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Effect of *Isoberlina* Wood Fillers on the Mechanical and Thermal Properties of PVC Composites

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Abstract: *Mechanical and thermal properties of Isoberlina (IS) wood reinforced polyvinyl chloride composites have been studied. The IS fibre was treated with sodium hydroxide solution to boast the adhesion between the hydrophilic natural fibre and the hydrophobic plastic matrix. The percentage fibre loading was varied from 0, 4, 8, 12, 16, 20 to 24. Dynamic Mechanical Analysis (DMA) technique was used to investigate the effect of Isoberlina wood powder on the thermal properties of polyvinyl chloride (PVC). The mechanical properties: ultimate tensile strength (UTS), elastic modulus and hardness showed an extensive improvement compared to the unreinforced PVC. DMA results showed that composite with 12 wt % IS have higher glass transition temperature and better stiffness stability at elevated temperature than the unreinforced PVC. Isoberlina wood powder can thus serve as a valuable reinforcement in the development of polymer composites.*

Key Words: *Dynamic mechanical analysis, Isoberlina wood, mechanical properties, polyvinyl chloride, thermal properties*

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1.0 Introduction

Polyvinyl chloride (PVC) is among the most widely used and commonest thermoplastic polymer due to its high density (specific gravity = 1.4), ease of availably, low cost, low modulus and good tensile strength (i.e rigid) (Cole, 2017; Yu *et al.,* 2016). However, it has very poor heat and electrical conducting properties and emits toxic fumes when melted (Crespo *et al.,* 2007). Therefore, in spite of its favourable mechanical and other properties, the application of the polymer can be limited by few of its properties. Therefore, research efforts are directed to measures of improving it properties in order to expands its industrial and other application. Blending is one of the best options that have given hope for improve mechanical, electrical, thermal and other properties of polymers (Chen *et al.,* 2018; Akpan *et al.*, 2019; Danladi *et al.*, 2020). Consequently, some works have been reported on improvement of performance properties of PVC.

Bishay *et al.* (2011) investigated electrical, mechanical and thermal properties of PVC composites filled with aluminum powder. Highest value of electrical conductivity of the composites was in the order of 10^{-8} Scm^{-1} which fitted the range of values (10^{-5} to 10^{-9} Scm^{-1}) recommended for electrostatic dissipation applications. Thermal strength was found to decrease with increase in the aluminum content while tensile strength and elongation at break decreased slightly after annealing at 100 °C. Scanning electron micrograph indicated that large agglomerates of aluminum concentration (20-30%) dispersed within the PVC to yield a conductive path through the composite. Thermal stability of the compound was found to increase with increase in aluminum content. Samira et al. (2016) observed drastic improvement of PVC mechanical properties as a result of blending with HDPE. Improvement in mechanical properties increases with increase in HDPE content. Hassan et al. (2012) found that the mechanical and thermal properties of PVC/ABS composites dependent on particle size and surface treatment of ground calcium carbonate and that their properties can be improved by considerable addition of these particles. Chakrabarti et al. (2004) studied PVC/PMMA and observed changes in physical, mechanical and thermal properties of the pure and blended polymers. The physical and mechanical properties of such polyblends revealed a substantial increase in toughness accompanied with unusual increase in modulus and ultimate tensile strength after an initial drop at the initial stages of PMMA incorporation compared to pure reference compound PVC.

The current trend of research in the field of natural fibre based composites is the application of dynamic mechanical analysis (DMA) technique (Jacob *et al.,* 2019a). DMA depicts the stiffness stability of the composites with increasing temperature, its glass transition temperature and its viscoelastic nature when stimulated by dynamic loading (Jacob *et al.,* 2019b). There is a need therefore, for a robust research that would give better performance characteristics to satisfy the quest of the end-use applications. This research work seeks to determine how *Isoberlina* wood filler could have a substantial mechanical and thermal property enhancement of PVC.

