

Blend Ratio Effects on Mechanical Properties of Waste Tyre Rubber/Sand Particles in Waste-High Density Polyethylene Hybrid Composites

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Abstract

Hybrid composites of waste tyre rubber particles and sand particles in waste high density polyethylene were prepared. Waste tyre rubber particles (250 μm) and sand particles (300 μm) were blended within 10% weight filler loading at interval of 2, 4, 6, 8 and 10 (with ratio 10:0, 8:2, 6:4, 4:6, 2:8, and 0:10 of wTRP: SP) using two roll mill and compression moulding techniques to obtain the hybrid composites. The effect of blend ratio on the mechanical and thermal properties were investigated. The results showed that blend ratio of 90/2/8 wHDPE/wTRP/SP (sample E) gave the best results for tensile modulus, flexural strength, flexural modulus, hardness and glass transition temperature (T_g) with values 1.72 GPa, 32.19 MPa, 0.90 GPa, 58.57 Hv and 112.6°C respectively. While, tensile strength, elongation at break and impact strength were found to decreased. It can be concluded that novel hybrid composite materials have been developed at 90/2/8 blend ratio of wHDPE/wTRP/SP (sample E) having the best properties. This suggests that, it can be used for both indoor and outdoor applications in various areas of automobile and building sectors such as partition boards, rubber tiles, interlocks and pavements. The success of these research reveals the possibility of using polymeric waste to develop novel engineering materials and reduces environmental pollution caused by polymer wastes.

Keywords: Hybrid composites, Polymer waste pollution, Waste tyre rubber particles, Waste high density polyethylene, Sand particles, Mechanical properties

1. Introduction

Management of solid waste is one of the most significant environmental issues facing the globe today (Sienkiewicz *et al.*, 2017). As a result, management of solid waste is critical in order to prevent the harmful effects and risks that come with waste contaminations (Mousa *et al.*, 2019). Polymer waste represents a considerable percentage of waste materials (Khan *et al.*, 2021), and the storage and disposal of synthetic polymer waste has become a growing environmental concern around the world, this is why so much effort was devoted in developing strategies to collect and recycle synthetic polymer wastes into commercial and environmental friendly products with economic values (Awad *et al.*, 2020; Awad and Abdellatif, 2019). The dynamic increase of polymeric wastes result from the increase of manufacturing and use of new polymeric items, thus, causing a severe environmental challenge (Sienkiewicz *et al.*, 2017). In many areas of application, polymeric materials have replaced great number of conventional materials such as wood and metal (Ramarad *et al.*, 2015), thus the recent period is sometimes called “Plastic Age” (Karger-Kocsis *et al.*, 2013). Polymer materials such as thermoplastics, thermosets and elastomers are used to manufacture items such as tyres, tubes, toys, containers, packaging films and bags, etc. which when dispose are not easily biodegradable leading to environmental pollution and health concerns (Alabi *et al.*, 2019; Karger-Kocsis *et al.*, 2013). Landfill, incineration, recycling and material recovery via pyrolysis are the primary methods of managing polymeric wastes. Landfill and incineration of polymer waste are highly discouraged as a means of polymer waste management due to the risk of environmental pollution and health concern caused by the release of toxic gases and

low molecular compounds leading to air, soil and water contaminations (Alabi *et al.*, 2019). Recycling involves reprocessing of polymer waste into new materials with the same properties or low properties via mechanical reprocessing and also recovery of fundamental materials via pyrolysis. Mechanical reprocessing has received much attention from researchers because it is economically viable with less setbacks, while pyrolysis requires high cost of running which make it less employed for polymer waste management (Danladi and Shu'aib, 2014; Fazli and Rodrigue, 2021).

The present pneumatic tyre evolved from old simple wheel and is a complex engineering structure consisting of different materials which make it to withstand wide range of conditions during processing, usage and storage. Automobile and truck tyres are the main consumers of vulcanized rubber which constitute about 40 – 48% of the tyre, while other materials include carbon black (20-28%), steel (13-27%), textiles (0-10%) and other additives (7-12%) depending on the tyre type (Fazli and Rodrigue, 2021; Ramarad *et al.*, 2015). Waste tyre is the one that is no longer suitable for its original intended purpose (Harrison-Obi, 2019), the drastic increase of waste tyres result from the increase of automobiles and trucks on the roads all over the world (Fazli and Rodrigue, 2022a; Sienkiewicz *et al.*, 2017). Management of waste tyres include reusing (5–23%), land-filling (20–30%), energy recovery and pyrolysis (25–60%), as well as blending with other materials to produce composite materials (3–15%) (Fazli and Rodrigue, 2022a). Tyres are the main sources of waste rubber particles with applications in many areas such as building and construction, asphalt road construction and polymer matrix composites (Sienkiewicz *et al.*, 2012).

High Density Polyethylene (HDPE) is one of the most widely used polyolefins, with applications in a variety of areas such as packaging, automotive, electrical, pipelines and fittings (Fazli and Rodrigue, 2022b), due to its good mechanical properties, resistance to chemicals, rigidity, low density, thermal stability, low cost, availability and ease of processing (Fazli and Rodrigue, 2021), hence high rate of waste generation. It has low degree of branching in its molecular chain resulting from the appropriate choice of catalyst (chromium or Ziegler-Natta) and reaction conditions (Danladi and Shu'aib, 2014). Sand is a naturally occurring material that is typically found on beaches, in riverbeds and in deserts. It is often composed of silica, silicon dioxide, quartz, or calcium carbonate and is available in a loose granular form. Sand has high hardness and provide bulk strength and can be obtained at low cost, these make it to be used widely in building and construction, water filtering, landscaping, sandpaper, glass manufacturing, metal cast moulding, etc. sand also has been used as mineral filler in polymer matrix composites for building materials application (Qing, 2018).

Polymer waste management should have no negative impact on the environment and should save natural resources by utilizing fewer raw materials and developing industrial uses with commercial added value (Fazli and Rodrigue, 2021). Recently, there has been a lot of interest in using polymer waste to produce composite materials with the aim of waste recycling, reduction of environmental pollution and adding value to the waste. For example, Fazli and Rodrigue (2021), reported the effect of particle size and content of ground tyre rubber (GTR) on the physical, mechanical, morphological and thermal properties of thermoplastic elastomers (TPE) blends based on recycled High-Density Polyethylene (rHDPE) (Fazli and Rodrigue, 2021). It was reported that adding Granite Marble dust (GM) affects the mechanical properties of WTRP-HDPE composites, GM result in the decrease of mechanical properties (Mousa *et al.*, 2019). The aim of this research is to develop composite material using polymer waste (waste tyre rubber particles, wTRP and waste high density polyethylene, wHDPE) and sand particles (SP) and studying the effect of blend ratio on the mechanical properties, thus reducing environmental pollution and adding value to the polymer waste.

2. Materials and Methods

2.1 Materials:

Waste tyre rubber particles (wTRP) was obtained from Possiag Nigeria Limited, Abuja, waste high density polyethylene (wHDPE) was obtained from Alabda Global Resources Limited, Katsina. Sand particles (SP) obtained from Civil Engineering Department, Ahmadu Bello University, Zaria.

