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MECHANICAL AND MORPHOLOGICAL PROPERTIES OF WASTE TYRE RUBBER/BANANA STEM PARTICLES IN RECYCLED LOW-DENSITY POLYETHYLENE HYBRID COMPOSITE

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ABSTRACT

The study investigated the potential of waste materials, specifically waste low-density polyethene, waste tyres, and banana stem fibres, for use in hybrid composites. Six different formulations were used to produce samples of hybrid composites. These samples were created by varying the compositions of recycled low-density polyethylene, waste ground tyre, and banana stem particulate loadings in weight percentages (Wt%). The loadings for each formulation were as follows: A (100/0/0), B (80/10/10), C (70/20/10), D (60/30/10), E (50/40/10), and F (40/50/10). The compounding process involved using a tworoll mill and hydraulic hot press method. The mechanical and morphological properties of the produced samples were investigated. Results showed that the tensile strength of the samples was lowest at sample E with 6.821 N/mm², while a peak strength of 12.265 N/mm² was observed at control sample A (100 wt % RLDPE). The tensile modulus of the hybrid composite was highest at sample F with 116.729 N/mm², while the lowest modulus was recorded at the control sample with 59.829 N/mm².The increased content of the waste ground tyre rubber increased the hardness property of the samples from 26.5 to 57.2 SHORE D. The impact strength of the samples increased from the control sample to sample E but increased at sample F. The SEM result of sample F revealed improved filler-matrix homogeneity and less agglomeration. Overall, this study demonstrates the potential of utilising waste materials in hybrid composites and provides valuable insights into their mechanical and morphological properties.

KEYWORDS

Recycled low-density polyethylene, waste ground tyre rubber, homogeneity, agglomeration, compounding

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INTRODUCTION

Hybrid composites are materials fabricated by combining two or more different fibres/fillers within a standard matrix. The most common hybrid composites are carbon aramid-reinforced epoxy (which combines strength and impact resistance) and glass-carbon reinforced epoxy (which gives a strong material at a reasonable price) (Levensalor, 2016). Hybrid composite materials are increasingly utilised in many engineering applications because they offer several enhanced properties and advantages over traditional composite materials.

The mechanical properties of hybrid composites consist of critical and jointly working phases. For this reason, the mechanical properties of hybrid composites are modelled using a linear coupling of numerical simulation models. However, the mechanical behaviour of hybrid composites depends not only on the character of a matrix and reinforcements but also on the properties of the interface between these components and the matrix, which must be considered in the numerical modelling of the mechanical properties. Furthermore, the effect of environmental ageing should be considered for the numerical modelling of hybrid composite materials (Kuehner & Marcel, 2016).

Low-density polyethylene (LDPE) is defined by a density range of 0.910–0.940 g/cm^3. LDPE has a high degree of short and long-chain branching, meaning the chains do not pack into the crystal structure either. LDPE is used for rigid containers and plastic film applications such as plastic bags and film wraps like other plastics. Low-density polyethylene can take decades to decompose in landfills. Hence, recycling is critical (Tokiwa *et al.*, 2013).

There has been a rapidly growing interest in fibre-reinforced polymer composites such as banana fibre and their applications in industry and fundamental research. Fibre-reinforced composites have high tensile, flexural, impact and compression strength over the synthetic polymers and copolymers without reinforcement. Various synthetic fibres, such as glass, carbon, aluminium oxide, and boron fibres, have been used commercially in reinforcing various polymeric materials. (Dixit *et al.*, 2017).

Numerous efforts have been ongoing to combine disposed waste tire rubber with used polymers for various applications ranging from household, healthcare, military, automotive and construction, improving various properties and end product satisfaction (Bockstal *et al.*, 2019). They still act as other forms of pollution (air pollution). Hence, an attempt is made to use this waste to produce a valuable material. Ground tire rubber (GTR) produced through the downsizing/grinding processes contains a high amount of quality natural and synthetic materials that can be used as a potential source for valuable raw materials incorporated into different polymer composites.

MATERIALS AND METHODS

Materials

The Waste Low-Density Polyethylene (WLDPE) was collected from Samaru Environs, Waste Ground Tyre Rubber (WGTR) was obtained from Local vulcanisers located at Samaru Market, Sodium hydroxide, Banana stem fibres (BSF), Stirring rod, Metal mould, Aluminium foil.

