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Compressive and viscoelastic behavior of Arenga Pinnata-Silicone Biocomposite ☆

Norhafizah Abdullah [a], Siti Humairah Kamarul Bahrain [b], Nur Aini Sabrin Manssor [c], Anwar P.P. Abdul Majeed [d], Jamaluddin Mahmud [a,*]

[a] Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[b] Faculty of Information Sciences & Engineering, Management and Science University, 40100 Shah Alam, Selangor, Malaysia
[c] Faculty of Mechanical Engineering, Universiti Teknologi MARA, 81750 Pasir Gudang, Malaysia
[d] Innovative Manufacturing, Mechatronics and Sports Laboratory, Faculty of Manufacturing & Mechatronic Engineering Technology, Universiti Malaysia Pahang, Malaysia

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ABSTRACT

This paper reports the compressive behavior of dry and soaked Silicone Biocomposite reinforced with Arenga Pinnata. In addition, for the first time load-unload tests were also carried out to highlight the hysteresis curves which reveal the viscoelastic behavior of Arenga Pinnata silicone biocomposite. Arenga Pinnata with several compositions of fiber (4 wt%, 8 wt%, 12 wt% and 16 wt%) was mixed with pure silicone and undergone compression set test (ASTM D395) and load unload tensile test (ASTM D412). For compression set test, the test was conducted in two conditions, which are dry and soaked specimens in seawater. The data from all the experiments had been analyzed to obtain compression set, stress strain relationship, and hysteresis loops. The results show that the compression set percentage peaked at 10% for silicone biocomposite of 16 wt%, and able to withstand 90 kPa compressive stress from the stress-strain curve. Hysteresis loop shows that the addition of Arenga Pinnata to pure silicone increases the energy dissipation of the material. This study discovered that the addition of different composition of Arenga Pinnata in pure silicone affects the mechanical behavior of the silicone biocomposite. More importantly, this study proves the viscoelasticity of this new material, Arenga Pinnata silicone biocomposite.

1. Introduction

Silicone rubber materials have been recognized to be useful in various applications such as thermal pads, thermal grease, biomedical applications and others due to it light weight behavior and having good impact resistance [1], In addition, it also has excellent chemical and thermal stability which makes it possible to survive in harsh surroundings [2]. Nevertheless, Noor et al. [3] found that silicone elastomer alone is comparatively restricted because of the rather weak mechanical properties particularly in room temperature compared to vulcanized silicone rubber. Therefore, reinforcing silicone matrix with certain fibers could overcome this weakness. This combination constitutes composite materials, where this bind provides stronger and stiffer reinforcement constituent [4,5]. These composite materials could offer a larger field of application due to the properties improved, such as light weight, has excellent mechanical properties, anti-corrosive, best acoustic and thermal insulation, and easy to be maintained [6].

In terms of reinforcing with natural fibers, biocomposite is defined as a material formed from a combination of matrix, such as resin and natural fiber acts as filler which are obtained from plants [7]. Namvar et al. had expressed that the first reason for the growth of biocomposites from natural fiber is flexibility of the reinforcing phases distribution in the composites and the pos-

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* Corresponding author.
E-mail address: jm@uitm.edu.my (J. Mahmud).

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sibility to obtain biocomposites having a wide range of mechanical and biological properties [8].

Natural fiber usage in industry promotes a sustainable material development through utilization of renewable resources [9]. The advantages of natural fibers are low weight, low cost, easily available and considered as renewable nature resources. At the same time, it has good thermal properties, non-toxic and environmental friendly [10]. The utilization of natural fiber in the early applications includes textile, roof, bricks and insulating material for walls [5]. Besides, I. Mukhtar had stated that mostly natural fibers are in the form of agricultural waste that is produced in billions of tons and could be utilized as fibers and fillers in polymeric composites [11]. There are many natural fibers that can be found such as coir, jute, gomuti (sugar palm fiber) and sisal [12]. In this study, Arenga Pinnata known as sugar palm fiber is used as it has great potential to be used as reinforcement in polymer composites. Arenga Pinnata has high durability and resistant to sea water [13,14].

In sealing application like gaskets and oil-ring, sealing agents such as silicone rubber is used as seal to prevent the loss of fluid and gas. Many researches have been done to improve the quality of sealing application. The properties of silicone reinforced with Arenga Pinnata is expected to be applied in sealing applications that suits the need of stiffness and durability. Therefore, the aim of this study is to investigate the mechanical properties of Arenga Pinnata silicone biocomposite for improving the capabilities of sealing application by quantifying the compression set percentage, impact energies and hysteresis.

2. Methodology

In general, the scope of this study covers investigating the compressive behavior and viscoelastic behavior of Arenga Pinnata silicone biocomposite. For the compressive tests, comparison was made between dry specimens and specimens soaked in seawater made.

