Pertanika J. Sci. & Technol. 32 (S5): 123 - 132 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Response Surface Methodology for Optimisation of Parameter on Water Absorption of Natural Fibre Hybrid Composite in Boat Construction

Suriani Mat Jusoh[1,2,3]*, Mohammad Fakhratul Ridwan Zulkifli[1,2], Samsuri Abdullah[1], Ayu Rafiqah Shafi[3], Mohd Fadzhel Mohd Nasir[4], Ummi Nurashira Maulana[1], Fathin Sakinah Mohd Radzi[1] and Syakir Hakimi Zainulabidin[1]

[1]Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[2]Marine Materials Research Group, Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[3]Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[4]National Tobacco and Kenaf Board (LKTN)), Kubang Kerian,16150 Kota Bharu, Kelantan, Malaysia

ABSTRACT

Today, the utilisation of natural or green fibre has supplanted engineered fibre as fibreglass has become a pattern in composite boat producing and other gears because of its lightweight, excellent relative mechanical properties, and more significant elements. For example, it is eco-accommodating, has manageable materials, and has lower costs compared to fibreglass. The utilisation of fibreglass is costly and has a high effect on the natural biological system. It also gets over the area of ecological contamination, word-related well-being, and security concerns. This study used the Woven Kenaf/fibreglass as reinforcement and polyester as matric to fabricate hybrid composite coupons. Response Surface Methodology (RSM) of Box-Behnken Design (BBD) was applied to optimise fibre contents (35 to 75 wt%) and water absorption performance for the development of Woven Kenaf/fibreglass to polyester hybrid composite material based on the parameters. The BBD revealed that 45% Woven Kenaf/fibreglass to polyester performed the optimum fibre content and water absorption. Analyses of variance (ANOVA) showed that the model satisfactorily correlated the parameters. After immersion, 45% Woven Kenaf/fibreglass to polyester composite also gained 9.48% weight.

Keywords: Box-Behnken design, hybrid composite, kenaf fibre, response surface methodology, water absorption

ARTICLE INFO

Article history:
Received: 15 March 2024
Accepted: 02 August 2024
Published: 30 October 2024

DOI: https://doi.org/10.47836/pjst.32.S5.06

E-mail addresses:
surianimatjusoh@umt.edu.my (Suriani Mat Jusoh)
fakhratulz@umt.edu.my (Mohammad Fakhratul Ridwan Zulkifli)
samsuri@umt.edu.my (Samsuri Abdullah)
ayurafiqah@upm.edu.my (Ayu Rafiqah Shafi)
fadzhel@lktn.gov.my (Mohd Fadzhel Mohd Nasir)
umminurashira@gmail.com (Ummi Nurashira Maulana)
fathinsakinah96@gmail.com (Fathin Sakinah Mohd Radzi)
syakirhakimi@gmail.com (Syakir Hakimi Zainulabidin)
*Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Natural fibre polymer composites are strikingly sought after among an assortment of applications from aviation, auto, development, and sea-to-home devices because of the benefits of being eco-accommodating and manageable materials. Natural fibres can be obtained from animals and plants (Jawaid & Khalil, 2011; Kamarudin et al., 2022; Syduzzaman et al., 2020) and can furnish a material with a high-solidarity-to-weight proportion and supplant the utilisation of synthetic fibres (Kabir et al., 2007; Karimah et al., 2021). However, natural fibres have disadvantages such as low modulus strength, impact properties, moisture resistance, limited durability, and poor fire resistance. This shortcoming is overcome using the hybridisation of natural fibre with synthetic fibre, i.e., fibreglass that delivers hybrid composites with the best properties of the elements, bringing about ideal, unrivalled, however savvy composites (Karimah et al., 2021; Radzi et al., 2019). Processing characteristics for each type of natural fibre and their parameter setting are different. Ideal boundary settings for elite execution composites utilising regular fibre lattice blends are expected to deal with strategies. Different factors can impact the properties of normal fibre polymer composites. Huge fibre stacking is typically expected to accomplish great natural fibre polymer composite properties and cycle boundaries that impact composites' properties and surface highlights. Accordingly, the appropriate cycle strategies and boundaries should be painstakingly distinguished to acquire the best elements of composites (Peças et al., 2018).