Plastic shredder/crusher (Locally fabricated), Two-roll Mill (Model: 5183 North Bergen U.S.A), Compression Moulding Machine (Model: 0557) and Izod Impact (Resil Impactor, Model No. 636) of 2J-25J capacity at the Nigerian Institute of Leather and Science Technology, (NILEST), Zaria. Laboratory standard sieves (Endocatts Ltd. PAT. No. 66724) and sieve shaker (Endocatts Model: 7416). Tensile Strength testing machine (Model: TM2101-T7) at the Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria. Universal Testing Machine (Cat Nr. Model: 26), Dynamic Mechanical Analyzer NETZSCH (DMA 242) and Vickers Hardness testing machine (Model MVI-PC, YADRAN- 416145, INDIA) at the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. Scanning Electron Microscopy (SEM) JOEL Model (JSM 7600F) at University of Ibadan.

2.2 Methods

2.2.1 Collection of Materials

The waste tyre dust was received from the buffing process of truck tyre retreading at Possiag Nigeria Limited, Abuja. It contains some pieces of steel wires and were removed by magnetic separation (Bekhiti *et al.*, 2014). It was then sieved into various particle sizes in micrometer (µm) using standard sieves (Endocatts ltd. PAT. No. 66724) and sieve shaker (Endocatts, Model: 7416).

The sand (river sand) was obtained from Department of Civil Engineering, Ahmadu Bello University, Zaria, it was air dried then sieved into various particle sizes (µm) using standard sieves (Endocatts Ltd. PAT. No. 66724) and sieve shaker (Endocatts Model: 7416).

Waste High Density Polyethylene engine oil containers were collected from Alabda Global Resources Ltd, Katsina as waste and were identified by checking the engraved resin label at the bottom of the containers. After collection, of the waste HDPE containers of engine oil, they were cleaned using premium motor spirit (PMS) to remove the remaining lubricant, and then washed with detergent and water, dried and cut into pieces to aid crushing. The plastic was then crushed into smaller pieces, using plastic crusher, to ease compounding.

2.2.2 Composites Preparation

The composites were compounded using two rolls mill (Model: 5183), the front and rear rolls were preheated for five (5) minutes at a temperature of 180°C. The weighed matrix (waste HDPE) was placed on the top nip of the rolls and rotated continuously, after it has melted, the weighed amount of filler was added to the molten wHDPE according to the formulation in Table 1, the mixing was continued for at least 5 minutes to ensure a homogeneous mixture is achieved. It was then removed and transferred into the mould then placed on to the cavity of the compression moulding machine preheated at 160°C for 5 minutes. The cavity of the mould was closed using a pressure of 4 Pa for 5 minutes to make the mixture filled the mould, then transferred to another compression moulding for cooling at a pressure of 4 Pa for 3 minutes, it is then removed after cooling. The composite material edges were trimmed using a pair of scissors to remove excess (spilled-up) material. This process was repeated for the other samples using the formulation in Table 1.

Table 1: Formulation of the Composites

Sample Name	Sample Code	%Weight (g) wHDPE	%Weight (g) wTRP (250µm)	%Weight (g) SP (300µm)
Control	100:0:0	100	0	0
A	90:10:0	90	10	0
B	90:8:2	90	8	2
C	90:6:4	90	6	4
D	90:4:6	90	4	6
E	90:2:8	90	2	8
F	90:0:10	90	0	10

2.3 Mechanical Properties

2.3.1 Tensile Test

Tensile strength test was carried out in accordance with ASTM D-638 standard using Tensile strength testing machine (Model: TM2101-T7) at the Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria. Load cell of 100kN was used at a crosshead speed of 4mm/minutes. The samples were cut into a dumb bell shape with dimension of 100 mm × 15 mm × 4 mm length, width and thickness respectively, and a gauge length of 40mm was used. Five replicate samples were used in each case and information obtained was used to determine tensile strength, tensile modulus and elongation at break (%).

2.3.2 Flexural Test

Flexural strength test was carried out according to the ASTM D-790 standard (3-point bending) using Universal Testing Machine (Cat Nr. Model: 26) at the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. The machine has a maximum force of 1kN, and sample dimensions were 100 mm × 30 mm × 4 mm length, width and thickness respectively and a gauge length of 80 mm was used. Data obtained was used to calculate flexural strength and flexural modulus.

2.3.3 Impact Test

Impact test was carried out according to ASTM D-256 using Izod Impact (Resil Impactor, Model No. 636) of 2J-25J capacity at the Polymer Section of the Nigerian Institute of Leather and Science Technology, (NILEST), Zaria. The samples were tested using simple pendulum hammer with an inclination angle of the pendulum of 150° with the force of 7.5J. Sample dimensions were 100mm × 13mm × 4mm length, width and thickness respectively with V-notched at the center.

2.3.4 Hardness

Hardness test was carried out in accordance with ASTM E-384 using Vickers Hardness testing machine (Model MVI-PC, YADRAN- 416145, INDIA) using diamond indenter at the Shell Professional Chair Mechanical Engineering Department, Ahmadu Bello University, Zaria. The machine load of 0.1kgf was used for each sample of dimensions 30mm × 25mm × 4mm (length, width and thickness respectively).

2.4 Surface Morphological Properties

2.4.1 Scanning Electron Microscopy (SEM)

The morphology of the fractured surface of tensile test sample were carried out using Scanning Electron Microscopy (SEM) JOEL Model (JSM 7600F) at University of Ibadan in accordance with the ASTM E-766-98. The test samples were coated with platinum coating which is an electrically conducting material, deposited on the sample using vacuum sputter coating to prevent any electrical discharge during the microscopic examination. The samples were inserted into the machine using the sample holder which was then viewed at an accelerating voltage of 15.0kV and magnification of 5000×.

2.5 Thermo-Mechanical Properties

2.5.1 Dynamic Mechanical Analysis

The dynamic mechanical analysis (DMA) was carried out according to ASTM D-5023 (DMA in Three Point Bending) standard using NETZSCH (DMA 242) dynamic mechanical analyzer at the Mechanical Engineering Department, Ahmadu Bello University, Zaria. The samples were cut into a rectangular shape with dimension of 40 mm × 10 mm × 4 mm length, width and thickness respectively. The analysis was carried out using three-point bending mode at temperature range 28°C to 120°C and multiple frequency of 2, 5 and 10 Hz, with heating rate of 6 kelvin/minute and test amplitude of 60 μm.

