THE EFFECTS OF DIFFERENT EGGSHELL-SILICONE BIOCOMPOSITE UNDER UNIAXIAL TENSILE LOADING

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ABSTRACT

Chicken eggshells are a major waste product in almost every country due to their extensive use as eggs are used in millions of household and industries. As a result, managing these waste products has become challenging as they not only occupy space in landfills but also release greenhouse gasses decomposition. In recent years efforts have been made to develop new materials using sustainable sources such as biocomposites. This study aims to fabricate eggshell silicone biocomposites and examine its behaviour under uniaxial tensile loading. This study consisted of two phases: fabrication of eggshell silicone biocomposite and mechanical testing under uniaxial tensile with 50 kN. During the first phase; eggshells were washed, sterilized, and crushed into powder form. Subsequently, they were mixed with silicone at different eggshell powder content (e.g., 5, 10 and 15 wt.%). In the second phase, the specimens underwent uniaxial tensile strength. The ultimate tensile strength increases from 0.43772 MPa to 0.47331 MPa from 5 wt.% to 10 wt.%. However, it decreases to 0.42535 MPa when reaches 15 wt.% eggshell weight. This study is in line with previous study that uses Arengga Pinnata silicone biocomposite.

Keywords: *Silicone, biocomposite, eggshell, uniaxial tensile test*

1.0 INTRODUCTION

Composites materials are a combination of two or more individual materials that are then combined to create a new material with better performance compared to their individual components. The materials are commonly made up of two parts which are the matrix and reinforcing component. The matrix secures the reinforcing components together as well as provide mechanical support while the reinforcing components primarily handles the load, usually in the form of flakes, fibers, whiskers, or particles [1].

Silicone is a versatile material and is used to make various products ranging from day-to-day objects such as footwear, automotive parts, and homeware products, to potentially life changing aids such as prosthetics. Although silicone is a versatile material, it also lacks tensile strength compared to most materials causing it to wear down when stress and deformation is applied. Silicone rubber contains siloxane bond (Si-O) of molecular structure as its primary chains thus containing better heat resistance, chemical stability, and electrical conductivity compared to other organic rubbers [2]. Meng et. al [3] have also shown that silicone happens to have high elasticity, compressibility, as well as being highly resistant towards low temperatures. However, a study conducted by Ziraki et.al [4] shows that pure silicone rubber material has weak chains causing it to have low tensile strength. This, however, can be improved by adding reinforcements into silicone rubber material. The process of adding reinforcements has led to the creation of silicone composites

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thus creating innovations that greatly affect technological industries. A review by Shit and Shah [5] stated that silicone rubber has a tear strength usually around 9.8kN/m but can be increased to a tear strength between 29.4 kN/m and 49.0 kN/m when it undergoes polymer modification and addition of certain fillers and cross linkers. They also state that strength of silicone rubber was no greater than organic rubbers when put against dynamic stress, but this issue is can be overcome with the development of silicone rubbers with flex fatigue resistance 8-20 times greater than conventional products.Silicone rubber composites are currently applied to various industries such as aerospace [6] the medical field [7] , construction [8] and even electrical [9].

Koushki et. al [10] conducted a study where silicone was reinforced with hemp fibers in additive manufacturing. The samples were prepared in 10 wt%, 15 wt%, and 20 wt% of hemp fibers and underwent tensile testing. The results show that as the fiber content increases, so does the tensile strength. The addition of 10%, 15%, and 20% of untreated hemp fibers had increased the tensile strength by 51%, 61%, and 68% respectively. The tensile modulus was also increased by 86%, 89%, and 94%, respectively. The elongation at break of the composites decreased as more fibers were incorporated. This shows that silicone and hemp fibers form a composite material capable of distributing applied stress successfully.

Another study by Song et. al [11] improved the mechanical properties of silicone rubber with the addition of graphene nanoplatelets. The study shows that graphene nanoplatelet (GNP)-silicone composite has higher tensile strength and modulus compared to pure silicone. Moreover, the tensile strength and modulus increases with the increase of GNP content. Composite with 8wt% graphene nanoplatelet has tensile strength and modulus increased by 143.20% and 156.67% respectively when compared to pure silicone. The elongation of brake for the specimen 8wt% increased by 480% in contrast to pure silicone. The findings reveal how the incorporation of GNP is useful in adding strength to pure silicone.