ML was used to predict trends, classification, and target detection, such as speech recognition, face recognition, house price prediction, and many more. Response Surface Methodology (RSM) is one of the Design of Experiment (DOE) techniques available in ML for optimisation in conditions of several potential input variables affecting a process or product's performance or characteristic (Cai et al., 2020; Iliyasu et al., 2022). Additionally, when contrasted with other DOEs, it can evaluate the impacts of various elements and their communications on at least one reaction factor. RSM is one of the most involved trial plans for advancement. RSM permitted assessing the impacts of various elements and their communications on at least one reaction factor. It is likewise a valuable technique, supplanting traditional strategy, as does the writing or experimentation to decide for proposed quantities of exploration. RSM was carried out to foster the measurable models to assess the impact of boundaries of any cycle as well as to upgrade the circumstances for helpful reactions as utilised to build the worth of the information assortment in combustibility and thermal properties of plant fibre half-breed composite (Gholamian et al., 2017; Pugliese et al., 2021). RSM of Central Composite Design (CCD) was also used to optimise biocomposites based on poly (lactic acid) and durian peel cellulose and to obtain the highest tensile strength and impact strength performance. RSM effectively explores how parameters like density, fibre weight, and polyester weight impact the water absorption of woven kenaf/fibreglass composites (Prabhu et al., 2022).

Using sophisticated statistical models, RSM predicts how much water these composites absorb. Analysis of variance (ANOVA) helps analyse the data thoroughly (Saaidia et al., 2022). In essence, RSM helps find the best ways to reduce water absorption in these composite materials. Furthermore, RSM's predictive design can specify composite material parameters without extensive experimentation, saving valuable time and resources (Makhlouf et al., 2022). Consequently, this study is to decide the impact of info variable of boundaries (fibre thickness, fibre support weight, and polyester pitch weight) on the water retention of polyester built-up woven kenaf hybrid with fibreglass composite material, as well as the enhancement of these boundaries to deliver the ideal fibre content to create hybrid composite material utilising the RSM.

MATERIALS AND METHODS

Response Surface Methodology with Box-Behnken Design

This study used RSM based on the Box-Behnken Design (BBD) for the experimental investigation. There was a total of 15 experimental runs. The parameters were configured as shown in Table 1. Based on preliminary research, these parameter settings were considered. The tool for data statistical analysis was Design Expert software version 13 (US, Stat-Ease Inc.).

Table 1
Parameters and levels

	Parameter Unit	Minimum	Maximum	Coded Low	Coded High
A	Density (g/mm^3)	1.0000	1.03	-1 ↔ 1.000	+1 ↔ 1.03
B	Weight of fibre (%)	15	75	-1 ↔ 15	+1 ↔ 75
C	Weight of polyester (%)	15	85	-1 ↔ 15	+1 ↔ 85

Fabrication of Composite Coupon

Fabrication of Woven Kenaf/fibreglass hybrid composite materials was conducted using the hand lay-up technique. The composite coupons were prepared using different fibre content (weight percentage) compositions of Woven Kenaf/fibreglass-to-polyester, such as 15, 45, 60, and 75 wt% (Table 3). Table 2 depicts the Composite Coupon Designation of each weight percentage material. The polyester and catalyst were blended completely to ensure the combination was well-blended before filling the mould.

The composite coupons were prepared with dimensions of 230 mm (length) x 5 mm (thickness) x 160 mm (width). The mould surface was cleaned and waxed to make the composite easily removed from the mould. After completing the hand lay-up process, the top surface of the composite was rolled with a roller to remove air or bubbles. The mould with the composite was left at room temperature for 24 hours.

Table 2
Density of materials composite coupon designation of each weight percentage materials

Percentage of materials (wt%)	Designation of each weight percentage materials				
	0 wt% (Control sample)	15 wt%	45 wt%	60 wt%	75 wt%
Polyester + catalyst	90	75	45	30	15
Natural fibres (woven Kenaf)	0	15	45	60	75
Fibreglass	10	10	10	10	10

Water Absorption Test

Composite coupons were submerged in tap water in a room with 40% relative humidity at 30°C temperature. The specimens were removed from the water, cleaned, dried to eliminate the surface dampness, and afterwards weighed to obtain the weight gain because of the water ingestion. The mass of the dried samples, M_o, was measured after oven drying at 100°C for 10 minutes and left at room temperature for 24 hours. The water ingestion test was performed adhering to the ASTM D570 standard. Composite samples are considered equilibrium when their daily weight gain is less than 0.01%. Moisture content percentage, $\Delta M(t)$, was calculated using Equation 1:

$$\Delta M(t) = \frac{Mt - M_0}{M_0} \text{ x } 100 \tag{1}$$

where M_o is the weight of the coupons before immersion and M_t represents the weight of the coupon after immersion at a specific time. Assuming the absorption process was linear at the early stage of immersion, times were taken at the beginning, so the weight change is expected to vary linearly with the square root of time. The percentage of moisture absorption was plotted against the square root of time ($\sqrt{t}$, hours).

