A Tensile Behavioural Analysis Incorporating Tensile Extensions and Energy at Break of Agro-Waste Filled Composites for Lightweight Application

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Abstract. *Tensile strength analyses of novel agro-waste-filled composites for lightweight applications are presently indispensable as they aid designers to produce efficient and economic designs. However, existing tensile behavioural reports lack completeness; new composites in hybrid agro-waste fillers involving some selected agro-waste such as orange peels, periwinkle shell, palm kernel shell, coconut shell and eggshell are not captioned in the tensile literature. In this article, an account of the tensile extension and energy at break is given to update the literature on hybrid composites. The comprehensive alternatives in the composite formulations were considered in the experimental test under room temperature and pressure conditions. For many of the tested composites enhancement in the tensile strength was recorded while the energy at break dropped indicating that the composite has less toughness. However, other composites maintained enhanced tensile strength coupled with high toughness property. Overall, the results indicated that hybrid composites are a potential candidate for lightweight applications. The tensile analysis revealed the influence of stress and strain on the material behaviour of the hybrid composite. The usefulness of this work is to assist design engineers to implement efficient and cost-effective designs for a long lifespan of composites.*

Received by	09 June 2021
Revised by	18 June 2022
Accepted by	23 June 2022

Keywords:
tensile strength, elongation, energy at the break, agro waste

1. Introduction

In the composites development industry, the tensile strength analysis of agro-waste-filled composites for lightweight applications is presently indispensable as they aid designers to produce efficient and economic designs [1]. As tensile behavioural information is inevitable in design, the literature affirms that without tensile information predictions, wrong and faulty designs may be the result. Hence several authors have strongly depended on tensile prediction for quality designs [1],[2],[3],[4],[5],[6],[7],[8],[9]. Predictions were also achieved by the applications of several models, including the Kolarik model, Quali model, analytical models [4], quasi-static model [10], and Kelly–Tyson theory [11]. While these mathematical models are comprehensive and useful, none has been developed for agro-waste composites with epoxy resin as the matrix where combinations of particulate orange peels, periwinkle shell, egg shell and palm kernel shell have been made in varied proportions. More importantly, the tensile behaviour that this article proposes has not been analyzed in the literature. Undeniably, a growing number of researchers have appreciated dual reinforced composites using agro-waste but their analysis of tensile strength is usually scarce and not many proportions of the reinforcements to matrices are considered in each case. This leaves a huge literature gap that research should fill up.

Furthermore, the literature shows that despite the wide application of tensile studies in the composites literature, the types of composites have been restricted to the following among others: Kenaf fibre reinforced composites [12], carbon nanotube composites [11], [13], carbon fibre reinforced plastic composites [14], Delonix regia seed composites [15] and polymer/clay composites [16], [17]. Interestingly, the tensile behaviour of the combined particulate of orange peels, periwinkle shell, egg shell, coconut shell and palm kernel shell has not been reported. It is worrisome to also notice the absence of the tensile strength research for the aforementioned hybrid composites considered in this work using epoxy composites despite the interest of some researchers to analyse the tensile behaviour of other matrices excluding epoxy resin such as thermoplastics [18], [19], bio-based polyamide [20].

Furthermore, Tonatto et al. [21] studied the tensile strain behaviour of polyester, polyamide and hybrid/polyamide cords and implanted the cords in rubber belts for testing in unique designed rotating pulley equipment which accommodates the monitoring and controlling of tensile force, frequency and strain level. Stress control made was used to carry out the tests and the tensile residual strength of the cord's tensile level. Experimental findings reveal that compressive and tensile cyclic strains reduce tensile properties while hybrid cords number of cycles. Curosu et al. [22] studied the tensile behaviour of high-strength strain-hardening cement-based composites with four different types of dispersed high-performance polymers fibres-specifically high-density polyethylene, poly(p-phenylene-terephthalamide) (aramid), as-spun poly (p-phenylene-2, 6-benzobisoxazole) (PBO) and high modulus PBO fibers were inspected regardless of their reinforcing ability in a high strength, finely grained, cementitous matrix. Tensile experiments using a single fiber pull-out test were carried out to characterize the micromechanical properties of the material.

Lee [23] analysed the tensile strength of particle-filled elastomeric composites regarding the particle volume content (loading) and particle size. A fracture mechanical model to determine the tensile strength was formulated to appreciate the reinforcing effects of the particle and provide the necessary conditions for a better composite. Lan et al. [24] studied the tensile strength of parallel carbon fiber reinforced (CFRP) wire stay cable on a macro-sized scale. It was concluded that the strength of parallel CFRP wire cables, length effect and Daniel's effect should be integrated into the design of the CFRP cables to provide safety and reliability.