There are several studies on the mechanical behavior of soft silicone biocomposites that use Ecoflex combined with woods, such arenga pinnata and kenaf, to name a few. [12-13]. Both studies compare the hyperelastic characteristics of the silicone biocomposite to that of skin. Their results depicted that the increase in the fiber amount increases the material constants, C1 in Neo-Hookean hyperelastic model. Although comparisons were made to skin elasticity, the biocomposites are not to be made as a substitute for skin up to date.

Chicken eggshells compose about 95% of calcium carbonate and have characteristics which are akin to limestone giving it reinforcing properties. The introduction of eggshells into various composite materials such as aluminum-silicon alloys and cement, have shown to have an increase in strength and provide support [14-15]. Eggshells are currently being used in a wide range of studies due to their availability and low cost. Its high amount of $CaCO_3$ also gives it potential of becoming an alternative to limestone in mixtures such as cement.

A review done by Vandeginste [16] focused on the vast range of eggshell waste used in polymers, metal and ceramic composites, as well as in other applications such as adsorbents, catalysts, additives and other functional materials (hydroxyapatite). The review paper also included eggshell derived calcium carbonates particles with elastomers. The elastomers used were limited to those from natural rubber to form a foam used for insulation and flame retardant. The addition of eggshells in composites provides an improvement of mechanical properties such as tensile strength, comparable to synthetic fillers making for a high-availability, sustainable, and eco-friendly composite material.

Gbadeyan et al [17] carried out a study to investigate the mechanical properties of achatina fulica snail shell and eggshells reinforced epoxy. The study used a wt% ranging from 5 to 20% of shell powder. Although the results show that achatina fulica snail shell had higher tensile strength at 5 wt%, 10 wt%, and 20 wt%, eggshells had a higher tensile strength at 15 wt%. The tensile strength of eggshell had an increase from 5wt% to 15 wt% but showed a decline at 20 wt%. The addition of 5wt%, and 10wt%, eggshell improved tensile strength of epoxy composite by 4.83% and 11.54 %. With this, eggshells do have potential in aiding tensile strength while being a sustainable source of reinforcement for composites.

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Furthermore, there are also other studies using eggshells in various types of composites such as polypropene [18], polylactic acid [19], and metal matrice composites [20].

With this, a new biocomposite consisting of eggshell and silicone will theoretically have better tensile properties compared to silicone individually. Nonetheless, there is a lack of research on the production and study of eggshell-silicone biocomposite. This study aims to fill in the gap in information as an eggshell-silicone biocomposite would produce a material with strong tensile strength at a low cost and using sustainable materials. The new material would have the potential to be used in various applications, where the low tensile strength of silicone biocomposite is relevant. A tensile test would be required in order to determine if the new material is able to sustain the tensile stresses applied upon it as applications such as prosthetics would require the material to be able to handle various stresses constantly. Therefore, this study is attempted to fill in the knowledge gap.

2.0 METHODOLOGY

The methodology for this study is divided into two phases: Fabrication of eggshell – silicone biocomposite, and mechanical testing of eggshell–silicone biocomposite under uniaxial tensile stress.

2.1 Fabrication of Eggshell-Silicone Biocomposite

In the first phase, the specimens were prepared in three different compositions: 5wt%, 10wt%, and 15 wt% of eggshell powder. Raw eggshells were collected, washed, sterilized, and made into powder form. The membrane of the eggshell was not removed. The eggshell powder was then combined with silicone and the eggshell-silicone mixture was poured into a "dog bone" shaped mold to cure. The silicone used in this study was Ecoflex 0030 from Smooth-On. The overall fabrication of eggshell biocomposite was summarized in Figure 1.

