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Quantifying the Tensile Properties of Hevea brasiliensis – Silicone Biocomposite using Neo – Hookean Model

Noorainol Faiz Noor Haris, Jamaluddin Mahmud, Mohd Azman Yahaya

Abstract*: Incorporation of natural fibers into composites have been continuously researched in moving towards a greener environment. As environmental issues such as climate change and global warming is becoming severe, green technology is one of the ways to reduce it. Hevea brasiliensis or commonly called rubber tree produced a lot of sawdust during the conversion of the raw material into product. The sawdust is known as an agricultural waste which has no economic value. Therefore, this study for the first time attempts to utilize the Hevea brasiliensis sawdust by incorporating it with silicone rubber in the making of a new biocomposite material. The samples were prepared in two weight compositions, 0 wt% and 16 wt% in accordance to ASTM D412. Tensile properties of biocomposite was then determined using 3382 Universal Testing Machine 100kN (Instron, U.S.A., 2008). Neo Hookean hyperelastic model was employed where the material constant, C1 values were obtained. The graph plotted shows that the hyperelastic model used can mimic the deformation behavior of silicone biocomposites. The material constants are observed to increase as Hevea brasiliensis fiber are introduced into it. Hence, it can be concluded that pure silicone rubber has higher tensile strength compared to 16 wt% hevea brasiliensis – silicone biocomposite and the addition of fiber increase the stiffness properties of material produced.

***Keywords*: Hevea brasiliensis, Natural fiber, Neo-Hookean hyperelastic model, Tensile properties**

I. INTRODUCTION

Natural fibers as reinforcement in fabricating lightweight, low-cost polymer composites have been gaining interest from scientists and researcher in this modern society. Some of their strong points are they are cheap but have good performance, biodegradable, low density and easily obtained due to their abundance in nature [1]–[3]. Natural fibers are also discovered to be less irritable to skin which lessens any health risk to human being [4]. Natural fibers may come from either plants or animals. Some examples of plant fibers are curaua, rice, milkweed and esparto while the examples of animal fibers are alpaca wool, camel hair and silk. Other examples of natural fibers can be seen in Fig. 1 shown.

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* Correspondence Author
Noorainol Faiz Noor Haris, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor Malaysia.
Jamaluddin Mahmud*, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor Malaysia
Mohd Azman Yahaya, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor Malaysia

By utilizing natural fibers, the use of synthetic fibers can be reduced. Synthetic fibers are non-biodegradable material and its product takes a long time to decompose which will harm the environment in the long term.

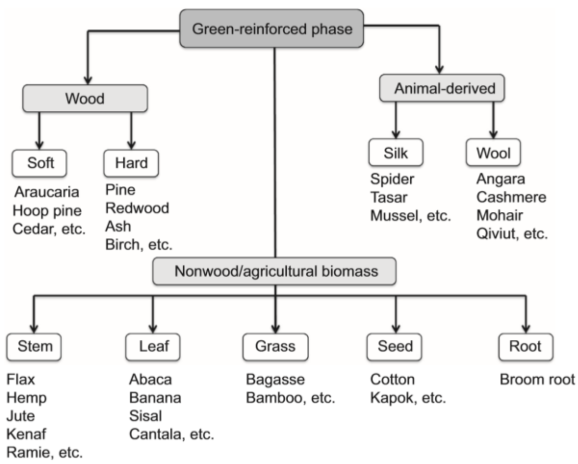

Fig. 1. Categorization of natural fibers [5]

Besides that, the use of natural fibers can reduce the dependence on non – renewable resources and fossil fuels which can leads to lower pollutant and greenhouse gas (GHG) emissions [6]. Global warming is a serious issue nowadays due to the high level of GHG emissions into the earth's atmosphere [7]. The level of GHG emissions are influence by some factors such as the population of the earth, economy, technology and the social trends [8]. The growing population of the earth and advancing of economy and technologies have somehow increased the level of GHG emissions. By promoting the use of natural fibers that are carbon – neutral [9], we can somehow reduce the impact of global warming. Hevea brasiliensis or rubber tree is a type of natural fiber that comes from the Euphorbiaceae family which falls under the hard wood category. It is one of the main plantation crops in Asia. It is estimated that there are more than 80% of total rubber plantation areas in Asia with Thailand, Malaysia and Indonesia covering almost 70% of it [10]. The main product is latex and the co – product is the rubber wood itself. The rubber tree have an economic lifestyle for 25 – 30 years where after that it will be cut down for replanting purpose [11], [12].