But having technical tensile information of these new hybrid composites of particulate orange peels, egg shell, periwinkle shell, palm kernel shell and coconut shell propels cost-effective composite development and design optimization and this action may consequently reduce the cost of structures manufactured from the composites [25]. By avoiding providing the technical tensile information, an underestimation of the potential of new and emerging reinforcements is made. Thus, reinforcements that may serve multiple purposes of economic prosperity for the industry, environmental profiting by reducing hazards and reduction of health costs through their use for productive activities instead of being indiscriminately dumped are avoided with these benefits hidden. In this article, a new tensile analysis is proposed for hybrid reinforced composites previously unexplored in tensile analysis. The tensile behaviour regarding tensile extension and energy at break is accounted for in the experimental data using tensile equipment.

Over the years, there is an increase in the importance given to innovation in the composite industry. Consequently, new composites are expected day by day to create design optimisation and improve the composite structure's overall cost. There is a tremendous estimate of cost advantage when new composites with enhanced tensile properties are discovered in the industry. The use of tensile extension and energy at the break to analyse the tensile behaviour of agro-waste hybrid epoxy composites is one potentially acceptable and growing option in practice despite its limited reports on the subject. Therefore, the evaluation of tensile behaviour of particulate orange peels, palm kernel, periwinkle shell, egg shell and coconut shell is important. Enhanced tensile extension behaviour and energy at break give good structural integrity to the composite and promotes the composite in the competitive market.

The originality of this article consists precisely of an analysis of the tensile behaviours regarding the tensile extension and energy at the break of a hybrid agro-waste epoxy composite which involves mixing particulates of orange peels, coconut shell, and periwinkle shell. The tensile stress was analysed against tensile extension and the energy at the break for the composite was evaluated. The tensile behaviour of the hybrid composites plays a significant function to understand how the tensile parameters relate in the best possible manner, has a vital function in aiding improved structural integrity of the composite and lowering the life cycle cost of the structure when produced as composite. Although numerous aspects remain unknown about the tensile strength of this new hybrid composite such as the treatment of the particulate reinforcement with sodium hydroxide aqueous solution and the introduction of binder to the particulates, new information on the tensile behaviour of this new hybrid composite contributes to technical design detail enough to promote enhance the structural integrity of the composite at a reduced cost. It may suggest new technical information to enhance the present design options in use in the industry and this is an important need of the hour for the composite industry at present.

2. Method

2.1 Procedure for the Method

Besides, based on the results of the literature review discussed in the previous section of this article, the concrete procedures for achieving the goals of this article are as follows:

Step 1: Identification of the alternative reinforcements for the epoxy composites: Literature survey was conducted to establish gaps and indication of what agro-waste reinforcements have not been studied under tensile test. It was concluded that blends of the following reinforcements have not been analyzed under the tensile test and should be explored: Particulate orange peel, periwinkle shell, egg shell, palm kernel shell and coconut shell.

Step 2: Transforming the reinforcements and matrix into composite: From the ground agro-waste, it was decided what proportions of agro-waste and epoxy matrix should be mixed. The proportions were decided to be wide-ranging. Mixing was done in the laboratory at room temperature and pressure conditions.

Step 3: Preparation of moulds: With the understanding that tensile samples have specified dimensions for the item to be workable on the equipment, the actual dimension to be supported by the equipment is decided upon. Mould was made in the laboratory the prepared composites were poured into the moulds and allowed to cure for hours and subsequently removed. They were afterwards sent to the laboratory where the tensile tests were conducted.

Step 4: Conducting tensile test: This was made to obtain measurements such as the tensile extension and energy at the break. However due to the miniaturization of what to read and also the sensitiveness of the measurements, equipment attached to the tensile testing machine was used and connected to the computer for an organized and detailed measurement.

Step 5: Analysis of data: After collecting data on the tensile properties of the materials analysis is done to know the relationship of the parameters contained in the process.

Step 6: Interpretation: The data is interpreted and conclusions are reached.

2.2 Tensile Measuring Equipment, Procedure and Test Conditions

The tensile measuring equipment used for the study is the computerized test metric model, a brand of universal testing machine. The motivation for its use is the quickness in yielding results, the ability to repeat experiments accurately and the highly reliable information obtainable from it and it has the patronage of other researchers such as Ike-Eze et al. [26] in experimental test usage. While testing these five formulations of agro-waste materials, the tensile test standard of ASTM 3039 was complied with. The tensile test is conducted by using grips and fixtures to hold and position the specimens in a vertical position for easy visualization and testing. To be specific gripping of the specimen formulation is done at the two ends of the tensile equipment. When energized by electricity, the tensile equipment gradually pulls the material along its length. As fracture occurs along the length of the specimen tensile readings are made. Of interest is the load otherwise called the load and the difference between the final length of the specimen and its initial length, measured using a graduated scale.

Furthermore, there is an acknowledged variation in the indoor temperatures and humidity conditions of the laboratory where the tensile tests have been conducted at the University of Johannesburg, South Africa. However, a temperature range of 20.2 to 25.7°C is assumed [27]. Furthermore, the ambient relative humidity levels were assumed at a range of 78.6% to 81.8% [27]. These were the conditions that permitted human comfort with the use of the universal testing machine.

