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# THERMO-MECHANICAL CHARACTERIZATION OF PLANTAIN PARTICULATE REINFORCED WASTE HDPE AS COMPOSITE WALL TILES

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## ABSTRACT

A plantain particulate reinforced high density polyethylene waste (wHDPE) was developed via melt mixing and compression moulding techniques having overall light-weight and good thermo-mechanical properties. Optimum mechanical property was determined at 20% and 80% formulation of plantain particulates and wHDPE respectively. This composition has tensile strength of 98.45 MPa, flexural strength of 55.56 MPa and Elastic modulus of 2.58 GPa with corresponding minimal water absorption of 4.5% over 30 days immersion period at ambient temperature. Dynamic mechanical analysis curves showed that the composite has higher glass transition temperature and better stiffness stability at higher temperature than wHDPE. Similarly, the composite has better load bearing capability at elevated temperature than wHDPE material.

**Keywords**: Creep, dynamic mechanical analysis, plantain particulate, wall tiles, waste high density polyethylene.

## INTRODUCTION

Plastics wastes have been a major environmental concern in recent times because of their increased usage in many commercial sectors and improper method of disposal. Recycling in form of composites is a preferable way of addressing this environmental challenge. Different types of waste materials (plastic waste and natural fibres) have been utilized in composite production; which offers an opportunity for waste material re-utilization and thereby reducing environmental pollution.

Low cost, readily available, easy to use, biodegradability and eco-friendly are some of the advantages of natural fibres that have attracted the interest of researchers both in the academia and in the industries. This has prompted the need to investigate their feasibility for reinforcement purposes, and to what extent they satisfy the required specifications of a good reinforcement in polymer composite for different applications [1].

The current trend of research in the field of natural fibre based composites is the application of dynamic mechanical analysis (DMA) technique. DMA depicts the stiffness stability of the composites with increasing temperature, its glass transition temperature and its viscoelastic nature when stimulated by dynamic loading [2]. The effect of variation in frequencies on dynamic mechanical properties of jute fibre reinforced epoxy composites has been studied by Gupta [3] and reported that the acceptable dynamic mechanical properties of jute composite indicates that it can be used in making the casing of electronic instruments such as mobiles, laptops, and so on.

Dan-asabe [4] also determined and characterized the thermo-mechanical properties of banana particulate reinforced PVC as piping material. Through dynamic mechanical analysis, the composition with optimum mechanical property of 42 MPa was estimated to have a long stress value of 25 MPa corresponding to 40% loss in strength over a period of 32 years.

The quest to clean up the environment and produce economically viable materials from wHDPE waste using cheap and readily available reinforcement has prompted the need for the present investigation.

## MATERIALS AND METHOD

### *Sample collection and preparation*

Waste bottle caps with resin identification code “2” made from commercially high density polyethylene (HDPE) was collected from refuse dumps and plastic waste collection centre in Samaru and Sabon Gari, Zaria, Kaduna State, Nigeria. These have been thoroughly washed with water, dried and shredded into particles of smaller sizes which constitute the polymer matrix.

The HDPE waste (wHDPE) was washed thoroughly with water, dried and shredded into smaller sizes using shredding machine. The plantain peel used as reinforcement was also sourced locally, sun-dried, pulverized and sieved to 150 μm. It was immersed in 10% NaOH for 6 hours with continuous stirring after which the solution was decanted off, washed several times with distilled water until the solution becomes neutral. Finally, the fibre was dried in an oven at 80 ℃ for 6 hours [5, 6].

**Plate I:** HDPE waste used in the study.

### *Composite production*

The materials were compounded via melt mixing at a temperature of 170 ℃ to obtain a homogeneous mixture. The % weight fraction of reinforcement was varied from 0-25 % (0, 5, 10, 15, 20, and 25. Curing of the samples was then carried out using hydraulic press at a temperature of 160 ℃ and a compression pressure of 4 Pa for 10 minutes. Samples obtained were cooled and machined in preparation for characterization tests [2].

### *Mechanical Property Test*

#### *Tensile test*

The tensile testing of the samples was done in accordance with ASTM D638 [7] standard. The samples were machined to dumbbell shape and then placed in computerized Instron universal tensile testing machine 3369 model and the tensile strength and elastic modulus were evaluated.

