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Effect of Variation in Frequencies on Dynamic Mechanical Properties of Plantain Peel Particulate Reinforced Recycled Polypropylene Composites

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Abstract: Plastic wastes pollution has captured worldwide attention from individual to business and to government. In the quest to clean up the environment and produce viable materials from these wastes, some dynamic mechanical properties of plantain peel particulate filled polypropylene composites were investigated via 242E Dynamic mechanical analyzer. In order to examine the influence of frequency variation on these properties, composite sample (A25) with the optimum thermal property was subjected to further test at three different frequencies of 2, 5 and 10 Hz respectively. Storage modulus was observed to increase with fiber loading from 5 wt. % (980 MPa) - 25 wt. % (1.2 GPa) compared to 980 MPa of the unreinforced recycled polypropylene. The loss modulus in the transition region was observed to be higher for the unreinforced (A0 = 130 MPa) than all the composites (A5 = 125 MPa), (A15 = 108 MPa), (A25 = 90 MPa) which implies that incorporation of the fiber decrease the energy dissipation of the material thereby improving its thermal stability.

Keywords: Dynamic mechanical analysis; Damping parameter; Loss modulus; Plantain peel particulate; Polypropylene

1. Introduction

Over the last few years, research has been conducted on the re-use of plastic waste for the development of other versatile materials. Many waste plastics are polyolefin based, such as polyethylene and polypropylene; and Nigeria as a developing country have continued to be bedeviled by this menace. Polypropylene wastes are the second most common plastic wastes in Nigeria after polyethylene. Several properties (physical, mechanical, morphological and thermal) of these composites have also been investigated to ascertain their suitability for different applications (Ahmed *et al.*, 2022; Awoyera & Adesina (2020); Dayamanti *et al.*, 2023).

A polymer composite's thermal properties are crucial, especially in terms of the processing conditions and application areas in which it is used. Dynamic mechanical analysis (DMA) or dynamic thermal mechanical analysis (DTMA), differential scanning calorimetry (DSC) and thermo-gravimetric analysis (TGA) are the most important methods used in studying thermal properties of polymers.

DMA is a method of computing viscoelastic behavior, storage modulus, loss modulus, creep compliance and damping parameter based on frequency or the combination of these parameters (Jacob *et al.,* 2019). An analysis of dynamic mechanical behaviour of polymeric materials is not solely dependent upon temperature and frequency, but also on the polymeric matrix used, stiffness of fibre, fibre loading, fibre orientations and above all the adhesion between fibres and matrix. Storage modulus (E'), loss modulus (E''), damping (tan ∂), effectiveness of reinforcement and glass transition temperature are some of the thermal properties that can easily and accurately be obtained by DMA (Atagur & Seki, 2020; Pujar & Mani, 2022; Shaikh *et al.*, 2023).These parameters can reflect the motion state inside the composites, and are important to the efficient use of fibre reinforced polymer composites (Rajesh *et al.,* 2021).

The dynamic mechanical analysis of natural fibre-based composites has been reported in several papers, and it has been shown that these composites exhibit acceptable thermal properties suitable for a wide range of applications. (Gupta, 2018) studied the effect of variation in frequencies on dynamic mechanical properties of jute fibre reinforced epoxy composites and the results indicated that thermal stability and load bearing capability were found to improve with increase in fibre loading in the composites. These acceptable dynamic mechanical properties of present jute composite indicate that it can be used in making the casing of electronics instruments such mobiles, laptops etc. apart from its traditional applications such as packaging and constructions. The effect of groundnut shell powder on the visco-elastic properties of recycled high density polyethylene composites has been reported by (Jacob *et al.,* 2018a). The results indicated that the thermal stability and load bearing capacity of the recycled high density polyethylene have been improved with the incorporation of treated groundnut shell powder. (Jacob & Mamza, 2021) also investigated the mechanical and thermal behaviour of plantain peel powder filled recycled polyethylene composites and the results showed that the mechanical, thermal and creep resistance of waste low density polyethylene could be improved by the plantain peel powder addition which implies better load bearing capability and their suitability as composites wall tiles. So many other studies have been carried out on the development and characterization of polymer composites and a lot of researches are still being carried out to evaluate their applications in different facets of human endeavor (Mothé *et al.,* 2016; Shen *et al.*, 2019; Anosike-francis *et al.*, 2022; Pujar & Mani, 2022). Plastic wastes pollution has continued to gain attention in both the academia and the industries; simple clean-ups are no longer enough. It is time therefore, to move away from the current linear business model of take, make and wastes and focus primarily on waste management: reuse, reduce and recycle. Recycling in form of composites is a preferable way of addressing this environmental challenge. It has become pertinent therefore to investigate the influence of variation in frequencies of plantain peel particulate filled recycled polypropylene composites with a view in determining its suitability for different applications.

