Quantifying and Predicting Tensile Properties of *Curcuma longa*-silicone Biocomposite

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This study was carried out to introduce newly developed silicone-biocomposite materials, namely *Curcuma longa*-silicone biocomposite; and assess its tensile properties of using the Neo-Hookean hyperelastic constitutive equation. The specimens were prepared from the mix of *Curcuma longa* fiber and pure silicone at various fiber composition (0 wt.%, 4 wt.%, 8 wt.%, and 12 wt.%). A uniaxial tensile test was carried out by adopting the ASTM D412 testing standard. The Neo-Hookean model was employed to obtain the material constant, C_1 value. Results obtained indicate that the incorporation of *Curcuma longa* fiber improves the stiffness of the silicone biocomposite as can be seen from the increase of the tensile modulus, while marginally decreasing its tensile strength. The material elastic constant, C_1 of silicone reinforced with *Curcuma longa* was then predicted by using Artificial Neural Network (ANN). The regression coefficients obtained by training the neural network are satisfactory, therefore the neural network can be used for predicting the material constant, C_1 of the silicone biocomposite. The prediction of ANN generates a better correlation if there are more data set and can be a good fit for predicting the unknown value.

Keywords: hyperelastic, artificial neural network, *curcuma longa*-silicone biocomposite, Neo-Hookean Model.

1. INTRODUCTION

The term of bio-composites has been widely used to denote the composites that are made using either the matrix or reinforcement or both from renewable resources that are biodegradable [1]. The use of natural fibres as a filler in composite material has become valuable as a substitute for greener synthetic fibre material. Natural fibres reinforced polymer composites give an adequate mechanical strength [2, 3]. The physical and mechanical behaviour of fibre reinforced composites have been studied for the past decades due to their biodegradable properties and environmentally friendly nature [4, 5]. It was found that to recuperate the material properties, the reinforcement of silicone composite with *Arenga pinnata* [6, 7], kenaf [8 – 10], bamboo cellulose [11], sisal fibres [12], and banana fibres [13] give rise to many benefits, such as durability, thermal stability, tensile properties, and improvement in the impact strength [1].

A study conducted on the mathematical modelling of silicone composite reinforced with *Arenga pinnata* reveals that it can nearly mimic the tensile curve whilst demonstrating good adhesion bonding and dispersion among the fibres and silicone rubber [7]. An opposite behaviour was seen nevertheless in a study of using kenaf as fibre reinforcement through experimental and numerical approaches, where the result shows that the numerical value of the material constant increases, as the percentage of fibre reinforcement of kenaf increases. However, the tensile strength of the material was observed to be decreased as the reinforcement increased [9]. Through the years, many studies have been conducted on quantifying the mechanical properties of fiber reinforced composite using numerous mathematical models yet predicting the properties via artificial neural networks (ANNs) methods are still developing. [14] conducted a study where ANN prediction profiles for the characteristics tribological properties of short fiber-reinforced polymer composites demonstrated very good agreement with the experimental results, indicating that a well-trained network was created.

Though many studies have been conducted on the natural fibre reinforced biocomposite, only a few studies have been reported on utilizing *Curcuma longa* in the composite. Natural cellulose fibres extracted from *Curcuma longa* stems have lignocellulosic crop residue fibre-like properties and inherent antimicrobial properties [15, 16]. *Curcuma longa* has been reported to possess many benefits such as healing properties and anti-inflammatory, cosmetic benefits such as antioxidant [17 – 19], and dermatology [16].

To date, there is no study has been reported about the reinforcement of *Curcuma longa* fibers into silicone rubber. Therefore, this study is novel as it introduces a newly developed silicone-biocomposite materials, namely *Curcuma longa* - silicone Biocomposite. The current work attempts to establish the tensile properties *Curcuma longa*-

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silicone biocomposite based on integrating prediction model using artificial neural network and the most common hyperelastic model, Neo-Hookean.

