Communication in Physical Sciences, 2025, 13(10) :1664-1677

Dynamic Mechanical Analysis of Biocomposites Produced from Recycled Polypropylene and Groundnut Shell Powder

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Received: : 14 May 2026/ Accepted: 12 September 2026/Published: 24 September 2026
https://doi.org/10.4314/cps.v13i10.7

Abstract: *The increasing accumulation of plastic waste and agricultural residues has stimulated interest in developing value-added polymer composites through waste recycling and biomass utilisation. This study investigated the dynamic mechanical and thermal properties of recycled polypropylene (rPP) composites reinforced with groundnut shell powder at loadings of 1, 5, 10, and 15 wt%. The composites were fabricated using a two-roll mill at 160 °C for 10 min, followed by compression moulding at 170 °C for 10 min. Dynamic mechanical analysis (DMA) was performed over a temperature range of −40 to 150 °C at a heating rate of 3 °C min⁻¹, a frequency of 1 Hz, and a strain amplitude of 0.1%. Thermogravimetric (TG), derivative thermogravimetric (DTG), and differential thermal analyses were conducted from room temperature to 800 °C at a heating rate of 10 °C min⁻¹ under nitrogen. The unreinforced rPP exhibited a storage modulus of 1,375 MPa at 25 °C, whereas the composite containing 15 wt% groundnut shell powder exhibited a loss modulus of 67 MPa at the same temperature. Glass transition temperatures estimated from the loss modulus and tan δ curves differed by no more than 7 °C, with tan δ peaks occurring between approximately 0 and 20 °C. Thermal analysis revealed lignocellulosic decomposition in the approximate range of 200–380 °C for the groundnut shell powder, while the principal degradation of the rPP matrix occurred between approximately 400 and 484 °C. The composite containing 15 wt% filler reportedly exhibited the highest residual mass at 800 °C. Overall, the findings demonstrate the feasibility of incorporating groundnut shell powder into recycled polypropylene, with the 5 wt% formulation identified as a potentially promising composition based on its reported dynamic mechanical response. Further quantitative comparisons of mechanical performance and thermal stability are required to establish the optimum formulation and suitability for specific applications.*

Keywords*: Recycled polypropylene; groundnut shell; polymer composites; dynamic mechanical analysis; thermal stability*

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1.0 Introduction

Plastic materials have become indispensable in modern society because of their versatility, low density, durability, relatively low cost, and adaptability to a wide range of applications. They are widely used in packaging, construction, transportation, electronics, healthcare, and consumer products. However, the widespread production and consumption of plastics have created significant waste-management challenges, particularly because many conventional polymers persist in the environment for extended periods. The Organisation for Economic Co-operation and Development (OECD, 2022) reported that global plastic waste increased from 156 million tonnes in 2000 to 353 million tonnes in 2019, while only 9% of the waste generated was ultimately recycled. These figures highlight the need for more effective approaches to plastic-waste recovery, reuse, and recycling.

Low-density polyethylene (LDPE) is particularly relevant to plastic-waste

management because of its widespread use in flexible packaging, shopping bags, and sachet-water packaging. Although its flexibility, low weight, and moisture resistance make it commercially valuable, discarded LDPE contributes to the accumulation of plastic waste when collection and recycling systems are inadequate. Conventional disposal practices, including uncontrolled dumping and open burning, can cause environmental pollution, while landfilling consumes space and retains potentially recoverable materials. Recycling offers an alternative by converting discarded polymers into secondary raw materials for new products. However, the practical benefits depend on the quality of the recovered material, the energy and resources required for processing, and the performance of the resulting products. The development of composites from recycled LDPE therefore represents a potential strategy for improving resource efficiency while creating value-added materials from waste.

One approach to enhancing the properties and potential applications of recycled plastics is the incorporation of natural fibres or plant-derived particulate materials as reinforcements or fillers. Natural fibres have attracted research interest because of their renewable origin, relatively low density, and potential to reduce the dependence of composite production on conventional synthetic reinforcements. Pickering et al. (2016) reviewed developments in natural-fibre composites and highlighted their potential advantages, including comparatively low cost and opportunities for more sustainable material development. Nevertheless, the performance of natural-fibre-reinforced polymer composites depends on several factors, including fibre characteristics, reinforcement loading, matrix compatibility, processing conditions, and interfacial adhesion. These factors influence the mechanical response, moisture absorption, thermal behaviour, and durability of the resulting materials.

Research has also demonstrated the feasibility of incorporating agricultural residues into recycled polymer matrices. Odetoye and Adeoye (2022) investigated the production of biocomposites using waste LDPE sachets and *Prosopis africana* pod residues. Their study evaluated tensile, flexural, impact, water-absorption, and biodegradability characteristics at different filler loadings. The authors reported improvements in selected mechanical properties at particular filler concentrations, demonstrating the potential of combining post-consumer plastic waste with locally available biomass residues to produce useful composite materials. However, their investigation focused on pod-derived particulate material rather than establishing the full thermal and dynamic mechanical behaviour of recycled LDPE reinforced with PA fibres. Consequently, the findings provide a relevant foundation for further research while leaving additional material-characterisation questions to be addressed.

The development of natural-fibre-reinforced polymer composites also requires an understanding of their thermal and viscoelastic characteristics. Thermal properties influence the selection of processing temperatures, the stability of materials during fabrication, and their suitability for different service environments. Dynamic mechanical analysis (DMA) provides complementary information by measuring the response of a material to oscillatory loading over a specified temperature or frequency range. Important parameters include storage modulus, which reflects the elastic component of the response; loss modulus, which represents energy dissipation; and the damping factor, which describes the relationship between energy dissipated and energy stored during cyclic deformation. Saba et al. (2016) demonstrated the importance of DMA in assessing the

viscoelastic behaviour of natural-fibre-reinforced polymer composites and examining how reinforcement characteristics affect their dynamic performance. These parameters are particularly useful when evaluating whether a composite can maintain appropriate stiffness and damping characteristics under changing operating conditions.