2.0 Materials and Methods

2.1 Sample collection and sample preparation

Sample of *Isoberlina* wood (Doka in Hausa and Baabo in Yoruba) was obtained from Hannu-Tara in Dansadau, Maru Local Government of Zamfara State, Nigeria. The wood was cut into pieces and then sun-dried to constant weight. The dried wood was pulverized into powdery form and sieved through mesh to 150 µm particles size. The wood powder was treated with sodium hydroxide solution to improve interfacial adhesion with the polymer matrix by immersing in a solution containing 50 g of IS powder in 10% NaOH for 5 hours with continuous stirring. The treated sample was washed to neutral pH with distilled water, filtered, dried in vacuum at 80 °C for 5 hours and preserved for use in the experiment (Jacob *et al.*, 2018).

2.2 Preparation of PVC-Isoberlina wood composites

The PVC resin and *Isoberlina* were prepared by compounding and compression moulding techniques on a Two Roll Mill (Model number 5183, New Jersey, USA) at the Polymer Recycling Laboratory, Department of Polymer Technology, Nigeria Institute of Leather and Science Technology (NILEST), Zaria. The composite samples were produced by the addition of the PVC resin while the rolls were in counter clockwise motion for10 minutes at a temperature of 250 °C. Immediately a paste-like matrix was achieved, the filler (*Isoberlina* powder) was gently and manually introduced as the rolls rotated at a rate of 500rpm.The fibre loading was varied: 0, 4, 8, 12, 16, 20, and 24 % while the percentage content of PVC were 96, 92, 88, 84, 80 and 76% respectively. The control was pure PVC sample (denoted as 0% blend). The compounded samples were cured on hydraulic machine (hot press) at 4 MPa for 10 minutes. Finally, the cured samples were removed from the mould after cooling and cut according to ASTM standard for characterization and mechanical test (Jacob, 2019).

2.3 *Mechanical property test*

Tensile testing for the samples was conducted at the Engineering Materials Development Institute, Akure, Ondo State according to the ASTM D638 (2014) standard. A dog bone-shaped specimen was cut and then placed in Instron universal testing machine 3369 model. The tensile strength and elastic modulus were evaluated.

Flexural strength of the composite was carried out at the Strength of Materials Laboratory, Department of Mechanical Engineering, Ahmadu Bello University, Zaria according ASTM D790 (2015).

The impact property of a material represents its capacity to absorb and dissipate energies under impact or shock loading (Mallick, 2008). The impact test was conducted at the Department of Materials Science and Engineering, Ahmadu Bello University, Zaria according to the ASTM D256 method.

Test for hardness of the samples was carried out using the method that is based on the relative resistance of its surface to indentation by an indenter of specified dimensions under a specified load (Jacob *et al.,* 2018). Samples of 30 mm x 30 mm x

4 mm were tested for shore hardness values with a Durometer. Three different measurements were performed on the sample at different spots and the average of the values was taken as the hardness of the sample.

DMA was carried out using DMA 242E machine in Strength of Materials Laboratory, Mechanical Engineering Department, ABU Zaria according to (ASTM D7028, 2015). The test parameters: E', E" and tangent of delta (Tan ∂) 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 3K/min were configured (Jacob, 2019).

3.0 Results and Discussion

3.1 *Mechanical properties*

Fig. 1 indicates the variation of the ultimate tensile strength (UTS) of *Isoberlina*-PVC composites with fibre loading. An increase in tensile strength was observed up to 12% fraction of reinforcement but a sudden decrease in tensile strength set in at 16 % blend composition. The decrease could be linked to wearing of the interfacial adhesion of the constituent composition as the fraction of PVC is reduced and as the weight fraction of reinforcement increased. Similar observations have been reported by other authors for various polymer blends including PVC composites (Dan-asabe, 2016, Shah *et al.,* 2016; Jacob *et al.,* 2018; Yusuf *et al.,* 2020).