2. MATERIALS AND METHODS

2.1. Specimens preparation

Silicone was selected as polymer matrix to the composite whilst the *Curcuma longa* powders were added, acting as fibre to provide strength to the composite. The silicone Ecoflex 00-30 used in this study consists of two parts: part A and part B (Hardener). The density of silicone rubber and *Curcuma longa* particulates were weighed using a Micromeritics pycnometer (Accu II 1340, U.S.A, 2013) and are shown in Table 1.

Table 1. Specification of matrix and fiber materials

Material	Brand/Scientific Name	Density, g/cm^3
Matrix – silicone rubber	Ecoflex 00-30	1.070
Fiber – turmeric	*Curcuma longa*	1.472

2.2. Powder preparation

The rhizomes of *Curcuma longa* fibers were used in this study where the matured rhizomes were harvested and cleaned. Then, rhizomes were cut into 1 mm thick slices (Fig. 1 a) using a cutter and heated in the drying oven at 100 °C for 24 hours before they were crushed. To obtain the fiber in powder form, all dried fibers were crushed by means of three-stage crushing or size reduction. Primary reduction is accomplished by using mortar grinder, secondary reduction by using the crushing machine to reduce its entanglement, and tertiary reduction via a planetary mono mill machine, arranged so that the crushed fibers are milled for 1.5 hours with 270 revolution per minute for 30 minutes and repeated 3 times. The milled fibers were lastly sieved using a 0.25 mm mesh size sieve frame. The crushing step is necessary to obtain the powder form of *Curcuma longa* as the final form (Fig. 1 b).

a b

Fig. 1. a – the *Curcuma longa* is cut into 1 mm length pieces; b – the finest *Curcuma longa* powder after the sieving process was carried out

2.3. Preparation of *Curcuma longa*-silicone biocomposite

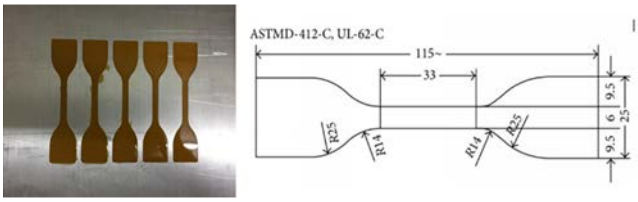
The weight of the powder was determined by using an electronic balance (Mettler Toledo, AG245, ±0.03 mg). Powdered *Curcuma longa* fiber was used to reinforce the hydrophobic silicone rubber following the composition required (0 wt.%, 4 wt.%, 8 wt.% and 12 wt.%). The total weight of the fiber and silicone was tabulated in Table 2. The specimens were prepared by properly mixing the silicone and *Curcuma longa* fiber and cured for 4 hours. The procedure (process) followed exactly like the previous which has shown good dispersion of fiber [6, 7].

Table 2. Composition of silicone and fibre specimens for tensile test

Volume mould, cm^3	Fiber composition, wt%	Mass of fiber, g	Volume of fiber, cm^3	Part A, cm^3	Part B, cm^3
6	0	–	–	3.00	3.00
	4	0.35	0.24	2.88	2.88
	8	0.71	0.48	0.48	2.76
	12	1.06	0.72	0.72	2.68

2.4. Uniaxial tensile test

To investigate the effect of *Curcuma longa* fiber on the tensile properties of silicone, uniaxial tensile tests were carried out to obtain the tensile behavior results. Five bio-composite specimens were prepared following the ASTM D412 standard (standard test method for vulcanized rubber and thermoplastic elastomers-tension) in which, the specimens with 3 mm of thickness were prepared into the dumbbell shape as shown in Fig. 2.



a b

Fig. 2. a – specimens which has fully filled the mould of the sample according to ASTM D412; b – dumbbell-shaped rubber specimen as per ASTM D412 standard

2.5. Predicting the hyperelastic material constant

Since the silicone is a soft composite and categorized under the hyperelastic material, these materials would fulfil the hyperelastic theory. The stress-strain relation obtained from the tensile test; the deformation behavior could be represented using Neo-Hookean stress-stretch relation. In determining the materials constant, C_1 of the specimens, the Neo-Hookean model was selected. Materials constant, C_1 represents the stiffness of the material. Considering model as an isotropic, incompressible and hyperelastic, it is expressed in terms of engineering stress (σ_E) – extension ratio (λ) relation under uniaxial load as shown in Eq. 1,

$$\sigma_E = 2C_1(\lambda - \frac{1}{\lambda^2}), \quad (1)$$

where λ is the extension ratio $\left(\frac{l}{l_0}\right)$; σ_E is the engineering stress, MPa; C_1 is the material constant.