Equipment

Table 1: List of equipment used for this research

S/N	EQUIPMENT	MANUFACTURER	MODEL NO.	SOURCE
1	Two-roll mill	Reliable rubber and plastic machinery	5185	Polymer workshop
2	Compression Machine	Carver inc., Wabash, nb USA	3851-0	Polymer workshop NILEST
3	Impact Tester	Cast	6957	Polymer Lab. NILEST
4	Hardness Tester	Vickers	MV1-PC	Mechanical Engineering, ABU
5	Tentiometer	Transcell Technology	BAB-200	Physical Testing Lab. NILEST
6	Abrasion Tester	Fortuna-Wepka machine	158/2FB	Polymer workshop NILEST
7	Scanning Electron Microscope	JEOL	JSM-7600F	Physical Testing Lab Ibadan

Methods

Collection and preparation of WLDPE and WGTR

The WLDPE and WTR were collected at Samaru, Zaria. The waste LDPE were shredded into smaller sizes, washed and sun-dried for three days while the WTR was washed thoroughly to remove impurities and then dried to remove moisture. It was then crushed and sieved to 150µm particle size for further processing.

Preparation of Banana stem Particles

Banana stem fibre was soaked in water with a 6% sodium hydroxide (NaOH) solution for 24 hours; the resulting mixture was then washed and dried at room temperature for two (2) days (Daut *et al.*, 2017) which was then ground and sieved to 150µm.

Table 2: Formulation table for compounding

S/N	**SAMPLE**	**WLDPE (g)**	**WASTE TYRE RUBBER**	**BANANA STEM PARTICLES (g)**
1	A	100	0	0
2	B	80	10	10
3	C	70	20	10
4	D	60	30	10
5	E F	50	40	10
7		40	50	10

Production of WGTR/ BF in waste low-density polyethylene hybrid composites

The two–roll mill machine was used to compound the materials according to the formulation table above at a temperature of 110 C for 15 minutes each. The waste LDPE was first introduced into the nip of the roll. It was allowed to form a band, introducing the WGTR and the banana particle. It was mixed homogeneously, the nip size was adjusted, and the compound was sheeted out. The compounded samples were moulded using a compression moulding machine at 150 ^{o} C for 5 minutes each. The moulded samples were cut into various dimensions for further mechanical and morphological testing.

Mechanical and Morphological Tests

Mechanical Tests Tensile

Test:

The tensile test was carried out using the Transcell Technology Tensometer (model BOB-200) CAP. 200 kg AT. 1.9951 MV/V according to ASTM D-638. A dumbbell-shaped sample was subjected to a tensile force, and tensile properties such as tensile strength, % elongation, and modulus for each sample were determined.

Hardness Test:

The hardness test was carried out using the Vickers Hardness tester with model MV1-PC, serial no. 07/2012-1329 on shore D scale following ASTM D 785-08 standard for hybrid composites. The sample was placed on the mounting stage, and the dial gauge was adjusted to zero (0). The hand lever was used to raise the stage such that the sample came in contact with the dial point, the exact pressure/force on the sample was measured, and the reading was taken. This was repeated three (3) times at different positions on the sample. The average hardness value was determined using the equation below.

Average Hardness = $\frac{1st + 2nd + 3rd\ readings}{3}$ ……………………………….Eqn 1

Impact Strength:

The impact test was carried out according to the standard specified by ISO 179 ASTM D-156; the specimen was cut to (50 x 10) mm at 7 mm thickness from all the produced samples. Izod Impact Tester (Resil impactor testing machine) was used for the impact energy test. The specimen was clamped vertically (IZOD) on the machine's jaw, and a hammer of weight 1500 N was released from an inclined angle of 150 °. The impact energy for the corresponding tested specimen was taken and recorded. The impact strength was calculated and recorded accordingly. The Impact strength was determined using the equation below.

Impact Strength = $\frac{Impact\ energy}{Thickness\ of\ Sample}\ (J/mm)$ ……………………………….Eqn 2

Morphological Test

Scanning Electron Microscopy (SEM) Test:

The samples were appropriately sized to 6-inch (15 cm) semiconductor wafers and tilted to 45 ^{0} to fit in the specimen chamber, which was gradually mounted rigidly on the specimen holder called a specimen stub. The Samples were coated with a platinum coating of electrically conducting material and deposited on the sample by low-vacuum sputter coating and high-vacuum evaporation.