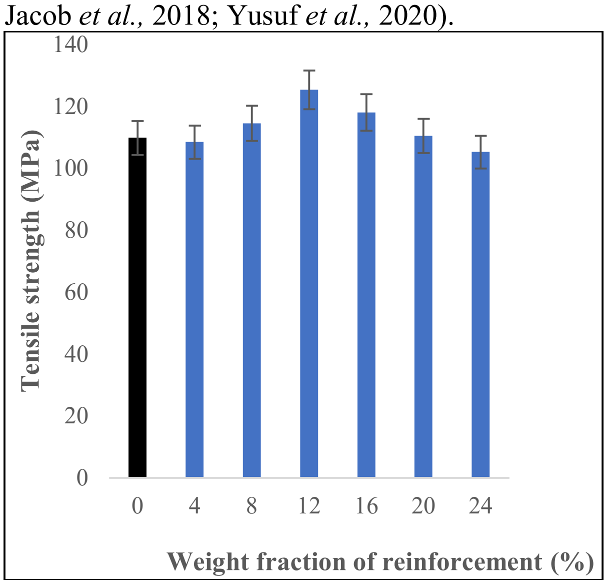

Fig. 1: Variation of tensile strength of IS reinforced PVC composites with % reinforcement

Fig. 2 represents the elastic modulus of the composite with increasing weight fraction of reinforcement. It could be observed that, 12% weight fraction of reinforcement demonstrated a substantial increase in elastic modulus from 1400MPa to 5300MPa.This momentous increase in the elastic modulus may be connected with better interaction between the *Isoberlina* fibre and the polymer matrix. Similar trends and findings have been observed for some polymer composites (Dan-asabe, 2016, Jacob *et al.,* 2018; Yusuf *et al.,* 2020).

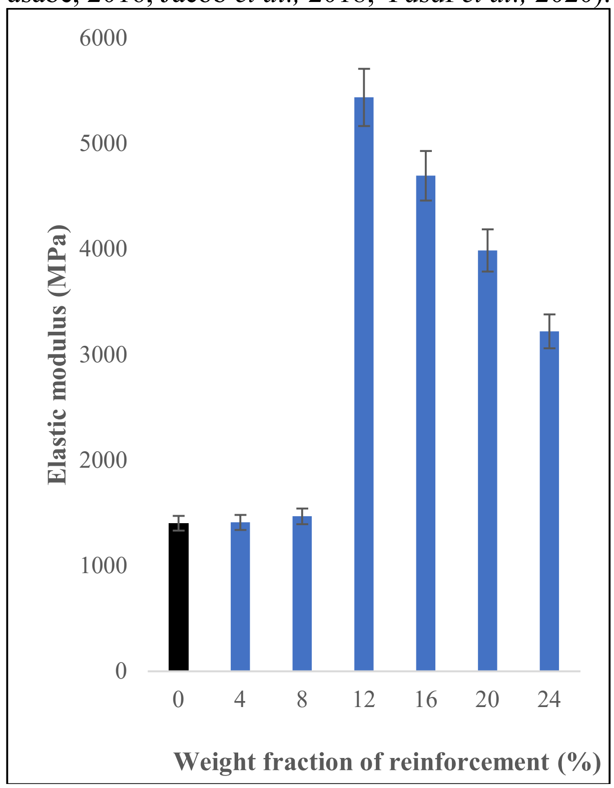

Fig. 2 : Variation of elastic modulus of IS reinforced PVC composites with percentage reinforcement.

Fig. 3 depicts the flexural strength of the composites. From the result, flexural strength of *Isoberlina* reinforced PVC composites was observed to increase with incremental increase in percentage IS reinforcement. Optimum increase was however observed with 4% weight fraction of reinforcement and is attributed to better interaction and stress transfer between the IS and PVC matrix. However, at higher fraction of IS fibre, the flexural strength was observed to decrease with increase in percentage reinforcement due to poor fibre-matrix adhesion (Al-Mosawi *et al.*, 2013, Jacob *et al.,* 2019, Yusuf *et al.,* 2020).