Earlier research by Zampaloni et al. (2007) examined the fabrication of kenaf-fibre-reinforced polypropylene composites, addressing manufacturing challenges and the potential of natural-fibre reinforcement in polymer-based materials. Although their work concerned polypropylene rather than recycled LDPE, it provides relevant background on the processing and performance considerations associated with natural-fibre composites. Taken together, the literature establishes that plant-derived reinforcements can modify the properties of polymer matrices, but the resulting improvements are not necessarily uniform across all mechanical, thermal, and dynamic performance indicators. The effects must therefore be evaluated experimentally for each combination of matrix, reinforcement, fibre characteristics, and processing conditions.

Despite these advances, the relationships among PA fibre incorporation, the physical properties, mechanical performance, thermal response, and dynamic mechanical behaviour of recycled LDPE composites require further investigation. In particular, the effects of PA fibre reinforcement on the balance between stiffness, strength, thermal stability, and viscoelastic response cannot be reliably inferred from studies involving different polymer matrices or particulate fillers. This constitutes the principal knowledge gap addressed by the present study. A systematic evaluation of these properties is necessary to establish whether PA fibres can provide useful reinforcement for recycled LDPE and to identify the material characteristics that may determine its suitability for specific applications.

Accordingly, the aim of this study is to investigate the effects of *Prosopis africana* fibre incorporation on the physical, mechanical, thermal, and dynamic mechanical properties of recycled low-density polyethylene composites. Specifically, the study evaluates changes in these properties associated with fibre incorporation to establish the potential benefits and limitations of the resulting composites.

The significance of this research lies in its contribution to plastic-waste valorisation, the utilisation of locally available plant-derived materials, and the development of potentially cost-effective composite products. By investigating the performance of PA-fibre-reinforced recycled LDPE, the study provides experimental evidence that may support material selection, composite formulation, and processing decisions. The findings may also inform the development of products for applications where the measured mechanical, thermal, and dynamic properties are adequate for the intended service conditions. More broadly, the research contributes to efforts to improve material resource efficiency by combining recovered polymer waste with renewable biomass resources, although the overall environmental benefits would require further assessment through life-cycle and end-of-life studies.

2.0 Materials and Methods

2.1 Sourcing and Preparation of Raw Materials

Post-consumer polypropylene (PP) plastic waste was collected from refuse dumps in and around the Gudi Campus of Nasarawa State University, Keffi, Nigeria. The collected plastic waste was washed thoroughly with water to remove dirt and other surface contaminants and subsequently dried before being used as the polymer matrix for composite fabrication.

Groundnut shells were obtained from farmers in Gudi Town, Nasarawa State, Nigeria. The shells were washed to remove adhering impurities and dried before being ground into a fine powder. The resulting powder was sieved using a 25 µm mesh to obtain particles within the required size range. The groundnut shell powder was subsequently treated with sodium hydroxide (NaOH) solution to modify its surface characteristics and potentially improve interfacial adhesion between the hydrophilic lignocellulosic filler and the relatively hydrophobic polypropylene matrix. The NaOH concentration, treatment duration, washing procedure, and final drying conditions should be specified to ensure reproducibility.

2.2 Preparation of Polypropylene–Groundnut Shell Composites

The recycled polypropylene (rPP) and groundnut shell powder composites were prepared using compounding and compression-moulding techniques. The cleaned and dried rPP was first processed using a two-roll mill (Model No. 5183, New Jersey, USA; manufacturer to be confirmed). The polymer was processed at 160 °C for 10 min, with the rollers rotating in opposite directions, until a softened and workable polymer mass was obtained.

The groundnut shell powder was then introduced gradually into the softened rPP while mixing continued to promote uniform distribution of the filler throughout the polymer matrix. The average roller speed was reported as 1,000 rpm; this value should be verified against the equipment specifications and laboratory records. Composite formulations containing different groundnut shell powder loadings, ranging from 1 to 20 wt%, were prepared by varying the proportions of the filler and rPP. The exact filler concentrations used for the individual formulations should be stated explicitly, together with the composition of the unreinforced rPP control, if one was prepared.

Following compounding, the composite materials were transferred to a hydraulic compression-moulding press and processed at 170 °C for 10 min. The applied pressure was reported as 3 Pa; this value requires verification because it appears unusually low for compression moulding. The actual pressure and its correct unit should be established from the experimental records before publication. The moulded composites were subsequently cooled, removed from the mould, and machined into specimens of the appropriate dimensions for characterisation. The specimens were prepared for testing following the procedures described by Jacob et al. (2023).

2.3 Characterisation of Composite Properties

2.3.1 Dynamic Mechanical Analysis

The dynamic mechanical properties of the rPP–groundnut shell composites were evaluated using a dynamic mechanical analyser (DMA Q800, TA Instruments). Measurements were conducted at a heating rate of 3 °C min^{-1}, a frequency of 1 Hz, and a strain amplitude of 0.1% over a temperature range of −40 to 150 °C. The specimens measured 37 × 13 × 2 mm. These conditions were applied to assess the temperature-dependent viscoelastic response of the composites. The storage modulus, loss modulus, and damping factor were determined where supported by the instrument output. The specimen clamping mode and the precise definition of the applied strain should also be reported to facilitate reproducibility.