2.1. Sample preparation

The first stage of the work involved of the preparation of Arenga Pinnata powder. The Arenga Pinnata fibers (Fig. 1a) was collected from sugar palm trees at Kuala Pilah, Negeri Sembilan, Malaysia. The fibers were first cleaned and rinsed thoroughly to remove dirt and contaminants from the core. The clean fibers then were left at room temperature for 24 h to dry. The dried Arenga Pinnata fibers were crushed using crusher machine and milled using planetary mono mill machine. The Arenga Pinnata powder were sieved using vibratory sieve shaker into 0.16 mm size (Fig. 1b). Arenga Pinnata powder composed of 4 wt%, 8 wt%, 12 wt% and 16 wt% were weighted using electronic balance device.

Silicone Ecoflex 00-30 platinum cure was used as the polymer matrix, which was supplied by Cashmech Technologies Sdn. Bhd, Malaysia. The product is in liquid form, consists of Part A and Part B to be mixed accordingly following instructions provided by the manufacturer to produce silicone solution. The Arenga Pinnata powder with different compositions prepared earlier were added to the silicone solution and stirred well to make sure homogeneity between the powder and solution. The 0 wt% sample is pure silicone without any addition of Arenga Pinnata powder. Finally, the mixture was poured into specific molds following the mechanical testing requirement, and at least five specimens were prepared for each test to obtain statistically significant data.

2.2. Compression test

The compression test was conducted using compression set device based on standard ASTM D395B for dry and soaked specimens. The diameter of the specimen was 29 mm ± 0.5 mm in cylindrical shape and the thickness was 12.9 ± 0.5 mm (Fig. 2a). The initial thickness of the specimens was measured. For soaked specimens, the medium used in this study was seawater. They were fully immersed in seawater for a week as shown in Fig. 2b after all the specimens are fully cured.

During testing, the specimens were clamped on the compression set device, and hold for 22 h. Once completed, the specimens were relaxed for 30 min at room temperature before final thickness is recorded. The compression set value is calculated according to Eq. (1).

$$C = \frac{(t_0 - t_i)}{(t_0 - t_s)} \times 100 \quad (1)$$

where C is compression set in percentage, t_0 is initial thickness, t_i is final thickness and t_s is thickness of specimen during testing.

The compression set tests do not generate stress-strain curves. Therefore, to obtain the stress-strain curves for the specimens, the standard compression test was conducted using Instron 3382 Universal Testing Machine in the Strength of Material Laboratory, Universiti Teknologi MARA, Shah Alam. The same specimens used in compression set test (dry and soaked) were used in this procedure. The machine was set at speed of 1.3 mm/min and set up 25% of the thickness.

2.3. Load-unload test

To investigate the elastic behavior of Arenga Pinnata silicone biocomposite, load-unload tests were conducted using Shimadzu Universal Testing machine, equipped with a 5 kN load cell. The specimen dimension was prepared according to ASTM D412 as shown in Fig. 3. The test was set up with the speed of. 10 cycles of loading–unloading were performed at the speed of 300 mm/

(a) (b)

Fig. 1. (a) Arenga Pinnata fibers after cleaned and dried; (b) Arenga Pinnata powder of size 0.16 mm.

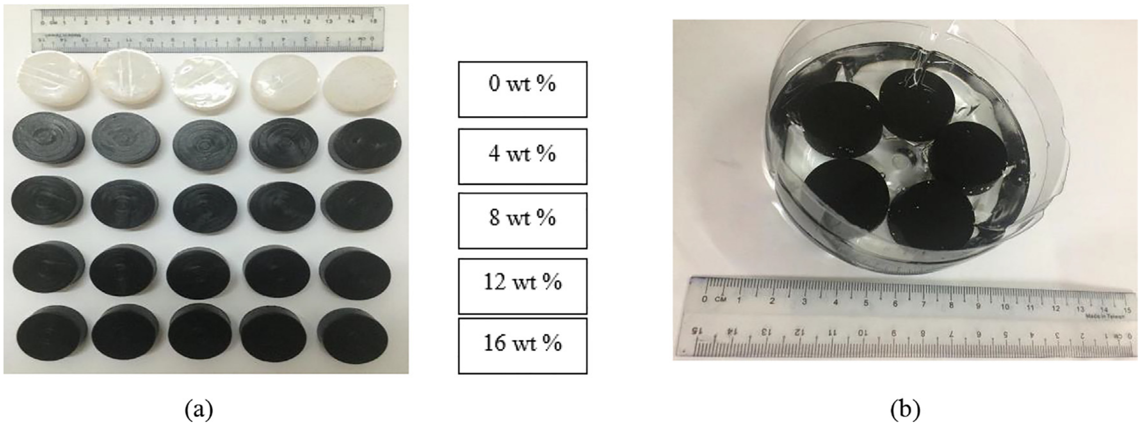

Fig. 2. a) Compression test specimens with 0, 4, 8, 12 and 16 wt% b) Specimens immersed in seawater for compression test.