2.2 Uniaxial Tensile Test

All specimens underwent tensile loading using Instron Universal testing machine with 50kN and speed of 100 ± 50 mm/min. The stress-strain relation of the biocomposite was recorded, and the average value of the Young's modulus for each variant was calculated. Figure 2 depicted the tensile testing setup for eggshell silicone biocomposite.

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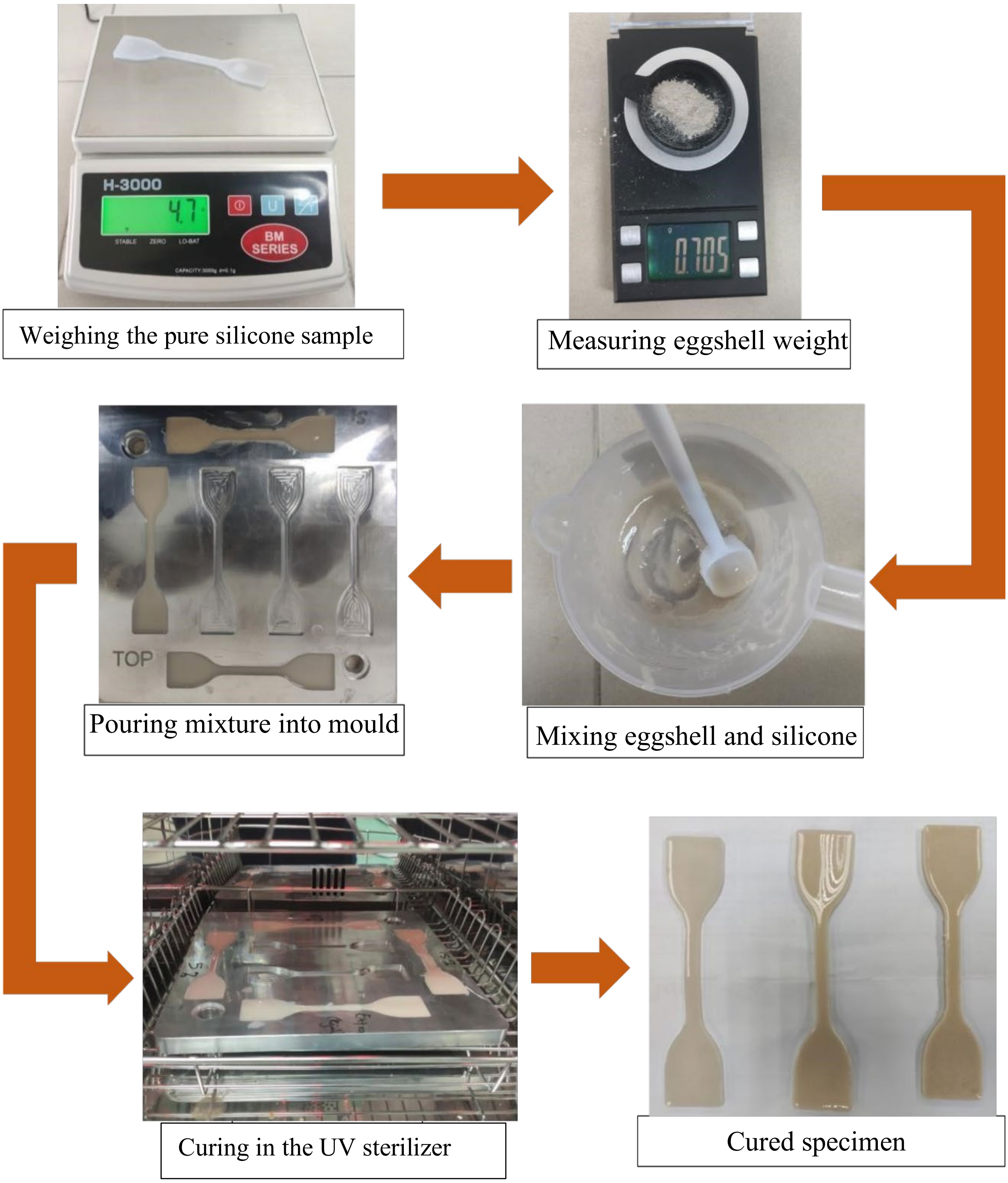

