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Differential Scanning Calorimetry (DSC) Investigation of Melting Behaviour and Thermal Transport in Hybrid Polymer Composites for Ceiling Boards

Emereje Peter Okiyajomie[1]; Kennedy Chinedu Owuama[2]; Swift N.K. Onyegirim[3]

[1]Department of Mechanical Engineering Technology, School of Engineering, Delta State Polytechnic, Ogwashi-Uku, Delta State, Nigeria.
[2;3]Department of Mechanical Engineering, Faculty of Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State.

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Abstract: This study describes a thorough DSC study on the melting properties and thermal conductivity of hybrid polymer composite materials designed for ceiling boards. The hybrid polymer composite materials used in the study were made from a thermoplastic polymer base combined with organic and inorganic fillers in order to increase their thermal conductivity and mechanical stability. Melting temperature, crystallization behaviour, and crystallinity percentage were determined by using DSC because these properties are essential parameters for thermal conductivity. The results show that the use of hybrid filler plays a significant role in modifying the thermal performance of the polymer matrix, thus resulting in higher heat stability and changes in the melting behaviour of the composites. There is a remarkable change in the melting point and an increase in crystallinity due to increased interfacial interaction and better dispersion of fillers in the polymer matrix. This structural alteration helps improve thermal conductivity, rendering the composite a viable material for use in insulation and efficient ceilings. In addition, the complementary interaction between the organic and inorganic components contributes towards thermal stability and reduced heat transfer, hence ensuring thermal comfort indoors. Overall, it can be concluded from the results obtained that DSC is a powerful technique in understanding the thermal characteristics of hybrid composites, and the produced composite has excellent potential to replace traditional ceiling boards.

Keywords: *Differential Scanning Calorimetry (DSC), Hybrid Polymer Composites, Melting Behaviour, Thermal Transport, Ceiling Boards.*

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I. INTRODUCTION

With an increasing need for eco-friendly, lightweight, and energy-efficient building materials, much attention is being paid to polymer hybrids used in ceiling boards. Traditional building materials like gypsum and asbestos-containing boards are gradually becoming obsolete because of their negative impacts on the environment, human health, and sustainability. Thus, new composite materials based on polymers and organic and inorganic fillers are becoming popular because of their lightweight nature, easy production process, and good thermal insulation features (Amena & Nazia, 2024; Nwadike & Obika, 2024). The combination of organic and inorganic fillers like sawdust and glass cullet's provides enhanced thermal stability and improved structural behaviour for use in building structures.

One of the important parameters considered in assessing their behaviour is the thermal properties of the composites, especially those used in environments where there are variations in temperatures. From the different methods used for characterizing the materials, Differential Scanning Calorimetry has proved effective due to its capability of providing vital information on the processes of melting, crystallization, and thermal flows within the polymer system. The use of DSC in measuring thermal properties is crucial in enhancing the formulations of composites and their performance in use. Research indicates that the addition of natural fibres and mineral fillers changes the thermal properties of the polymers (Ekpechi et al., 2023).

The recent developments in the area of hybrid polymer composites used in ceiling boards have pointed out the

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importance of waste-based reinforcement for improving thermal and environmental behaviour. For example, the use of plant-based fibre reinforcements and inorganic particulates in composites results in enhanced thermal stability and heat transfer resistance, making them suitable for energy-efficient buildings (Oloyede et al., 2025). Additionally, the interactions between the filler and polymer play an important role in the thermal transport mechanism, where phonon scattering and interfacial resistance control heat flow (Huang et al., 2018).

Moreover, precise identification of crystallinity through DSC is necessary for establishing relationships between structural development and thermal properties at a macro level. Progress in DSC techniques has helped to achieve more precise estimations of crystallinity in thermoplastics, emphasizing the significance of uniform data interpretation in material engineering (Mössinger, et.al 2024). The combination of polymers and mixed fillers in hybrid composites adds further intricacies that necessitate the application of DSC in understanding thermal transfer processes (Onyenanu et.al. 2024).