3 Results and Discussion

3.1 Mechanical Test

3.1.1 Tensile Strength

As shown in Figure 1, the control sample (100% wHDPE) has a tensile strength of 23.99 MPa which is within the theoretical range of the tensile strength of HDPE (21 – 38 MPa) (Joel, 2016), the tensile strength decreased to 20.04 MPa and 22.27 MPa after adding 10% of wTRP and SP respectively. In the hybrid composites, tensile strength decreased with increase of sand particles proportion in the composite material, it decreased from 19.69MPa (17.92% decrease) to 19.27MPa (18.34% decrease) for B (90/8/2 – wHDPE/wTRP/SP) and E (90/2/8 – wHDPE/wTRP/SP) respectively. This is as a result of the increase of incompatibility between the fillers and the matrix within the composite structure, and the possibility of interfacial contact between the particles resulting to SP-wTRP, wTRP-wTRP and SP-SP contact, these point act as stress concentration points from which cracks and defects start and propagates into the other parts of the composites. It was reported that tensile strength decreases by the addition of Granite Marble (GM) dust and silica extracted from rice husk in GM-Silica particle-natural rubber hybrid composite at a selected weight percentage (wt.%) of natural rubber of 40wt.%. This means that by increasing wt.% of GM, there was a deterioration in tensile strength. The granite marble dust acts as a stress concentration point in the matrix which will affect the load carrying capacity of the sample (Mousa *et al.*, 2019). This might be attributed to the poor interfacial adhesion between matrix and fillers in the composite structure.

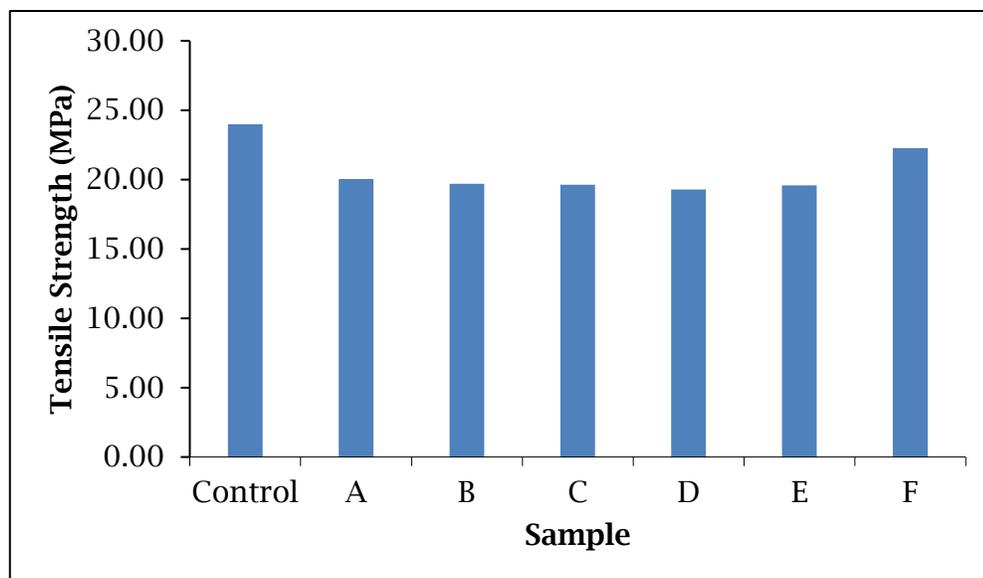


Figure 1: Effect of blend ratio on the Tensile strength (MPa) of WTRP/SP/wHDPE composites

3.1.2 Elongation at Break (%)

As shown in Figure 2, the elongation at break of the control sample (100% wHDPE) was 51.53 which is within the range of the elongation at break of virgin HDPE (20 – 130) (Joel, 2016). Addition of fillers in the wHDPE matrix causes decrease of elongation at break of the composites especially with the addition of sand particles (SP) due to the brittleness caused by the sand particles in the composites. At 10% filler loading of both wTRP and SP fillers, the elongation at break was observed to be 20.62 (60% decrease) and 10.27 (80.10% decrease) for A (10% wTRP) and F (10% SP) respectively. In the hybrid composites, elongation at break decreases from 22.25 (56.82% decrease) for B (90/8/2 – wHDPE/wTRP/SP) to 11.40 (78% decrease) for E (90/2/8 – wHDPE/wTRP/SP), due to the increase of the composite brittleness caused by the increase of SP in the hybrid composites. One of the common requirements of thermoplastic elastomer is to have an elongation at break of at least 100%, however, elongation at break and

toughness were severely reduced with the introduction of GTR/RTR onto the thermoplastic matrix (Ramarad *et al.*, 2015). Li *et al.*, (2004) reported decreasing elongation at break of HDPE from 800 to 33% after the addition of 40 wt.% GTR (Li *et al.*, 2004). The poor GTR distribution in the polymer matrix promoted particle-particle interactions and contributed to weak sites upon stress-transfer between the rubber and matrix interface which are failure points (Fazli and Rodrigue, 2022b).

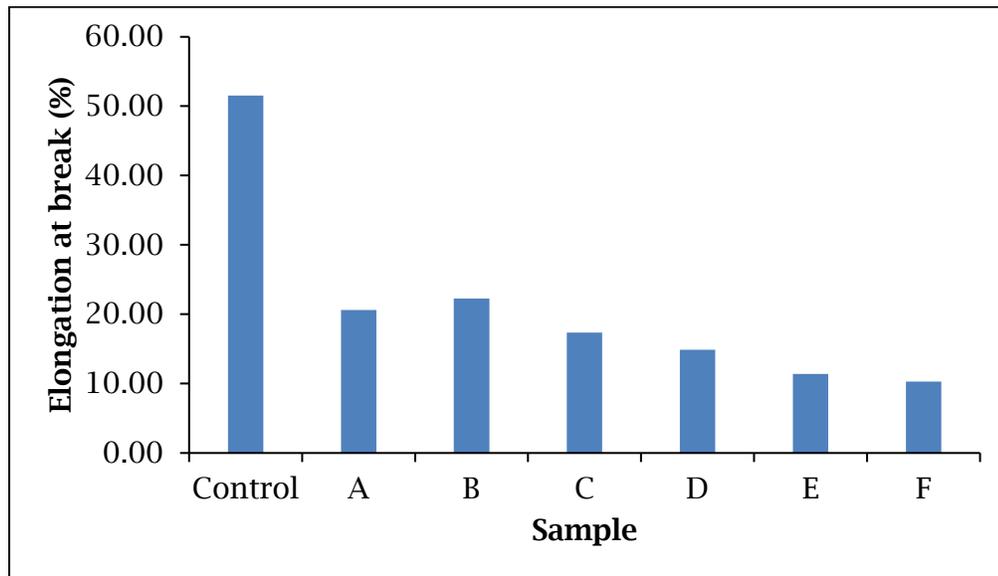


Figure 2: Effect of blend ratio on the Elongation at break (%) of WTRP/SP/wHDPE composites

3.1.3 Tensile Modulus

As shown in Figure 3, tensile modulus of the hybrid composite increased with increase of SP in the composite material, the tensile modulus of control sample (100% wHDPE) was 0.47 GPa, which is within the range value of the tensile modulus of virgin HDPE (0.41 – 1.24 GPa) (Joel, 2016). The tensile modulus increases to 1.72 GPa for B (wHDPE/wTRP/SP – 90/2/8) hybrid composite that is about 266% increase. This indicates that despite the decrease of tensile strength and elongation at break with increase of sand particles in the hybrid composites, tensile modulus of the material is reasonable. Tensile modulus has an inverse relationship with elongation at break thus increases with the rate of decrease of elongation at break. It was reported that tensile modulus increased with increase of percentage weight filler loading and is dependent on the type and size of the filler (Achukwu *et al.*, 2022). It was also reported in a review paper that addition of silica, organoclay improves the tensile modulus of thermoplastic – Ground Tyre Rubber (GTR) composites (Karger-Kocsis *et al.*, 2013).

