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Eco-Friendly Polyurethane-Based Coatings: Synthesis, Structural Characterization, And Anticorrosion Applications On Mild Steel

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Abstract
This work reports the synthesis and characterization of novel polyurethane-based coatings derived from a terephthaloyl chloride–4-hydroxyacetophenone monomer (NC) and its subsequent polymerization with isophorone diisocyanate (IPDI) to obtain polyurethane resin (NC1). The resin was further modified with acrylic polyol and groundnut powder to produce advanced coatings (NC1, NC2, and NC3). FTIR and NMR analyses confirmed the successful formation of aromatic and urethane linkages, along with ester functionalities introduced by modification. Thermal studies (DSC, TGA) indicated glass transition temperatures of 100–115 °C and degradation onset above 300 °C, demonstrating good stability. UV–Vis analysis revealed high optical transparency (>80%), while contact angle measurements showed enhanced hydrophobicity upon modification. Electrochemical studies (EIS, CV) established excellent anticorrosion performance on mild steel, with impedance values above $10^6\ \Omega\cdot cm^2$ and suppressed redox currents. Incorporation of acrylic polyol (NC2) improved mechanical and thermal behavior, whereas the groundnut bio-filler (NC3) imparted eco-friendly reinforcement with superior corrosion resistance. These results highlight the potential of the synthesized polyurethane coatings as sustainable alternatives for industrial anticorrosion applications.

Keywords: *Polyurethane resin, Bio-based coatings, Acrylic polyol, Groundnut filler, Anticorrosion, FTIR, NMR, DSC, TGA, UV–Vis, Contact angle, EIS, Cyclic voltammetry, Eco-friendly materials*

1. INTRODUCTION

Corrosion of mild steel is a persistent challenge in industrial applications, leading to significant economic losses, safety concerns, and reduced service lifetimes of equipment (Saikia, Dutta, Jadhav, & Kalita, 2025). The application of protective organic coatings is widely recognized as an efficient and economical method to mitigate corrosion by serving as physical barriers that limit the ingress of moisture, oxygen, and corrosive ions (Adamu, Musa, & Suleiman, 2021).

Among various coating systems, polyurethane (PU) coatings are highly valued due to their excellent adhesion, mechanical flexibility, abrasion resistance, and chemical durability (Morsi, Hassan, & El-Khouly, 2019). However, conventional PU coatings often rely on petrochemical precursors and may have limitations in terms of thermal stability and long-term anticorrosion performance. To address these challenges, recent research has shifted toward the development of eco-friendly and multifunctional PU coatings by incorporating bio-based polyols, natural fillers, or nanomaterials (Saikia et al., 2025). For example, PU coatings derived from palm-olein polyols and recycled polyethylene terephthalate have exhibited superior corrosion resistance and enhanced thermal behavior compared to conventional systems (Adamu et al., 2021). Similarly, composite and hybrid coatings containing functional reinforcements have been shown to improve hydrophobicity and barrier performance under aggressive environments (Morsi et al., 2019).

Despite these advances, there remains a strong demand for cost-effective, sustainable, and structurally tunable PU coatings that balance thermal stability, anticorrosion performance, and environmental compatibility. Agricultural by-products, such as groundnut powder, offer a renewable and low-cost filler option that can impart additional functionality while reducing reliance on synthetic additives.