Since Eq. 1 is expressed in terms of engineering stress-stretch ($\sigma_E - \lambda$) relation, the engineering stress-strain ($\sigma_E - \varepsilon$), data obtained previously from the uniaxial tensile test are converted into engineering stress-extension ratio ($\sigma_E - \lambda$) relation using Eq. 2:

$$\lambda = 1 + \varepsilon , \quad (2)$$

where ε is the strain.

A curve fitting procedure was performed using Eq. 1 and Eq. 2 to get the best match curve by employing the engineering stress-extension ratio curve from the experiments as the reference. The best match curve would compose the material constant parameters that describes the mechanical behaviour of the materials under investigation. By doing this, the material constant; C_1 is determined.

To predict the new set of biocomposite tensile properties, the artificial neural network (ANN) model used in this study is said to be capable of 80 % prediction accuracy to the experimental value. The material constant, C_1 of the *Curcuma longa*-silicone composite was predicted using the ANN toolbox in MATLAB, where the weightage ratio (wt.%), the load applied, and the elongation obtained from the uniaxial tensile experiment were to be put as input variables (Fig. 3).

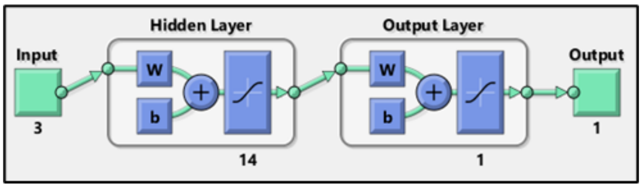


Fig. 3. Schematic diagram of Neural Network with three (3) input and one (1) output

Fourteen neurons were used in the hidden layer to obtain the output, namely the material constant for the Neo-Hookean model, C_1. In this network, samples 1, 2, 3 and 4 data set were given as input variables for training the network, whilst the sample 5 data set were used for validation and testing.

3. RESULTS AND DISCUSSION

3.1. Uniaxial tensile test

The material constant of the pure silicone and *Curcuma longa* – silicone biocomposite were determined by using the Neo-Hookean which represents the non-linear behavior of elastic materials. The values of Neo-Hookean material constant, C_1 are tabulated in Table 3 with four differences in weight percent (wt.%) of *Curcuma longa*-silicone biocomposite.

Table 3. The determined Neo-Hookean material constants for various fiber composition

Fibre composite, wt.%	Neo-Hookean, C_1, MPa
0	0.0317
4	0.0361
8	0.0426
12	0.0470

Fig. 4 shows the material constant, C_1 pattern for the Neo-Hookean model for pure silicone rubber (0 wt.%), 4 wt.%, 8 wt.% and 12 wt.% *Curcuma longa*-silicone biocomposite where *y*-axes and *x*-axes represent the engineering stress and extension ratio, respectively.

It can be observed from Fig. 4 that the pure silicone rubber (0 wt.% of *Curcuma longa* fiber) possessed the highest tensile strength and elongated the most, compared to *Curcuma longa*-silicone composite.