3. Results and Discussion

The presentation of results and their discussion will be made based on the different formulations, particularly the five categories used in this article. These five formulations considered in this article were subjected to tensile tests based on the following motivation. The target for use of these formulations is the lightweight materials but to establish the mechanical performance of these formulations the tensile test is important with tensile test results it is possible to distinguish one formulation from another regarding how each formulation could withstand tearing because of tension. Since lightweight materials such as light rope, light metal beams and light wines may be produced from the formulations, it is considered whether the formulations could afford continuous use for the materials under the different conditions of normal and heated states of the environment. Thus, to capture information for further inputs in the composite design process the tensile test is essential.

3.1 Formulations

Formulation 1: Hybrid Orange peel Coconut shell (OP-CS) particle reinforced polymer composite

The first composite under this group is the 25% OP PRPC which contains 25 % particulate orange peel by weight percent. Its tensile strength was measured as 3.51 MPa which is lesser than that of the control sample. The composite was found to also have low energy at break of 0.8 J which is about 50 % of energy at break measured for the control sample. The tensile extension at break was evaluated as 7.95 mm which is 31.7 % obtained by the control sample. The time at the break for the 25 % OP PRPC was measured as 4.92 s which is 1.95 s lesser than the time measured for the control sample. From the foregoing parameters, the composite has less tensile strength, ductility and a shorter time to failure.

Furthermore, the stress-strain behaviour of the HY 20% OP, 5% CS PRPC is such that with the introduction of 5 % CS into the composite, higher energy at break of 1.108 J was recorded while a higher yield strength of 3.84 MPa which is 8.59 % more than the 25 % OP PRPC. Another major improvement in the mechanical properties of the Hybrid composite is that it obtained higher values for tensile extension and time to break at 8.84 mm and 5.6 s, respectively. These values represent a 10.06 and 12.14 % improvement over the values estimated for the 25 % OP composite. These results imply that the composite has better tensile strength, and ductility and would take a longer time to experience failure.

Moreover, the tensile behaviour of the Hybrid 15 % OP, 10 % CS PRPC is such that higher energy at break of 1.12 J and tensile strength of 4.623 MPa which represents an improvement of 28.57 and 24.07 % respectively, over that of the 25 % OP composite. The improvement in the mechanical properties can be attributed to the introduction of the 10 % CS into the composite. The composite recorded an improved tensile strength of 12.82 % over the control sample while the energy at break was comparatively lesser. The tensile extension and time at the break for the composite were measured as 8.023 mm and 5.06 s. Thus, the composite recorded higher toughness and tensile strength, but lower ductility and a shorter time to experience failure than the 25 % OP composite. It can be gainfully applied for higher stress applications.

Besides, with the inclusion of 15 % CS into the composite, a significant improvement was observed for most of the properties. With a tensile strength of 4.819 MPa which is 16.37 and 27.37 % higher than the obtained values for the control sample and 25 % OP PRPC, respectively. This means the composite has a great ability to resist loads tending to pull it apart from more than other composites considered. The composite also has better toughness with energy at a break of 1.55 J. The tensile extension at break and time at break were measured as 11.23 mm and 6.6 s, respectively. This indicates greater ductility and a prolonged lifetime before failure. Overall, the Hybrid 10 % OP, and 15 % CS PRPC is capable of being applied in high-stress and energy applications where good ductility is required.

Additionally, the stress-strain behaviour of the Hybrid 5 % OP, and 20% CS PRPC is described. Except for the tensile strength which was evaluated as 4.791 MPa which represents a 15.88 % improvement over the control sample, all other properties of the composite experienced a decline. This suggests that the percentage combination of the two reinforcement particles may not produce optimal results for all the mechanical properties of the composite. The composite's higher tensile strength is an indication it could be employed usefully.

Furthermore, the stress-strain behaviour of the 25 % CS PRPC is presented here. With the absence of orange peel particles, there was a remarkable improvement in the properties of the composite. It has better toughness with energy at a break of 1.79 J which is the highest in this composite category. A tensile strength of 4.698 MPa was measured which represents a 16.57 and 25.28 % increment over values obtained by the control sample and 25% OP composite, respectively. The composite's tensile extension and time at break were measured as 10.23 mm and 6 s, respectively, which were not the highest in this group. The 25 % CS PRPC toughness and tensile strength make it suitable for high strength and energy operations.

In summary, the addition of orange peel and coconut shell particles as reinforcement in singular or combined forms has increased the mechanical properties of the epoxy composite. A uniform reduction of the area was measured for all the composites in this group at 96.88 %. This means that an equal amount of necking was experienced by all the composites at the cross-sectional area where the rupture occurred. However, no particular percentage produced optimal results for all the mechanical properties tested. The 10 % op, 15 % CS composite produced the highest tensile strength, ductility and longer time to failure, while the 25 % CS composite obtained the optimal toughness with energy at a break of 1.79 J. Fig. 1 and Fig. 2 describe the tensile strength and energy at the break for all the composites in this group, respectively.