2. Methodology

2.1 Sourcing and preparation of plantain peel and waste polypropylene

The RPP samples were prepared using the procedure earlier reported (Jacob *et al.,* 2019). The plantain peel used as reinforcement was pulverized and sieved into 100 μm sieve size. The powdered sample was then chemically modified with benzoyl peroxide solution for 8 h and washed several times with distilled water until neutral. The resultant residue was then dried at 80°C in an oven for 6 h (Jacob *et al.,* 2018b).

2.2 Experiments

2.2.1 Dynamic mechanical analysis

This was performed using a DMA 242E machine in accordance with ASTM D7028, 2015 as reported earlier by (Jacob *et al.,* 2019). The various parameters (storage modulus, loss modulus and damping) were investigated at temperature range of 25 –170 °C at different frequencies of 1, 2, 5 and 10 Hz. In order to study the effect of frequency on the Dynamic mechanical properties, a Mathematical Software, MATLAB was used to plot the variation of these properties with weight fraction of reinforcement and frequency.

Table 1: Nomenclature of Plantain peel powder filled recycled polypropylene composites

Symbols	Composites
A0	Unreinforced RPP
A5	RPP composite reinforced by 5 wt. % PPP
A15	RPP composite reinforced by 15 wt. % PPP
A25	RPP composite reinforced by 25 wt. % PPP
A25F1	RPP composite reinforced by 25 wt. % PPP at 1 Hz frequency
A25F2	RPP composite reinforced by 25 wt. % PPP at 2 Hz frequency
A25F5	RPP composite reinforced by 25 wt. % PPP at 5 Hz frequency
A25F10	RPP composite reinforced by 25 wt. % PPP at 10 Hz frequency

3. Results and Discussion

3.1 Effect of plantain peel powder on the storage modulus of recycled PP

The storage modulus (E') of a material provides an insight into its stiffness and load bearing capabilities as a function of temperature. Figure 1 shows the variation of E' with temperature for the control (unreinforced PP) and benzoyl peroxide treated PPP filled composites. With the addition of plantain peel particulate, the storage modulus of recycled polypropylene matrix was greatly increased in the elastomeric region, due to an increase in the stiffness of the matrix and the reinforcing effect imparted by the fibre. There is also a clear increase in E' with weight fraction of reinforcement (from 5 % wt – 25 % wt) with the maximum value obtained for the composite with the highest PPP content (sample A25). This may be associated with the strong fibre/matrix interaction between the PPP and RPP composites. The drop in storage modulus on passing through the glass-transition temperature is comparatively less for the reinforced composites than for the unreinforced sample (A0). The presence of fibres embedded in visco-elastic materials has a combination of hydrodynamic and mechanical effects, resulting in reduced matrix mobility. Other authors have reported similar observations (Palanivel *et al.,* 2017). However, a decrease in E' is observed at elevated temperatures for all the composites due to loss in stiffness of fibres at higher temperature.