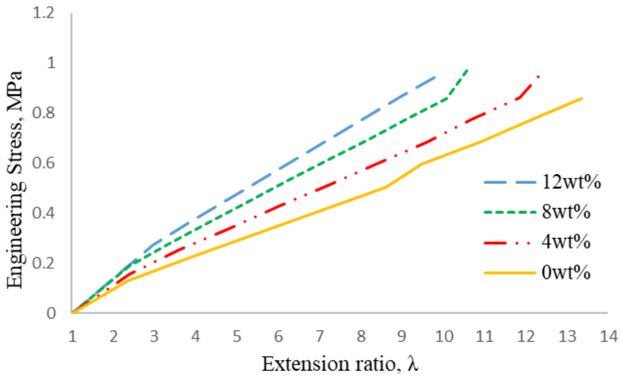


Fig. 4. Engineering stress-extension ratio curves of pure silicone biocomposite and three different weight percent of *Curcuma longa* – silicone biocomposite

Nonetheless, the plotted graph using the Neo-Hookean model evidently shows that the value of material constant, C_1, for the highest composition of *Curcuma longa* fiber (12 wt.%), is the highest amongst all (0.0470 MPa). The results prove that the initially extremely soft behavior of the silicone has been improved and more practical, where when the fiber content is increased, this silicone-biocomposite material becomes stiffer.

A similar pattern was observed in a study hyperelastic behaviour of kenaf reinforced silicone composite conducted by [9] and *Arenga pinnata*-silicone biocomposite [7]. The results show that the numerical value of the material constant increases, as the percentage of the reinforced fiber increases. However, these values shown in this study are considered to be relatively higher when compared to the kenaf reinforced silicone composite [9], which suggests that the *Curcuma longa* fiber has better tensile properties than the kenaf fiber.

The curves obtained from Fig. 4 are also similarly observed in the *Arenga pinnata* reinforced silicone composite [7]. The curve for pure silicone rubber appears to exhibit nonlinear tensile behavior where it can be seen to increase concavely upward. Oppositely, the *Curcuma longa* – silicone biocomposite displayed an almost linear pattern as the fiber loading increased.

The average mechanical tensile properties values were established and shown in Fig. 5.

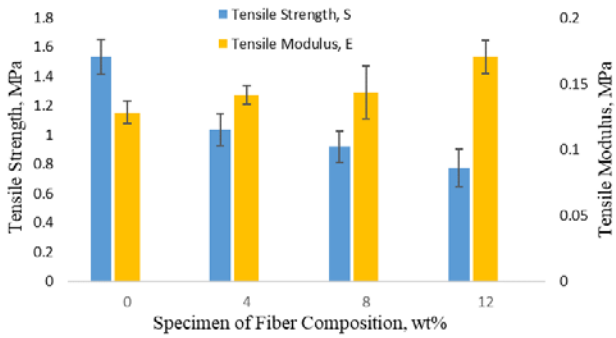


Fig. 5. Tensile strength and modulus of pure silicone compared with three different weight percent of *Curcuma longa*-silicone biocomposite

Tensile strength is the amount of load per unit area a material can withstand axial load until it breaks, while tensile modulus defines the strain levels at the maximum load thus the stiffness of the material. It was observed from Fig. 5 that the pure silicone has the greatest tensile strength (1.532 MPa), followed by 4 wt.% (1.0382 MPa), 8 wt.% (0.918 MPa) and 12 wt.% (0.7742 MPa) of *Curcuma longa* fiber.

From the result obtained, it can be deduced that the incorporation of fibers in the matrix increases the tensile modulus (stiffness) of the silicone biocomposite (Fig. 4 and Fig. 5) while marginally decreasing its tensile strength (Fig. 5). A similar pattern was also observed in silicone composite when added by *Arenga pinnata* fiber (tensile strength and modulus of pure silicone compared with three different weight percent (wt.%) of *Curcuma Longa*-silicone biocomposite [7] where the tensile modulus is increased, as the fiber content increased [20].

3.2. Quantifying the Hyperelastic Material Constant, C_1

Neural networks are trained, before they can be employed to predict the output, which is the Neo-Hookean material constant, C_1. The training is performed in a way that the weight of coefficients is regularly updated to get the output closer to the expected value. The association between the input and the output in this study was expressed by R^2; the proportion of variation in the experimental values described in a linear relationship between the predicted and experimental values.

The predicted value for material constant, C_1 can be observed in the results shown in Fig. 6 – Fig. 9.