2.3.2 Thermogravimetric and Thermal Analysis

Thermal characterisation of the composites was performed using a simultaneous thermal analyser (SDT Q600, TA Instruments). Approximately 5 mg of each sample was analysed under a nitrogen atmosphere at a heating rate of 10 °C min^{-1}, from room temperature to 800 °C. The nitrogen flow rate was reported as 120 mL min^{-1} and should be confirmed against the instrument settings.

Thermogravimetric analysis (TGA) was used to evaluate mass changes as a function of temperature, while derivative thermogravimetric (DTG) analysis was used to identify the rate of mass loss and the temperatures associated with maximum degradation rates. Differential thermal analysis (DTA) was also reported as part of the thermal characterisation; however, the actual measurement mode should be confirmed from the instrument configuration and recorded data. Where the SDT Q600 was operated in simultaneous TGA–DSC mode, the thermal signal should be reported as differential scanning calorimetry (DSC), rather than DTA, unless a separate DTA measurement was performed.

3.0 Results and Discussion

3.1 Dynamic Mechanical Analysis

Dynamic mechanical analysis (DMA) was used to evaluate the temperature-dependent viscoelastic behaviour of the recycled polypropylene (rPP) matrix and its groundnut shell powder composites. The storage modulus (E′), loss modulus (E″), and damping factor (tan δ) were examined to assess the effects of groundnut shell powder incorporation on the stiffness, energy-dissipation behaviour, and glass transition characteristics of the materials. The corresponding results are presented in Figs. 1–3.

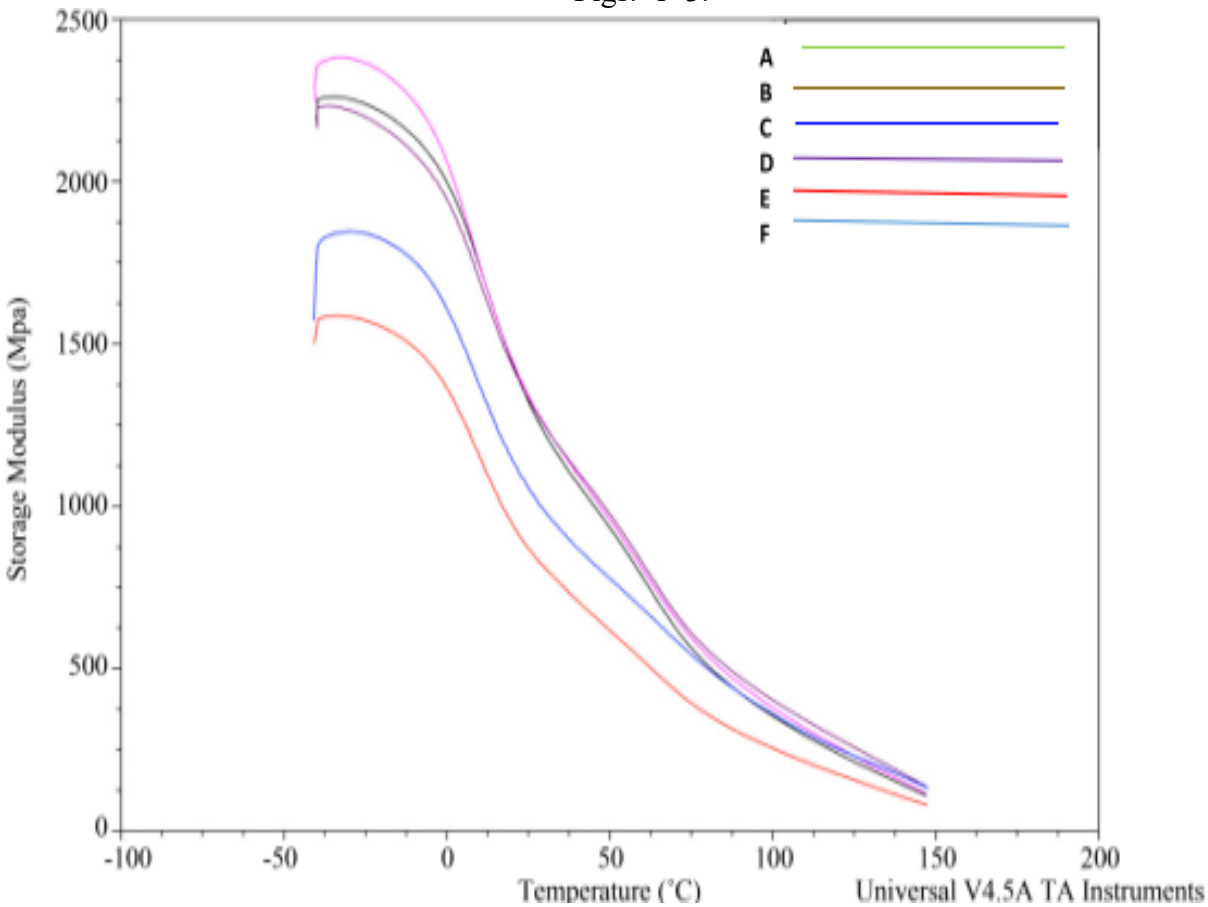


Fig. 1: Comparison of storage modulus (E′) versus temperature for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene)

3.1.2 Loss Modulus and Glass Transition Behaviour

Fig. 2 presents the loss modulus (E″) as a function of temperature for the groundnut shell powder, the reinforced rPP composites, and the unreinforced rPP matrix. The loss modulus represents the energy dissipated by a material during cyclic deformation and provides information about its viscoelastic response. Changes in E″ with temperature can indicate variations in molecular mobility and the occurrence of relaxation processes.