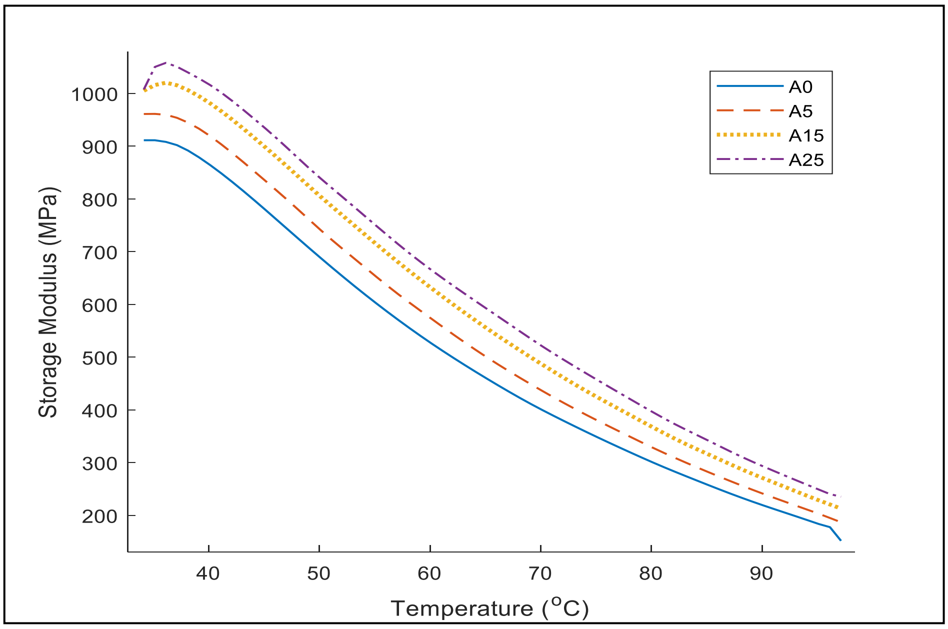

Figure 1: Variation of storage modulus with temperature of PPP-RPP composites at 1 Hz

3.2 Effect of plantain peel powder on the loss modulus of recycled PP

The loss modulus is defined as the maximum amount of energy dissipated by a material during deformation. It is a measure of the viscous response of materials, which is determined by the motion of polymeric molecules in them. The variation of loss modulus with temperature of PPP-reinforced RPP composites is shown in Figure 2. The figure depicts an improvement in loss modulus of the composites as a result of PPP incorporation. The loss modulus in the transition region is higher for the unreinforced (A0) than the composites, which implies that incorporation of the fibre decrease the energy dissipation of the material and thereby improving its thermal stability. The higher thermal stability could be associated with the decrease in mobility of the matrix due to incorporation of plantain peel fibres. The decrease in loss modulus with weight fraction of reinforcement has been reported by other authors (Gupta, 2018; Jacob *et al.,* 2018a).

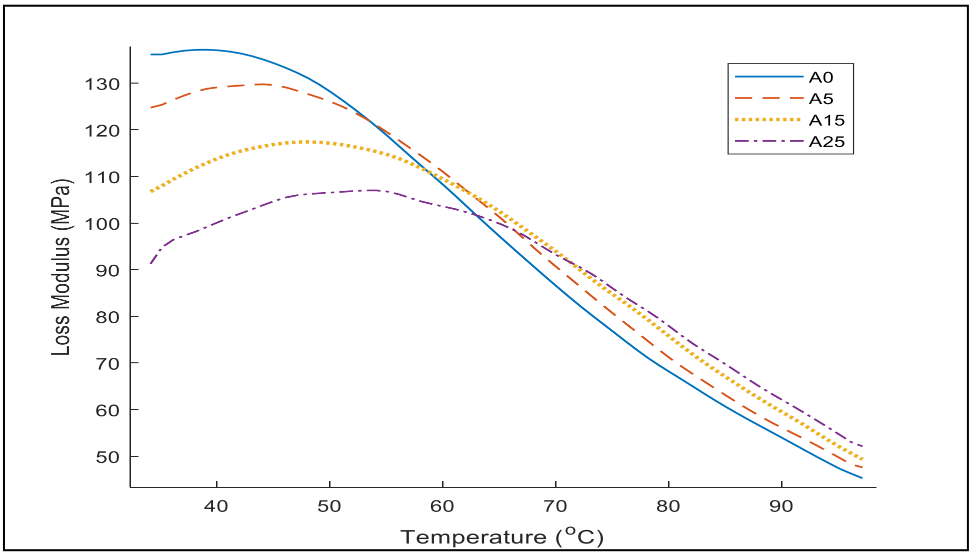

Figure 2: Variation of loss modulus with temperature of PPP-RPP composites at 1 Hz.