#### *Flexural strength*

Flexural strength was measured under a three-point bending approach using a universal testing machine according to ASTM D790 [8]. The distance between the spans was 40 mm and the strain rate was 5 mm/min. The flexural strength (MPa) was calculated using equation (1):

$$\sigma = \frac{3Pl}{2bt^2} \quad (1)$$

l = length of specimen span between support (mm)

P = maximum deflection force (N)

b = width of specimen (mm)

t = thickness of specimen (mm)

### *Water Absorption*

Water absorption test was carried out according to ASTM D570 [9] with oven dried specimen of dimension 76 x 25 x 5 mm immersed in water at ambient temperature for 24 h. After immersion for 24 h, the specimens were removed and patted dry with a cloth (lint free) and then reweighed using a Sartorius Analytical balance ED 224S digital Analytical balance. In order to evaluate long term moisture absorption on the composites, the process was repeated at 48, 72, 96, up to 720 h exposure. The dried weight before immersion ($W_{initial}$) and the weight after immersion ($W_{final}$) were noted. The water absorption was determined as follows:

$$W = \frac{W_{final} - W_{initial}}{W_{final}} (\%) \quad (2)$$

## Thermal Properties

### *Dynamic Mechanical Analysis*

DMA was carried out using DMA 242E machine in strength of Materials Laboratory, Mechanical Engineering Department, ABU Zaria according to ASTM D7028 [10]. The test parameters: storage modulus (E'), loss modulus (E") and tangent of delta (Tan $\partial$) were first configured via the proteus software using personal computer. Instrument set up included the sample holder (3-point bending), furnace temperature range of 30-110 ℃, dynamic load of 4 N, frequency range of 1-10 Hz and heating rate of 3 K/min were configured. Sample dimension of 60 x 12 x 5 mm were produced for each test. The test specimens were loaded into the machine using a three- point bending and locked into the furnace.

### *Creep*

Creep is one of the supplementary characterizations that can be done using the Dynamic Mechanical Analyzer. The creep test was conducted for 60 min at a load stress of 100 $KN/m^2$ at 70 ℃.

## RESULTS AND DISCUSSION

### *Mechanical Properties*

### *Tensile strength*

Figure 1 depicts the ultimate tensile strength (UTS) of the composites with increasing weight of reinforcement. The tensile strength increases and then decreases steeply. This could be due to weakening of the interfacial attraction of the constituent composition as the fraction of the

RHDPE is reduced with increasing weight fraction of reinforcement. Similar observations have been reported by other authors [4, 2].

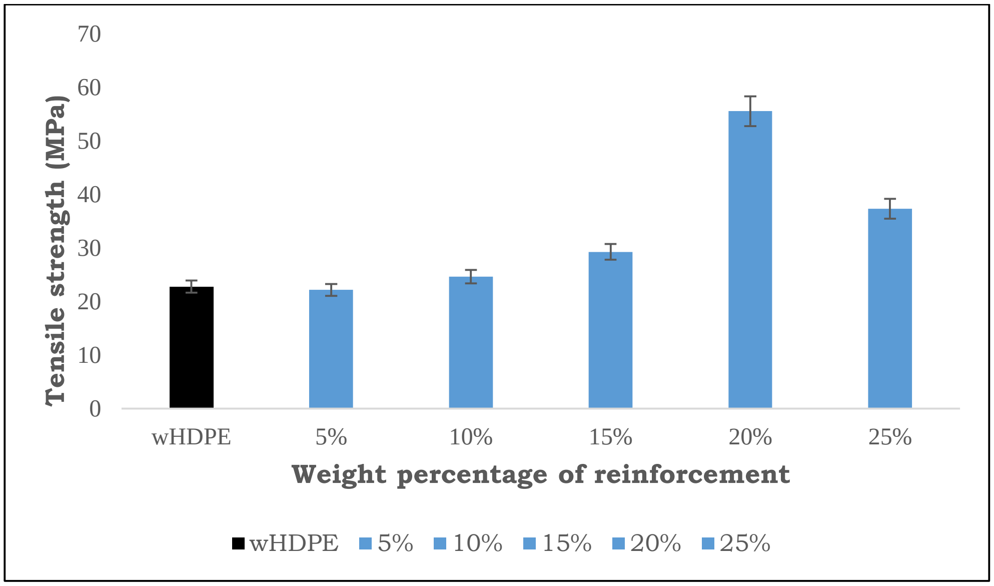


Figure 1: Effect of plantain peel powder on the tensile strength of waste HDPE composites