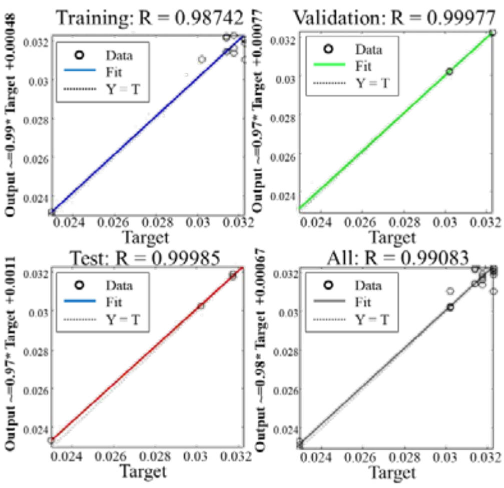


Fig. 6. Regression plot of the 0 wt.% model in predicting the material constant, C_1

By training the artificial neural network for pure silicone (0 wt.%) and *Curcuma longa*-silicone biocomposite (4 wt.%, 8 wt.%, and 12 wt.%), the obtained total regression coefficients are 0.99038, 0.9151, 0.98681 and 0.88663, respectively (Fig. 6 – Fig. 9). The total regression coefficient for a neural network is expected to be equal to or greater than 0.95 for it to be satisfactory. Therefore, from the results shown in Fig. 6 and Fig. 8, it can be observed that the regression coefficients for pure silicone and 8 wt.% of *Curcuma longa* are both acceptable, except for the coefficients obtained for 4 wt.% and 12 wt.% of *Curcuma longa*-silicone biocomposite.

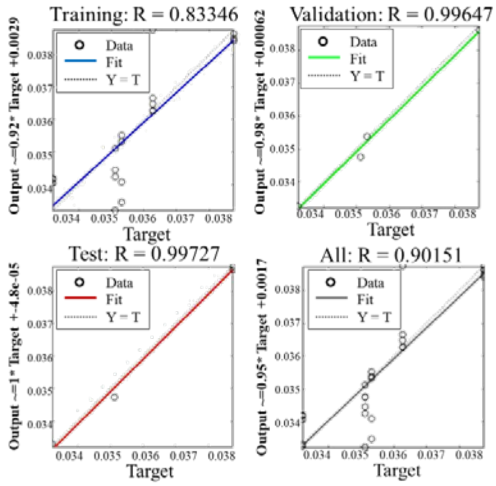


Fig. 7. Regression plot of the 4 wt.% model in predicting the material constant, C_1

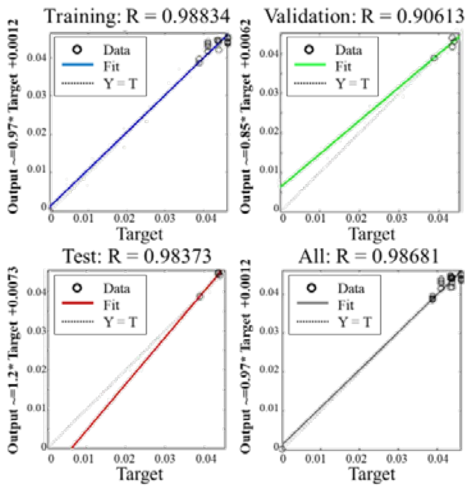


Fig. 8. Regression plot of the 8 wt.% model in predicting the material constant, C_1

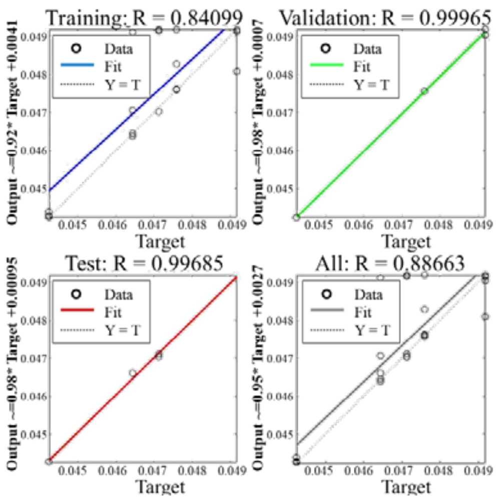


Fig. 9. Regression plot of the 12 wt.% model in predicting the material constant, C_1