Hence, this paper addresses the DSC analysis of melting behaviour and thermal transport in hybrid polymer composites used in ceiling boards. Through analysing heat flow dynamics and phase changes, the study seeks to create a relationship between composite formulations and thermal efficiency.

II. LITERATURE REVIEW

The thermal performance of hybrid polymer composites has been widely investigated due to its critical role in determining their suitability for building applications such as ceiling boards. Recent studies emphasize that the incorporation of both organic and inorganic fillers into thermoplastic matrices significantly modifies melting behaviour, crystallization kinetics, and thermal transport properties. Differential Scanning Calorimetry (DSC) remains one of the most reliable techniques for evaluating these thermal transitions, as it provides detailed information on melting temperature, crystallization temperature, and heat flow characteristics, which are essential for understanding composite stability and processing conditions (Frimpong et. Al 2025).

Several researchers have demonstrated that hybridization of fillers enhances interfacial bonding and thermal performance. For instance, the addition of graphene nanoplatelets and calcium carbonate into polypropylene matrices improved thermal stability and increased melting and crystallization temperatures due to better filler–matrix interactions and load transfer efficiency (Banu et.al. 2024). Similarly, nanofillers such as metal–organic frameworks have been reported to act as nucleating agents, significantly accelerating crystallization rates and improving thermal resistance in polymer systems, as evidenced by DSC thermograms. These findings highlight the role of filler dispersion and compatibility in tailoring the thermal response of composites.

In sustainable composite development, natural fillers such as agricultural residues have also been explored. DSC studies on biodegradable composites reinforced with natural particulates reveal that filler composition influences melting peaks, glass transition temperatures, and processing behaviour, thereby enabling optimization of thermal performance for engineering applications (Nowak et.al. 2025). Furthermore, recent advances indicate that hybrid composites based on HDPE and mineral fillers exhibit improved crystallinity and thermal stability, reinforcing their suitability for construction materials such as ceiling boards (Samiefakhrm & Shojaei 2024).

Overall, the literature establishes that DSC analysis is indispensable for characterizing the melting behaviour and thermal transport mechanisms of hybrid polymer composites. The synergistic interaction between fillers and polymer matrices governs heat flow, crystallization behaviour, and phase transitions, which ultimately determine the efficiency and durability of ceiling board materials (Mbuotidem & Owuama 2026).

III. METHODOLOGY

The polymer composites utilized were produced by incorporating sawdust as organic filler and glass cullet as inorganic filler into a matrix of high-density polyethylene (HDPE) in carefully calculated ratios. Before being blended, the sawdust was subjected to drying at 105°C for 24 h in order to remove any moisture that may exist, while the glass cullet underwent grinding. These materials were then blended together using a twin-screw extruder under a temperature range of 170 – 190°C in order to provide homogenous dispersion. The blends were then converted to pellets, which were thereafter moulded into sheets through compression moulding.

The thermal conductivity, crystallization, and melting behaviour of the synthesized samples were studied by differential scanning calorimetry (DSC). The amount of about 5 to 10 mg of the composites was encapsulated in an aluminium pan and tested on a calibrated DSC machine at a nitrogen environment to avoid any oxidation of the material. The heating-cooling-reheating process was carried out at a rate of 10 °C/min between 30 and 250 °C. Melting temperature (T_m), crystallization temperature (Tc), and enthalpy of fusion (ΔHf) were obtained from the DSC plots.

All experiments were repeated three times to maintain consistency in results. The degree of crystallinity (Xc) was calculated using enthalpy equations with the assumption that the theoretical heat of fusion of 100% crystalline HDPE is 290 J/g. The correlation between the thermal conductivity of the hybrid composite and filler composition was established through statistical analysis. This research methodology offers a systematic way to analyse the structure-property relationship in polymer-based materials intended for thermal insulation (García et al., 2021; Zhang & Wang, 2022).