***Elastic modulus***

Figure 2 shows the elastic modulus (stiffness) of the composite against weight of reinforcement. A similar trend of increase in modulus of elasticity with weight fraction of reinforcement (plantain peel powder) could be observed. The elastic modulus of the composites increases from 0.44GPa to 2.58GPa which could be attributed to better interaction between wHDPE and the PPP. An increase in elastic modulus with weight fraction of reinforcement has been reported by other authors [11, 4].

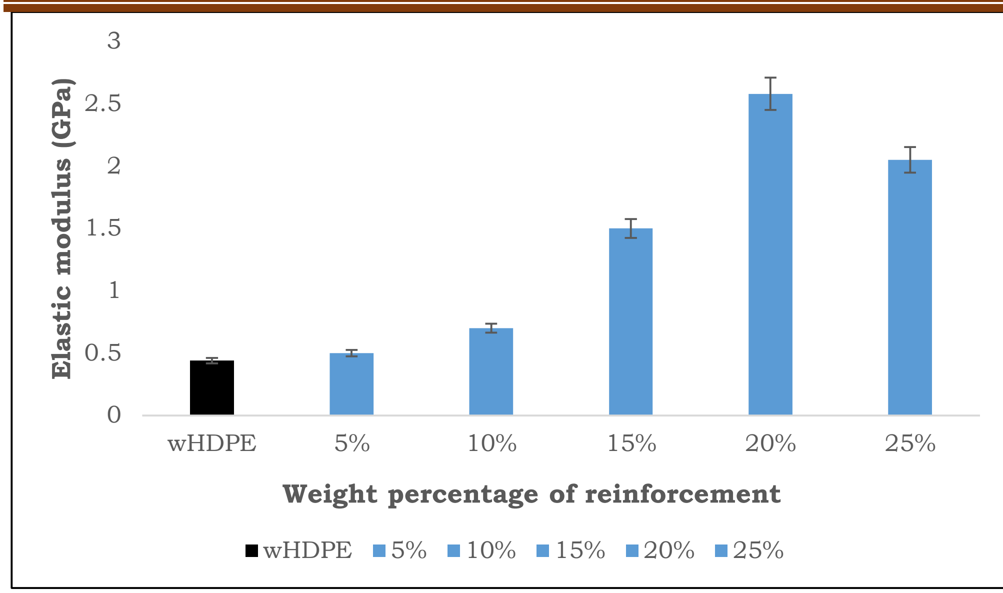


Figure 2: Effect of plantain peel powder on the elastic modulus of waste HDPE composites

***Flexural strength***

Figure 3 depicts the modulus of rupture of the composites. From the figure, the MOR of ground nut shell powder reinforced wHDPE composites increases with weight fraction of reinforcement and then decreases, with the maximum value of 31.58 MPa at 20 % wt of reinforcement. This is an indication of improved interaction and stress transfer between the particles. Further increase in weight fraction of reinforcement to 25 % however decreases the MOR value due to weak fibre-matrix adhesion. Similar results have been reported by [12, 13].