3.1.4 Flexural Strength

As shown in Figure 5, the flexural strength of the control sample (100% wHDPE) was 25.67 MPa. Flexural strength decreased to 22.21 MPa (13.48% decrease) after adding 10% wTRP, while there was an increase to 35.67 MPa (38.96% increase) after adding 10% SP, this might be as the result of reinforcing ability of the sand particles. In the hybrid composites, increase of flexural strength was observed with increase of sand particles proportion in the composite material. It initially decreases from 25.67 MPa for the control sample to 21.82 MPa (15% decrease) for B (wHDPE/wTRP/SP – 90/8/2) hybrid composite, it later increases with increase of sand particle in the composites to 32.19 MPa (25.4% increase), this is due to the reinforcing ability of the sand particles to increase the stiffness of the composite material thereby causing it to become rigid, thus requires a lot of force to bend it.

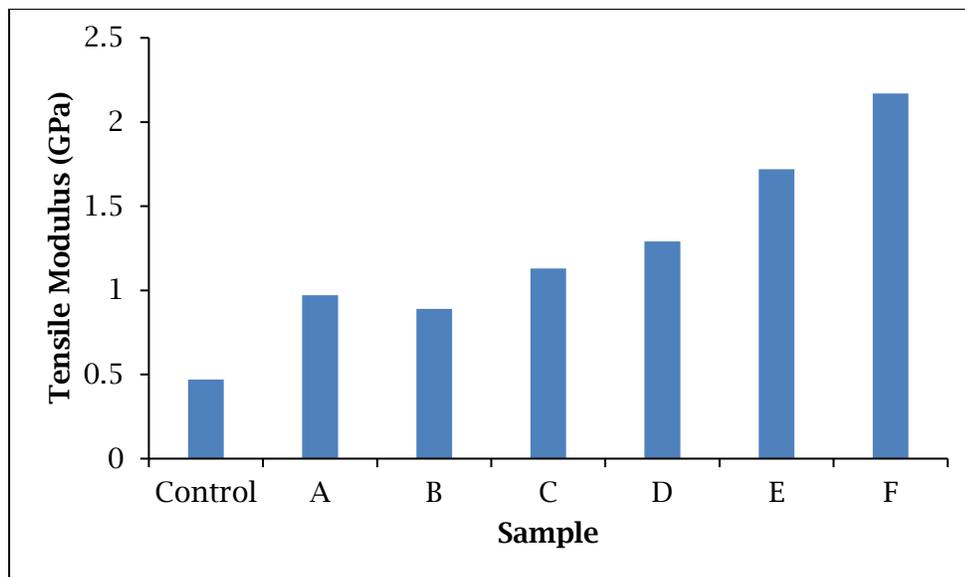


Figure 3: Effect of blend ratio on the Tensile Modulus (GPa) of WTRP/SP/wHDPE composites

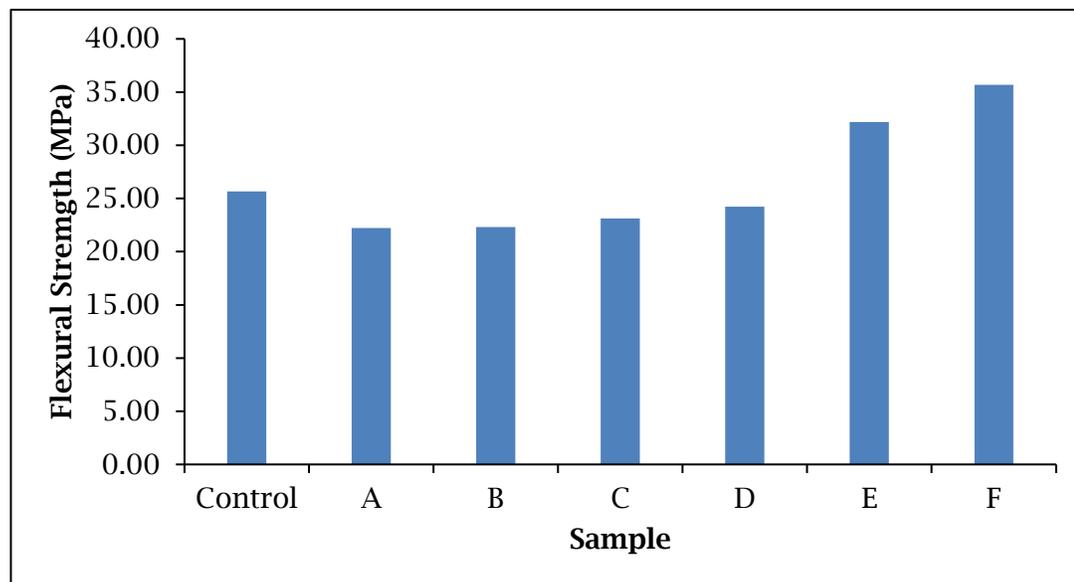


Figure 4: Effect of blend ratio on the Flexural strength (MPa) of WTRP/SP/wHDPE composites

3.1.5 Flexural Modulus

Figure 5, shows the flexural modulus of the composite materials, it can be seen that the flexural modulus of 100% wHDPE matrix was 464.21 MPa, at 10% filler loading of wTRP it decreases to 381.19 MPa (17.88% decrease) due to the softness of the wTRP fillers, while at the same filler loading (10%) with SP, flexural modulus increases to 662.79 MPa (42.78% increase) as a result of the reinforcing ability of sand particles. Flexural modulus of the hybrid composite increases with the increase of sand particles proportion and decrease of wTRP in the composite material, it was found to increase from 395.65 MPa (14.77% decrease) to 898.57 MPa (93.57% increase) for B (wHDPE/wTRP/SP – 90/8/2) and E (wHDPE/wTRP/SP – 90/2/8) respectively. Similar trend of increase in the flexural strength and flexural modulus in their various studies using thermoplastic matrices (HDPE, LDPE and PP) with granite and marble, and granite dust as filler was reported by (Awad *et al.*, 2020) and (Awad and Abdellatif,

2019). This increase of flexural strength and flexural modulus was due to the deflection of the composite material, deflection of the composite decreases with increase of sand particles in the composite material.