Figure 1: The fabrication of eggshell silicone bio composite process

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Figure 2: The tensile testing set-up

3.0 RESULTS AND DISCUSSION

Figure 3 plots the average tensile behaviour of eggshell-silicone bio composite with 5wt%, 10wt%, and 15 wt% of eggshells. The x-axis represents Strain while the y-axis represents Stress respectively. It was observed that as the wt% of ES powder in silicone increased the ability to handle stress load up to a certain point. The specimen containing 10wt% ES powder produced the highest nonlinear elastic curve compared to 5wt% and 15wt% ES powder specimen. In the initial phases, all specimen portrayed similar line curves where the lines were slightly upward when approaching strain value 2. After strain value 2, line curve of all three specimens began to bend slightly concave upwards. From strain value 0 to 2, line curve for specimen 5wt% and 10wt% are similar and appear to be almost identical. Compared to the specimen 15wt% ES powder, the 5wt% and 10wt% specimen showed more elongation at a smaller stress load value.

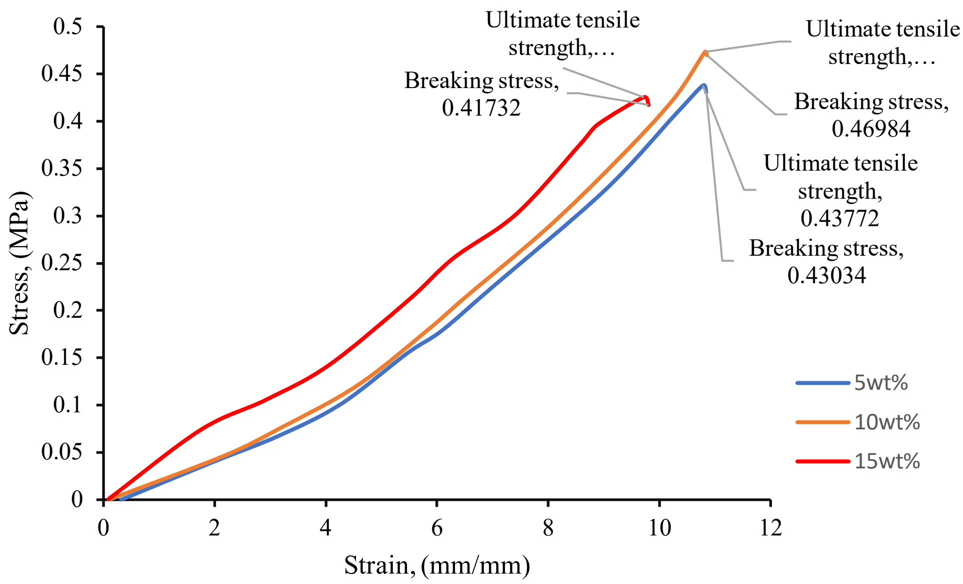

Figure 3: The average stress (MPa) against Strain, (mm/mm) of Eggshell-silicone biocomposite

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As the wt% of ES powder added into the composite was increased, the gradient of the line-curve increased too. From that, it was inferred that the appearance of ES powder in the composite caused it to resist the deformation that occurred under tensile loading. With this, it stipulated that the stiffness of the composite increased with the addition of ES powder.

Generally, polymer chains of silicone in its pure state have weak intermolecular interactions, resulting in it having poor mechanical strength. The addition of ES powder as a filler lowers the mobility of polymeric chains in the composite by having the ES powder take up space between the chains. A previous study conducted by Benevides et al. states that, the filler in the composite makes it have a higher resistance to deformation as it does not move easily with the movement of the polymer chain, making it stiffer.

Table 1 lists the average tensile properties for each composition. From the table, it can be deduced that specimen with 10wt% ES powder has the highest tensile strength, tensile stress, and breaking stress at 4.7331 MPa, 1082.02%, and 0.46984 MPa respectively. The ultimate tensile strength between specimen 5wt% and 10wt% increased by 8%, which was 0.438 MPa to 0.473 MPa. However, it decreases to 0.425 MPa between specimen 10wt% and 15wt%.