The rubber wood that have been cut down are made into products such as furniture and particle board. It is found that 90% of the wood results in residues where 54% are from small branches, 32% are wastes from the sawmill and 4% more are from the furniture factories. Only 10% of the wood are fully utilized into products [13].

Composite is a material that is fabricated from the combination of two or more different materials whether in terms of its chemical or physical properties, with aim to produce a new material with better characteristics. Combining two or more materials can sometimes produce some unique properties that cannot be obtained by using one of the materials alone [14]. The term 'biocomposite' is used when natural fibers are used as an alternative in making the composite whether it is the matrix material or the filler which are biofibers (e.g. lignocellulosic fibers) [15], [16].

Silicone rubber or also called as siloxane is an elastomer which structure composed of a chain of oxygen (O) and Silicon (Si) atom [17]. Silicones are very stable at low and high temperature with working temperature found to be from -100 ^{0}C to 300 ^{0}C. Some of other advantages of silicone are they have outstanding elasticity, good aging resistance, low toxicity and is oxidation resistant [18]. Silicone rubber are widely used in the biomedical field where they are made into implants or as synthetic skin because of its good biocompatibility and physiologically inert properties [19]. Other than that, they are also used as electrical insulation [20] and sealing material [21] [22].

During the processing of Hevea brasiliensis, a lot of sawdust waste is generated. Therefore, this study uses the sawdust produced to mix it with silicone rubber in making the Hevea brasiliensis – silicone biocomposite. Later, the mechanical properties were assessed via uniaxial tensile test and the material constants were quantified using the Neo – Hookean Model by comparing between 0wt% (pure silicone rubber) and 16wt% Hevea brasiliensis – silicone biocomposite.

II. METHOLODOLOGY

A. Sample preparation

The silicone rubber used in this study is Silicone Ecoflex 00-30 while the natural fiber chosen as the filler is Hevea brasiliensis fiber. Hevea brasiliensis fiber was obtained from the furniture industry in Selangor, Malaysia. For this case, the fiber is in the form of sawdust which is as the result of cutting and planning of wood. The sawdust obtained are crushed in planetary mono mill until powder form are obtained. It is sieved to 0.16 µm as shown in Fig. 2 and later dried at 110 ^{0}C for 24 hours to remove moisture.

Fig.2. Powder obtained after sieving process

There are two parts for the Silicone Ecoflex 00-30 which are Part A and Part B (Fig. 3). For the pure silicone rubber, both parts were mixed at an equal ratio. While for the 16wt%, the ratio was calculated and the Hevea brasiliensis fiber was added during the stirring process of the silicone solution. It is then poured into the mold and left to cure for at least 4 hours.

Fig. 3. Silicone Ecoflex 00-30

B. Uniaxial Tensile Test

The sample prepared are subjected to tensile load according to ASTM D412 standard [23]. Size of the sample are shown in Fig. 4. The tests were done using 3382 Universal Testing Machine 100kN (Instron, U.S.A., 2008). Six samples are prepared for each composition and the tensile test are done with speed rate of 500mm/min until failure state. Fig. 5 shows the sample undergoing tensile test. The data obtained are in the form of stress – strain (σE – ε) relation.

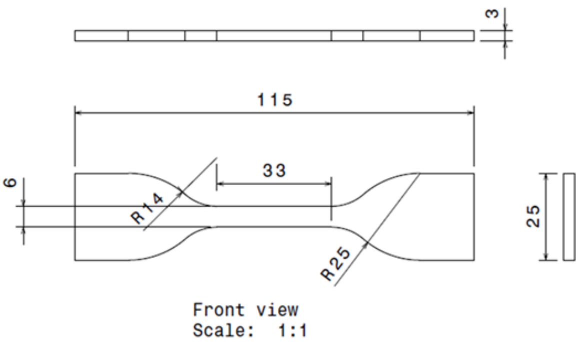

Fig. 4. Sample size according to ASTM D412

Fig. 5. Sample under tensile loading

C. Applying Neo Hookean Hyperelastic Model

Neo Hookean Hyperelastic Model was selected in investigating the deformation behavior of silicone rubber and hevea brasiliensis – silicone biocomposite. Assuming the materials are incompressible, hyperelastic and isotropic, the model is expressed as Eq. (1)

$$\sigma_E = 2C_1\left(\lambda - \frac{1}{\lambda^2}\right) \qquad (1)$$

The data obtained is in the form of stress – strain ($\sigma_E - \varepsilon$). Therefore, in order to use the Neo – Hookean model, it is converted to stress – stretch ($\sigma_E - \lambda$) relation by using Eq. (2).

$$\lambda = 1 + \varepsilon \qquad (2)$$

For the material constant, C1, the value was obtained by using Excel Solver.