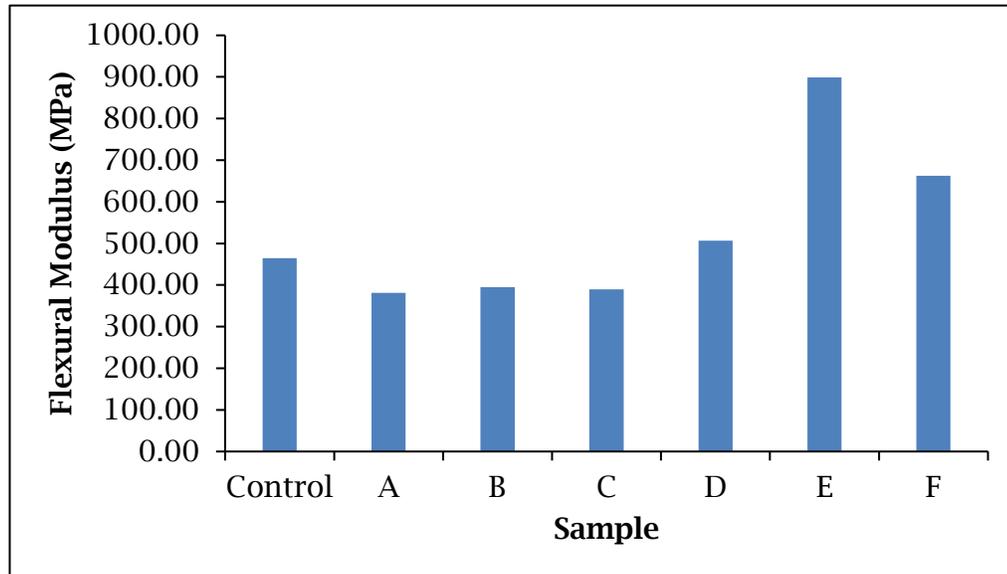


Figure 5: Effect of blend ratio on the Flexural Modulus (MPa) of WTRP/SP/wHDPE composites

3.1.6 Impact Strength

Figure 6 shows the impact strength of wTRP/SP/wHDPE composites, the impact strength of the control sample (100% wHDPE) was 2.91 J/mm² and it decreases after the addition of the fillers. At 10% filler loading of both wTRP and SP, impact strength decreases to 2.89 J/mm² (0.69% decrease) and 2.37 J/mm² (18.56% decrease) respectively, this shows that addition of sand particles in the waste high density polyethylene (wHDPE) matrix causes the decrease of the impact strength, this may be attributed to the incompatibility between the matrix and the fillers. Impact strength of the hybrid composites decreases with the increase of sand particles (SP) proportion in the composites, the impact strength of the hybrid composite decreases from 2.75 J/mm² (5.5% decrease) to 2.39 J/mm² (17.87% decrease) for B (wHDPE/wTRP/SP – 90/8/2) and E (wHDPE/wTRP/SP – 90/2/8) respectively. This may be due to the incompatibility and poor interfacial adhesion between wHDPE, wTRP and SP which results in weaker bonding between the matrix and filler phases. Despite the decrease in the impact strength, none of the samples broke during the test, this might be attributed to the toughness of HDPE which is capable of absorbing reasonable amount of energy.

Fazli and Rodrigue (2021) reported that the addition of Ground Tyre Rubber (GTR) decreased the impact strength of the neat recycled high density polyethylene (rHDPE), due to low compatibility between the recycled crosslinked rubber particles and the thermoplastic phase, since the rubber molecules do not have enough freedom to entangle within the rHDPE (recycled HDPE) molecules and create strong bonding (Fazli and Rodrigue, 2021). Similar trend of decrease of impact strength with increase of filler loading and is dependent on the type and nature of the filler used (its compatibility with the matrix, processing history of the matrix and the filler, amount, size and orientation of the filler in the matrix) was reported by (Ong *et al.*, 2021; Qing, 2018; Sienkiewicz *et al.*, 2017).

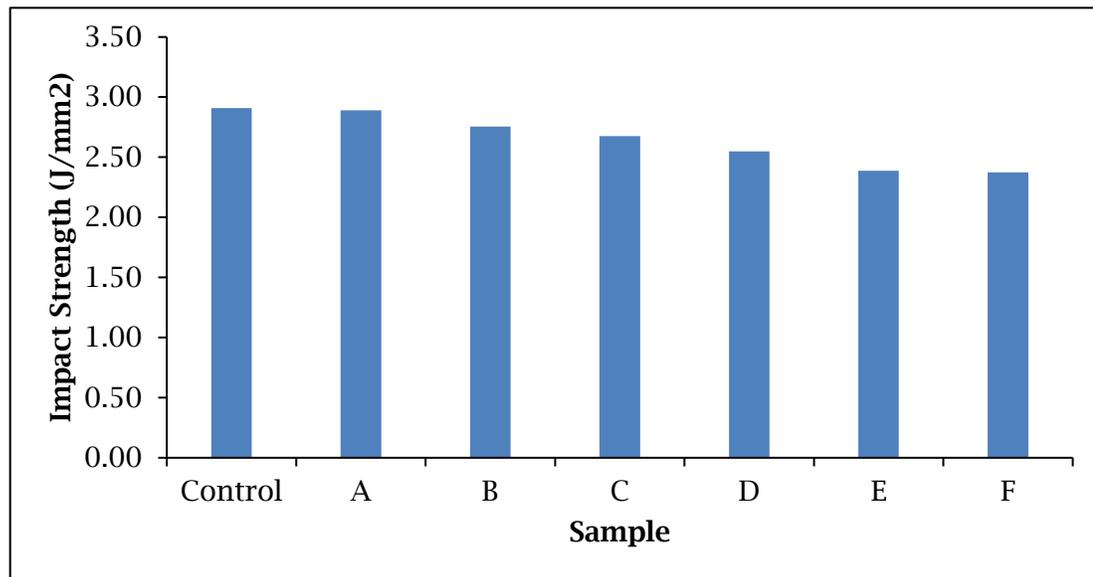


Figure 6: Effect of blend ratio on the Impact Strength (J/mm²) of WTRP/SP/wHDPE composites

3.1.7 Hardness

Figure 7 shows the hardness of the composite materials, the hardness of control (100% wHDPE) 20.60 Hv, addition of fillers causes an increase of hardness. At 10% filler loading of both wTRP and SP, the hardness of the composite material increases from 20.60 Hv to 35.67 Hv (73.16% increase) and 63.23 Hv (206.94% increase) for A and F composites respectively. The hardness of the hybrid composites increases with increase of sand particles proportion in the composites, it increases further from 46.67 Hv (126.55% increase) to 58.57 Hv (184.32% increase) for B (wHDPE/wTRP/SP – 90/8/2) and E (wHDPE/wTRP/SP – 90/2/8) respectively. The increase of the hardness is due to the reinforcing capabilities of sand particles and hardness nature of the sand particles (Puri, 2014). Ahmed *et al.* (2013) investigate the addition of marble dust and silica to natural rubber, it was reported that hardness of the hybrid composite was improved with the addition of silica (Ahmed *et al.*, 2013). It was also reported that hardness of Polypropylene (PP) reinforced with marble dust increases with the increase of the marble dust in the composite, the improvement of the hardness was predicted that since PP is relatively soft when compared with marble dust which is hard, this contributes positively to the hardness of the composites. It is widely known that the hardness is a localized deformation under specific conditions. The increase of hardness is related to the hard particles that act as barriers to the dislocation movement in the matrix (Awad *et al.*, 2019). Mousa *et al.*, (2019) also reported that hardness increases with increase of the percentage weight of granites and marble in WTRP-HDPE-GM hybrid composites. This may be due to the decreased flexibility and plasticity of wTRP chains by the incorporation of GM in WTRP-HDPE-GM hybrid composite resulting in more rigid and harder hybrid composite material (Mousa *et al.*, 2019).