The results also showed that specimen 10wt% ES powder also was the most elastic among all the other specimens. Specimen with 15wt% ES powder had the lowest tensile strength, tensile strain, and breaking stress at 0.42535 MPa, 971.90%, and 0.41732 MPa respectively. The Young's Modulus from 10% to 15 % of eggshell powder showed no significant difference, which can also be observed in Figure 3 as well, where the gradient for both variances almost overlapped. The results in Table 1 were in line with previous studies.

Table 1: The average tensile Properties for Each Composition

Wt (%)	**Maximum Force, (N)**	**Ultimate Tensile Strength, σ (MPa)**	**Ultimate Tensile Strain, ε (%)**	**Young's Modulus, *E* (MPa)**	**Breaking Force, (N)**	**Breaking Stress, (MPa)**	**Breaking Strain, (%)**
5	7.87891	0.43772	1078.06	0.04060	7.74610	0.43034	1084.215
10	8.51954	0.47331	1082.02	0.04374	8.45703	0.46984	1085.4875
15	7.65625	0.42535	971.90	0.04376	7.51172	0.41732	980.42375

One of the previous studies include the study conducted by Gbadeyan et. a; [17], in which eggshells particles were used to reinforce epoxy composites showed similar behavior where the tensile strength of epoxy increased as eggshells particles content was increased but began to decrease after a certain point. Meanwhile, different studies done by Jusoh et. al [21] and Kamarul Bahrain et. al [12] also produced similar results where the tensile strength of silicone rubber decreased as the amount of Moringa Oleifera Bark and Arenga pinnata in the silicone rubber was increased from 12% to 16%, respectively. This happens as the fiber bonds with the silicone rubber causing it to be stiffer and reduced its elasticity when put under tensile loading. Reduced elasticity and resistance from the fibers produces an earlier fracture due to the material not being able to fully stretch. Furthermore, the varying characteristics of fiber and matrix such as one being hydrophobic and one being hydrophilic may also cause tensile strength to weaken from an uneven load transfer, as in [22]. This could result in a declining tensile strength and elongation at break. Increasing the amount of filler in a composite could lead to agglomeration in the composite samples as well as a weak filler-matrix interface. Moreover, [23] elaborates in the study that agglomerations affected the dispersion of fillers and the filler-matrix interaction as the amount of exfoliated graphite reached above 7phr. The results convey an increasing tensile strength from specimen of pure silicone to 7phr specimen but decreased as the fiber content surpassed 7phr. This is consistent with the finding by Betancourt and Cree [24], which concluded that the agglomeration occurred resulted from the

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tendency of the micro particles to be attracted to one another by electrostatic forces and Van der Waals forces made the tensile load applied to it had lower efficiency of stress transfer.

Furthermore, [25] found that deterioration of materials occurs due to tiny voids forming and getting trapped in the composite during the manufacturing process. These voids increase as the filler in the composite increases.

This study had validated previous studies which showed that the increase in fillers enhance the mechanical properties of silicone up to a saturated point, which in this case, the optimum value of eggshell was 10% weightage. It happens due to the eggshell powder bonded with the silicone rubber hence reduce its elasticity. Reduced elasticity and resistance from the brittle eggshell powder produces an earlier fracture due to the material not being able to fully stretch. Besides, the increase in eggshell to 15% weightage also increases the voids between the silicone -eggshell interaction.

4.0 CONCLUSION

A novel material of silicone biocomposite has been developed by using eggshell powder to reinforce silicone rubber. The tensile properties of eggshell-silicone biocomposite have been obtained through conducting tensile tests. The objectives of this study which was to find the tensile strength of eggshell-silicone biocomposite with different eggshell powder weight percentage had been achieved. The tensile properties of the specimen were found to have enhanced and improved as the weightage of eggshell powder was increased but only up to a certain point, as the further increase in eggshell powder agglomerated and reduced the mechanical strength of the the biocomposite.

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