At 25 °C, the composite containing 15 wt% groundnut shell powder was reported to exhibit a loss modulus of 67 MPa. This value should be compared with the corresponding measurements for the other formulations to establish the influence of filler loading on energy dissipation. A lower loss modulus may indicate reduced energy dissipation under the specified testing conditions; however, this interpretation should be considered alongside the storage modulus and damping factor rather than used independently to infer improved mechanical performance.

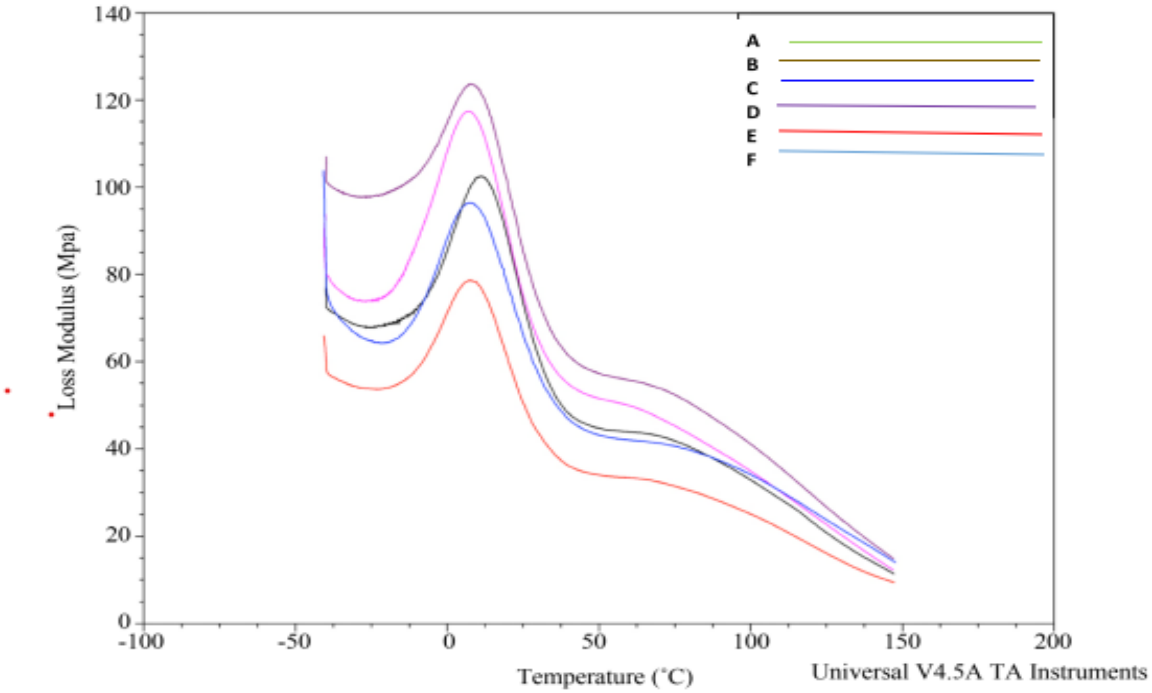


Fig. 2. Comparison of loss modulus (E″) versus temperature for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene).

The temperature-dependent loss modulus curves also provide a basis for estimating the glass transition temperature (Tg). The Tg values determined from the loss modulus and tan δ curves were reported to differ by no more than 7 °C. This relatively small difference indicates that the two methods produced broadly comparable estimates of the transition temperature. However, the precise Tg values and the criterion used to identify each transition should be reported to permit a quantitative comparison among the formulations.

The reported similarity in Tg across the different groundnut shell powder loadings suggests that filler incorporation did not substantially alter the temperature at which the principal glass-transition-related relaxation

occurred under the measurement conditions. This finding does not necessarily establish that molecular mobility was unchanged, because the magnitude and position of relaxation peaks can also depend on interfacial interactions, filler dispersion, and the measurement method. The relationship between the storage and loss moduli should therefore be interpreted together with the tan δ response.

3.1.3 Damping Factor (tan δ)

Fig. 3 shows the damping factor (tan δ) as a function of temperature for the groundnut shell powder, the rPP composites, and the unreinforced rPP matrix. The damping factor is defined as the ratio of the loss modulus to the storage modulus and provides an indication of the relative energy dissipated during cyclic deformation.