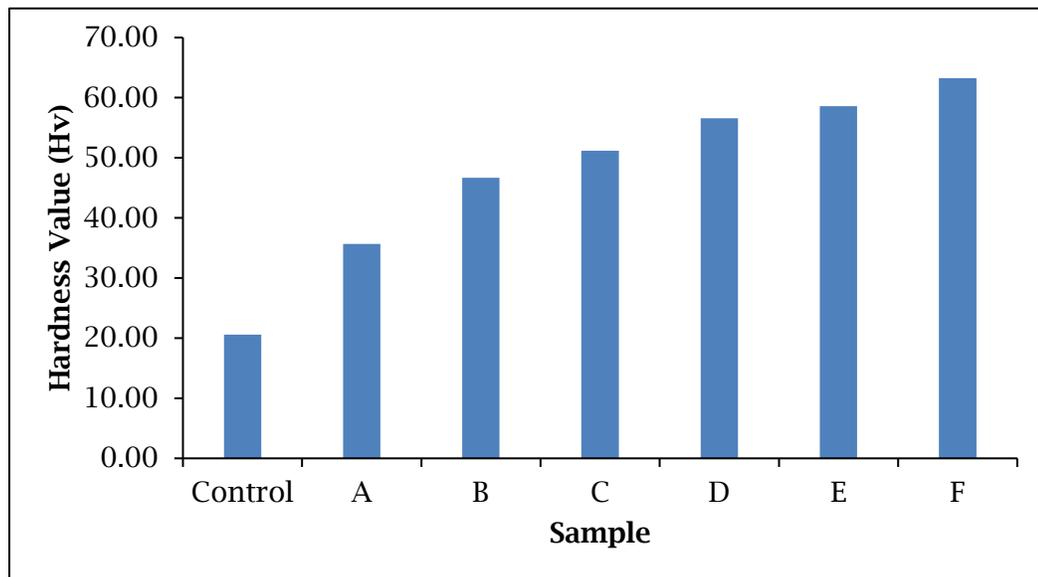


Figure 7: Effect of blend ratio on the Hardness Value (Hv) of WTRP/SP/wHDPE composites

3.2 Scanning Electron Microscopy (SEM)

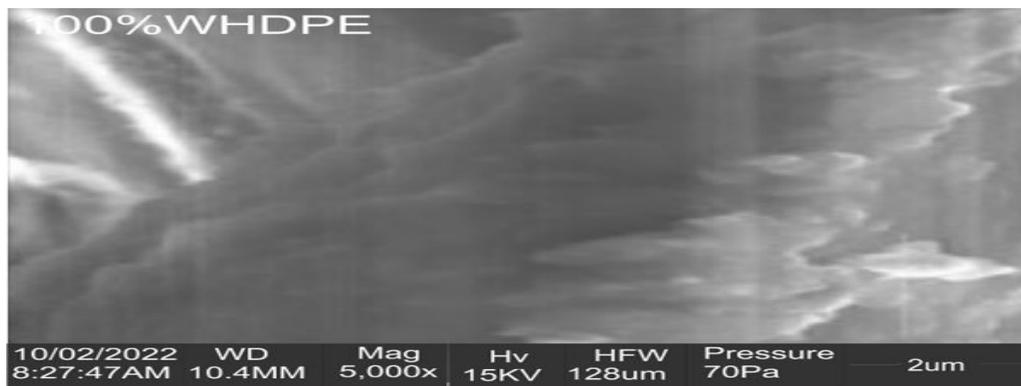


Figure 8: SEM micrograph of the control sample (100% wHDPE) at 5000× magnification.

Figure 8 shows the SEM image of control (100% wHDPE matrix), it can be seen that, there was no micro voids in the scanned surface but there is a development of spurs, deformation bands and serrated edges which indicates the ductile failure of the matrix material, this proves the ductile nature of HDPE thermoplastic. It can be observed that there is no micro voids in the micro structure of the broken tensile strength test sample resulting in higher tensile strength of 23.99 MPa when compared with the other filled composite samples (A – F) and this is in agreement with the range of the tensile strength of virgin HDPE from 21 – 38 MPa (Joel, 2016). The development of spurs and deformation bands is a typical feature of fractured ductile thermoplastic polymer materials (Murtaja, 2020). Figure 9 shows the SEM image of B (wHDPE/wTRP/SP (90:8:2)) hybrid composites. It can be seen that the particles are dispersed in the wHDPE matrix as a result of lower percentage filler loading, but however, there is presence of micro voids in the microstructure of the composite as a result of poor mixing of the matrix with the fillers due to incompatibility between matrix and fillers, which acts as weak point in the structure resulting in the development and propagation of failure resulting to the decrease of tensile strength of the material from 23.99 MPa to 19.69 MPa for control (100%wHDPE) and B (wHDPE/wTRP/SP (90:8:2)) hybrid composite respectively.

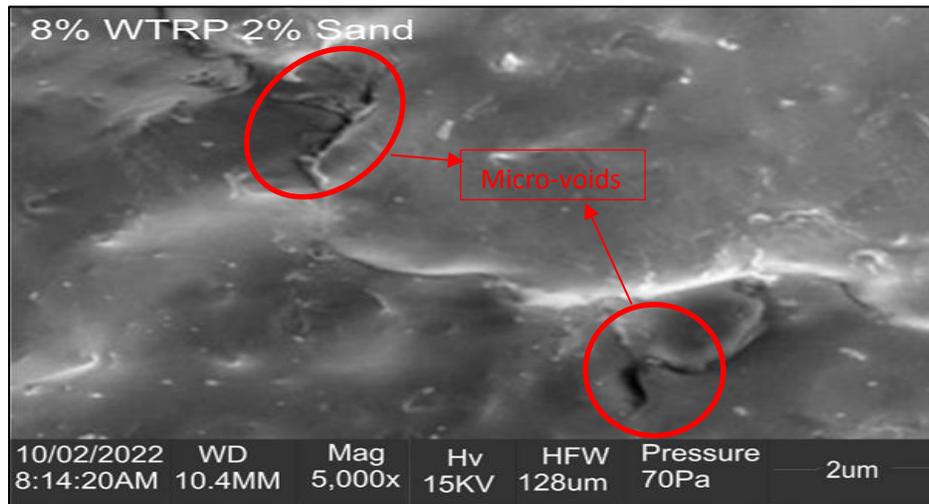


Figure 9: SEM Micrograph of sample B hybrid composite with blend ratio (90/8/2 (wHDPE/wTRP/SP)) at 5000× magnification