Materials

Treated Woven Kenaf/fibreglass was used as reinforcement, and polyester was used as the matrix to fabricate Woven Kenaf/fibreglass to polyester composite materials. The Woven Kenaf was treated by soaking the fibre in 5% Sodium Hydroxide (NaOH) for a day and then drying at 80°C for 24 hours. Woven Kenaf was provided by the Institute of Tropical Forestry and Forest Product (INTROP), UPM, while MSET Inflatable Composite Corporation Sdn supplied fibreglass (CSM 225) and unsaturated polyester resin Reversol P-9509 Sdn. Bhd.

RESULTS AND DISCUSSION

Results obtained from the experimental runs are tabulated in Table 4. The water absorption ranged from 15 to 75 wt% fibre content, while water absorption ranged between 1.39 and 10.89 g.

Table 4
Results of experimental runs

Factor 1	Factor 2	Factor 3	Response 1
A: Density g/cm^3	B: Weight of fibre (%)	C: Weight of polyester (%)	Water absorption (%)
1	45	85	1.39
1.03	45	15	3
1.015	45	50	4.43
1	75	50	6.29
1.03	45	85	6.11
1.015	45	50	6.64
1	15	50	1.78
1.015	45	50	7.65
1.015	15	15	1.78
1	45	15	8.14
1.015	75	15	10.2
1.015	15	85	2.08
1.03	75	50	10.63
1.015	75	85	10.89
1.03	15	50	2.97

Analysis of Variance (ANOVA)

Table 5 contains an analysis of variance (ANOVA) data for water absorption. The ANOVA results were applied to provide additional insights.

The ANOVA results in Table 4 show that the model was viewed as huge, with a *P*-value of 0.0028 (under 0.05) and an F-value of 9.49. The huge model terms were An and A2. Table 6 listed the coefficient R^2 of 0.5504 and predicted R^2 of 0.7843, which demonstrated that the model satisfactorily addressed the genuine connection between the viable factors.

Table 6
Adjusted R^2 and Predicted R^2

Std. Dev.	0.3491	R^2	0.8768
Mean	2.25	Adjusted R^2	0.7843
C.V. %	15.50	Predicted R^2	0.5504
		Adeq Precision	8.1839

Optimisation of Fibre Parameters Using RSM

The response surface condition could be utilised to compute the most extreme and ideal qualities anticipated for water ingestion from the trial. By and large, expanding the heaviness of the fibre support works on many of the mechanical properties. As per a few investigations, increasing the weight of the fibre support will, in general, work on the mechanical properties; notwithstanding, past a specific weight, one of a kind to various filaments, the physiochemical properties will often decline (Jariwala & Jain, 2019). Hence, the impacts of fibre support weight, polyester weight, and fibre thickness of the composite were researched in this review to find the ideal blend for polyester-based built-up woven Kenaf crossover with fibreglass composite material.

The impact of these three boundaries on the water assimilation can be approximated by following genuine coded condition Equation 2:

$$\text{Square root of X (water absorption)} = 57.6159 + (-55.6075) * A + (-0.177987) * B + (-1.16926) * C + 0.201766 * AB + 1.14947 * AC + (-4.28092)^{e}\text{-}07 * BC \tag{2}$$

Where X is the predicted response value (water absorption).

Table 6 shows the coefficient of determination (R^2) and the changed coefficient of determination (changed R^2) water ingestion, demonstrating whether a relapse model is satisfactory. The meaning of the coefficients of the quadratic polynomial conditions was resolved by utilising ANOVA. A huge *F*-value and a small *P*-value show that each term has a massive impact (Peças et al., 2018; Penjumras et al., 2015). The most extreme and ideal qualities anticipated for water retention with the collaboration of the boundaries are introduced in 3D plots in

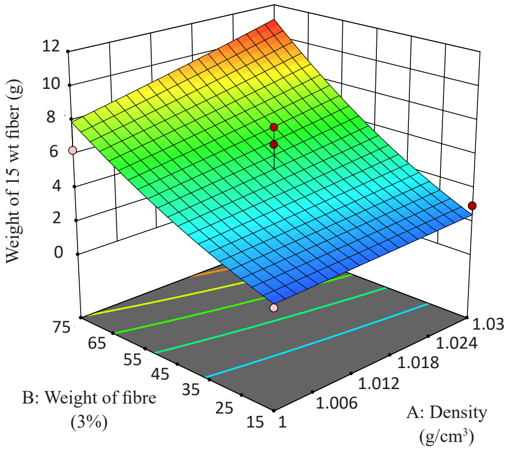

Figure 1. Response surface plots representing significant interaction on water absorption interaction with fibre reinforcement weight of 45 wt%