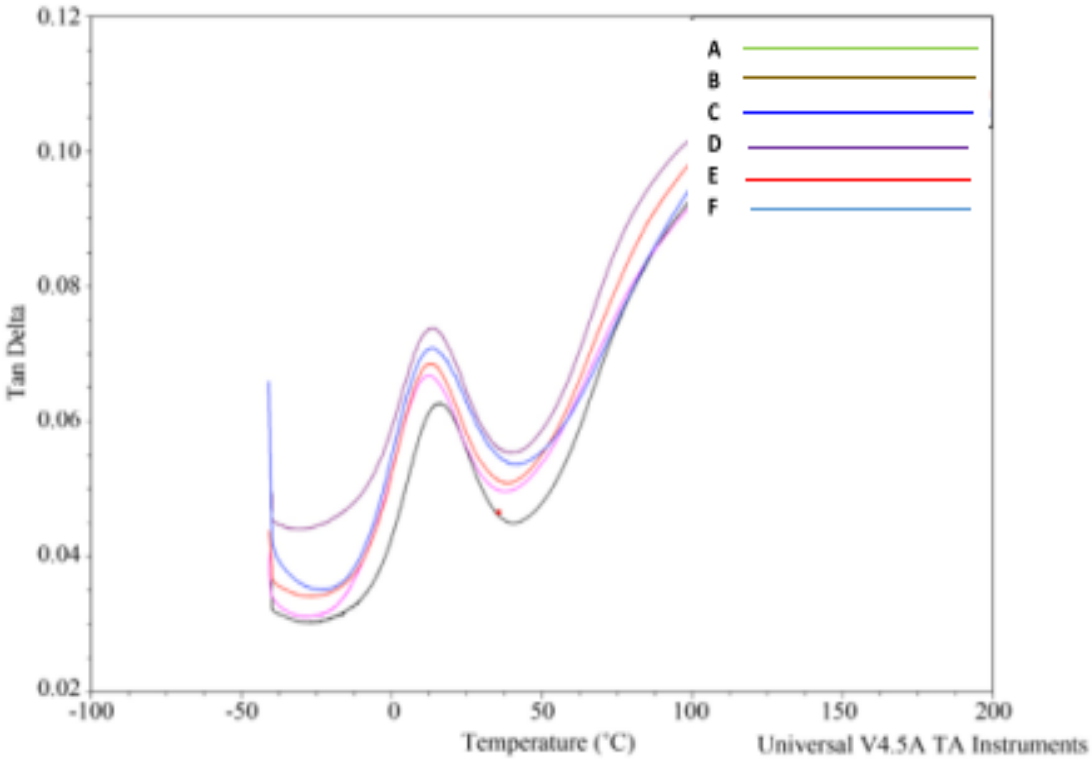


Fig. 3. Comparison of damping factor (tan δ) versus temperature for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene).

The tan δ curves exhibited peaks within the reported temperature interval of approximately 0–20 °C. These peaks were attributed to the glass-transition-related relaxation of the polymeric materials. The reported peak positions were broadly consistent with the Tg estimates obtained from the loss modulus curves, with differences of no more than 7 °C between the two approaches. The similarity between these estimates supports the use of both DMA parameters to characterise the viscoelastic transitions of the composites.

The positions and magnitudes of the tan δ peaks should be considered when evaluating the influence of groundnut shell powder on the relaxation behaviour of rPP. A shift in peak temperature may indicate changes in molecular mobility or polymer–filler interactions, whereas a change in peak height may reflect differences in damping behaviour. Since the

individual peak temperatures and tan δ values have not been provided in the accompanying text, it is not possible to establish conclusively whether increasing the filler content enhanced or reduced damping.

The reported trends may be compared with studies of natural-filler-reinforced polymer composites, including investigations involving almond shell particles and alkali-treated jute fibres (Essabir, 2013; Ray et al., 2021). Such comparisons should be made cautiously because the matrix polymer, filler composition, surface treatment, and DMA conditions may differ among studies.

3.2 Thermal Analysis

Thermal analysis was conducted to evaluate the thermal degradation behaviour of the groundnut shell powder, the rPP composites, and the unreinforced rPP matrix. Thermogravimetric (TG), derivative thermogravimetric (DTG), and differential thermal analysis (DTA) curves were used, as applicable to the recorded experimental data, to examine mass loss, degradation rates, and thermal events. The corresponding results are presented in Figs 4–6.

3.2.1 Thermogravimetric Analysis

3.2 Thermal Analysis

Thermal analysis was conducted to evaluate the thermal degradation behaviour of the groundnut shell powder, the rPP composites, and the unreinforced rPP matrix. Thermogravimetric (TG), derivative thermogravimetric (DTG), and differential thermal analysis (DTA) curves were used, as applicable to the recorded experimental data, to examine mass loss, degradation rates, and thermal events. The corresponding results are presented in Figs. 4–6.

3.2.1 Thermogravimetric Analysis

Fig. 4 compares the thermogravimetric (TG) curves of Sample A (groundnut shell powder), Samples B–E (composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced rPP). The TG curves show the variation in sample mass with increasing temperature and provide information about moisture loss, the degradation of organic constituents, and the thermal decomposition of the polymer matrix.

The groundnut shell powder exhibited two principal mass-loss regions. The first occurred between approximately 25 and 100 °C and was attributed mainly to the removal of moisture and other volatile constituents. The second occurred between approximately 200 and 380 °C and was associated with the thermal decomposition of lignocellulosic constituents, including hemicellulose, cellulose, and lignin. These components degrade over overlapping temperature intervals, and their individual contributions cannot be distinguished reliably from the TG curve alone. The observed behaviour is broadly consistent with the established thermal-degradation characteristics of lignocellulosic biomass (Bam et al., 2023; Abisha et al., 2023; Parparita, 2014).

The groundnut shell powder composites also exhibited mass-loss regions associated with the decomposition of the biomass filler and the polymer matrix. The first reported degradation region extended from approximately 230 to 418 °C and was attributed mainly to the decomposition of the lignocellulosic constituents. The second region extended from approximately 403 to 484 °C and was associated primarily with the degradation of the polypropylene matrix. The overlap between these temperature intervals indicates that the degradation processes were not completely separated.

The unreinforced rPP exhibited a principal decomposition region between approximately 400 and 484 °C. This behaviour provides a reference for assessing the thermal degradation of the composites relative to the polymer matrix. The presence of the additional lower-temperature degradation region in the filled composites is consistent with the contribution

of the lignocellulosic filler to the overall mass-loss behaviour.

The TG results therefore demonstrate that the composites undergo thermal degradation involving both the groundnut shell constituents and the polymer matrix. However, the claim that the composites retained the same thermal stability as unreinforced rPP requires quantitative confirmation using parameters such as the onset degradation temperature, temperature at a specified percentage of mass loss, maximum degradation temperature, and residual mass. The degradation intervals alone are insufficient to establish equivalent thermal stability. Relevant comparisons with previous work on biomass-derived fillers and polymer composites may provide additional context, provided that the cited studies examine comparable materials and conditions (Khalaf, 2015; Jacqueleen et al., 2024; Azzaoui et al., 2023).