III. RESULT AND DISCUSSION

A. Uniaxial Tensile Test

After the test was done, the data collected are analyzed to study its tensile properties. 6 samples are tested for both composition and the average values were later taken to be plotted in a graph of stress, σ_E vs stretch, λ as shown in Fig. 6.

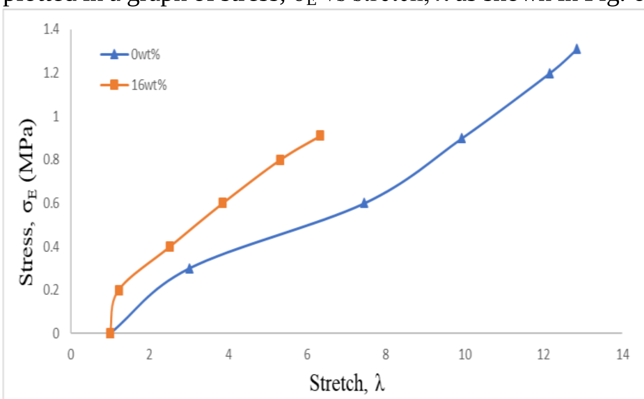

Fig. 6. Stress-stretch graph for pure silicone rubber and 16wt% Hevea brasiliensis – silicone biocomposite

From the fig. 6, it is noticed that pure silicone rubber has higher tensile strength up to 1.31 MPa compared to 16wt% Hevea brasiliensis – silicone biocomposite with tensile strength of 0.91 MPa. The elongation of pure silicone rubber is also observed to be greater than 16wt% Hevea brasiliensis – silicone biocomposite which can be seen from the stretch values stated.

B. Determining Neo Hookean Material Constant

From the Fig. 7 shown, we can see the pattern for pure silicone rubber subjected to tensile test. It is observed that the experimental data and Neo Hookean model does not imitate perfectly with each other. This means that the Neo Hookean model are not capable to demonstrate the highly nonlinear deformation behavior of pure silicone rubber. Both shows a slight concave downward pattern while for the experimental data, there seems to be a concave upward pattern present.

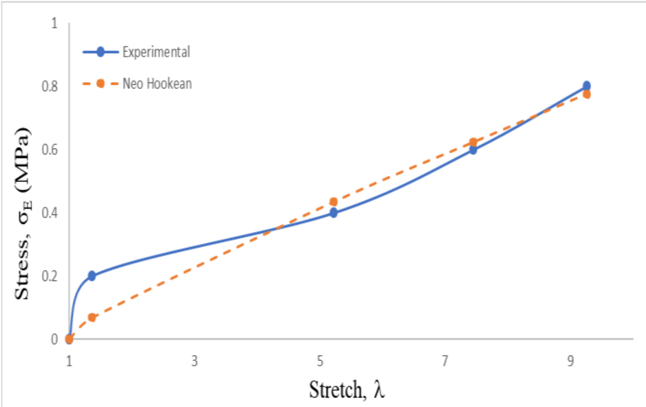

Fig. 7. Pure silicone rubber

However, for 16wt% Hevea brasiliensis – silicone biocomposite, a better result can be seen as displayed in Fig. 8. The experimental data and the Neo Hookean model can imitate each other better than the pure silicone rubber. Although they are not exactly the same, both methods can be seen closely attached to each other with a slight concave downward pattern.

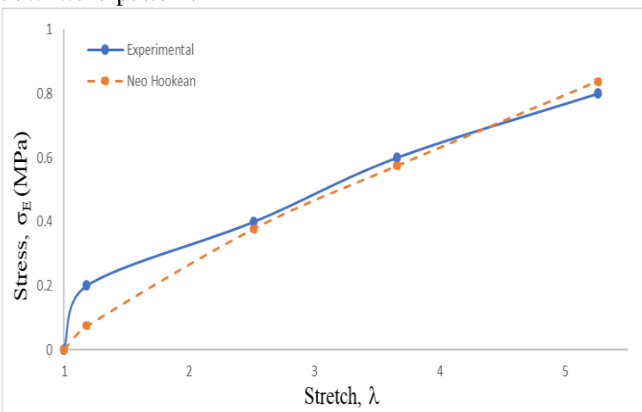

Fig. 8. 16wt% Hevea brasiliensis – silicone biocomposite

To summarize, it can be stated that Neo Hookean models shows a similar pattern for both composition which is slightly concave downward. 16wt% Hevea brasiliensis – silicone biocomposite shows a better result than the pure silicone rubber which means that the Neo Hookean model is suitable to predict deformation behavior of materials that is less nonlinear elastic. With the help of Excel Solver, it can assist in solving equations of this curve fitting study.

