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Arenga pinnata – Silicone Biocomposite: Quantifying its Tensile Properties using Neo-Hookean Model

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Abstract*: *Silicone rubber has unique properties where it has the ability to elongate in large deformation and thus, its property is often investigated using hyperelastic theory. However, silicone rubber experiences weak mechanical strength and improvement via filler addition might counter several weaknesses in silicone rubber. Furthermore, due to the increase awareness on environmental issues, this study introduces the use of natural fibre; Arenga pinnata fibre reinforced with silicone rubber to promote biomaterials which are safe to be used and easy to decompose. In this study, the tensile properties of pure silicone rubber, 8wt% and 16wt% Arenga pinnata – silicone biocomposite were investigated and compared. The samples were prepared and tested using uniaxial tensile test machine according to ASTM D412. Neo-Hookean model is employed to determine its material constant, C_1 value. Results indicate that Neo-Hookean model show good performance to mimic the 16wt% Arenga pinnata – silicone biocomposite deformation behaviour compared to pure silicone rubber and 8wt% Arenga pinnata-silicone biocomposite. It is also found that the material constant, C_1 shows increasing value which indicates that material stiffness increase with the increase of fibre content. As a conclusion, this study shows that the addition of Arenga pinnata fibre enhances the stiffness of silicone rubber. Moreover, unlike synthetic materials, the use of natural fibres could preserve the environment.

Index Terms*: *Arenga pinnata, Hyperelastic, Neo-Hookean model, Silicone biocomposite.

I. INTRODUCTION

The development of silicone composites is becoming popular for the applications of thermal interface and electrical insulations such as thermal pads [1], LED encapsulants [2], microwave substrate [3], etc. Silicone rubber itself has been used widely for biomedical purposes such as implants and synthetic skin as it is known to have good biocompatibility [4]. Several fillers such as nanosilica [5], organically modified montmorillonite (OMMT) [6], carbon nanotube (CNT) [7], graphite nanoplatelets (GNP) [8], alumina [9] and many others were being incorporated with silicone rubber due to silicone rubber experiences weak mechanical strength [10].

In addition, these soft materials have been investigated in depth by a few researchers to quantify its elastic properties using hyperelastic theory. Benevides & Nunes [9] has conducted monotonic tensile loading on alumina filled silicone rubber. They employed Yeoh and Lopez-Pamies model to obtain the material parameters. Besides that, using five hyperelastic models, Meunier et al. [11] investigated the mechanical behaviour of unfilled silicone rubber under five different tests. The use of Neo-Hookean and Mooney-Rivlin models were also found in a previous study to quantify the silicone rubber's material constants [12]. Besides rubber, these established hyperelastic constitutive models have also been widely explored to characterize the mechanical properties of skin [13].

However, from literatures, it is observed that there is lack of study that has reinforced natural fibres with silicone rubber. Natural fibres have recently discovered widely among researchers to seek its potential in promoting greener materials. This is due to the awareness rises on saving the earth by reducing the amount of harmful gases which finally causes the environment to experience global warming [14]. Besides that, the air that we breathe in is dangerous to be inhaled when these harmful gases are released. One of the main sources of the released of harmful gases came from non-biodegradable synthetic fibres such as glass fibres, carbon fibres, Kevlar and many others. These materials are extensively employed in the making of composite materials. They are preferable to be used as reinforcement in composite materials as they promote beneficial properties such as light weight, corrosion resistance and strong.

Due to several drawbacks of synthetic fibre especially when decomposed, natural fibres became an alternative to replace them. Natural fibres also exhibit unique characteristics as they possessed low density, cheaper, bio-degradability and most of all they can be obtained easily as they are abundant in nature. Besides that, natural fibres are safe to be used compared to synthetic fibre which can cause harm and environmental problems [15]. Thus, this study introduces natural fibre named Arenga pinnata fibre or can be called by its local name; ijuk as the reinforcing material for silicone rubber in conjunction to introduce new silicone biocomposite from the source of natural fibres.

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Nevertheless, Arenga pinnata fibre reinforced with other types of thermoset such as epoxy matrix has been studied in depth by other researchers.

"Arenga pinnata", "Ijuk" or "Arenga saccharifera" is a multipurpose plant as almost all parts of the tree can be utilized [16]. They are traditionally used in the making of ropes for ship cordages, roofs, brooms and mats due to its high durability and high resistance to seawater [17, 18]. Back in 19th century during the colonialism of British, the Arenga pinnata fibre was planted in Penang by East India Company (EIC) or also known as British East India Company to produce rope for its high durability characteristic [18]. Meanwhile, a previous study has found that Arenga pinnata fibres also exhibit good mechanical properties (strain and tensile properties) which are also comparable to other natural fibres [19].