3.2.2 Derivative Thermogravimetric Analysis

Fig. 5 presents the derivative thermogravimetric (DTG) curves for the groundnut shell powder, the groundnut shell powder–rPP composites, and the unreinforced rPP. DTG analysis represents the rate of mass change with temperature and helps identify the temperatures at which the principal degradation processes occur.

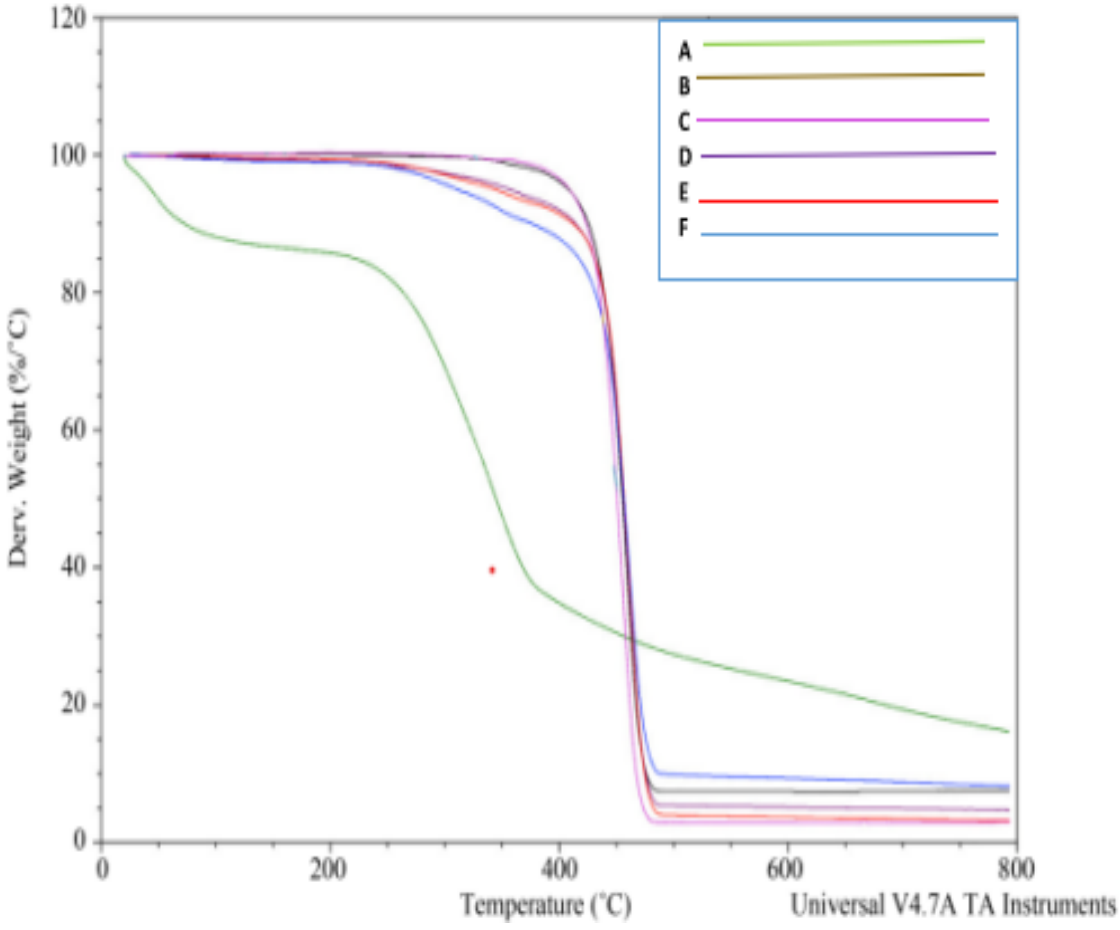


Fig. 4. Comparison of thermogravimetric (TG) curves for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene)

The rPP matrix and its composites exhibited a major degradation event at approximately 460 °C. This observation is consistent with the principal polymer-decomposition region identified in the TG curves in Figure 4. The similarity in the reported degradation temperature suggests that the polypropylene matrix remained the dominant contributor to the high-temperature degradation event across the formulations. Nevertheless, differences in peak intensity, peak width, or peak temperature would need to be quantified before determining whether groundnut shell powder altered the degradation kinetics of the matrix.The groundnut shell powder exhibited two reported DTG peaks, at approximately 47 and 345 °C. The first peak was attributed mainly to moisture loss and the release of volatile constituents, whereas the second was associated with the principal decomposition of lignocellulosic components. These assignments are consistent with the general thermal behaviour of biomass materials, although the exact contributions of cellulose, hemicellulose, and lignin cannot be resolved from the DTG curve alone (Jacob, 2019; Garcia-Garcia et al., 2015; Abisha et al., 2023).