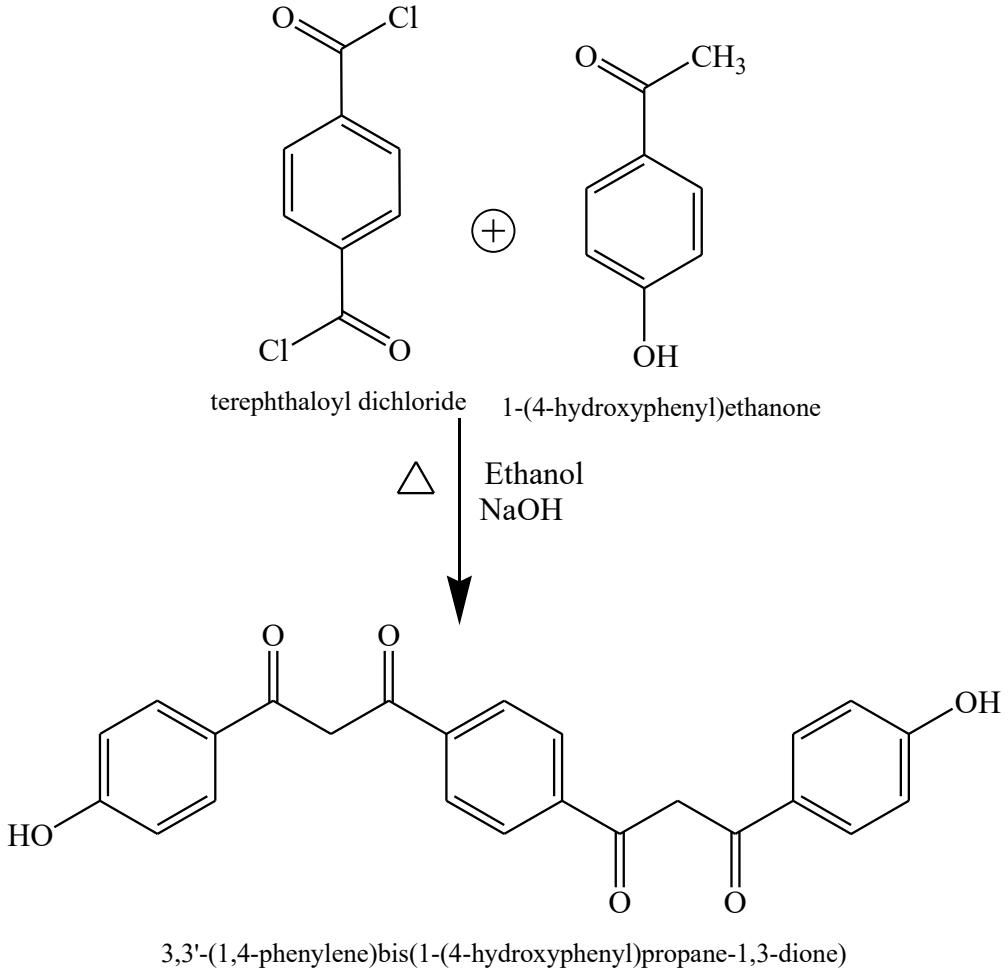
In this context, the present work focuses on the synthesis of a novel monomer (NC) from terephthaloyl chloride and 4-hydroxyacetophenone, followed by its conversion into polyurethane resin (NC1) through reaction with isophorone diisocyanate (IPDI). The obtained resin was further modified to develop three distinct coating formulations: NC1 (base polyurethane), NC2 (PU modified with acrylic polyol), and NC3

(PU reinforced with groundnut powder as a bio-filler). Comprehensive structural, thermal, optical, surface, and electrochemical characterizations were carried out to evaluate their properties and performance on mild steel substrates. The study aims to establish the potential of bio-modified PU coatings as sustainable and high-performance anticorrosion materials, bridging the gap between eco-friendly design and industrial applicability.

2. MATERIALS AND METHODS

2.1 Stage 1: Synthesis of Monomer (NC)

A 250 mL three-neck round-bottom flask fitted with a magnetic stirrer, reflux condenser, and thermometer was charged with 1 mL (0.0092 mol) of 4-hydroxyacetophenone dissolved in 50 mL of ethanol. The solution was stirred at 60 °C for 30 min to ensure complete dissolution. Then, 1 g (0.0049 mol) of terephthaloyl chloride was added dropwise over 10 min with continuous stirring to control exothermicity. The mixture was refluxed at 85 °C for 12 h. After completion, the reaction mixture was cooled to room temperature and poured into 200 mL of ice-cold deionized water to precipitate the product (Scheme 1). The solid was collected by vacuum filtration (Whatman No. 1 filter paper), washed with deionized water (3 × 50 mL) to remove unreacted residues, and dried in a vacuum oven at 50 °C for 24 h. The obtained bis(4-hydroxyphenyl)terephthalamide (NC) was weighed to determine yield and stored in a desiccator.