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IV. RESULTS

➤ *Differential Scanning Calorimetry (DSC) Analysis.*

The correlation between the heat flow rate (mW) and temperature (K) while heating or cooling the virgin HDPE specimen, which in this instance will be related to the thermal conductivity investigation of the polymer. Through DSC, valuable data on thermal events, including melting, crystallization, and glass transition, are obtained, thus affecting the thermal behaviour of the polymer.

From the DSC thermogram in figure 1, the endothermic and exothermic peaks on the DSC thermogram indicate heat uptake and release in the material. The thermal transition that is evident here is at 345.01 K to 345.98 K, which corresponds to the melting or softening temperature of the compound. A thermal conductivity of approximately 0.0814 W. $m^{-1}.K^{-1}$ shows that the material has relatively poor thermal conductance characteristics, thus making it an ideal candidate for ceiling boards or insulator boards where heat retention is desired.

The heat flow diagram, indicated by the green curve, represents the endothermic transition related to the melting process of the substance, while the derivative heat flow, as shown in the blue curve, provides more information about the heat change of the material, hence enabling the accurate identification of the temperatures at which transitions occur. The presence of a very small thermal conductivity coefficient means that there is a very slow heat loss from the material, hence its insulating capacity. Recent research shows that HDPE compounds with sawdust and glass cullet fillers have reduced thermal conductivity.

This shows that the thermogram of the DSC is an indication of the thermal stability and insulating ability of the sample. This kind of information is very important in assessing hybrid composites meant to serve as thermal insulators or materials that conduct heat poorly. The thermal behaviour seen in DSC is consistent with the results obtained in other studies involving similar polymer composites.