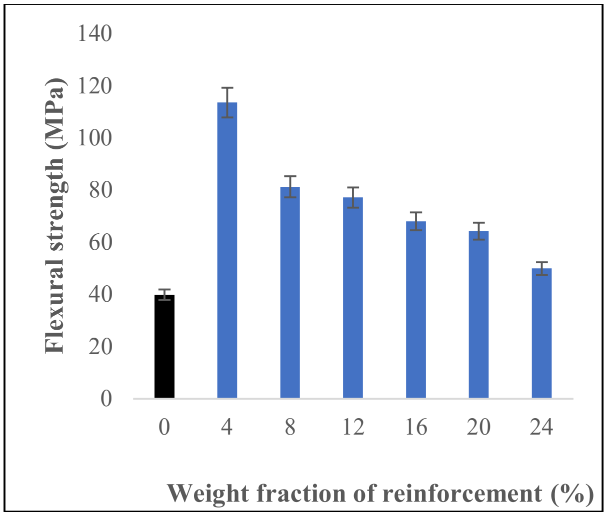

Fig. 3: Variation of flexural strength of IS reinforced PVC composites with percentage reinforcement

Fig. 4 shows the impact strength of the composites. From the figure, it could be seen that incorporation of *Isoberlina* wood fibre in PVC increased the impact strength of the composites substantially but dropped down with increase in the percent fibre content. The increase may be attributed to the good interfacial adhesion between the *Isoberlina* wood fibre and the plastic matrix. The steep decrease could be due to the decrease in interfacial attraction as the fibre content in the PVC is increased. The result conforms with the findings of Joshi and Marathe (2010) who worked on the mechanical properties of highly filled PVC/Wood-flour composites.

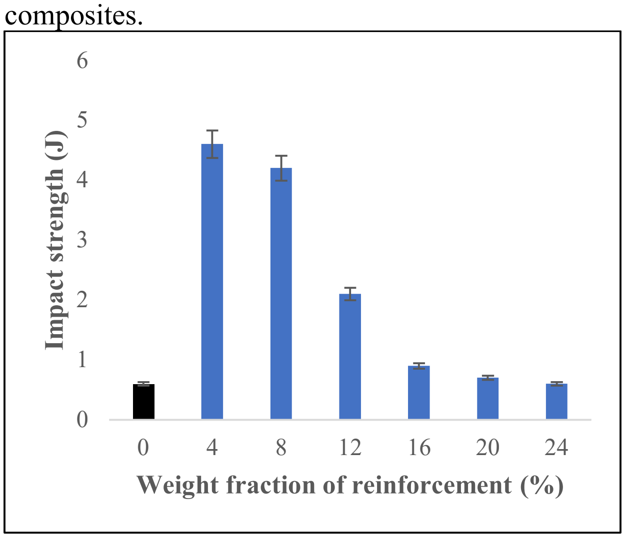

Fig. 4: Variation of impact strength of IS reinforced PVC composites with percentage reinforcement

Fig. 5 depicts the hardness values of IS reinforced PVC composites. The composition with highest fraction of reinforcement exhibited the maximum value of 98. This is due to better interfacial attraction between the *Isoberlina* fibre and the polymer matrix**.** The observed trend supports the findings reported by Yusuf *et al.* (2020) who investigated the effect of *Prosopis* africana wood fillers on the mechanical properties and creep resistance of polyvinyl chloride composites.

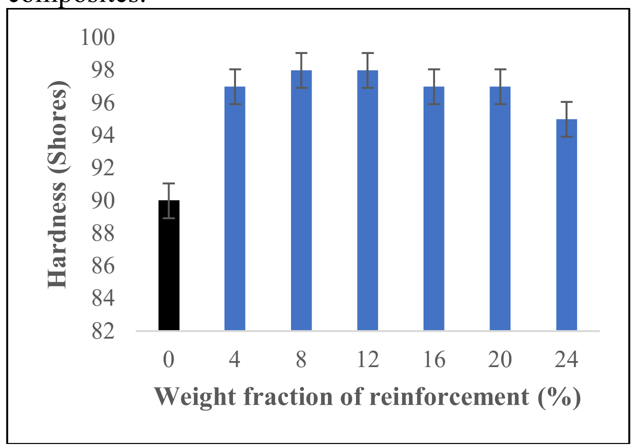

Fig. 5: Variation of hardness of IS reinforced PVC composites with percentage reinforcement