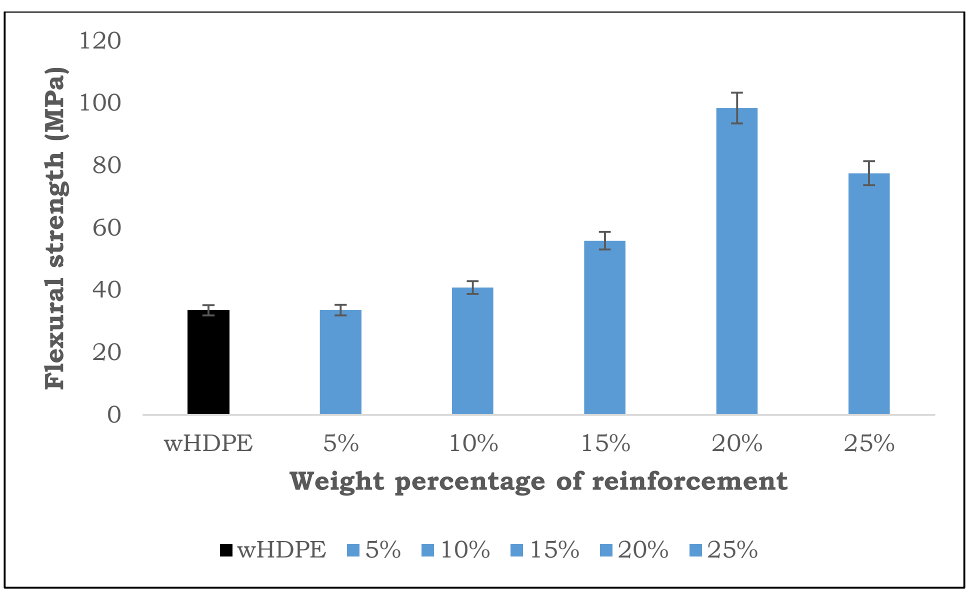


Figure 3: Effect of plantain peel powder on the flexural strength of waste HDPE composites

### *Water absorption*

Figure 4 depicts the % moisture absorption against the square root of time for plantain peel powder reinforced wHDPE composites immersed at room temperature (RT) for 720 hours (30 days). With the exception of the control sample which hardly absorbs water, the rate of water absorption in the composites was observed to be linear in the beginning, slows and approaches saturation after prolonged time following Fickian diffusion process. Both the initial rate of water absorption and the maximum were observed to increase with weight percentage of reinforcement.

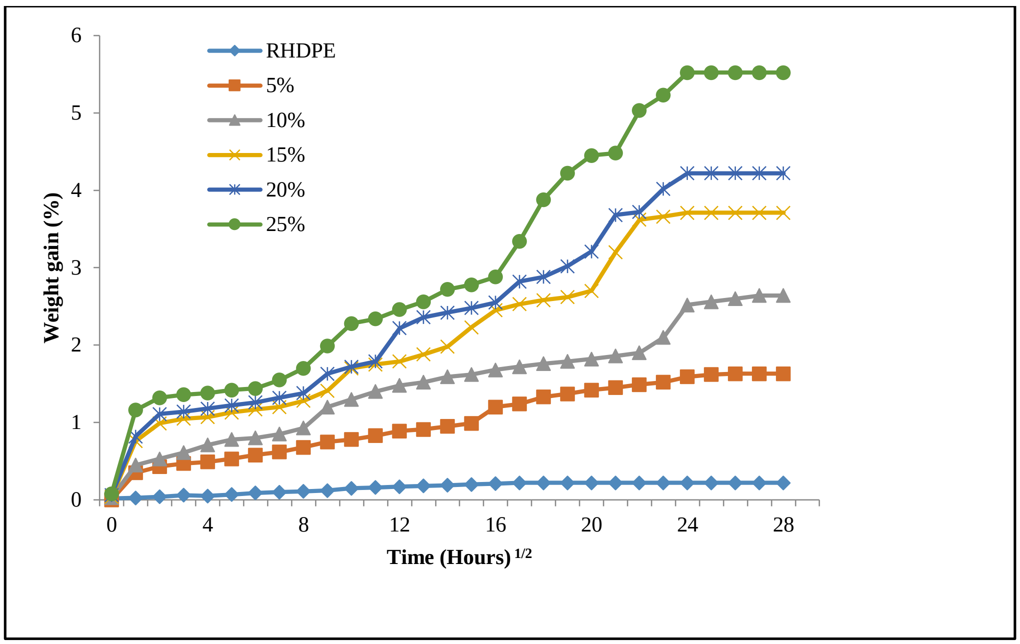


Figure 4: Water absorption curves of the composites immersed at RT for 30 days.

### *Dynamic mechanical properties*

### *Storage modulus*

Storage modulus (E') of polymeric materials represents how the materials are stiffer [3]. In other words, it describes the energy stored in the system which depicts the elastic portion. Figure 5 depicts the storage modulus of unreinforced HDPE waste at frequencies of 1, 5 and 10 Hz respectively. The curve shows that the material is unstable at temperatures below 40 ℃. The maximum stiffness of 0.3GPa could be observed with glass transition temperature of 38.2 ℃.