This study, therefore, aims to assess the mechanical properties of Arenga pinnata – silicone biocomposite via uniaxial tensile test and thus, to quantify its material constants using Neo-Hookean model by comparing between 0wt% (pure silicone rubber), 8wt% and 16wt% Arenga pinnata – silicone biocomposite.

II. METHODOLOGY

A. Specimens Preparation

Selected silicone rubber used in this study is Silicone Ecoflex 00-30 and the chosen filler; Arenga pinnata fibres (Fig. 1) were obtained from local people in Kuala Pilah, Negeri Sembilan, Malaysia. The fibres were cleaned thoroughly and allowed to dry at room temperature before underwent crushing process using crushing machine and planetary mono mill machine until powder form fibres can be obtained. The powdery fibres were then sieved using 0.25 mm mesh size sieve frame.

Fig. 1: Arenga pinnata tree

The silicone Ecoflex 00-30 consists of two parts; Part A and Part B. For pure silicone rubber, both Part A and Part B were mixed thoroughly with equal ratio. The weighted Arenga pinnata filler with 8wt% and 16wt% were added as soon as the silicone solution was fully stirred. The addition of filler must be well stirred with silicone mixture to ensure homogeneity between the filler and the matrix is achieved. The solution was then poured into the mould and allowed to cure for at least 4 hours.

B. Uniaxial Tensile Test

According to ASTM D412 standard, the specimens were exposed to tensile load using 3382 Universal Testing Machine 100kN (Instron, U.S.A, 2008). The test was conducted in the Strength of Materials Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi MARA. Nine specimens for each compositions were prepared for comparison purposes with sample size according to Fig. 2. Fig. 3 shows the specimen exposed to tensile test with speed rate of 500 mm/min until failure state reached. The tensile test data will be obtained in terms of engineering stress- strain ($\sigma E - \varepsilon$) relation.

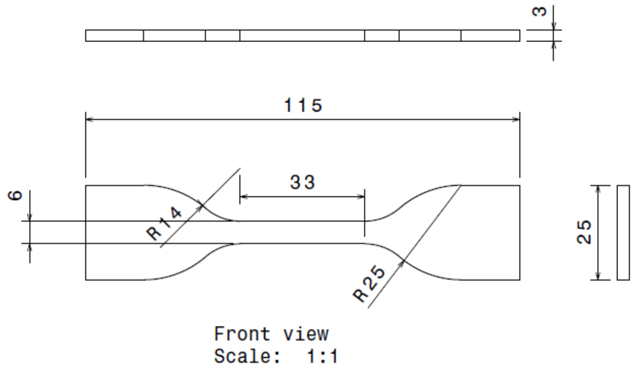

Fig. 2: Schematic drawing of sample according to ASTM D412

Fig. 3: Specimens under tensile test

C. Employing Hyperelastic Model

To investigate the high deformation behaviour of the pure silicone rubber and Arenga pinnata-silicone biocomposite, selected hyperelastic model; Neo-Hookean model is employed in this study due to its simplicity.

Considering the materials as isotropic, incompressible and hyperelastic, the Neo-Hookean model is expressed as in Eq. (1).

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

The Neo-Hookean model is expressed in terms of engineering stress– stretch, (σ_E – λ) relation and thus, the engineering stress- strain (σ_E – ε) data obtained in Section B has to be converted using Eq. (2) in order to employ the data with the hyperelastic equation. The new converted tensile data engineering stress–stretch, (σ_E – λ) relation were denoted experimental results.

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

In order to obtain the Neo-Hookean's material constant, C_1 two methods were executed. Method 1 was executed by reversing the equation in each data point and average C_1 value were calculated from each C_1 values obtained. While C_1 value using Method 2 was computed using Excel Solver.

III. RESULTS AND DISCUSSION

A. Uniaxial Tensile Test

Fig. 4 shows the average tensile properties for pure silicone rubber, 8wt% and 16wt% Arenga pinnata – silicone biocomposite where y- and x-axes represent engineering stress, σ_E and stretch, λ respectively. Its maximum tensile strength, σ and maximum stretch, λ were analysed.