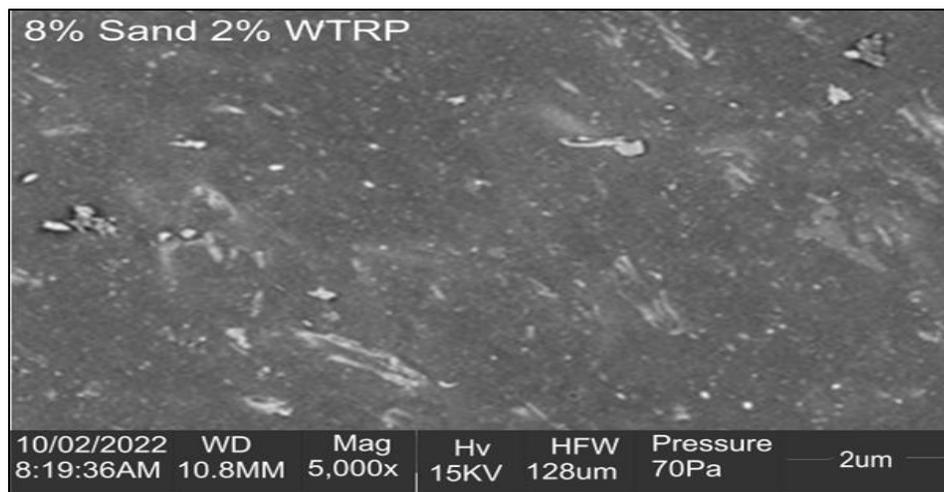


Figure 10: SEM Micrograph of sample E hybrid composite with blend ratio (90/2/8 (wHDPE/wTRP/SP)) at 5,000× magnification.

Figure 10 shows the micrograph of E (wHDPE/wTRP/SP – 90:2:8) hybrid composite. It can be observed that fillers are dispersed in the matrix due to lower percentage filler loading but however, it can be seen that due to the increase of sand particles in the hybrid composite, the composite material became brittle due to the nature of the sand particles thus resulting in the decrease of the tensile strength and elongation at break. Tensile strength decreases from 23.99 MPa and 19.69 MPa for control (100%wHDPE) and B (wHDPE/wTRP/SP (90:8:2)) respectively to 19.59 MPa for E (wHDPE/wTRP/SP (90:2:8)) hybrid composite.

3.3 Dynamic Mechanical analysis

From the dynamic mechanical analysis (DMA), the viscoelastic properties (behaviour) of the composites are greatly affected by frequency, temperature, fillers and their nature. Storage modulus, loss modulus decreases with increase

of sand particles in the composites, temperature and frequency of testing. The peak of tan delta was used as the identifier (indicator) of the glass transition temperature (T_g) of the composite material, T_g increased with increase of sand particles proportion in the hybrid composite. DMA helps in determining the stiffness, damping and range of temperature of material application.

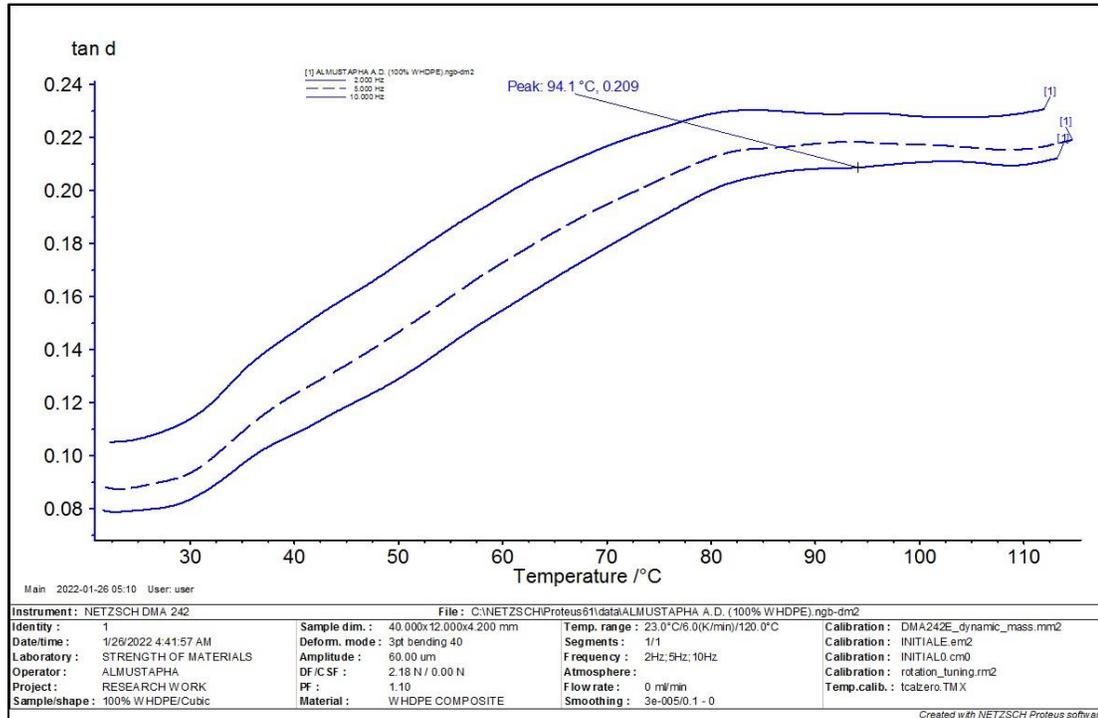


Figure 11: Dynamic mechanical analysis of control sample (100% wHDPE).

Figure 11, show the DMA result of control (100% wHDPE), it shows the effect of frequency and temperature on the $\tan \delta$ (damping) of the wHDPE, $\tan \delta$ decreased with increase of frequency of dynamic loading due increase of the loading cycle. Also, it was observed that $\tan \delta$ increased with increase of temperature reaching peak point at 94.1°C ($\tan \delta = 0.209$). it can be deduced that the peak temperature corresponds to the T_g (glass transition temperature), thus the T_g of the sample is 94.1°C. As shown in figure 12, $\tan \delta$ decreases with the increase of frequency of the dynamic loading, while the damping ($\tan \delta$) of the composite increase with increase of temperature reaching peak point at 0.219 at 111.1°C which correspond to the glass transition temperature (T_g) of the composite. This shows an increase of T_g (18.07% increase) of the hybrid composite B due to the addition of fillers (8% wTRP and 2% SP) in the matrix (90% wHDPE).

Figure 13 shows the effect of temperature and frequency on the tangent ratio ($\tan \delta$) of E (wHDPE/wTRP/SP (90/2/8)) hybrid composite. $\tan \delta$ decreased with increase of loading frequency, while $\tan \delta$ increased with increase of temperature. It was observed that, the peak temperature is at 112.6°C ($\tan \delta = 0.217$) which corresponds to the T_g of the hybrid composite E (wHDPE/wTRP/SP – 90/2/8). it was also observed that as the ratio of sand particle increased in the hybrid composite T_g increased owing to the nature of sand particles which increases the stiffness of the material thereby increasing rigidity subsequently causing restriction of chain mobility in the composite material, thus resulting to the increase of T_g i.e., about 19.66% increase.