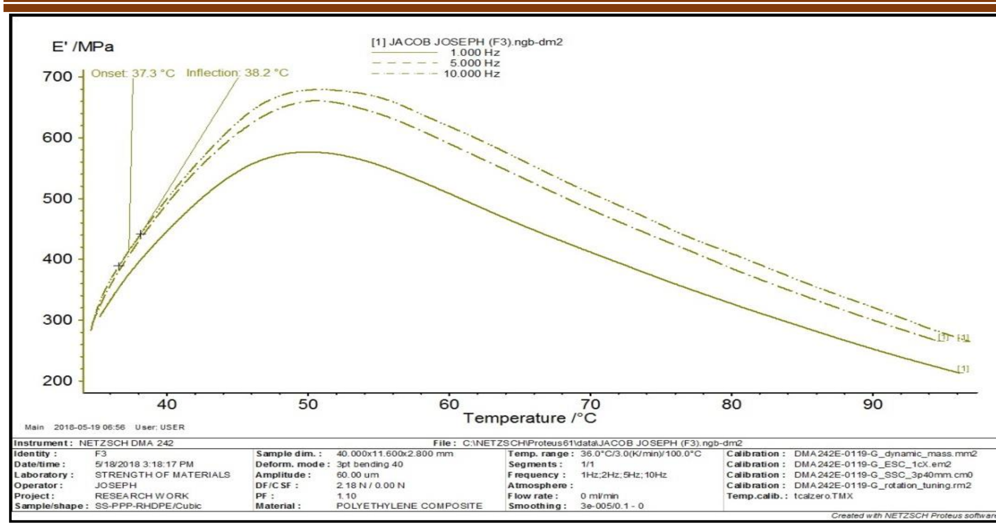


Figure 5: Storage modulus curve of waste HDPE at 1, 5 and 10 Hz.

Figure 6 shows the storage modulus of the composite of plantain peel powder at frequencies of 1, 5 and 10 Hz respectively. The curve shows that the composite is stable under dynamic loading with increasing temperature up to 60 ℃ before its point of inflection of 66.4℃ which is taken as its glass transition temperature. Similar result has been reported by Dan-asabe [4]. The curve also shows loss in stiffness from 2.0 GPa to 0.5 GPa at 60 ℃. This indicates the suitability of the material up to 60 ℃ [14].

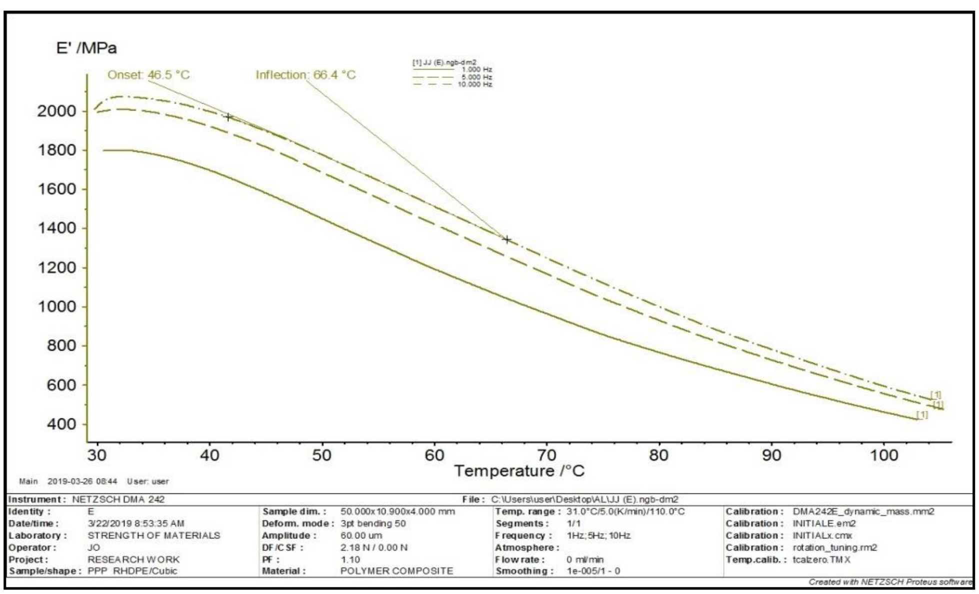


Figure 6: Storage modulus curve of 20% wt plantain peel powder reinforced waste HDPE composite at 1, 5 and 10 Hz.