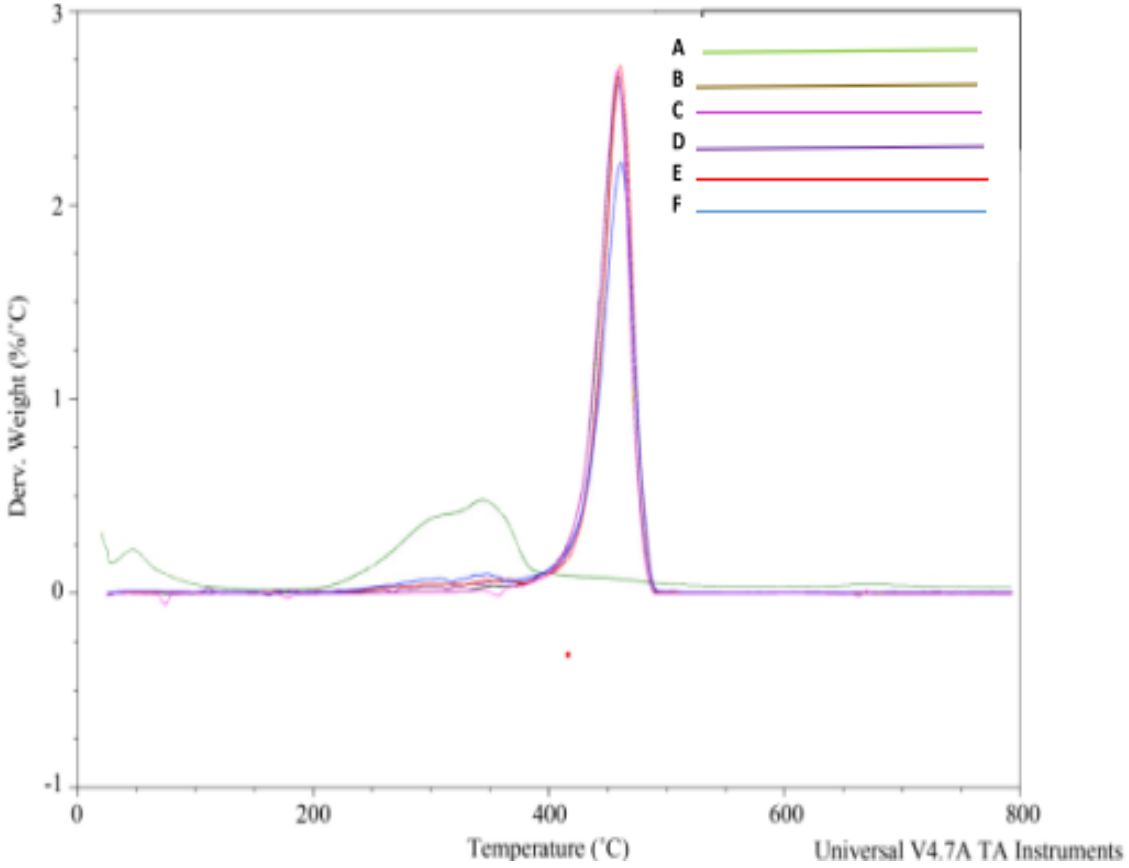


Fig. 5: Comparison of derivative thermogravimetric (DTG) curves for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene)

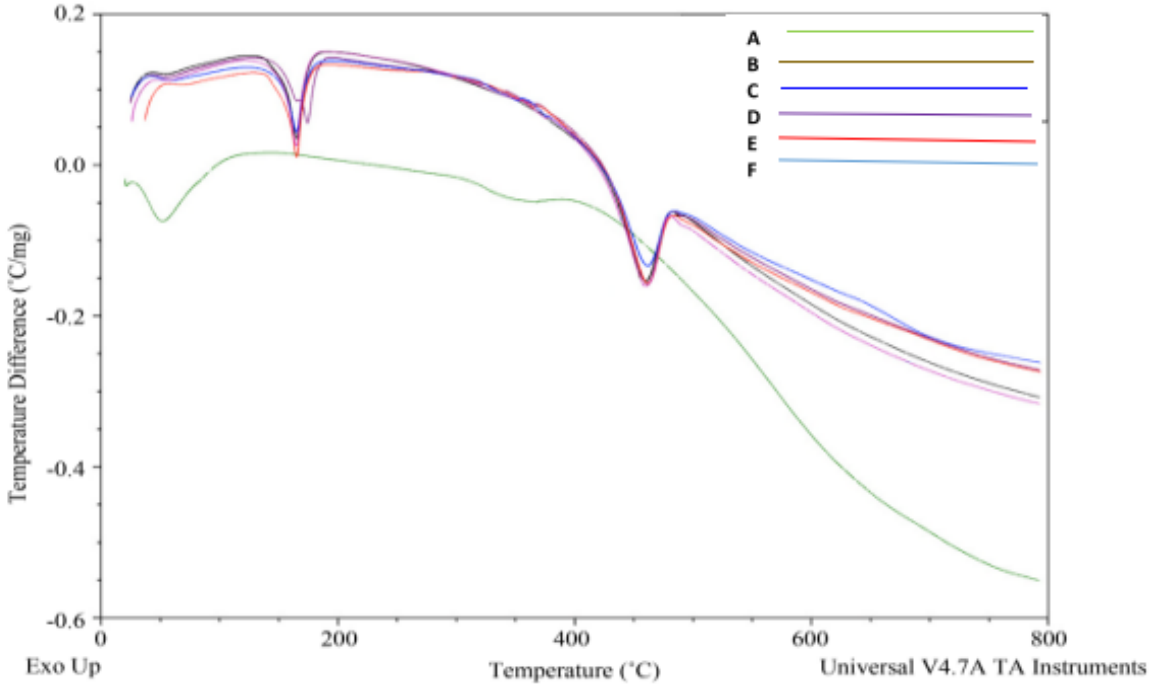
The composite containing 15 wt% groundnut shell powder was reported to exhibit the highest residual mass at 800 °C. This observation, if confirmed by the TG data, indicates that the formulation retained a greater proportion of its initial mass after heating to the

final test temperature. The higher residue may be associated with the increased proportion of biomass-derived constituents and the formation or retention of thermally persistent material. However, residual mass should not be interpreted directly as evidence of greater thermal stability because it may also reflect the inorganic content of the filler and the formation of char. The residual mass values and their relationship to filler loading should therefore be reported quantitatively.