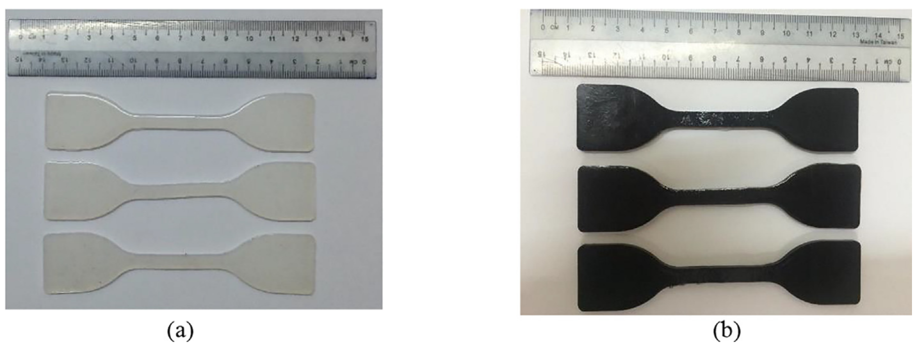

Fig. 3. Load-unload test specimens for a) 0 wt% and b) 16 wt% according to ASTM D412.

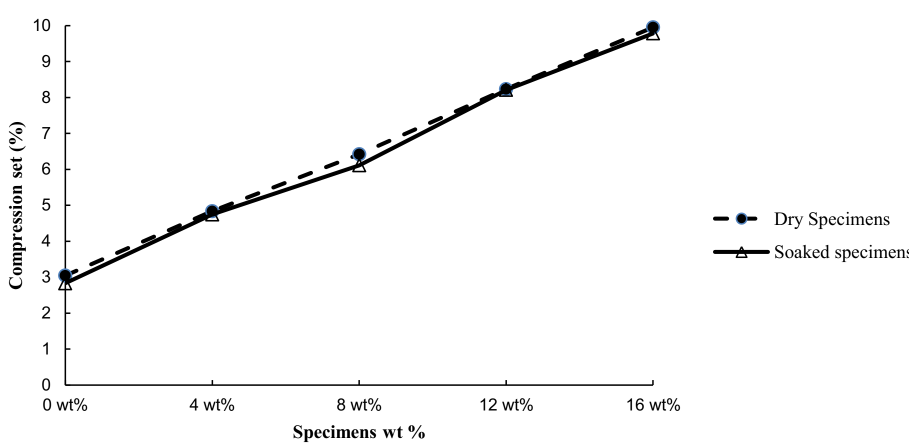

Fig. 4. Comparison of compression set percentage for dry and soaked specimens for 0, 4, 8, 12 and 16 wt%.

min and 60 mm stroke, to cover different phases that describe the behavior of the biocomposite.

3. Results and discussion

3.1. Compression set percentages

Compression test using standard ASTM D 395B has been conducted to observe the changes happen to the specimens as it undergoes constant deflection 25% from its height. The specimens were left 30 min for relaxation before measuring its final thickness. Compression set was the measure of specimen's permanent deformation under compression stress. Eq. (1) was used to determine compression set percentage to show the value which the specimen failed to retain of its original thickness. The calculated percentages were plotted in graphs as in (Fig. 4) which shows that both dry and soaked specimens exhibit increasing trend as the wt % of Arenga Pinnata increased. The compression set increases, as the compositions of Arenga Pinnata fibers increases. This behavior is similar as reported by studies by Bahrain et al. [2] as it was expected that the presence of Arenga Pinnata fiber will increase the stiffness of the silicone, hence reducing its elasticity to bounce back to its original thickness. In addition, the study also stated that the rubber chain mobility of the silicone is reduced when fiber had filled its space.

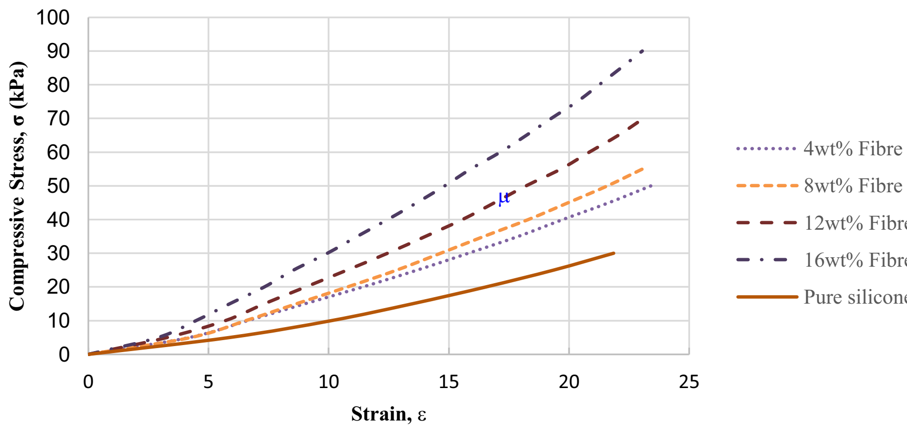

Fig. 5. Stress- strain curves for all compositions shows increasing trend of strain and stress as Arenga Pinnata wt % increases.