3.2 *Dynamic mechanical properties*

Storage modulus

Storage modulus of polymeric materials represents how the materials are stiffer (Gupta, 2018). It also describes the energy stored in the system and depicts the elastic portion (Jacob *et al.,* 2019a).

Fig. 6 shows the storage modulus of pure PVC at frequencies of 2.5, 5 and 10 Hz. The curve also shows that unreinforced PVC is unstable at temperatures above 60 ℃ with maximum stiffness ~~of~~ stability parameters of 1.70 GPa and 10 Hz respectively.

Fig. 7 shows the storage modulus of *Isoberlina* wood reinforced PVC at 2.5 Hz, 5 Hz and 10 Hz frequencies respectively. The curve reveals that the composite of IS reinforced PVC is stable under dynamic loading as the temperature increases up to 50 ℃ before it approached its point of inflection at 55 ℃ which is taken as its glass transition temperature (Dan-asabe, 2016; Jacob *et al.,* 2019a). From the storage modulus curve of unreinforced PVC (Fig. 6) and that of IS reinforced PVC at under the same conditions, it is evident that incorporation of treated *Isoberlina* wood powder into PVC increased its stiffness stability by 2.8 GPa which is in agreement with the observation reported by Jacob *et al.* (2019a).

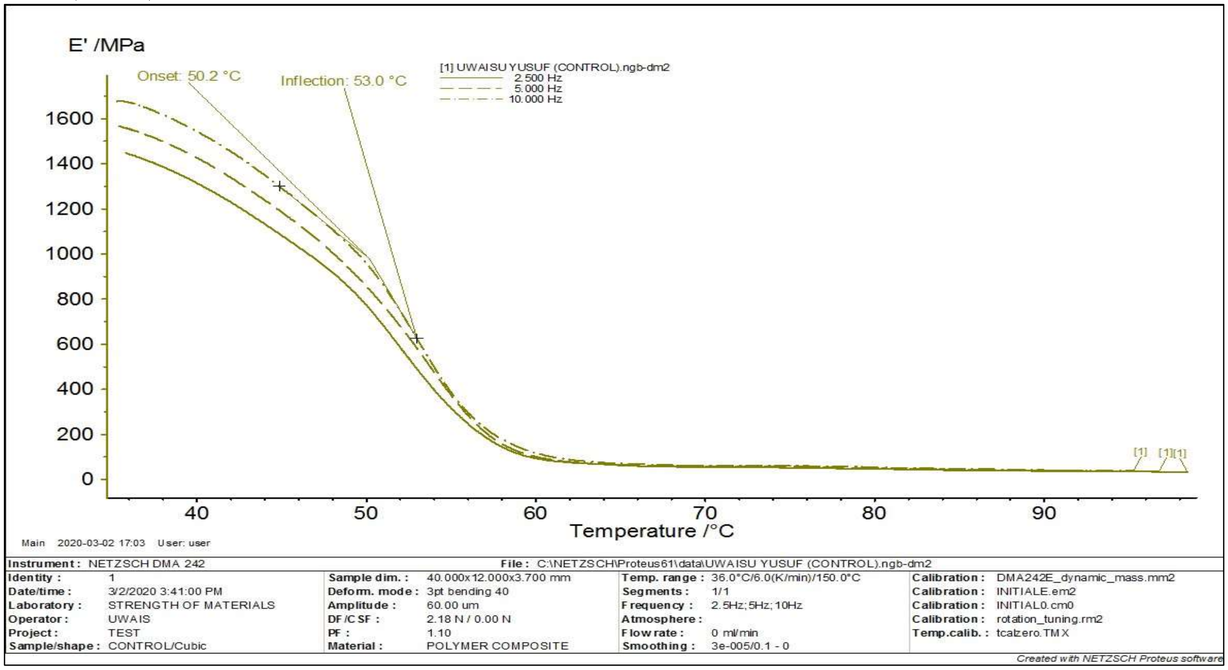

Fig. 6: Storage modulus curve of unreinforced PVC at 2.5, 5 and 10 Hz

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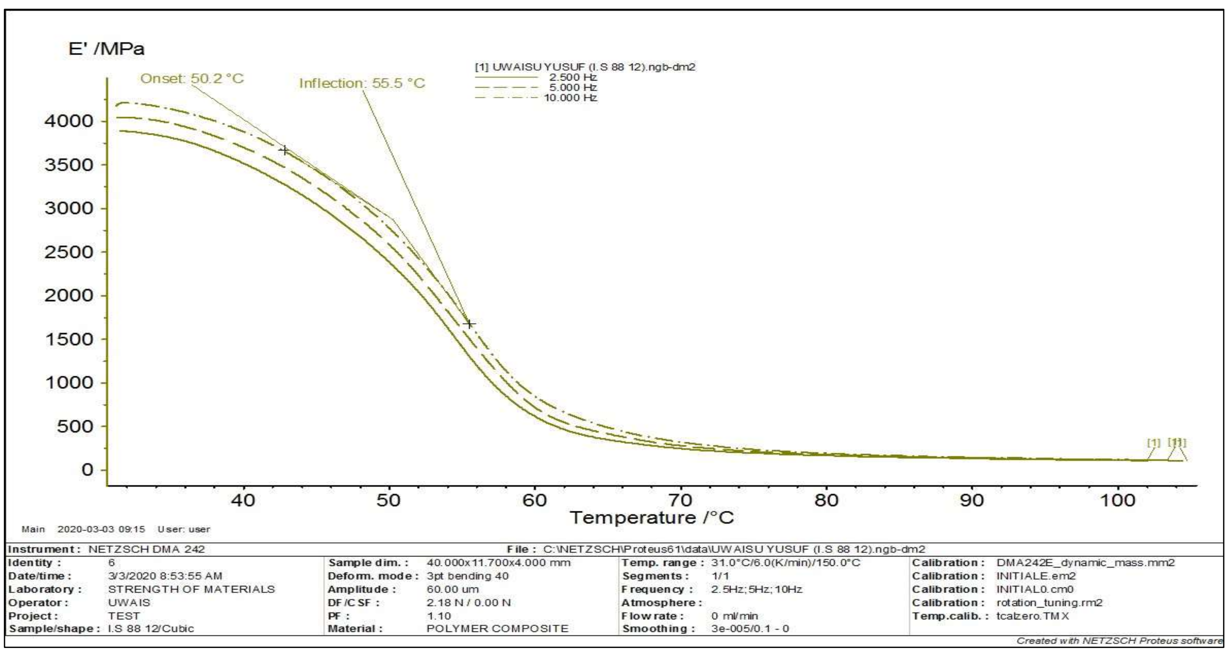

Fig. 7: Storage modulus curve of 12 wt% IS-PVC composites at 2.5, 5 and 10 Hz Damping

The ratio of loss modulus to storage modulus is called mechanical loss factor or damping. The damping properties of a material give the balance between the elastic and viscous phases in a polymeric structure ((Palavinel, *et al.,* 2017).

Fig. 8 depicts the damping curve of 12 % IS-PVC composites at three different frequencies. It has been observed that as the temperature increases, the damping values pass through the maximum in the transition region and then decrease in the rubbery region. A glass transition temperature of 64.0 °C was observed in the damping curve compared to 55.5 ℃ deduced from the storage modulus curve and 53.0 ℃ for the unreinforced PVC respectively. This indicates that incorporation of *Isoberlina* wood powder improved the thermal stability of PVC (Jacob *et al.,* 2019a). Below the glass transition temperature, damping is low because, in this region, the chain segments are in the frozen state. Also, in the rubbery region, the molecular segments are ~~quite~~ free to move and hence damping is low and thus there is no resistance to flow. Similar observation has been reported by Palanivel *et al.* (2017) who investigated the dynamic mechanical analysis and crystalline analysis of fibre reinforced cellulose filled epoxy composite.