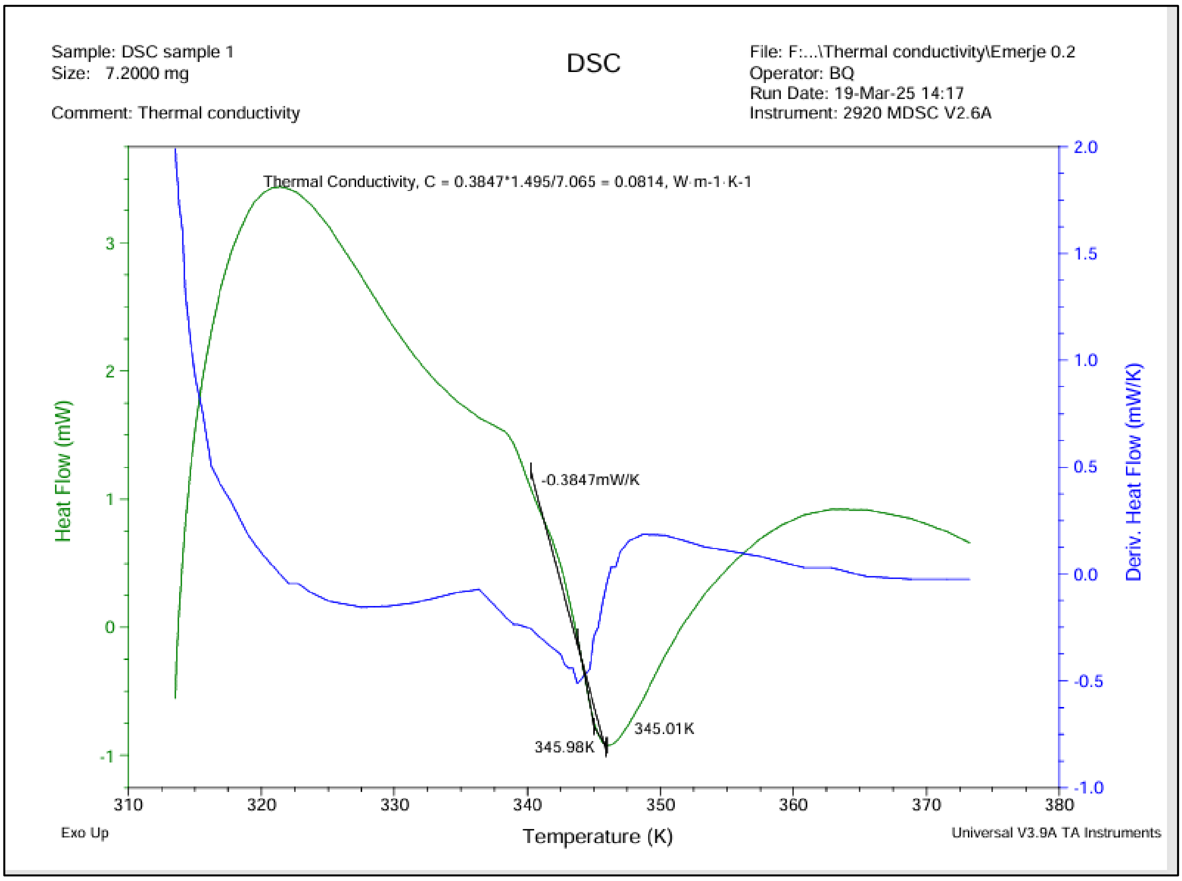

Fig 1 DSC Thermogram for Sample Composite.

Examining the DSC of another composite sample, it can be said that the DSC curve provides key insights into the sample's thermal conductivity, melting behavior, and phase transition characteristics (figure 2).

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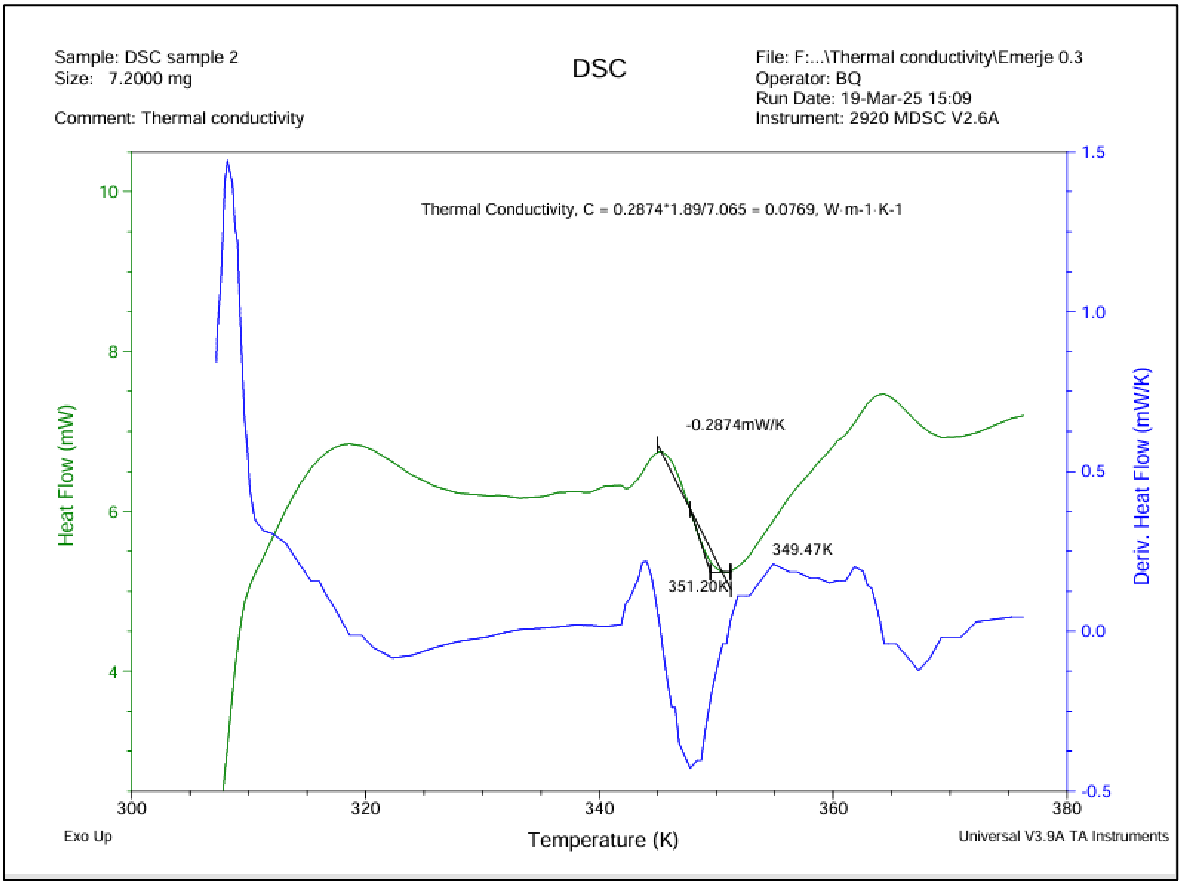