Confirmation Test

The confirmation test was directed to check the accuracy of forecasts and to affirm that there were no progressions and that the reaction values were near the anticipated values. The model conditions will give the greatest anticipated values to water retention and if others esteem as well as exploratory ideal qualities for amplifying the two reactions. The ideal boundary setting was at the thickness of 1.00 g/cm³, 45% of fibre support weight, and 45% of polyester acquired utilising point forecast from the mathematical streamlining accessible of

RSM. Under the ideal boundary setting conditions, the upsides of water retention from the affirmation run were acquired, as displayed in Table 7.

The weight of water absorbed increased with soaking time and stabilised after saturation, and the weight content percentage also influenced the moisture uptake. Basically, the chemical properties of natural fibres also affect water absorption (Ishak et al., 2012; Rashdi et al., 2010; Saxena et al., 2011). As Elfaleh et al. (2003) mentioned, applying natural plant fibres as reinforcement in polymer materials has limitations due to certain drawbacks, such as water absorption. Lignocellulose in plant fibres consists of hydroxyl groups, making them hydrophilic and unsuitable for use with hydrophobic thermoplastics such as polyester, resulting in poor moisture resistance. The hybridisation of natural fibres, particularly synthetic and Kenaf fibres, is an excellent method to improve the mechanical characteristics of the fabricated hybrid composite, as reported in many works (Suriani et al., 2021). Figure 2 illustrates the moisture uptake of Woven Kenaf/fibreglass-reinforced polyester composite materials.

Table 7
Results with optimal setting parameters of confirmation test

Density (g/cm^3)	Fibre weight (%)	Polyester resinweight (%)	Water absorption (%)
1.00	45	85	1.39

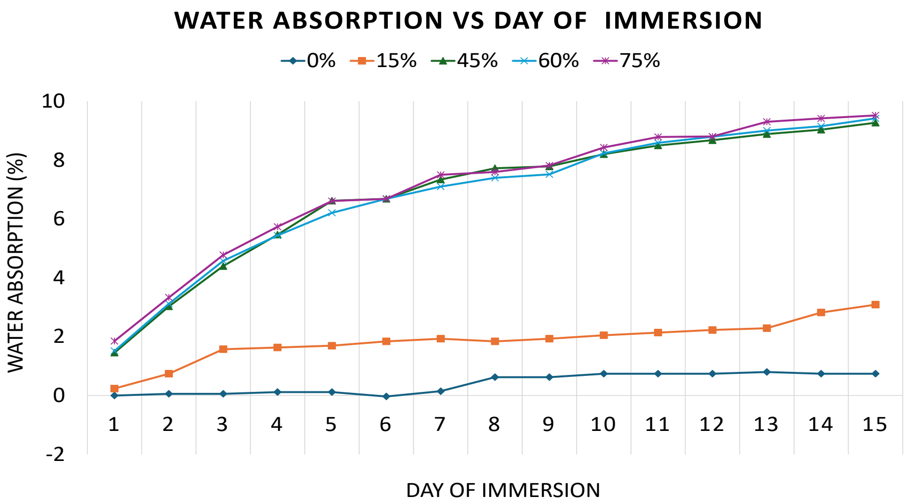

Figure 2. Water absorption results from experiments

The increase in weight content fibres in the specimen permitted more water diffusion into the interface via micro-cracks, and water absorption increased on day 15 (Hamdan et al., 2019; Verma et al., 2021). The 0% weight content sample exhibited the least moisture absorption at 0.50% because there were no Kenaf fibres in the specimen—the most minimal moisture take-up Kenaf filaments displayed in 15 wt% of fibre content at 3.08 g. The properties of the 45% fibre content examples after 15 days of water immersion were noticed. The water retention uncovered that the examples had a direct ascent in water take-up, showing a 9.48% weight gain. The water assimilation for 60% fibre content was 9.39% on day 15, and for 75% fibre content was 9.54 g. The effect of fibre contents on water absorption of Woven Kenaf/fibreglass reinforced polyester composites was studied following immersion at room temperature for 15 days. Moisture uptake increased with fibre volume fraction increments due to increased voids and cellulose content. These results are fixed with the water absorption pattern of non-woven hemp fibre-reinforced unsaturated polyester composites reported by Dhakal et al. (2007). The water absorption pattern of these hybrid composites for 15 days at room temperature was to follow Fickian behaviour.