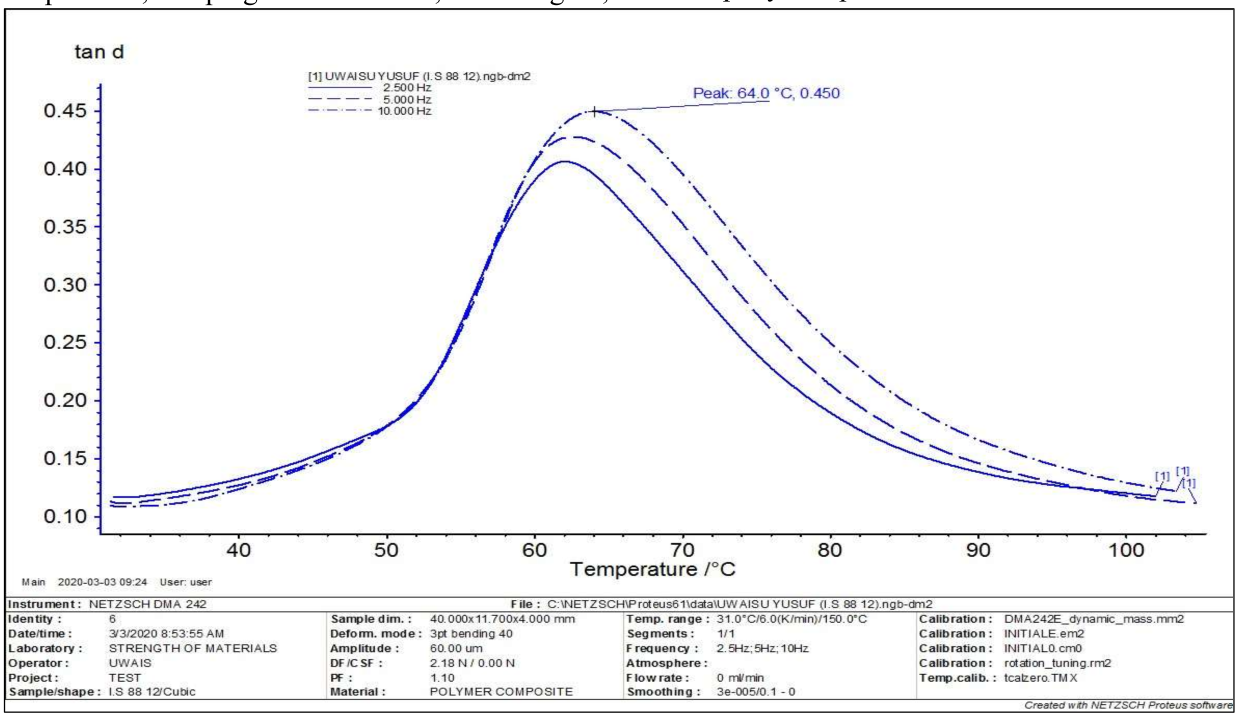

Fig. 8: Damping curve of 12 wt% IS-PVC composites at 2.5, 5 and 10 Hz.

3.0 Conclusion

Isoberlina wood reinforced PVC was developed using locally sourced wood fibre that is available and has demonstrated substantial mechanical properties enhancements compared to the unreinforced PVC. Best mechanical properties were observed at 4%, 8%, 12% and 16% weight fraction of reinforcements. Dynamic mechanical properties analysis showed that storage modulus increased with increasing frequency and decreases with increase in temperature which was due to the reinforcement effect imparted by the fibres. Incorporation of IS wood fibres into PVC increases its glass transition temperature by 11.0 ℃.

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