RESULTS AND DISCUSSION

Plate I: Waste tyre rubber

Plate II: Ground waste tyre rubber

Plate III: Banana stem fibres extract after treatment

Plate 1V: Banana stem particles

Mechanical tests

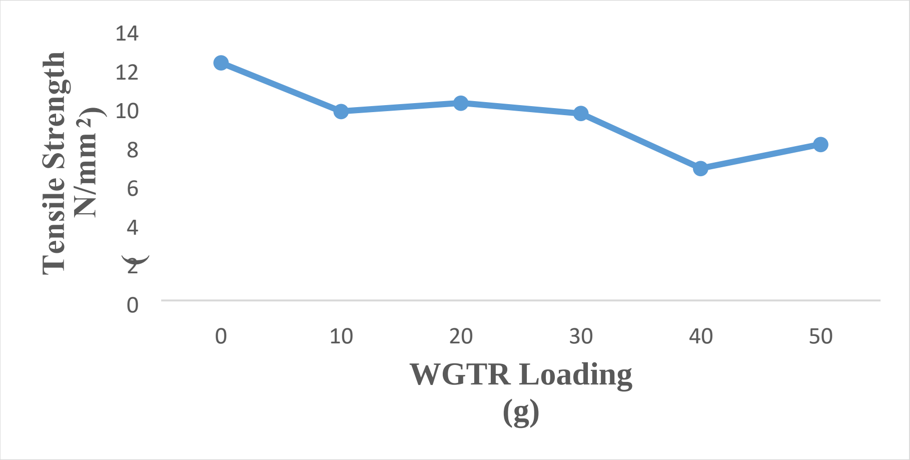


Figure 1: Effect of WGTR on the tensile strength of the hybrid composite.

Figure 1 represents the result of the tensile strength of the hybrid composite at different loading of WGTR. Tensile strength is the maximum stress a material can withstand while being stretched or pulled before breaking. Tensile stress is when the two sections of material on either side of a stress plane tend to pull apart or elongate. The capacity of a material or structure to withstand loads tending to elongate is known as ultimate tensile strength (González-Viñas & Mancini, 2004).

The result shows that the tensile strength of Sample A (control sample) is higher than the other samples. This is because, at a higher percentage of the rubber particles at 40-50wt%, there is a low interfacial adhesion between the WLDPE and WGTR, which is associated with the rubbery nature of the WGTR phase, leading to limited stress transfer between two phases (Fazli & Rodrigue., 2020).

Meanwhile, due to the incorporation of banana stem particles, there was an increment from 10 wt% to 20 wt%. It was observed that 40 wt% has the lowest tensile strength compared to others.

The increment in tensile strength from 10-20wt% of the WGTR could be a result of the influence of the high strength of the banana stem particulate, which improves the matrix-matrix-particulate composition, and the decrement could be attributed to poor wettability.

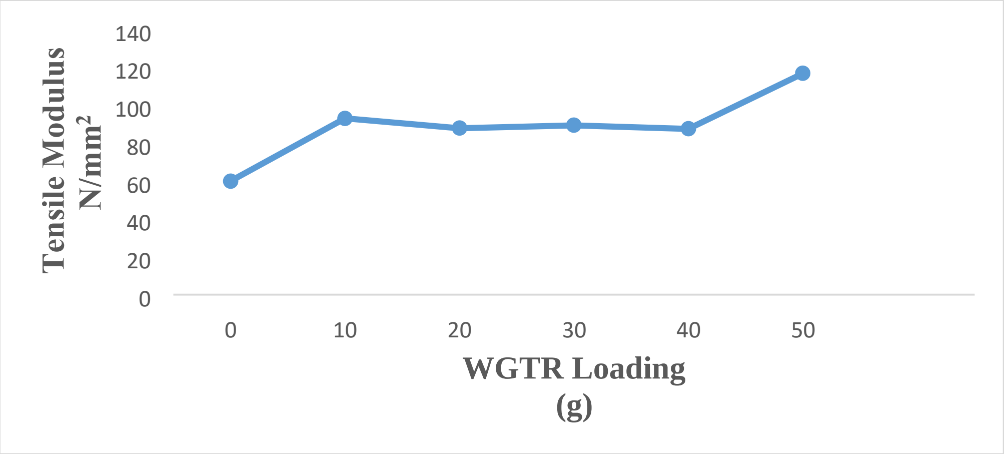


Figure 2: Effect of WGTR loading on the tensile modulus of hybrid composite.

Figure 2 represents the results of the tensile modulus of the WGTR/BSP/WLDPE-hybrid composite at different loading of WGTR. Tensile modulus measures the tensile stiffness of the material under force (Jastrzebski, 2012). The result shows the same trend as observed in the tensile strength of the hybrid composites. The hybrid composite of 50 wt% has the highest stiffness compared to others. This trend could result from the better adhesion between the matrix particulate.