CONCLUSION

The impact of fibre support weight, the thickness of the composite, and the polyester gum weight boundaries on the water assimilation of woven Kenaf reinforced composite in boat development were researched through RSM. The fibre support weight-thickness of composite collaborations was found to fundamentally affect the water ingestion of the Kenaf woven crossbreed composite. 3D reaction surface plots were utilised to decide the ideal region in the assigned scope of the cycle, and 45 wt% was not set in stone as the ideal fibre content. The most noteworthy water ingestion was accomplished through the streamlined boundaries. In this review, the boundaries are essential for manufacturing Woven Kenaf/fibreglass reinforced composites, and all of these affect their water retention. Extra boundaries, as well as reactions, such as combustibility and warm properties, could be utilised for future review.

ACKNOWLEDGEMENT

The authors thank all the staff of Maritime Technology Lab (UMT), Biocomposite Lab (INTROP, UPM) and MSET Inflatable Composite Corporation Sdn. Bhd., Malaysia for their great help. This research was funded by Matching Grant 1+3)/Determination of Manufacturing Defects and Interfacial Adhesion of Woven Kenaf Fibre Reinforced Hybrid Composites Via Machine Learning Approaches for Boat Construction/ Vot No 53571.

REFERENCES

Cai, J., Chu, X., Xu, K., Li, H., & Wei, J. (2020). Machine learning-driven new material discovery. *Nanoscale Advances*, *2*(8), 3115-3130. https://doi.org/10.1039/d0na00388c

Dhakal, H. N., Zhang, Z. Y., & Richardson, M. O. W. (2007). Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. *Composites Science and Technology*, *67*(7-8), 1674-1683. https://doi.org/10.1016/j.compscitech.2006.06.019

Elfaleh, I., Abbassi, F., Habibi, M., Ahmad, F., Guedri, M., Nasri, M., & Garnier, C. (2023). A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. *Results in Engineering, 19,* 101271.https://doi.org/10.1016/j.rineng.2023.101271

Gholamian, B., Shahnazi, H., & Hassanzadeh, A. (2017). The prevalence of internet addiction and its association with depression, anxiety, and stress, among high-school students. *International Journal of Pediatrics*, *5*(4), 4763-4770. https://doi.org/10.22038/ijp.2017.22516.1883

Hamdan, M. H. M., Siregar, J. P., Cionita, T., Jaafar, J., Efriyohadi, A., Junid, R., & Kholil, A. (2019). Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites. *International Journal of Advanced Manufacturing Technology*, *104*(1-4), 1075-1086. https://doi.org/10.1007/s00170-019-03976-9

Iliyasu, I., Bello, J. B., Oyedeji, A. N., Salami, K. A., & Oyedeji, E. O. (2022). Response surface methodology for the optimisation of the effect of fibre parameters on the physical and mechanical properties of deleb palm fibre reinforced epoxy composites. *Scientific African*, *16*, 1-11. https://doi.org/10.1016/j.sciaf.2022.e01269

Ishak, M. R., Sapuan, S. M., Leman, Z., Rahman, M. Z. A., & Anwar, U. M. K. (2012). Characterisation of sugar palm (*Arenga pinnata*) fibres tensile and thermal properties. *Journal of Thermal Analysis and Calorimetry*, *109*(2), 981-989. https://doi.org/10.1007/s10973-011-1785-1

Jariwala, H., & Jain, P. (2019). A review on mechanical behavior of natural fibre reinforced polymer composites and its applications. *Journal of Reinforced Plastics and Composites*, *38*(10), 441-453. https://doi.org/10.1177/0731684419828524

Jawaid, M., & Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate Polymers*, *86*(1), 1-18. https://doi.org/10.1016/j.carbpol.2011.04.043

Kabir, M. M., Wang, H., Aravinthan, T., Cardona, F., & Lau, K.-T. (2007). Effects of natural fibre surface on composite properties : A review. *Energy, Environment and Sustainability*, 94-99.