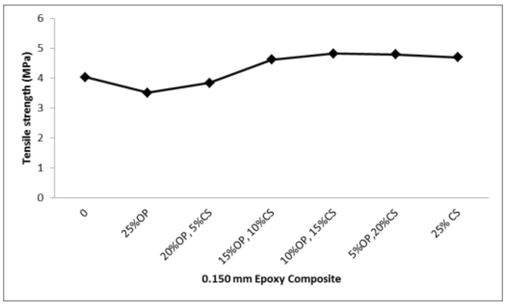

Fig. 1 Tensile strength for Hybrid 0.150 mm OP, CS PRPC

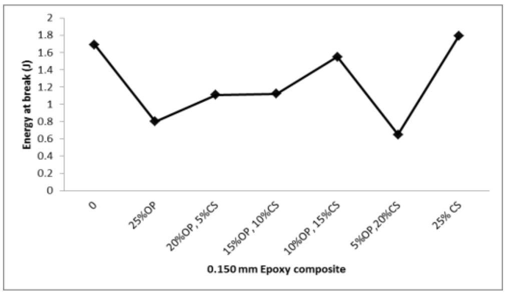

Fig. 2 The energy at the break for Hybrid 0.150 mm OP, CS PRPC

Formulation 2: Hybrid Palm kernel, Coconut shell particle reinforced polymer composite (HYPKCSPRPC)

The tensile behaviour of the 25 % PK PRPC is described. It has an energy of break of 1.17 J and tensile strength of 3.38 MPa which means it is comparatively lower than the values obtained by the Formulation 1 composite. The tensile extension at break and time at break were measured as 10.234 and 6.1 s, respectively. This shows that the impregnation of the 25 % palm kernel reduced the ductility and time at the break of the epoxy composite.

Besides, with the introduction of a 5 % coconut shell into the epoxy composite, there was an increment in the tensile strength of the material to 4.03 MPa. This was accompanied by energy at a break of 1.053 J which is a 10 % improvement over the 25 % PK PRPC. However, the tensile extension at break and time at break were measured as 7.017 mm and 4.45 s respectively, which is a 30.98 and 27.04 % reduction from that of the 25 % PK composite. This can be interpreted as a reduction of ductility and a shorter time to failure in the new composite. The stress-strain curve of the Hybrid 15 % PK and 10 % CS composite was considered. The composite exhibited remarkable improvement in its mechanical properties as a result of the combined percentage of the reinforcement particles. It has higher toughness with energy at a break of 2.32 J which was followed by a resultant tensile strength of 4.896 MPa. These values represent a percentage improvement of 27.15 and 17.68 % over values obtained by the control sample, while an improvement of 49.56 and 30.96 % were recorded in comparison to the energy at break and tensile strength of the 25 % PK composite. Remarkably, the composite also has a tensile extension and time at a break of 13.927 mm and 8.4 s, respectively. Thus, the composite has a greater capacity to sustain stress before failure, better ductility and longer to break.

Additionally, the tensile behaviour of the Hybrid 10 % PK, and 15 % CS PRPC was considered. The combined effect of the reinforcement particles also resulted in good mechanical properties. The energy at break was measured as 1.86 J showing that the composite has better toughness than the control sample and 25 % PK composite, while the tensile strength recorded as 4.742 MPa is equally superior to those of the control sample and 25 % PK sample. However, lower tensile extension and time to break were obtained by the sample between the control sample and the palm kernel composite. The composite can still be suitably applied where high stresses and toughness are required.

Also, with the addition of 20 % CS, the stress-strain curve of the new hybrid composite was considered. Again, the reduction of the PK particles and the increase in CS particles reduced the energy at the break to 1.06 J which represents a 45.91 % reduction from that of the control sample. The same trend was observed as the tensile extension and time to break also declined. However, there was an improvement in the tensile strength by 14.21 and 28.05 % over the control sample and 25 % PK sample, respectively. For this group of epoxy composites, the Hybrid 15 % PK, and 10 % CS PRPC exhibited optimal mechanical properties with higher energy at a yield of 2.32 J, the tensile strength of 4.896 MPa, and tensile extension and time at a yield of 13.927 and 8.4 s respectively. This translates to better toughness, tensile strength, ductility and longer time to rupture. The tensile strength end energy at the break for each of the composites in the group is displayed in Fig. 3 and Fig. 4.