From the storage modulus of the unreinforced waste HDPE and the composite of plantain peel powder-waste HDPE, it is evident that incorporation of treated plantain peel powder into waste HDPE increased the stiffness stability by 1.7 GPa with about 28.2 ℃.

3.3.2 Damping parameter

Tan delta (Tan ∂) or damping is the ratio of loss modulus to storage modulus which is related to impact resistance of materials [3]. It is the measure of visco-elasticity of materials. A high value of damping is indicative of a material with high non-elastic strain behaviour while low value of damping indicates that the material is more elastic. Figure 7 depicts the damping curve of 20% plantain peel powder reinforced waste-HDPE composite. The visco-elasticity of the composite of plantain peel powder is eminent at tan delta value of 0.5 from 30 ℃ up to a maximum of 0.188 at 81.5℃.

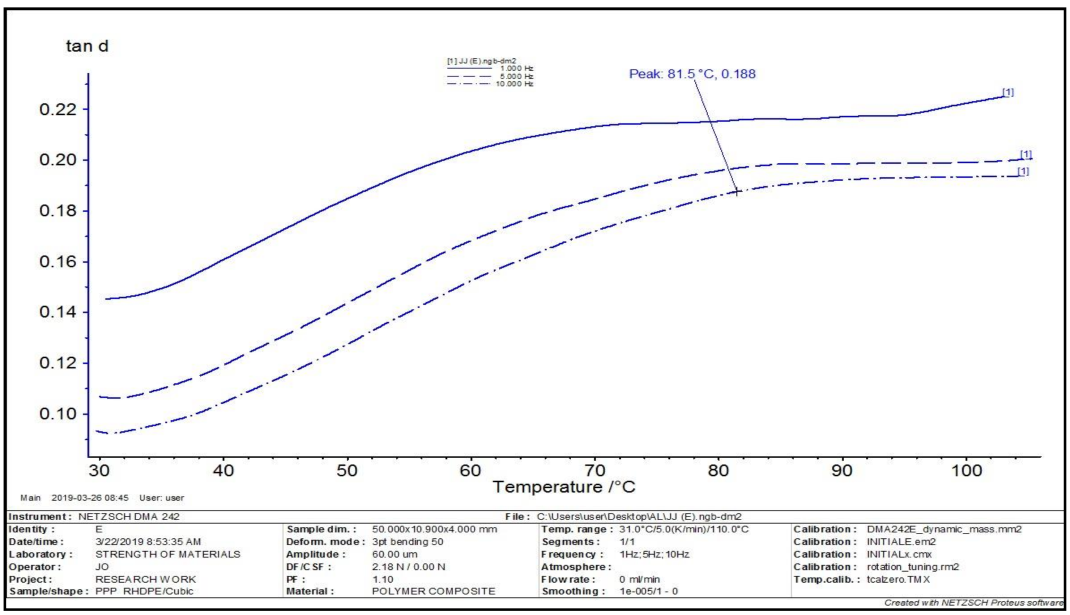


Figure 7: Damping curve for 20 % wt plantain peel powder reinforced waste HDPE composite at 1, 5 and 10 Hz

***Creep***

Creep is deformation of material under constant stress, dependent on time, stress, temperature, and material properties, etc. Creep deformation can exceed the creep limit and cause product failure, especially in applications with long-term loading. Figure 8 shows the creep result of 20 % plantain peel powder reinforced waste HDPE composite at 70 ℃. The initial large vertical strain was due to the applied constant load after which the strain rate decreases with time up to

52.3 min where the strain rate was very small known as the equilibrium strain rate. This stage is known as secondary creep and must be considered in load bearing capability of the composite. Similar results have been reported by other authors [4, 14].