The material constants, C1 for both compositions are shown in Table I below. It is observed that the value increases as Hevea brasiliensis powder are introduced into silicone rubber which shows that the stiffness also increases.

Table I. Material constants for pure silicone rubber and 16wt% hevea brasiliensis – silicone biocomposite

Composition	Material Constants, C1 (MPa)
Pure silicone rubber	0.0419
16 wt%	0.0802

IV. CONCLUSION

The tensile properties of Hevea – brasiliensis – silicone biocomposite are successfully quantified and established in this study. Pure silicone rubber displays higher tensile strength compared to 16wt% of composition. The elongation of pure silicone rubber is also found to be greater compared to after hevea brasiliensis fiber was added into it. However, in terms of stiffness, material stiffness increases as hevea brasiliensis fibers are incorporated into silicone rubber as indicated by the increase in material constant, C1 values. In conclusion, this study has contributed in the understanding of tensile behavior of Hevea brasiliensis – silicone biocomposite.

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AUTHORS PROFILE

Noorainol Faiz Noor Haris is currently pursuing his master’s study (by research) at Universiti Teknologi MARA (UiTM) Shah Alam. He has graduated with a Bachelor of Engineering (Hons.) Mechanical from Universiti Teknologi MARA (UiTM) Shah Alam in Mac 2019. His current areas of research interest focus on Engineering Mechanics and Composite Materials.

Prof Ir Dr Jamaluddin Mahmud obtained his PhD degree in (Biomechanical) Engineering from Cardiff University UK; MSc (Manufacturing) Engineering degree from International Islamic University Malaysia (IIUM); and B.Eng. (Hons.) Mechanical Engineering degree from Universiti Teknologi MARA (UiTM). He joined the Faculty of Mechanical Engineering UiTM as a lecturer in 2001 and currently he is a Professor. He has served UiTM Management Team at various levels such as a Deputy Dean, Head of Academic Programmes and the Head of Industry Linkage at the Chancellery’s Office of Industry, Community and alumni Network (ICAN). He has more than two years of industrial experience, working as a service executive at UMW Equipment Sdn. Bhd. His competency in mechanical engineering supported by his past experience in industry and current involvement with industries has enabled him to register as a Professional Engineer (Ir) with the Board of Engineers Malaysia (BEM). Prof J Mahmud has been lecturing on Biomechanics, Composite Materials, Finite Element Method and Engineering Design, which happens to be his areas of research interest and has published more than 100 technical papers in journals and conference proceedings locally and internationally. Due to his expertise and experience, he has been appointed as a judge in design competitions, external examiner, keynote speaker, panel evaluator, visiting researcher and a member in various technical committees at national and international level.

Dr Mohd Azman Yahaya obtained Bachelor of Science (B.Sc) in Mechanical Engineering in 1999 from Clarkson University, New York, United States of America and Master of Science (M.Sc) in Impact and Explosion Engineering in 2004 from the University of Manchester Institute of Science and Technology (U.M.I.S.T) United Kingdom. He then, obtained his Doctor of Philosophy (PhD) in Mechanical Engineering (Impact Mechanics of Advanced Material) in June 2015 from Swinburne University of Technology, Melbourne, Australia. While doing his PhD, he worked as a research assistant at Swinburne University executing project collaboration with Australian Defence Material Technology Center (DMTC). As a lecturer since 2002, he has taught degree level courses as well as conducting consultation and research work. He has published a number of technical papers in reputable journals and international conferences in the area of engineering education, impact mechanics, material response and energy absorption. During his appointment as the coordinator of industrial training, he introduced several innovations to the faculty such as the use of student handbook, proper design of industrial logbook and a set of industrial training regulation that is currently employed in the faculty. The innovations were not limited in the faculty level but also in the university level. He also held a certificate of competency from Malaysia Productivity Corporation (MPC) in efficient management.