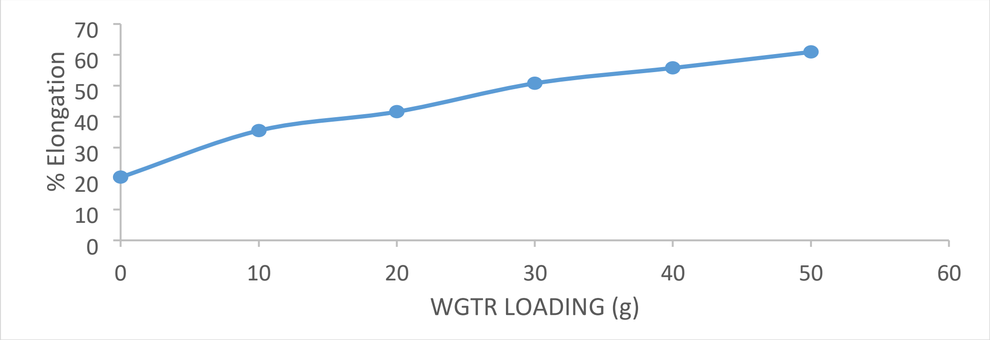


Figure 3: Effect of WGTR Loading on the % elongation of the hybrid composite.

Figure 3 represents the results of the percentage elongation of the WGTR/BSP/WLDPE-hybrid composite at different loading of WGTR. Percentage elongation is the length at the breaking point (Czeslaw, 2022). The elongation values at the fracture of samples generally increased as the filler (WGTR) loading increased from 0 to 50 g. However, elongation at fracture composites peaked at the control sample and decreased as the WGTR loading increased, having the highest elongation at 50 g filler loading. The trend of the composites' elongation can be attributed to the effect of the elastomeric behaviour of the WGTR as it increases rapidly in the hybrid composite.

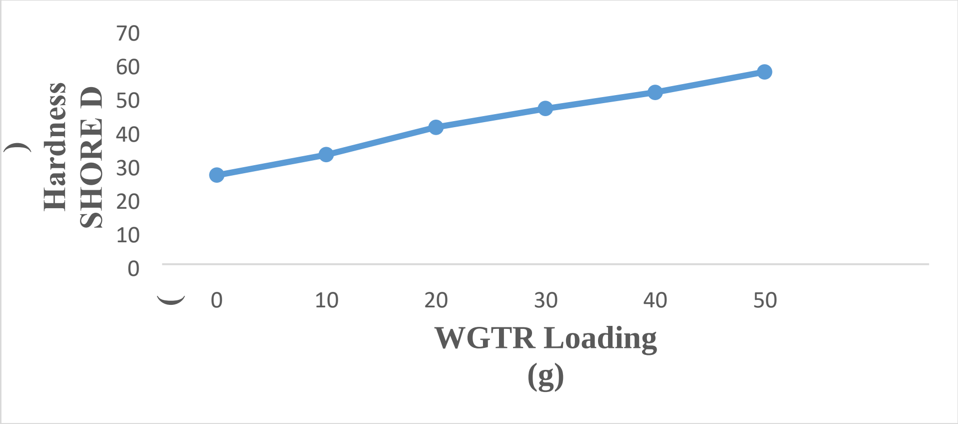


Figure 4: Effect of WGTR loading on the hardness of the hybrid composite.

Figure 4 shows the result of the hardness of the WGTR/BSP/WLDPE-hybrid composite at different loading of WGTR. Hardness measures the resistance to deformation induced by mechanical indentation (Wredenberg, 2009). The result shows that the samples increased with increasing waste ground tyre rubber. This trend could be attributed to the better interaction between the matrix-matrix-particulate, corresponding to the increasing hardness property of the samples; the substantial increase was observed due to the addition of the banana stem particles in the samples, which also led to a significant increase in hardness properties of the hybrid composite.