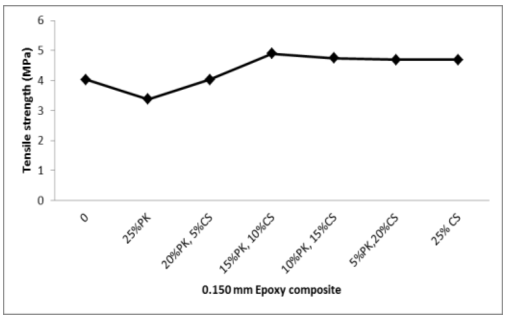

Fig. 3 Tensile strength for Hybrid 0.150 mm PK, CS PRPC

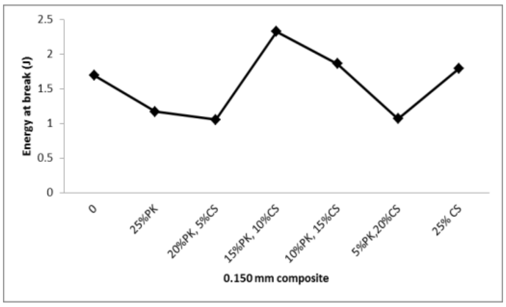

Fig. 4 The energy at the break for Hybrid 0.150 mm PK, CS PRPC

Formulation 3: Hybrid Periwinkle, Egg shell particle reinforced polymer composite (HYPWESPRPC)

The inclusion of 5 % ES into the composite produces the hybrid 20 % PW 5% ES composite with its stress-strain behaviour. However, the presence of the 5 % ES did not bring about any remarkable improvement in the mechanical properties of the new composite. The energy at break reduced significantly by 57.55 % to that of the 25 % PW composite to 0.59 J while the tensile strength dropped to 3.335 MPa which represents a 1.3 % drop from the 25 % PW composite. From the stress-strain diagram, a shorter tensile extension and time at break were also measured at 6.29 mm and 4.2 s which indicate less ductility and a shorter time to rupturing. The inferior mechanical properties may be due to the insignificant contribution of the 5 % ES to the new composite.

Additionally, the tensile behaviour of the hybrid 15 % PW, and 10 % ES composite was considered. The addition of 10 % ES results in significant improvement in the mechanical properties of the hybrid composite compared to the 25 % PW composite. The tensile strength increased to 4.523 MPa which represents a 25.29 % increment over the tensile strength of the 25 % PW composite. However, the energy at the break, tensile extension and time at the break did not experience any improvement. By implication, the composite can sustain a higher load during service but with lower ductility and a shorter time to rupturing.

Besides, the tensile behaviour of the 10 % PW, and 15 % ES composite was considered. With the addition of 15 % ES into the composite, the composite exhibited better toughness with energy at a break of 1.386 J and tensile strength of 5.295 MPa which represents a 36.18 % improvement over that of the 25 % PW composite. The tensile extension at break was found to be 9.23 mm which is 20.79 % less than the value of the 25 % PW composite. The time at break was measured as 5.79 s representing a 19.91 % drop compared to the value of the 25 % PW composite. As a result of its high tensile strength, the composite can be suitable for high-stress applications.

The stress-strain diagram of the 5 % PW, and 20 % ES composite was also considered. The percentage combination of the two particles produces a new hybrid composite with energy at a break of 4.6 MPa and tensile strength of 4.6 MPa. The tensile extension and time at break were also evaluated as 7.86 mm and 4.7 s for the hybrid composite, which represents a reduction of 32.47 and 32.54 % reduction in ductility and time to rupture in comparison to the 25 % PW composite. Therefore, careful consideration should be made before its application.

Furthermore, the tensile behaviour of the 25 % ES composite was considered. Due to the presence of only 25 % egg shell particles, there was a 53.38 % reduction in the toughness of the composite with energy at a break of 0.648 J and an 8.2 % increase of the tensile strength to 3.681 MPa compared to the 25 % PW composite. This also accompanied tensile extension and time to break of 6.66 mm and 4 s, which represents a decrease in ductility and shorter time to rupture of 44.7 and 44.67 %, respectively.

Also, for this group of composites, it can be observed that the energy at break decreased with a percentage increase in the egg shell particles which indicates improved toughness, while there was an improvement in the tensile strength as the egg shell increased. This is evidenced by the 25 % PW composite having higher energy at the break over the 25 % ES composite, while the 25 % ES composite has a higher tensile strength over the 25 % ES composite. The 25 % PW composite exhibited the optimal toughness with energy at a break of 1.39 J as well as the best ductility and longer rupture of 11.653 mm and 7.23 s, respectively. However, the 10 % PW, and 15 % ES composite have the highest tensile strength of 5.295 MPa and lowest percentage reduction in the area of 96.721 % compared to 96.88 % for the remaining group of composites. This implies that it experienced a lesser amount of necking at the cross-sectional area where the fracture takes place. Fig. 5 and Fig. 6 describe the tensile strength and energy at the break of the composites.