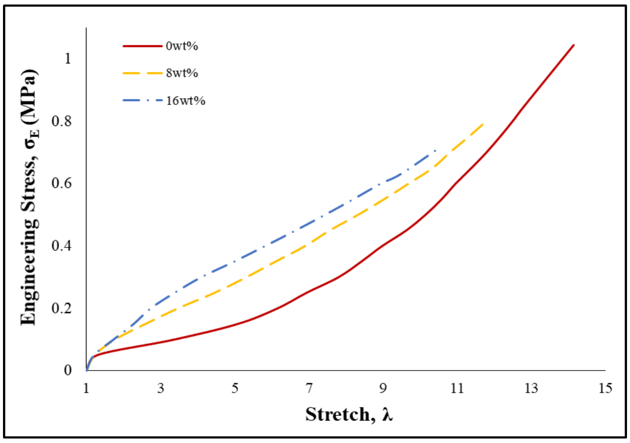

Fig. 4: Engineering stress-stretch curves of pure silicone rubber and Arenga pinnata – silicone biocomposite

From Fig. 4, it can be observed that pure silicone rubber possessed the highest tensile strength of up to 0.85 MPa compared to 8wt% and 16wt% Arenga pinnata – silicone biocomposite with maximum tensile strength up to 0.75 MPa and 0.63 MPa respectively. Pure silicone rubber also elongates the most followed by 8wt% and 16wt% specimens. Its average mechanical tensile properties values are tabulated in Table 1. All graphs show similar behaviour at the beginning with a slight concave downward. For pure silicone rubber, it appears to exhibit highly nonlinear tensile behaviour where it continues to increase with concave upward pattern. The Arenga pinnata – silicone biocomposite for both 8wt% and 16wt%, on the other hand, display an almost linear pattern as the fibre loading increases.

TABLE 1: Average mechanical tensile properties values of pure silicone rubber and Arenga pinnata – silicone biocomposite

Specimens	Mechanical Tensile Parameters	
	Maximum Tensile Strength, σ (MPa)	Maximum Stretch, ε
Pure silicone rubber	1.04	14.15
8wt%	0.80	11.81
16wt%	0.71	10.49

B. Quantifying Hyperelastic Material Constant

Fig. 5 shows the nonlinear elastic pattern of pure silicone rubber under tensile test. Visibly, the analysis shows that Neo-Hookean model is unable to mimic perfectly the experimental data. Both methods display that it could mimic only at low stretch values up to 1.288. The results from both methods show a slightly concave downward pattern. This obviously indicates that Neo-Hookean model is incapable to demonstrate the behaviour of the pure silicone rubber with a highly nonlinear deformation behaviour. Similar Neo-Hookean curve can be found in Shahzad et al. [20] study where the model is also incapable to mimic their experimental curve.

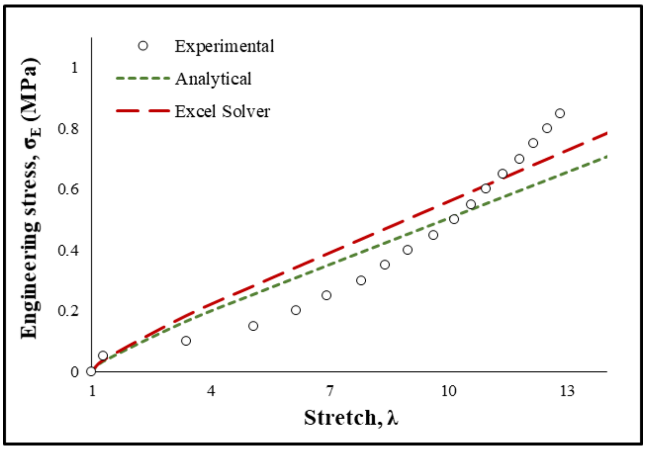

Fig. 5. Pure silicone rubber

Fig. 6 highlights a slightly nonlinear elastic behaviour of 8wt% Arenga pinnata – silicone biocomposite. Apparently, the Neo-Hookean model also displays inaccurate curve fit to model the tensile behaviour. However, both methods still can be seen to closely attached and lay over the experimental curve showing its capability in capturing the experimental data.

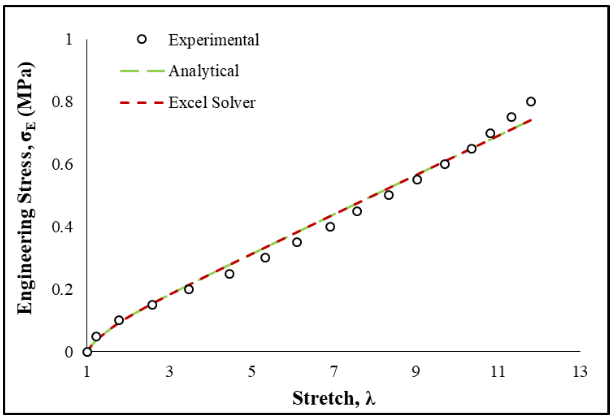

Fig. 6. 8wt% Arenga pinnata – silicone biocomposite

Last but not least, Fig. 7 shows good results where Excel Solver method shows it can demonstrate better in mimicking the 16wt% Arenga pinnata – silicone biocomposite curves compared to the analytical approach. The Neo-Hookean curve shows excellent performance to demonstrate a linear pattern in the 16wt% Arenga pinnata – silicone biocomposite.