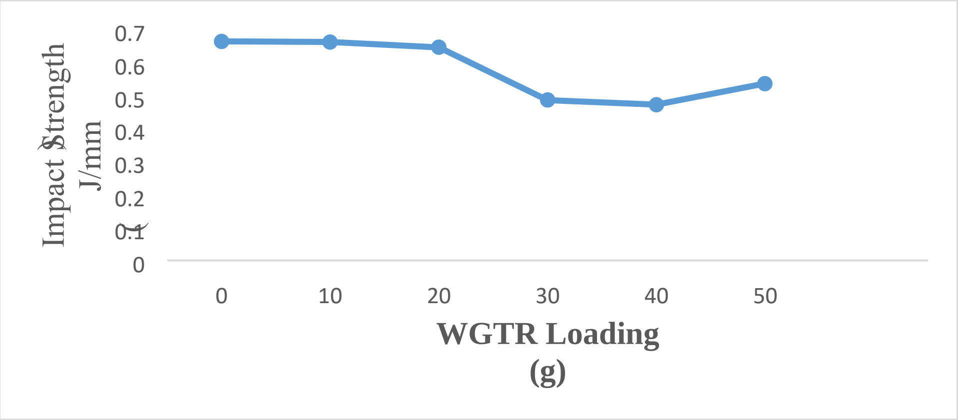
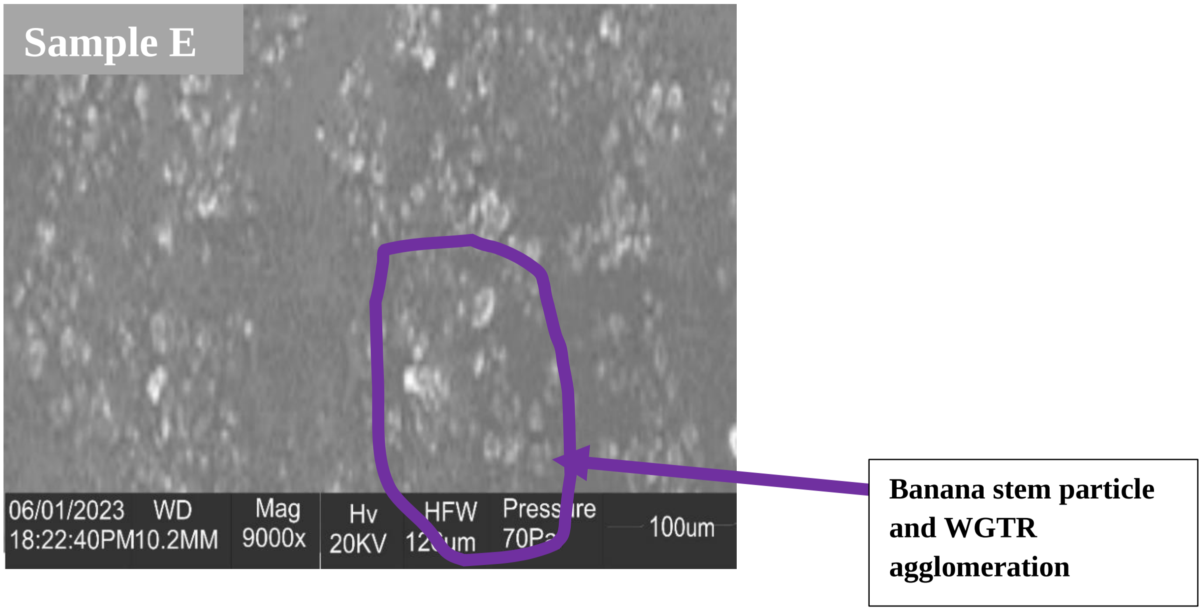


Figure 5: Effect of WGTR loading on the impact strength of the hybrid composite.

Figure 5 represents the results of the impact strength of the hybrid composite at different loadings of WGTR. Impact strength is the energy a sample absorbs before it breaks (Joseph, 2003). The results showed that the WGTR had no significant effect from 10-20wt%. The result also showed that the impact strength of the hybrid composite decreased with increasing filler loadings from 3050 wt% of the WGTR. This effect could be due to the weak interfacial interaction between the banana particulate and the WGTR at that composition. Also, the low-impact behaviour shows the effect of the WGTR as it increases in the hybrid composite.