In addition to the regression coefficient, a diagram of validation performance for each model to predict the material constant, C_1 was acquired and compared. Fig. 10

shows that the best validation performance for pure silicone biocomposite is for iteration 0 and it is 1.1829 e-07. Meanwhile, the 4 wt.% of *Curcuma longa*-silicone biocomposite portrays that the best validation performance obtained as 3.9005 e-08 at epoch 5 (Fig. 11). Both models continued the training for 6 iterations before it stopped.

The 8 wt.% and 12 wt.% of *Curcuma longa*-silicone biocomposite, on the other hand, performed the best validation at epoch 0 as 9.1577e-07 and 6.1145e-09, respectively (Fig. 12 and Fig. 13).

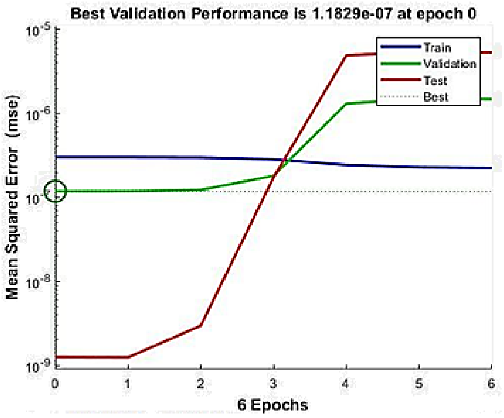


Fig. 10. Validation performance of pure silicone biocomposite (0 wt.%) model

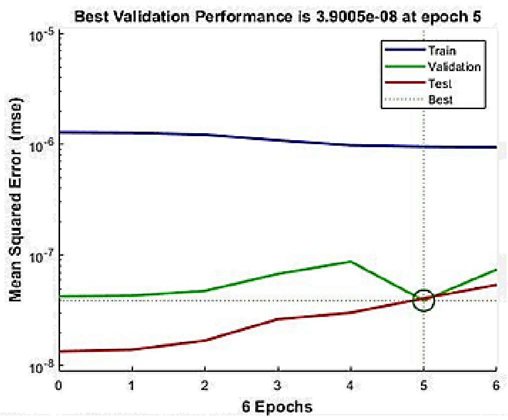


Fig. 11. Validation performance of 4 wt.% *Curcuma longa*-silicone biocomposite model

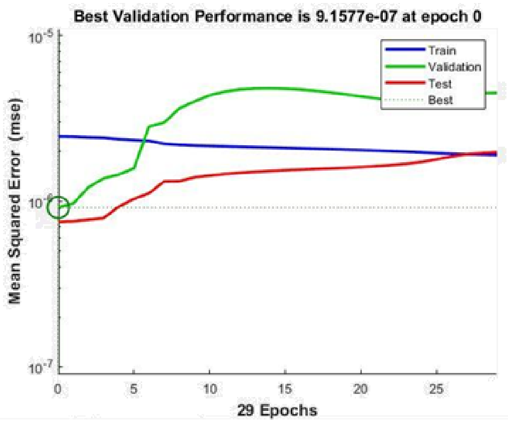


Fig. 12. Validation performance of 8 wt.% *Curcuma longa*-silicone biocomposite model

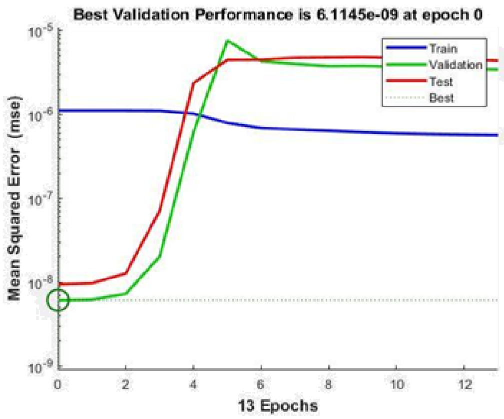


Fig. 13. Validation performance of 12 wt.% *Curcuma longa*-silicone biocomposite model