Comparing the percentage values between dry and soaked conditions for all compositions of Arenga Pinnata, it was observed that the soaked specimens able to retain their original thickness better than dry condition, thus showing that seawater has improved the silicone condition as in agreement with the finding from Bahrain et al. for soaked specimens [2].

3.2. Stress-strain curves

Further analytical method is conducted via stress strain relationship to investigate the nonlinear behavior of the silicone. Stress-strain curves for each composition have plotted together as presented in Fig. 5. The pattern shows an increasing value of strain as the stress increase. Besides, it was observed that as the percentage of Arenga Pinnata composition increases, the stress value also increases. In addition, the 4 wt% and 8 wt% compositions behave almost comparably while the other compositions behave significantly different. The curves also depict an excellent compressive strength of silicone biocomposite as compared to pure silicone. In fact, the material is able to withstand as high as 90 kPa of compressive stress at 16 wt% of Arenga Pinnata fibers, in contrast to pure silicone which only able to withstand 30 kPa compressive stress.

3.3. Load-unload tensile test

Fig. 6 presents the hysteresis loops generated from the load-unload tensile test conducted on Arenga Pinnata-silicone biocomposite. The hysteresis loop represents an energy dissipation since the load and unload path does not overlap. It could be seen that the energy dissipation increases as the composition of the filler increases, which possibly due to the loss of elasticity in the specimens. The small relative change of energy loss occurring in pure silicone suggesting that pure silicone has high fatigue resistance.

4. Conclusion

This paper has successfully reported the investigation of the compressive and viscoelastic behavior of Arenga-Pinnata silicone Biocomposite. The results shown include the stress strain curves, compressive behavior of dry and soaked specimens; as well as hysteresis loops under various composition of Arenga Pinnata fibers. It is interesting to highlight that even though Arenga-Pinnata silicone biocomposite has high compressive set compared to pure silicone, the addition of the filler also increased its compressive strength. However, hysteresis loops generated from the load-unload test reveals that Arenga Pinnata silicone biocomposite may has lower fatigue resistance compared to pure silicone. Therefore, from the results and findings, it can be concluded that this study has con-

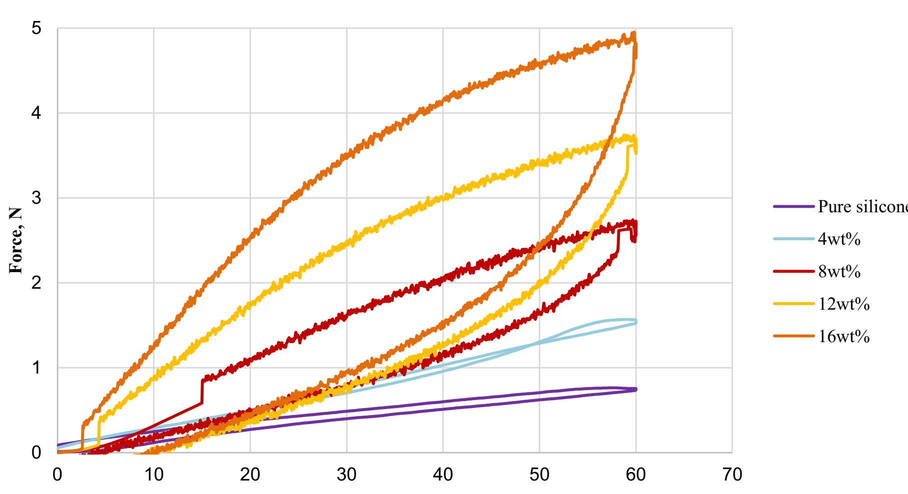

Fig. 6. Hysteresis loops obtained from a load-unload tensile test performed on Arenga Pinnata silicone biocomposite.

tributed significant knowledge in understanding better the compressive and viscoelastic behavior of Arenga Pinnata silicone biocomposite.

CRediT authorship contribution statement

Norhafizah Abdullah: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft. **Siti Humairah Kamarul Bahrain:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft. **Nur Aini Sabrin Manssor:** Investigation, Resources, Data curation, Writing - original draft, Project administration, Funding acquisition. **Anwar P.P. Abdul Majeed:** Conceptualization, Methodology, Data curation, Writing - review & editing, Data curation, Funding acquisition. **Jamaluddin Mahmud:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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