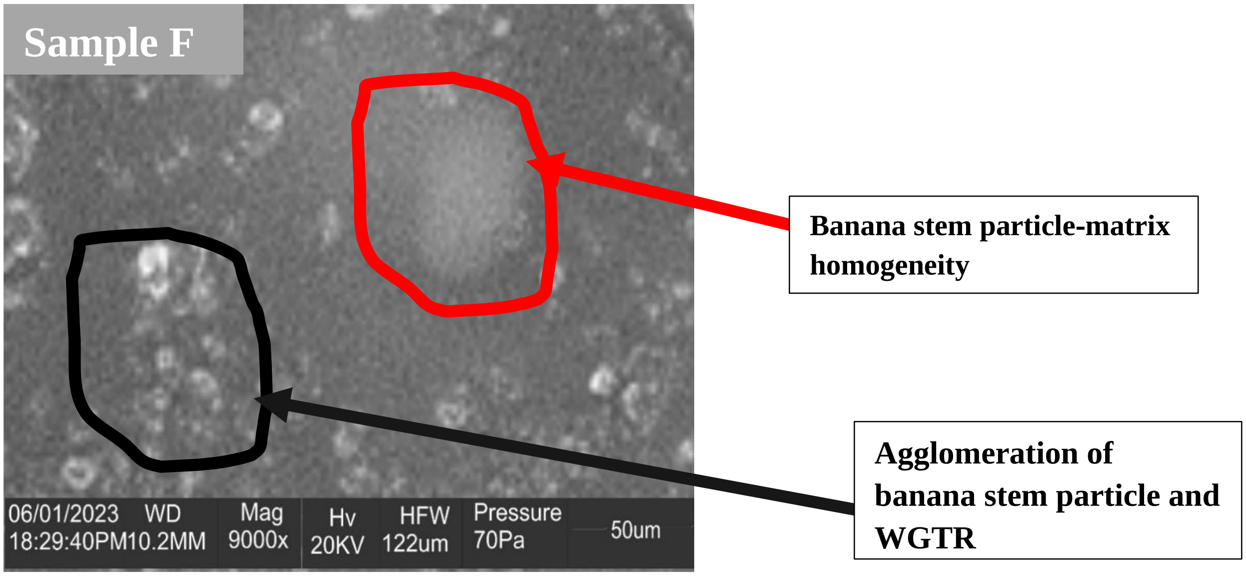
Morphological Test

SEM Result



Banana stem particle and WGTR agglomeration

Plate V: Sample E (50RLDPE/40WGTR/10BSP) SEM image



Banana stem particle-matrix homogeneity

Agglomeration of banana stem particle and WGTR

Plate VI: Sample F (40RLDPE/50WGTR/10BSP) SEM image Plates V and VI show the Scanning Electron Microscopy (SEM) of produced hybrid composite surfaces at 9000x magnification for samples E and F. The SEM morphology of the hybrid composite represented in Plates V and VI.

Plate V show the surface morphology of the composite at 50wt% RLDPE, 40 wt% WGTR and 10 wt% BSP, indicating the particulate and WGTR

appearance of the surfaces, thus suggesting that the failure mode is more of a ductile than of brittle nature without no surface fractures. In addition, the WGTR and the banana particulates are pretty distributed, even though there are little clusters and agglomeration on the matrix. However, the filler-matrix homogeneity is poor, indicating low wettability between the two components.

Plate VI shows the sample F composite's surface morphology, consisting of 40 wt% RLDPE, 50 wt% WGTR and 10 wt% BSP. It can be observed that there are more visible banana stem particulate and WGTR agglomeration on the surface of the matrix. It was further observed that the sample has no surface cracks, and the agglomeration is less when compared to sample F (50/40/10wt %). The WGTR-matrix homogeneity of the samples was lower, which could be due to poor adhesion between the filler and the matrix.

CONCLUSION

The effects of waste ground tyres on the mechanical and morphological properties of recycled lowdensity polyethylene hybrid composite have been reported, and the following conclusions were drawn. First, the results confirmed that mechanical properties and morphology properties are all influenced by the volume of waste ground tyre rubber and banana stem particulate in the recycled low-density polyethylene. Second, the tensile strength of the samples is lowest at sample E (50/40/10 wt % RLDPE/WGTR/BSP) with 6.821 N/mm^2 and a peak of 12.265 N/mm^2 at control sample A (100 wt% LDPE).

Also, the tensile modulus of the hybrid composite has a peak of 116.729 N/mm^2 for sample F, and the lowest modulus is recorded at control sample A with 59.829 N/mm^2. The hardness property of the samples increased with increasing waste ground tyre rubber, which ranges from 26.5 to 57.2 SHORE D. Furthermore, the impact strength of the samples decreased at sample E but increased slightly at sample F. The percentage elongation increased rapidly with increasing WGTR loading from 10-50 g. This is due to the elastomeric behaviour of the WGTR, which is associated with an increase in its %elongation. Finally, the SEM results confirmed that sample F showed better filler-matrix homogeneity and less agglomeration.

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