure 11, respectively. As previously mentioned by Oromiehie et al. [29], such defects result in a sudden loss of the load-carrying capability of a structure due to the change in moment of inertia at the defect area local buckling of sub-laminates. Additionally, the hybrid J-Ro-J composites possessed a strong tensile strength and the tensile modulus with the value of 32.77 MPa and 1165.57 MPa, respectively, compared to non-hybrid composite J-J-J. Studies conducted by Maslinda et al. [30] also stated that hybrid composite has better load-sharing property due to each fibre's different properties, which resulted in better tensile and modulus strength.

CONCLUSION

This study involved in the investigation of the water absorption behaviour and its effect on the mechanical strength of pure/hybrid jute and roselle fibres as reinforcement for the unsaturated polyester. All types of composites had shown an increasing trend in terms of their weight and thickness throughout the whole water immersion period. For instance, the 3-layer Ro-Ro-Ro composite showed the highest percentage of weight gain and thickness swelling compared to other types of composites. In contrast, the 3-layer hybrid J-J-Ro composite results showed the lowest in both percentages of weight gain and thickness swelling effect. For the 2-layer composite, Ro-Ro composite exhibited the highest weight gain and thickness swelling through water absorption, whereas J-Ro showed the lowest in both. From the results, the 2-layer pure Ro-Ro composite showed the most significant reduction in both tensile and modulus strengths, whereas the 2-layer pure J-J composite experienced the least depletion in both aspects after five weeks of water immersion. The hybridisation of roselle fibre with jute fibre can reduce its water absorption ability and enhance its dimensional stability. The tensile strength and tensile modulus of the composite showed a decreasing trend after five weeks of water immersion, with the total percentage drop ranging from 10% to 30%. This is due to the weakening of the adhesion bond between the fibre and matrix.

ACKNOWLEDGEMENT

The authors would like to express gratitude to the Universitas Malahayati, INTI International University and Universiti Malaysia Pahang for providing the laboratory facilities. A special thanks to Mr Hew Wei Zhuang for his dedication and hard work completing the project.

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