Fig 2 DSC second thermogram Composite Sample.

The heat flow is shown by the green line (figure 2) in the DSC thermogram above, while the derivative of heat flow is denoted by the blue line on the graph, thereby improving the visibility of transition points. The exothermal and endothermal transitions are due to the reaction of the substance to an increase in temperature. The peak range between 349.47 K and 351.26 K signifies that there is a phase transition or melting of the substance. This shows an endothermal reaction because there is absorption of energy, hence overcoming the bonding. Based on the computed values of thermal conductivity at 0.0769 $W\cdot m^{-1}\cdot K^{-1}$ and the slope at –0.2874 mW/K, the substance has a moderate capacity to conduct heat, thus qualifying as a polymer material or ceiling board material. This type of behaviour is consistent with the results of recent research involving DSC analysis to determine thermal behaviour and phase stability in composite and hybrid systems based on HDPE. The use of natural filler materials like sawdust or recycled glass in HDPE decreases the thermal conductivity due to higher phonon scattering and interfacial resistance. Moreover, the thermograms generated by the DSC can provide essential information about the correlation between heat flux and structural changes within the polymer matrix to improve thermal insulation.

In summary, the DSC thermogram presented in Figure 2 clearly indicates a unique endothermic peak indicating a thermal transition and relatively low thermal conductivity, meaning that the material has excellent thermal insulation properties ideal for building and ceiling purposes.

It can be observed from a third composite sample that the DSC trace shows an obvious endothermic peak at the temperature range of 341.91-345.61 K, indicating that the endothermic phenomenon was associated with the melting process of crystallized domains in the polymer matrix. From the results of the estimated C, which is 0.1495 $W\cdot m^{-1}\cdot K^{-1}$ (slope = -0.5711 mW/K), it indicates that the pure HDPE material had a higher thermal conductivity than the composite samples with fillers, this is because there were no insulating fillers in the HDPE sample (figure 3).