3.3 Effect of plantain peel particulate on the damping of recycled PP

The ratio of loss modulus to storage modulus is known as damping or tan ∂. It also refers to the imaginary part of the complex modulus and is a measure of polymer of polymer composites' viscous response. The peak of loss modulus curve for polymer composites is known as dynamic glass-transition temperature (Gupta & Bharti, 2017). Graphical depiction of damping parameter with increasing weight fraction of reinforcement indicated decrease in loss factor of the composite (Figure 3). From the curve, it is obvious that the PPP-based composites showed a lower tan ∂ than the unreinforced RPP. This could be attributed to good interactions between the PPP and the polymer matrix. It is also evident from the lower damping value that the composites have a high load-bearing capability. The sharp rise in tan ∂ curve of the unreinforced (control sample) at temperature above 95 ^{0}C indicates that the energy dissipation of the material was rapid.

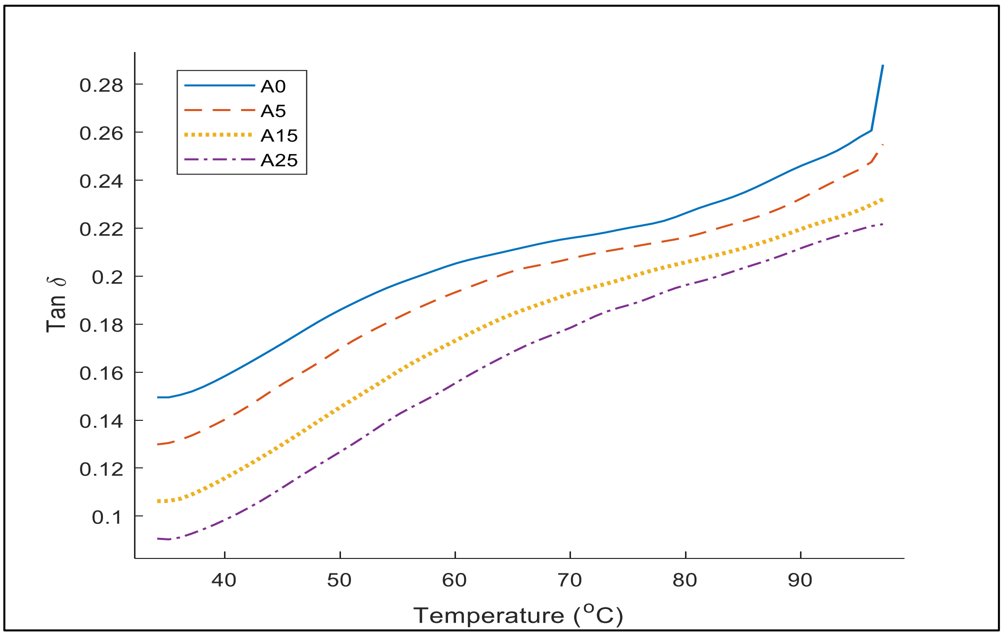

Figure 3: Variation of damping parameter with temperature of PPP-RPP composites at 1 Hz.

3.4 Dynamic mechanical properties at different frequencies

After obtaining the better dynamic mechanical properties of plantain peel powder reinforced polypropylene for composite A25, the effect of increase in frequencies on its dynamic mechanical properties at different frequencies was studied as follows:

3.4.1 Storage modulus at different frequencies

The variation in storage modulus with increasing temperature of plantain peel particulate-RPP composites at different frequencies is depicted in **Figure 4.** A considerable effect can be observed on storage modulus of the composites because of variation in frequencies (Gupta, 2018). In the glassy region, highest value of storage modulus is shown by the composite at 10Hz frequency and its lowest value is shown at 1Hz frequency. This implies that the storage modulus of PPP-RHDPE composites increase with increase in frequency and follow the order: A25F10>A25F5>A25F2>A25F1. In the rubbery region, highest value of storage modulus is also shown by 10Hz frequency. This could be explained as follows: stress applied for a short time because of increase in frequencies leads to an effective stress transfer. However, its lowest value is shown at 1Hz frequency may be due to improper stress transfer. It is also interesting to note that the effect of frequencies at lower temperature (glassy region) is slightly higher than at higher temperature (rubbery region).