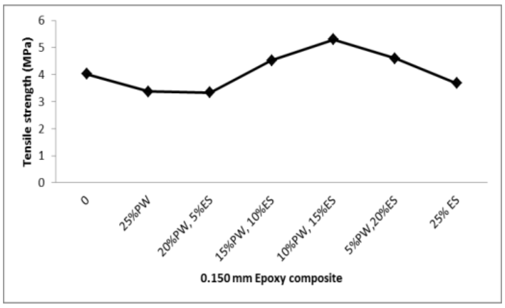

Fig. 5 Tensile strength for Hybrid PW, ES particle reinforced polymer composites

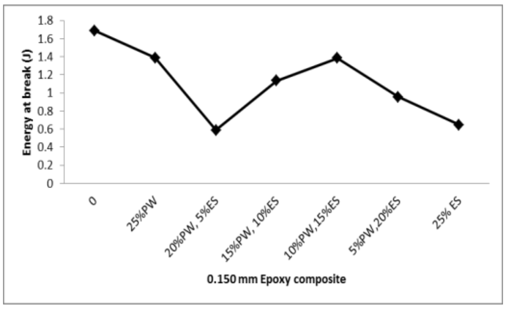

Fig. 6 The energy at the break for Hybrid PW ES particle reinforced polymer composites

Formulation 4: Hybrid Orange peel, Periwinkle particle reinforced polymer composite (HYOPPWPRPC)

The tensile behaviour of the Hybrid 20 % OP and 5 % PW composite was considered. With the addition of 5 % PW into the composite, there is an added toughness of 10.81 % over the 25 % OP composite with the energy at break measured as 0.897 J. Besides, the tensile strength is reduced by 11.68 % to 3.1 MPa. There was a reduction in the tensile extension and time at break which also signifies lower ductility and a shorter time to rupture. With the inclusion of 10 % periwinkle particles, a new stress-strain curve was obtained. The energy at break was found to be 1.126 J which represents a 28.95 % increment over the energy at break of the 25 % OP composite, while the tensile strength measured as 3.3 MPa is a 5.98 % decline. The tensile extension and time at break were found to increase with a higher presence of the periwinkle particles which translates to more ductility and a longer time to rupture. Also, as the percentage composition of the periwinkles increased in the composite to 15 %, the tensile strength increased to 5 MPa. The energy at break also increased to 1.283 J which is a 37.64 % increment over that of the 25 % OP composite. However, the reduction in the tensile extension to break and time to break reduced significantly by 16.72 and 10.56 %, respectively. This translates to less ductility and a shorter time to rupture for the new composite. Furthermore, the tensile behaviour of the Hybrid 5 % OP and 20 % PW composite was considered. The energy at the break of the composite is increased by 10.01 % to 0.889 J and higher tensile strength of 4.47 MPa which is a 21.47 % increment. Concerning the 25 % OP composite, there was a reduction in tensile extension to break and time to break for the new hybrid composite. The composite tensile strength makes it suitable for high-stress applications.

Also, in terms of tensile strength, the 10 % OP, and 15 % PW composite exhibited the highest tensile strength and toughness with energy at a break of 1.283 J, while the 15 % OP, and 10 % PW composite have the optimum ductility and longest to failure with a tensile extension of 8.97 mm and time at break of 5.6 s. all the composites experienced a uniform percentage reduction of area of 96.88 %, which means they all had the same amount of necking at the cross-sectional area where rupture takes place. The tensile strength and energy at the break for the composites are described in Fig. 7 and Fig. 8.

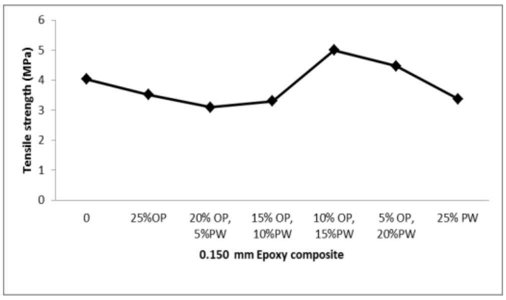

Fig. 7 Tensile strength for Hybrid OP PW particle reinforced polymer composites

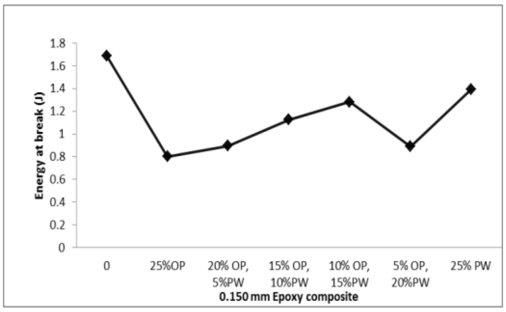

Fig. 8 The energy at the break for Hybrid OP PW particle reinforced polymer composites

Formulation 5: Hybrid Palm kernel, Egg shell particle reinforced polymer composite (HYPKESPRPC)

With the addition of 5 % ES into the 25 % PK composite, the energy at break of the new hybrid composite increased by 19.8 % to 1.459 J, while the tensile strength dropped by 8.4 % to 3.096 MPa. The tensile extension and time at break rose by 26.23 % to 15.78 mm, while the time at break increased by 27.37 % to 9.46 s. The composite possesses good toughness, ductility and a longer time to failure. Besides, the tensile behaviour of the Hybrid 15 % PK and 10 % ES composite was considered. The composite recorded lower energy at a break of 0.732 J but the tensile strength appreciated by 8.88 % to 4.423 %. This was followed by a reduction in the tensile extension and time to break to 5.582 m and 3.7 s, respectively. Also, with the addition of 15 % ES particles into the composite, the stress-strain behaviour of the new composite was considered. There was a percentage improvement in the energy at the break by 14.78 % to 1.373 MPa, which was followed by a 37.59 % rise in its tensile strength to 5.416 MPa. The tensile extension and time to break dropped to 8.582 mm and 5.4 s, respectively. The superior energy at break and tensile strength of the composite showed that it can be used where good toughness and high tensile strength are required.