Kamarudin, S. H., Mohd Basri, M. S., Rayung, M., Abu, F., Ahmad, S., Norizan, M. N., Osman, S., Sarifuddin, N., Desa, M. S. Z. M., Abdullah, U. H., Mohamed Amin Tawakkal, I. S., & Abdullah, L. C. (2022). A review on natural fibre reinforced polymer composites (NFRPC) for sustainable industrial applications. *Polymers*, *14*(17), 1-36. https://doi.org/10.3390/polym14173698

Karimah, A., Ridho, M. R., Munawar, S. S., Adi, D. S., Ismadi, Damayanti, R., Subiyanto, B., Fatriasari, W., & Fudholi, A. (2021). A review on natural fibres for development of eco-friendly bio-composite: characteristics, and utilisations. *Journal of Materials Research and Technology*, *13*, 2442-2458. https://doi.org/10.1016/j.jmrt.2021.06.014

Makhlouf, A., Belaadi, A., Boumaaza, M., Mansouri, L., Bourchak, M., & Jawaid, M. (2022). Water absorption behavior of jute fibres reinforced HDPE biocomposites: prediction using RSM and ANN modeling. *Journal of Natural Fibres, 19*(16), 14014-14031. https://doi.org/10.1080/15440478.2022.2114976

Peças, P., Carvalho, H., Salman, H., & Leite, M. (2018). Natural fibre composites and their applications: A review. *Journal of Composites Science*, *2*(4), 1-20. https://doi.org/10.3390/jcs2040066

Penjumras, P., Abdul Rahman, R., Talib, R. A., & Abdan, K. (2015). Response surface methodology for the optimisation of preparation of biocomposites based on poly(lactic acid) and durian peel cellulose. *Scientific World Journal*, *2015*(1), 293609. https://doi.org/10.1155/2015/293609

Prabhu, S. V., Wilson, V. H., Anand, K. T., Jose, S., Sivamani, S., Gomadurai, C., & Kifetew, M. (2022). Water absorption behavior of teff (*Eragrostis tef*) straw fibre-reinforced epoxy composite: RSM-based statistical modeling and kinetic analysis. *Advances in Polymer Technology, 2022*, 1-6. https://doi.org/10.1155/2022/8188894

Pugliese, R., Regondi, S., & Marini, R. (2021). Machine learning-based approach: Global trends, research directions, and regulatory standpoints. *Data Science and Management*, *4*(November), 19-29. https://doi.org/10.1016/j.dsm.2021.12.002

Radzi, A. M., Sapuan, S. M., Jawaid, M., & Mansor, M. R. (2019). Mechanical performance of Roselle/Sugar palm fibre hybrid reinforced polyurethane composites. *BioResources*, *13*(3), 6238-6249. https://doi.org/10.15376/biores.13.3.6238-6249

Rashdi, A. A. A., Salit, M. S., Abdan, K., & Megat, M. M. H. (2010). Water absorption behaviour of kenaf reinforced unsaturated polyester composites and its influence on their mechanical properties. *Pertanika Journal of Science and Technology*, *18*(2), 433-440. https://doi.org/10.1177/096739111001800606

Saaidia, A., Belaadi, A., Boumaaza, M., Alshahrani, H., & Bourchak, M. (2022). Effect of water absorption on the behavior of jute and sisal fibre biocomposites at different lengths: ANN and RSM modeling. *Journal of Natural Fibres, 20*(1), 2140326. https://doi.org/10.1080/15440478.2022.2140326

Saxena, M., Pappu, A., Haque, R., & Sharma, A. (2011). Cellulose fibres: Bio- and nano-polymer composites. In S. Kalia, B. S. Kaith, & I. Kaur (Eds.). *Cellulose fibres: Bio- and Nano-Polymer Composites* (pp. xx-xx). Springer Berlin. https://doi.org/10.1007/978-3-642-17370-7

Suriani, M. J., Rapi, H. Z., Ilyas, R. A., Petrů, M., & Sapuan, S. M. (2021). Delamination and manufacturing defects in natural fiber-reinforced hybrid composite: A review. *Polymers, 13*(8), 1323.https://doi.org/10.3390/polym13081323

Syduzzaman, M., Al Faruque, M. A., Bilisik, K., & Naebe, M. (2020). Plant-based natural fibre reinforced composites: A review on fabrication, properties and applications. *Coatings*, *10*(10), 973. https://doi.org/10.3390/coatings10100973

Verma, R., Shukla, M., & Shukla, D. K. (2021). Effect of glass fibre hybridisation on the water absorption and thickness of alkali treated kenaf-epoxy composites. *Materials Today: Proceedings*, *44*, 2093-2096. https://doi.org/10.1016/j.matpr.2020.12.181