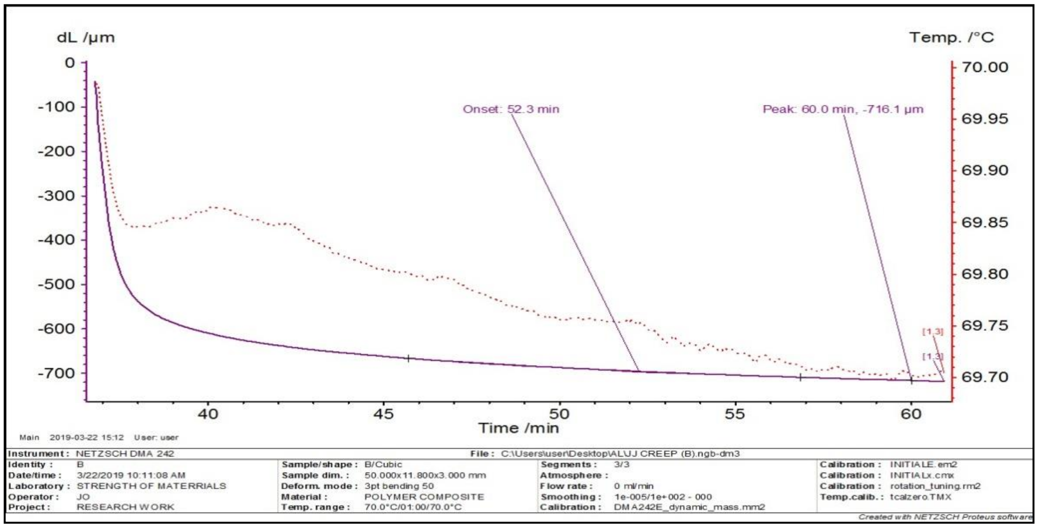


Figure 8: Creep curve of 20 wt % plantain peel powder-RHDPE composite

Figure 9 depicts the creep curve of the control sample (waste HDPE). The equilibrium strain rate occurred at 46.6 min which is lower than that of the composite. This indicates that the load bearing capability of waste HDPE has been improved with the incorporation of plantain particulate.

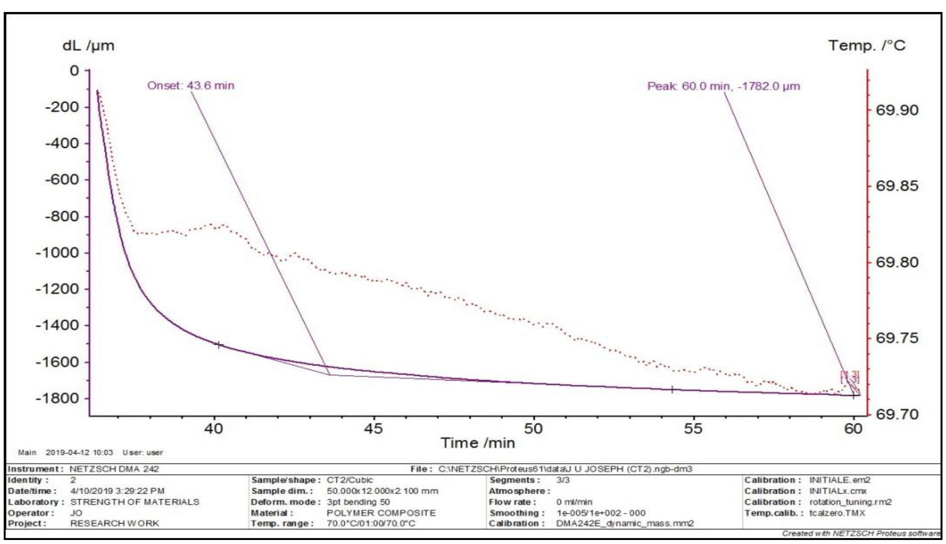


Figure 9: Creep curve of unreinforced wHDPE

## CONCLUSION

From the characterization carried out and the results obtained, the following conclusions are made:

- The composites were developed with low cost materials having an overall light-weight and good thermo-mechanical properties.
- Optimum mechanical property was determined at 20% and 80% formulation of plantain peel particulates and wHDPE respectively, having elastic modulus of 2.58 GPa, tensile strength of 55.56 MPa, flexural strength of 98.45 MPa and minimal water absorption of 4.5% over 30 days immersion period at ambient temperature.
- DMA curve showed that the composite has higher glass transition temperature and better mechanical (stiffness) stability at higher temperature under dynamic loading than the unreinforced (wHDPE). The composite shifts glass transition temperature of wHDPE by 28.2 ℃.
- The creep curve showed the composites have better creep stability at elevated temperatures than the wHDPE material under constant loading. This implies the load bearing suitability for different wall tiles applications.

Plate II: Some of the produced composite wall tiles.

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