Furthermore, the stress-strain behaviour of the hybrid 5 % PK and 20 % ES composite was considered. The composite has lesser toughness and strength with energy at a break of 0.874 J and tensile strength of 3.176 MPa. A reduced tensile extension and time to break of 7.934 mm and 4.9 s were also observed from the composite. This means there was a decline in the ductility and time to reach rupture of the composite. For this group of composites, it can be observed that the addition of egg shell particles resulted in increasing tensile strength while the inclusion of palm kernel particles gave added energy at the break. In terms of optimality, the Hybrid 20 % PK 5 % ES composite possessed the optimal toughness, ductility and time at the break with energy at break of 1.459 J, tensile extension and time at break of 15.78 mm and 9.46 s, respectively.

Again, the Hybrid 10 % PK 15 % ES composite exhibited the highest tensile strength for this group of composites with a tensile strength of 5.416 MPa. The tensile behaviour of the composites and their energy at break is described in Fig. 9 and Fig. 10, respectively.

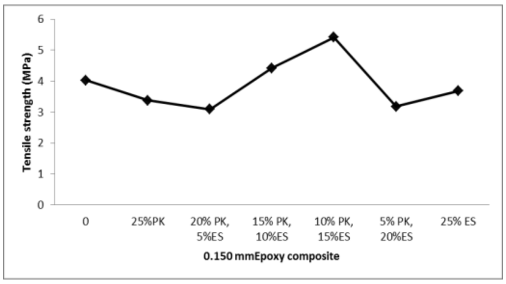

Fig. 9 Tensile strength for Hybrid 0.150 mm PK ES particle reinforced composites

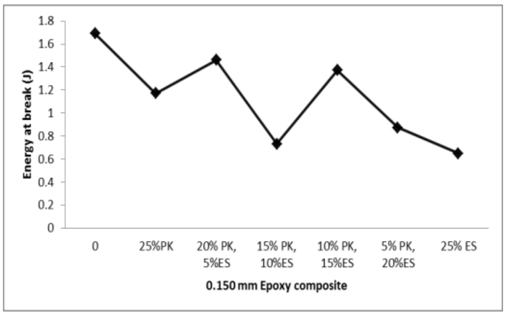

Fig. 10 The energy at the break for Hybrid 0.150 mm PK ES particle reinforced composites

This article has investigated the use of mixtures of particulates of orange peels, coconut shell, periwinkle shell, egg shell and palm kernel shell, which are agro-wastes, as reinforcements for lightweight (automobile) value-added bio-oriented composite materials. The motivation is the results obtainable from their tensile behaviours regarding the tensile extension and energy at the break. In automobile design and development, measurements of energy utilization by automobiles while being built up from certain materials are important, especially in lightweight parts of vehicles such as non-structural vehicle parts. The population of these parts includes door linings and car bumpers. In this context, agro-waste materials with reduced weights but promising tensile attributes are better choices than conventional metals and aluminum. However, lightweight materials (agro-based) are low-density materials, which when used in automobiles, reduce energy losses, and enhance efficiency thus minimizing fuel consumption and emissions from automobiles. Furthermore, the range of agro-waste considered in this article is biodegradable, recyclable, renewable and sustainable are opposed to metals, plastics or synthetic materials.

Moreover, the obtained results from the work will help the design engineers produce efficient and economic designs. Efficient design evaluates the design engineers in a team and whether all the available options and methods to optimize the lightweight object design have been considered. In the present context, five formulations (options) were considered for the choice of the best regarding energy needed at break and the tensile strength of the formulation: Thus, the design engineers could contemplate these options for efficient design. Furthermore, efficient design judges how they employ the material quantities to offer interest capability at a reduced cost. Besides, the results of this work aid in achieving economic designs from the following perspective. With further work and analysis, quantification of the benefits and costs related to the lightweight production is made by the design engineer to establish if the production project will save enough funds to necessitate capital investments in the lightweight material production project.

3.2 Possible Industrial-Scale Production of the Hybrid Agro-Waste Epoxy Composites

In this article, the hybrid agro-waste epoxy composites which involve particulates of orange peels, coconut shell and periwinkle shell among others are considered. However, the goal of laboratory-scale testing is to progress to commercialisation. This commercialisation could be on a small or large scale. But considering the developing countries, large-scale production is encouraged for the hybrid composites particularly focusing on the Nigerian environment. Chete et al. [28] declared the economic activity in Nigeria to include only 16% of the industrial sector. However, the present instance of the Nigerian economy is the government's investment to be established and the formula help in achieving the government's intention by improving the gross domestic product of Nigeria. The hybrid epoxy composites may target only lightweight industries. The industrial-scale production lowers the production cost greatly. The industrialist could purchase electricity and production inputs such as the epoxy at cheap rates thereby facilitating reduced per unit expenditure.