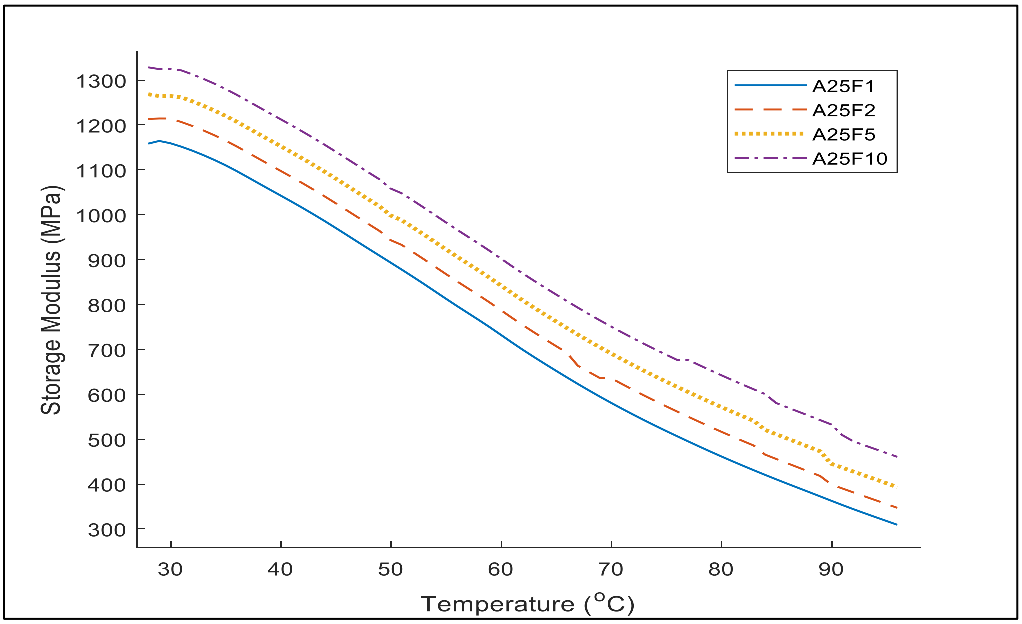

Figure 4: Variation of storage modulus with temperature of PPP-RPP composites at different frequencies.

3.4.2 Loss modulus at different frequencies

The variation in loss modulus of PPP-RPP composites as a function of temperature at different frequencies is shown in Figure 5. Similar to storage modulus results, a significant effect of variation in frequencies was also observed on loss modulus of the composites. It could be observed that peaks of loss modulus curve were found to increase with increase in frequencies. The highest peak of loss modulus curve was shown for composite A25F10 followed by A25F2, A25F5 and then A25F1. The increase in highest values of loss modulus curve could be due to increase in molecular mobility with increase in frequencies. It is important to note that on increasing the frequencies, the values of glass-transition temperatures were found to reduce. This is because increase in frequency (increase in number of cycles per second), leads to losing of bonds between fibres and matrix. The highest value of glass transition temperature for PPP-RPP composites at different frequencies follows the order: A25F1>A25F5>A25F2>A25F10. . Similar observation has been reported (Gupta, 2018). Thermal stability mainly depends upon adhesion between fibres and matrix which restricts the movement of polymers chain. On increasing the frequencies, movement of polymers chain was increased and hence decreases its thermal stability.

3.4.3 Damping parameter at different frequencies

At different frequencies, the variation in damping (Tan ∂) of PPP-RPP composites as a function of temperature is shown in Figure 6. Thermal stability was found to reduce with increase in frequencies. The highest thermal stability was found at lower frequency 1Hz, whereas lowest thermal stability was obtained at higher frequency 10Hz. These results indicated a considerable effect of variation in frequencies on damping of PPP-RPP composites.