4. CONCLUSIONS

This paper reports the work related to the establishment of the tensile properties of newly introduced silicone biocomposite materials, namely *Curcuma longa*-silicone biocomposite. The variation of the experimental data for all set was found to be acceptable. It was observed that the value of the material constant, C_1 which indicates the stiffness of the material obtained using the hyperelastic constitutive model (Neo-Hookean) is improved through the reinforcement of 4 wt.% of *Curcuma longa* fibers into the silicone rubber. Moreover, a satisfactory prediction of the elastic behavior of the tested specimens was demonstrated by the Neo-Hookean model, suggesting its efficacy in predicting the behavior of the proposed biocomposite. The regression coefficients obtained by training the neural network can be assumed to be adequate, therefore the neural network can be further used for predicting the material constant, C_1 of the silicone biocomposite. The obtained regression coefficient for predicting the material constant is like those that can be found in the available literature. Future works are somehow needed to investigate the swelling and compressive behavior of the *Curcuma longa* reinforced silicone biocomposite to provide further insight into its potential and practical applications.

Acknowledgments

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REFERENCES

1. **Abidin, N.A.Z., Jailani, M.Z.H.M., Hussain, A.K., Mahmud, J.** Experimental-Numerical Analysis of Woven Laminates under Tension *Materials Science (Medžiagotyra)* 26 (4) 2020: pp. 505 – 512. https://doi.org/10.5755/j01.ms.26.4.22898
2. **Bharath, K.N., Basavarajappa, S.** Applications of Biocomposite Materials Based on Natural Fibers from Renewable Resources: A Review *Science and Engineering of Composite Materials* 23 (2) 2016: pp. 123 – 133. https://doi.org/10.1515/secm-2014-0088