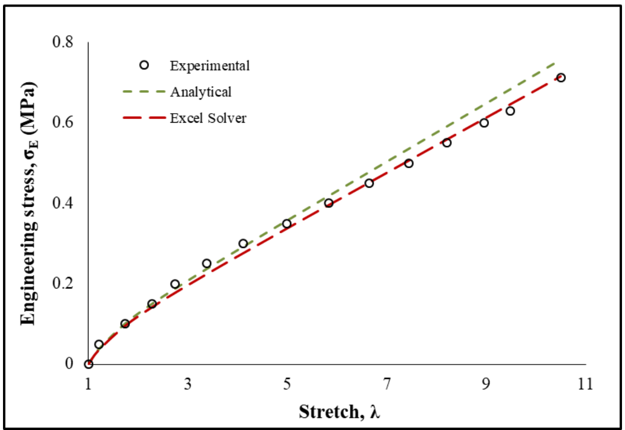

Fig. 7. 16wt% Arenga pinnata – silicone biocomposite

Overall, it can be summarized that Neo-Hookean model displays the same pattern with a slight concave downward curve and it is suitable to be employed to a material which is less nonlinear elastic. Tauheed et al. [21] in their study has also found that the Neo-Hookean model could only provide good fittings at low deformation and weak to predict the material stiffness at high deformation.

In comparing to both methods, method using Excel Solver can be assumed accurate to solve an equation for a curve fitting study. This can be observed in 16wt% Arenga pinnata – silicone biocomposite where Excel Solver method's curve could mimic better the pattern of the graph compared to the analytical method.

Table 2 shows the material constants, C1 for each specimen using both method; analytical and Solver. The pure silicone rubber shows the lowest value followed by 8wt% and 16wt% Arenga pinnata – silicone biocomposite. This indicates an increasing stiffness property in silicone rubber due to the addition of the Arenga pinnata fibre.

TABLE 2: Neo-Hookean material constants (MPa) for 0wt%, 8wt% and 16wt% Arenga pinnata – silicone biocomposite

Specimens	Material Constants, C_1 (MPa)	
	Analytical	Excel Solver
Pure silicone rubber	0.0253	0.0280
8wt%	0.0314	0.0314
16wt%	0.0360	0.0341

IV. Conclusion

The aim of this study to investigate the tensile properties of Arenga pinnata – silicone biocomposite has been successfully achieved. From uniaxial tensile test, it is found that pure silicone rubber shows the highest tensile strength compared to silicone reinforced with Arenga pinnata. In terms of stiffness, the Neo-Hookean material parameter, C1 shows the trend of increasing value when the fibre content increases. This indicates that reinforcing silicone with Arenga pinnata will increase the stiffness of the pure silicone rubber. These findings, therefore, show that the Arenga pinnata fibre has good potential to become filler in silicone rubber and thus, promoting new biocomposite materials. It can be concluded that the study has contributed significant knowledge to better understand the tensile behaviour of Arenga pinnata-silicone biocomposite.

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AUTHORS PROFILE

Siti Humairah Kamarul Bahrain was born in El paso, Texas, U.S.A on the 3rd June 1991. She is currently pursuing her PhD study, converted from her Masters study (by research) at the Universiti Teknologi MARA (UiTM) Shah Alam. She has graduated with a Bachelor of Engineering (Hons.) Mechanical from Universiti Teknologi MARA Shah Alam in April 2016 and a Diploma in Mechanical Engineering from Universiti Teknologi MARA Pulau Pinang in November 2012. During her bachelor’s degree study, she has received the Best Student Award in her fifth semester and during her Diploma study, she received the Vice Chancellor Award (Dean’s List all semesters).

Siti Humairah also has working experience for four months as a Mechanical Engineering Technician (Building Maintenance) which covers Air Conditioning Systems, Irrigation Systems, Pumps, Fans and etc. before she pursued her bachelor’s degree study. Her current areas of research interest focus on Engineering Mechanics and Biomaterials, which cover both hard and soft biocomposite materials.

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