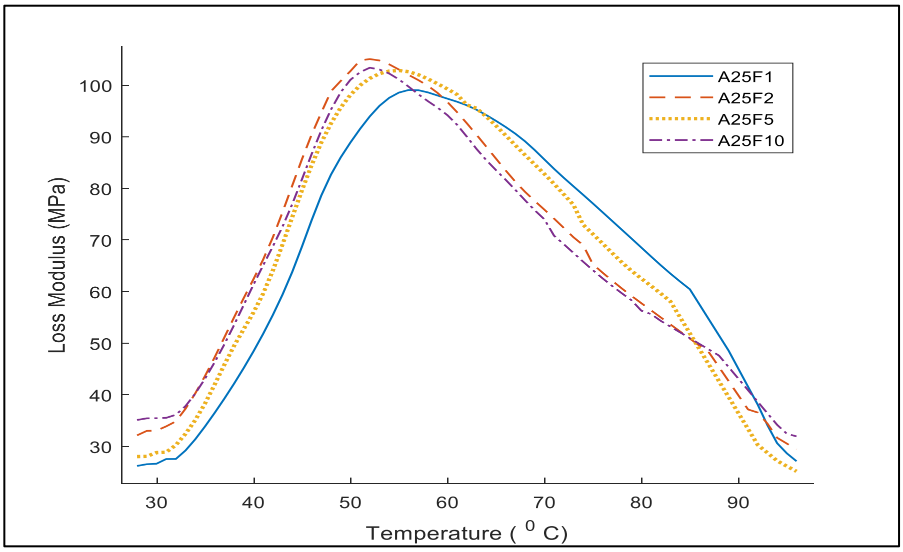

Figure 5: Variation of loss modulus with temperature of PPP-RPP composites at different frequencies.

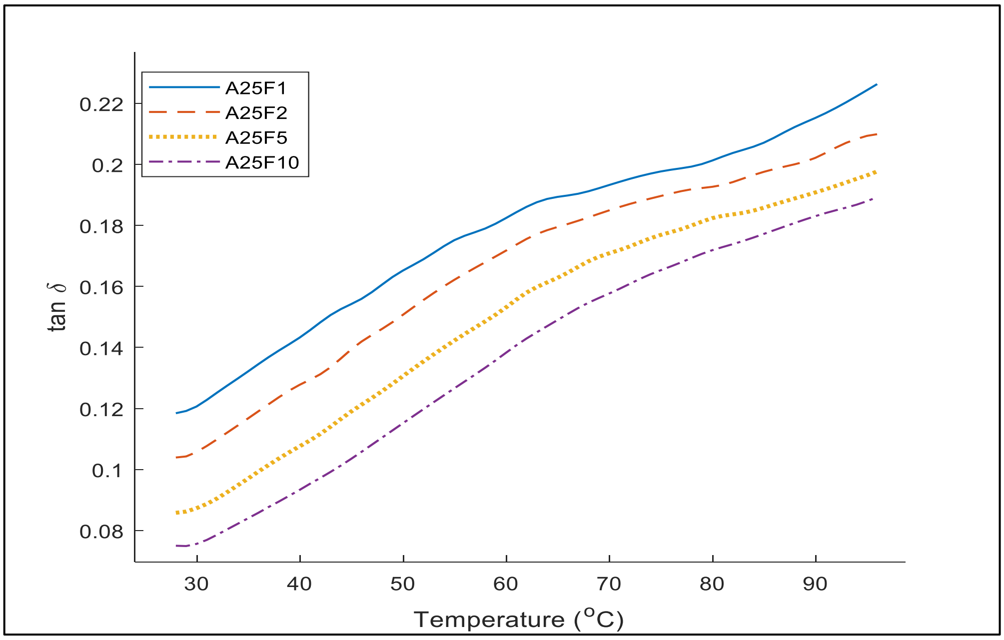

Figure 6: Variation of loss modulus with temperature of PPP-RPP composites at different frequencies.

Conclusion

Storage modulus and load bearing capacity were found to increase with weight percentage of fibres; the optimum being at 25%wt fibre content while loss modulus was found to decrease with increase in weight fraction of reinforcement**.** The effect of variation in frequencies investigated for the composites at 2 Hz, 5 Hz and 10 Hz revealed that increase in frequency increased the storage modulus while lowering the energy dissipation of the material. Incorporation of plantain peel particulate into recycled polypropylene has therefore improved its thermal stability.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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