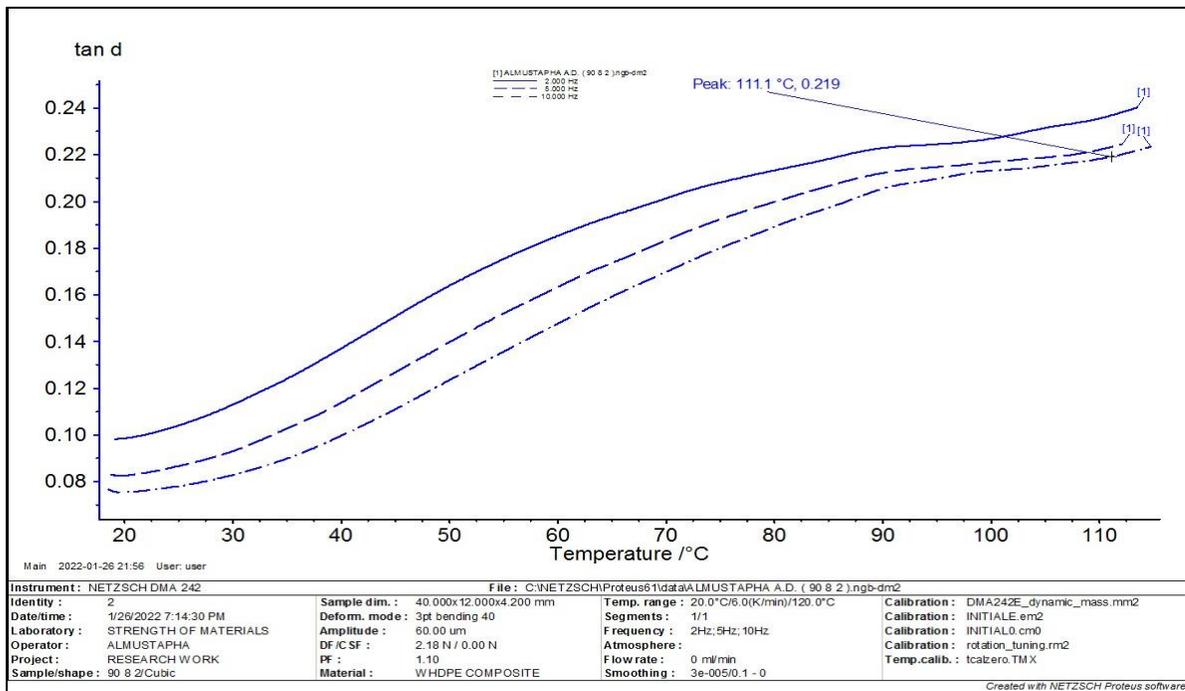


Figure 12: Dynamic mechanical analysis of sample B (90/8/2 (wHDPE/wTRP/SP)) blend ratio of the hybrid composite.

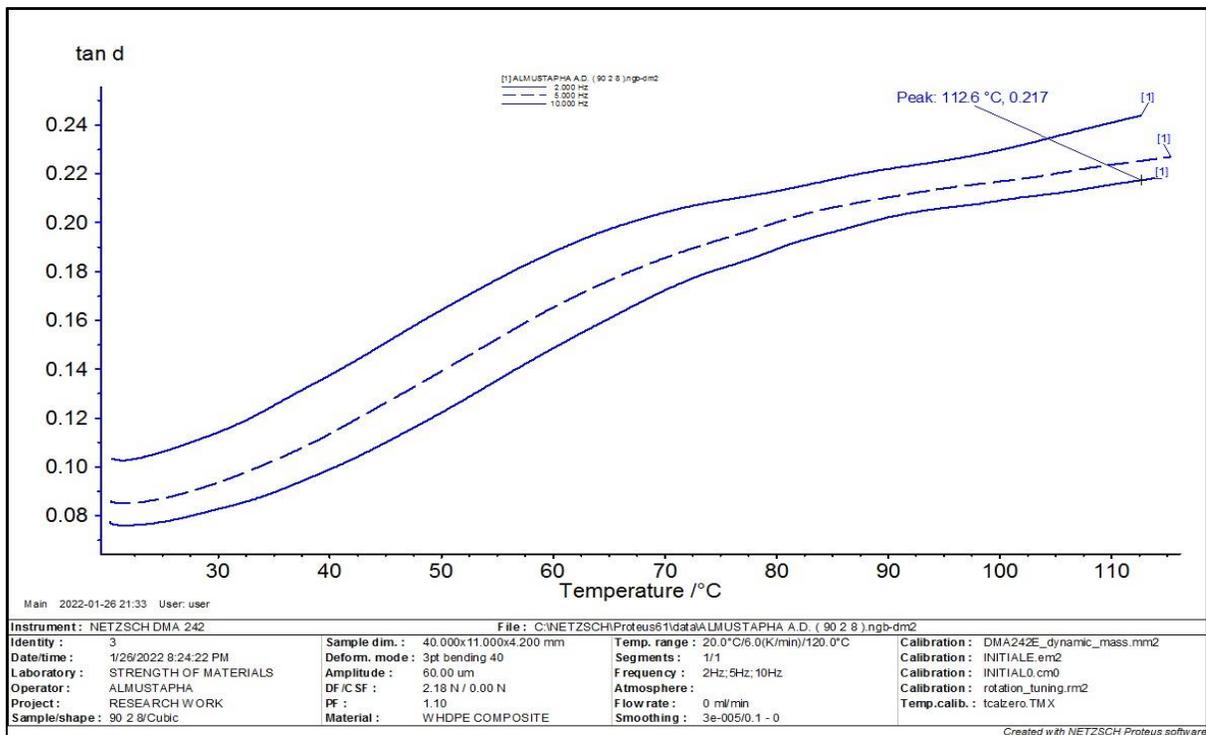


Figure 13: Dynamic mechanical analysis of sample E (90/2/8 (wHDPE/wTRP/SP)) blend ratio of the hybrid composite.

4. Conclusion

Hybrid composites of wTRP/SP/wHDPE were produced and tested, the results show that tensile modulus, flexural strength (25.4% increase), flexural modulus (93.57% increase) and hardness (184.32% increase) increased with increase of SP due to the reinforcing ability and hardness nature of SP which increases the stiffness and hardness of the material thus require higher forces to bend or indent the composites, these properties were optimum at E (wHDPE/wTRP/SP – 90/2/8) hybrid composite. Also, T_g increased with increase of sand particles proportion in the hybrid composite, it increases to 112.6°C (19.66% increase) for sample E (wHDPE/wTRP/SP – 90/2/8). On the other hand, tensile strength (18.34% decrease), elongation at break (78% decrease) and impact strength (17.87% decrease) decreases with increase of SP, due to the incompatibility between wTRP, SP and wHDPE. SEM micrographs shows good dispersion of the fillers in the matrix due to the lower percentage (%) filler loading, but there is a noticeable micro voids and cluster of particles in a particular position causing agglomeration of the particles thus acting as stress concentration points which causes the development and propagation of cracks/defects in the composite, hence decreasing the performance of the composite especially tensile strength.

These hybrid composites will be suitable for both indoor and outdoor application for structural and protection purposes, e.g., partition wall, floor tiles, outdoor interlocks, walk-way tiles, etc. Therefore, blending waste Tyre Rubber Particles (wTRP) with waste High Density Polyethylene (wHDPE) and Sand Particles (SP) to fabricate hybrid composites is an efficient, promising, and practical means to recycle large amount of the worn-out tyres.

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