Overall, the DTG curves complement the TG results by identifying the principal degradation events and providing a basis for comparing the degradation behaviour of the polymer matrix and its composites. A definitive assessment of the effect of groundnut shell powder on thermal stability requires comparisons of peak degradation temperatures, maximum degradation rates, and final residue values.

3.2.3 Differential Thermal Analysis

Fig. 6 presents the differential thermal analysis (DTA) curves for the groundnut shell powder, the rPP composites, and the unreinforced rPP. The reported thermal events for the polymer-containing samples occurred at approximately 160 and 460 °C. The event near 160 °C was attributed to the melting of polypropylene, whereas the higher-temperature event was associated with thermal decomposition.



Fig/ 6: Comparison of differential thermal analysis (DTA) curves for Sample A (groundnut shell powder), Samples B–E (rPP composites containing 1, 5, 10, and 15 wt% groundnut shell powder, respectively), and Sample F (unreinforced recycled polypropylene). Confirm whether the plotted signal represents DTA or DSC before finalising the caption

The thermal event near 160 °C is consistent with the melting behaviour commonly reported for polypropylene. Its presence in the composite curves indicates that the polymer matrix retained a melting-related transition after the incorporation of groundnut shell powder. The event near 460 °C corresponds broadly to the principal degradation region observed in the TG and DTG curves in Fig. 4 and 5, respectively. This agreement among the thermal-analysis results supports the interpretation that the principal high-temperature event is associated with the degradation of the polymer matrix.

The groundnut shell powder exhibited thermal events near 50 and 350 °C. The lower-temperature event was attributed mainly to moisture loss and the release of volatile constituents, while the event near 350 °C was associated with the decomposition of lignocellulosic components. These assignments are consistent with the mass-loss regions observed in Figures 4 and 5. Similar thermal events have been discussed in studies of biomass-based materials and natural-filler composites (Egere et al., 2025; Jacob et al., 2023), subject to confirmation that the cited publications support these specific interpretations.

The thermal events observed in the composites suggest that the addition of groundnut shell powder did not eliminate the characteristic melting-related behaviour of the polypropylene matrix. However, the available descriptions do not establish whether filler incorporation caused statistically or practically significant changes in the melting temperature, peak intensity, or degradation temperature. These effects should be evaluated from the actual thermal curves and the corresponding numerical data.

It is also important to verify the measurement mode used by the TA Instruments SDT Q600. If the instrument was operated in simultaneous thermogravimetric analysis and differential scanning calorimetry mode, the heat-flow results should be identified as DSC rather than DTA. The final figure caption and discussion must use the technique that corresponds to the recorded experimental data.

.0 Conclusion

This study investigated the dynamic mechanical and thermal properties of recycled polypropylene composites reinforced with groundnut shell powder at different loadings. The DMA results, presented in Figures 1–3, showed that the storage modulus, loss modulus, and damping factor varied with temperature and filler incorporation. The unreinforced rPP exhibited a storage modulus of 1,375 MPa at 25 °C, while the composite containing 15 wt% groundnut shell powder was reported to have a loss modulus of 67 MPa at the same temperature. The reported glass transition temperatures derived from the loss modulus and tan δ curves differed by no more than 7 °C, suggesting broadly comparable estimates from the two methods. The reported behaviour of the composites containing 1 and 5 wt% groundnut shell powder indicates that low filler loadings may preserve aspects of the viscoelastic response of the unreinforced polymer.

The thermal-analysis results, presented in Figures 4–6, revealed distinct degradation behaviour for the groundnut shell powder and the polymer-containing samples. The groundnut shell powder exhibited mass-loss regions associated with moisture release and lignocellulosic decomposition, whereas the composites displayed degradation regions attributable to the filler and polypropylene matrix. The major degradation event for the rPP matrix and its composites occurred at approximately 460 °C. The composite containing 15 wt% groundnut shell powder was reported to have the highest residual mass at 800 °C; however, this observation requires confirmation from the quantitative TG data and does not, by itself, establish superior thermal stability.

Among the formulations investigated, the composite containing 5 wt% groundnut shell powder was identified as a potentially promising formulation because its reported dynamic mechanical response was comparatively close to that of the unreinforced rPP. Nevertheless, a definitive recommendation requires comparison of the numerical storage modulus, loss modulus, damping factor, degradation temperatures, and residual mass for all formulations. The results demonstrate the potential for valorising groundnut shell waste through incorporation into recycled polypropylene, although the suitability of the

resulting composites for particular applications must be established through additional performance testing. Further investigations of tensile and flexural properties, impact resistance, water absorption, filler–matrix interfacial characteristics, durability, and environmental performance would help determine their practical applicability. The study therefore provides a basis for further development of waste-derived polymer composites while highlighting the need for quantitative property comparisons before selecting an optimal formulation.

Acknowledgement
The author appreciates and acknowledges funding from the Tertiary Education Trust Fund under the Institutional Based Research Intervention with the grant allocation number 'TETF/DR&D/CE/UNI/NSUKIBR/2025/VOL.1'.

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Declaration

Conflict of interest

The authors declare that they have no conflict of interest.

Availability of Data

Data shall be made available upon request

Ethical Consideration

Not applicable

Funding

This research was funded by the Tertiary Education Trust Fund under the Institutional Based Research Intervention with the grant allocation number 'TETF/DR&D/CE/UNI/NSUKIBR/2025/VOL.1'.

Author Contributions

All components of the work were carried out by the authors