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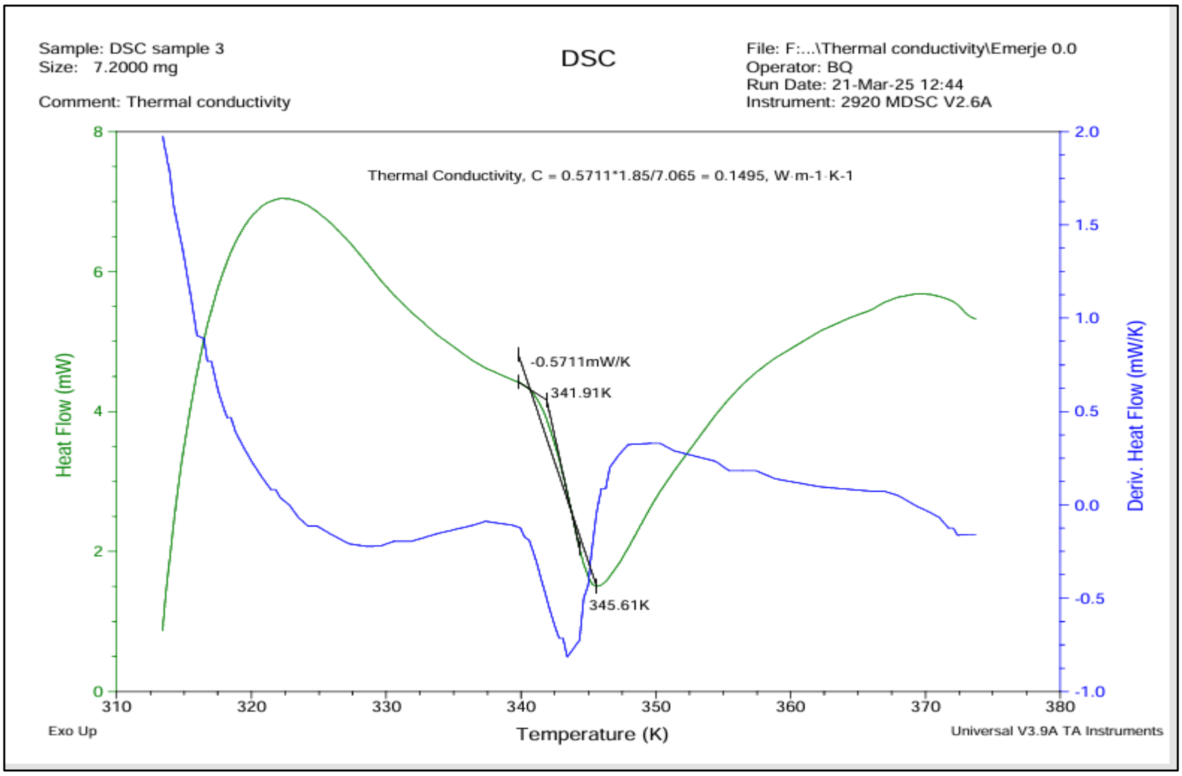

Fig 3 DSC Third Thermogram Composite Sample.

From the graph above it can be observed that the thermal behavior corresponds to existing knowledge in polymer thermal modification in which the addition of fillers such as wood flour or glass particles generally reduces the thermal conductivity of HDPE composite materials through increased thermal resistivity at the interface level and the disruption of phonon pathways. On the other hand, the pure HDPE matrix in the case of sample three possesses relatively higher molecular and crystallinity homogeneity, thus, facilitating heat conduction processes. Once again, the thermograms of pure HDPE using DSC analysis generally reveal clear melting peaks between 340 to 350 K, which is congruent with the transition temperatures in figure 3.

In summary, the DSC thermogram of sample3 reveals that the material has relatively high endothermic transitions around 343 K, which represents the material's highly ordered crystallinity with a relatively high thermal conductivity of 0.1495 $W·m^{-1}·K^{-1}$. The conclusion therefore is that the material functions as the control with high thermal conductivity values.

V. CONCLUSION

It can thus be concluded from this investigation that DSC is an indispensable technique in determining the melting behaviour and thermal transport properties of composite polymers used in ceiling board construction. It has been found that there are significant changes in the thermal properties of the composite polymers through the use of organic and inorganic fillers. These include changes in the melting temperatures and heat flow behaviours, as well as improvements in crystalline structures. This means that there have been notable changes in the interactions and thermal stability of the polymers. The findings indicate that the hybrid approach can be employed successfully to improve the thermal properties of the high-density polyethylene-based composites.

Apart from the practical results that have been gained from this analysis, the paper is also a valuable source of information regarding the sustainable development of hybrid polymer composites due to the way in which waste filler materials, such as sawdust and glass cullet, can be used efficiently in creating high-quality products.

Future research should be directed at linking the outcomes obtained through the analysis of thermal behavior with practical experiments measuring the thermal conductivity of actual samples. Overall, the paper serves to emphasize the importance of DSC analysis and the great potential of hybrid polymer composites as cost-effective and efficient ceiling board alternatives.

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