4.3 Mechanical Properties of the Selected Reinforcements

With the advent of miniaturization coupled with energy economy in utilizing materials on energy-consuming systems, the use of lightweight composites has been given priority. A key concern is to produce these materials as sustainable where the reaction of an applied load is concerned. Thus, it is essential to study the mechanical properties of the selected agro-wastes composites. In this context, the mechanical properties of these lightweight composites establish the scope of their usefulness and their projected service lives. The orange peel has been studied by Singh and Reddy [29] and the physicomechanical properties declared. The authors reported the following mechanical properties for the orange peels, which could be adopted in this article. The peak rupture force ranged from 10.8N to 15.6N, tensile strength ranged from 0.125MPa to 0.173 MPa and the modulus of elasticity ranged from 1.11MPa to 1.57MPa. These values are those of the ambient conduction. Assuming the material is to be used in a cold environment (i.e. cold room), the mechanical properties stated by Singh and Reddy [29] under refrigerated conditions are 12.7.N and 15.6N for the lower and upper peak rupture force, 0.138MPa and 0.173MPa for the lower and upper values of tensile strength and 1.03MPa and 1.5.7MPa for the lower and upper modulus of elasticity, for the orange peel. In addition to these data provided by Singh and Reddy [29], Gupta et al. [30] declared the shear strength of orange peels n epoxy composites to range from 3.69MPa to 4.14MPa while the orange peel reinforcement in the epoxy composite is 520. In summary, for orange peels, the reported literature mechanical properties are the shear strength, rupture force, tensile strength and modulus of elasticity.

For the periwinkle shell, Ibrahim and Sylvester [31] reported the tensile modulus of elasticity, percentage elongation, modulus of rupture and ultimate tensile strength of 25.90 MPa and 9.32MPa, respectively. Dagwa et al. [32] had an interesting report on palm kernel shells regarding the mean rupture force, which was evaluated along the width and thickness. These are 3174.5N and 2806.94N for the lower limits along the width and thickness, 3344.22N and 3305.39N for the upper limits along the width and thickness, respectively. Sudarsono et al. [33] reported on a coconut shell and palm fibre composite. In the work, the range of tensile strength, modulus of elasticity and elongation in the lowest and highest forms of volume fraction are 12.96 and 16.80 N/mm^2 (tensile strength), 12.76 and 16.44 GPa (modulus of elasticity) and 2.57 and 3.11 mm, respectively. Jasim et al. [34] while reporting on egg shell composite declared Young's modulus to range from 256.02 to 426.36 MPa with the highest at 3% filler content by weight.

4. Conclusions

Tensile behavioural analysis of novel hybrid agro-waste epoxy composite is a crucial requirement for the composite designer for design optimisation and cost-effectiveness through the composite industry, the design engineer needs to be fully aware of new technical tensile information for promising agro-waste epoxy composites consequently, in this article, experimental results regarding the tensile extension and energy at break are comprehensively analysed for five formulations regarding hybrid particulate orange peels, periwinkle shell, egg shell, palm kernel shell and coconut shell epoxy composites using the tensile measuring equipment. In this article, five formulations were made to offer a useful tool to consistently and widely classify the needed information by the design/composite engineer to have an idea of the composite. Thus, it is essential to choose the best formulation to form these options for further industrial processing. By considering the tensile strength for other composites apart from the periwinkle and egg shell combination, the range of tensile strength is usually between 3 and 5Mpa. However, an examining the measurement for the periwinkle and egg shell combination, it exceeds 5MPa and is therefore preferred to others since higher tensile strength. The higher tensile strength of the periwinkle and egg shells combination reveals enhanced mechanical performance with an attractive ability to withstand tearing because of tension. Besides, the energy at break is also an important criterion to judge the superiority of one formulation over the others. However, as the energy required breaking the composite of formulations 1, 3, 4 and 5 are roughly 1.8J, 1.75J, 1.7J and 1.75J being the highest for any of the variants within the formulation. Furthermore, it is surprising to observe formulations 2, which is the combination of palm kernel and coconut shells to produce a candidate variant that could absorb as high as 2.3J of energy, which occupies the first position among all the formulations regarding energy required to break. To be specific, for the best tensile strength specimen, the 10% orange peel and 15% periwinkle combination that exhibits roughly above 5MPa of tensile strength should be chosen. Besides, the best sample regarding energy at break is the 15% palm kernel shell and 10% coconut shell mixture that shows roughly 2.3J of energy at the break.

A potential direction of study associated with this research may be the preparation of the treated composite sample for tensile tests. Samples may be treated with aqueous sodium hydroxide for surface texture enhancement, which may positively enhance the tensile strength regarding the tensile extension and the energy at the break being studied.

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