3. **Thyavihalli Girijappa, Y.G., Mavinkere Rangappa, S., Parameswaranpillai, J., Siengchin, S.** Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review *Frontiers in Materials* 6 2019: pp. 226. https://doi.org/10.3389/fmats.2019.00226
4. **Arpitha, G., Yogesha, B.** An Overview on Mechanical Property Evaluation of Natural Fiber Reinforced Polymers *Materials Today: Proceedings* 4 (2) 2017: pp. 2755 – 2760. https://doi.org/10.1016/j.matpr.2017.02.153
5. **Kaniraj, S.R., Fung, Y.** Influence of Discrete Fibers and Mesh Elements on the Behaviour of Lime Stabilized Soil *Pertanika Journal of Science & Technology* 26 (4) 2018: pp. 1547 – 1570.
6. **Bahrain, S.H.K., Mahmud, J.** Swelling Behaviour and Morphological Analysis of Arenga Pinnata–Silicone Biocomposite *Materials Letters* 242 2019: pp. 32 – 34. https://doi.org/10.1016/j.matlet.2019.01.100
7. **Bahrain, S.H.K., Mahmud, J.** Arenga Pinnata—Silicone Biocomposite Properties via Experimental and Numerical Analysis *Materials Science (Medžiagotyra)* 24 (3) 2018: pp. 277 – 282. https://doi.org/10.5755/j01.ms.24.3.18296
8. **Ismail, A.S., Jawaid, M., Sultan, M.T.H., Hassan, A.** Physical and Mechanical Properties of Woven Kenaf/Bamboo Fiber Mat Reinforced Epoxy Hybrid Composites *BioResources* 14 (1) 2019: pp. 1390 – 1404.
9. **Azmi, N.N., Hussain, A.K., Mahmud, J.** Kenaf Silicone Biocomposites: Synthesis and its Hyperelastic Behaviour *Materials Science Forum* 900 (1) 2017: pp. 12 – 16. https://doi.org/10.4028/www.scientific.net/MSF.900.12
10. **Nishino, T., Hirao, K., Kotera, M., Nakamae, K., Inagaki, H.** Kenaf Reinforced Biodegradable Composite *Composites Science and Technology* 63 (9) 2003: pp. 1281 – 1286. https://doi.org/10.1016/S0266-3538(03)00099-X
11. **Singla, R., Soni, S., Kulurkar, P.M., Kumari, A., Mahesh, S., Patial, V., Yadav, S.K.** In Situ Functionalized Nanobiocomposites Dressings of Bamboo Cellulose Nanocrystalsand Silver Nanoparticles for Accelerated Wound Healing *Carbohydrate Polymers* 155 2017: pp. 152 – 162. https://doi.org/10.1016/j.carbpol.2016.08.065
12. **Li, C., Wan, J., Pan, Y.T., Zhao, P.C., Fan, H., Wang, D.Y.** Sustainable, Biobased Silicone with Layered Double Hydroxide Hybrid and Their Application in Natural-Fiber Reinforced Phenolic Composites with Enhanced Performance *ACS Sustainable Chemistry & Engineering* 4 (6) 2016: pp. 3113 – 3121. https://doi.org/10.1021/acssuschemeng.6b00134
13. **Amir, N., Abidin, K.A.Z., Shiri, F.B.M.** Effects of Fibre Configuration on Mechanical Properties of Banana Fibre/PP/MAPP Natural Fibre Reinforced Polymer Composite *Procedia Engineering* 184 2017: pp. 573 – 580. https://doi.org/10.1016/j.proeng.2017.04.140
14. **Phadi, P.K., Satapathy, A.** Analysis of Sliding Wear Characteristics of BFS Filled Composites Using and Experimental Design Approach Integrated with ANN *Tribology Transactions* 56 (5) 2013: pp. 789 – 796. https://doi.org/10.1007/s40204-017-0079-5
15. **Karłowicz-Bodalska, K., Han, S., Freier, J., Smoleński, M., Bodalska, A.** Curcuma Longa as Medicinal Herb in the Treatment of Diabetic Complications *Acta Poloniae Pharmaceutica–Drug Research* 74 (2) 2017: pp. 605 – 610.
16. **Thangapazham, R.L., Sharma, A., Maheshwari, R.K.** Beneficial Role of Curcumin in Skin Diseases *The Molecular Targets and Therapeutic Uses of Curcumin in Health and Disease* 2007: pp. 343 – 357. https://doi.org/10.1007/978-0-387-46401-5_15
17. **Sami, D.G.** Turmeric/Oregano Extracts as Wound Healing Agents in A Diabetic Animal Model, 2019.
18. **Kumar, G.S., Nayaka, H., Dharmesh, S.M., Salimath, P.** Free and Bound Phenolic Antioxidants in Amla (Emblica Officinalis) and Turmeric (Curcuma Longa) *Journal of Food Composition and Analysis* 19 (5) 2006: pp. 446 – 452. https://doi.org/10.1016/j.jfca.2005.12.015
19. **Naghshineh, N., Tahvildari, K., Nozari, M.** Preparation of Chitosan, Sodium Alginate, Gelatin and Collagen Biodegradable Sponge Composites and Their Application in Wound Healing and Curcumin Delivery *Journal of Polymers and the Environment* 27 (12) 2019: pp. 2819 – 2830. https://doi.org/10.1007/S10924-019-01559-Z
20. **Karthikeyan, R., Tjong, J., Nayak, S.K., Sain, M.M.** Mechanical Properties and Cross-Linking Density of Short Sisal Fiber Reinforced Silicone Composites *BioResources* 12 (1) 2017: pp. 211 – 227. https://doi.org/10.15376/biores.12.1.211-227.
21. **Hassan, K.N., Mahmud, J., Majeed, A.P.A., Yahaya, M.A.** Quantifying Tensile Properties of Bamboo Silicone Biocomposite using Yeoh Model *International Journal of Engineering & Technology* 7 (4.26) 2018: pp. 245 – 250. https://doi.org/10.14419/ijet.v7i4.26.22176