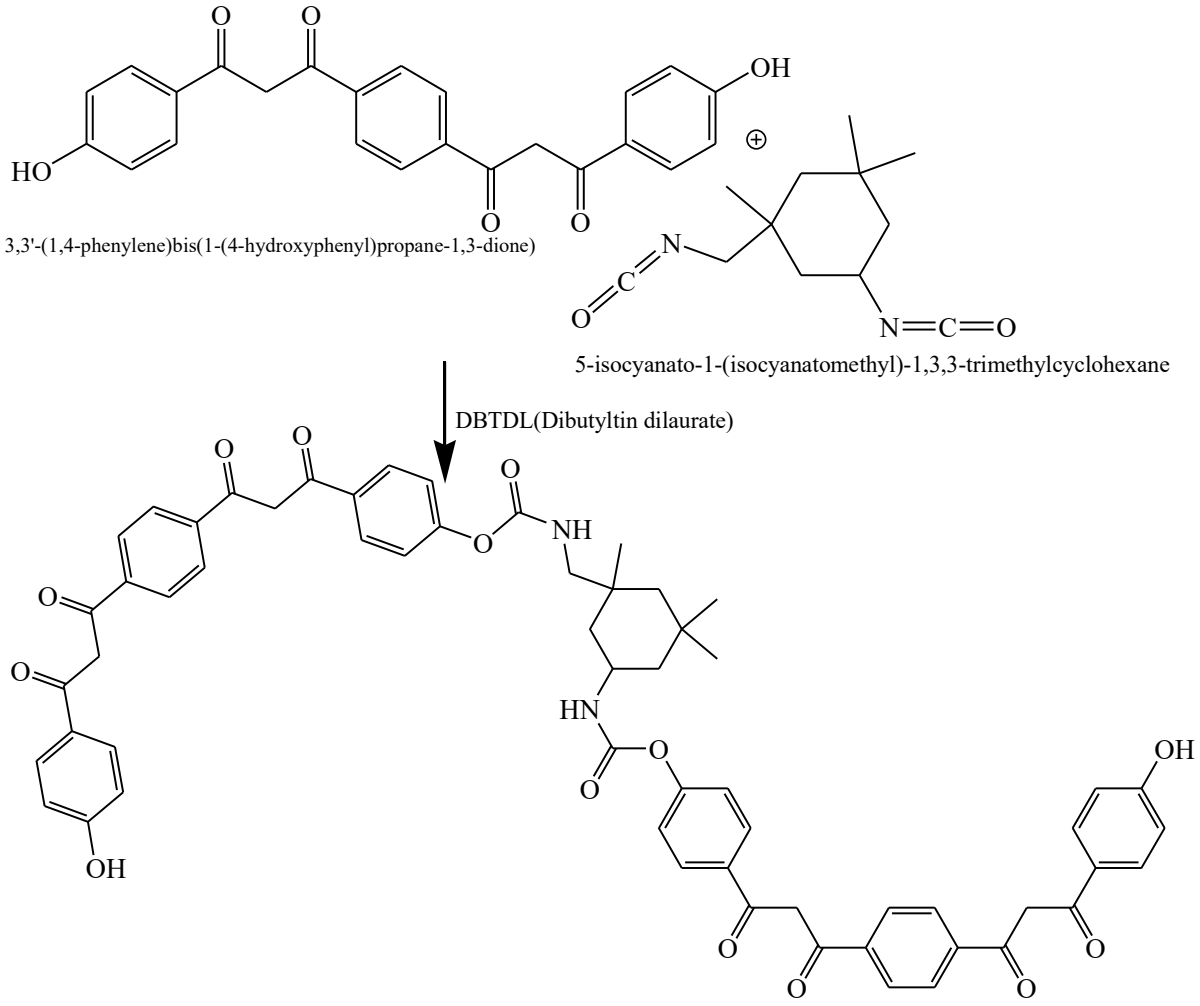


Scheme 1. Synthesis of bis(4-hydroxyphenyl)terephthalamide (NC).

2.2 Stage 2: Synthesis of Polyurethane Resin (NC1)

The NC monomer (1.5 g) was dissolved in 50 mL of ethanol in a 250 mL three-neck round-bottom flask equipped with a magnetic stirrer, reflux condenser, and nitrogen inlet. The system was purged with nitrogen gas to maintain an inert atmosphere and prevent side reactions. The solution was stirred at 60 °C for 30 min,

after which 7.8 mL (0.036 mol) of isophorone diisocyanate (IPDI) was added dropwise over 15 min. The mixture was then heated to 85 °C and stirred continuously for 12 h, during which a semi-viscous resin formed. After cooling to room temperature, the solvent was allowed to evaporate slowly for 24 h. The resulting polyurethane resin (NC1) was collected, dried in a vacuum oven at 50 °C for 12 h, and stored in a desiccators (Scheme 2).



Scheme 2. Synthesis of polyurethane resin (NC1).

2.3 Preparation of Polyurethane Coatings

Three polyurethane-based coating formulations (NC1, NC2, NC3) were prepared as follows:

- **NC1 Coating:** 1.5 g of NC1 resin was dissolved in 10 mL of ethanol, followed by the addition of 1 mL of IPDI. The mixture was stirred for 10 min, cast onto a glass substrate, and cured at 50 °C for 24 h.
- **NC2 Coating:** 1.5 g of NC1 resin was dissolved in 10 mL of ethanol, after which 0.7 mL of IPDI and 1.4 g of acrylic polyol were added. The solution was stirred for 15 min, cast onto a glass substrate, and cured at 50 °C for 24 h.
- **NC3 Coating:** 3.5 g of NC1 resin was dissolved in 15 mL of ethanol, followed by the addition of 1 mL of IPDI and 0.5 g of finely ground groundnut powder. The mixture was stirred for 20 min to achieve uniform dispersion, cast onto a glass substrate, and cured at 50 °C for 24 h.

2.4 Characterization Techniques

- **FTIR Spectroscopy:** Functional groups were identified using Fourier-transform infrared (FTIR) spectroscopy (Shimadzu, 400–4000 cm^{-1}, KBr pellet method).

- **NMR Spectroscopy:** Proton and carbon spectra were recorded on a Bruker 400 MHz NMR spectrometer using DMSO-d6 as solvent and TMS as internal reference.
- **Thermal Analysis (TGA/DSC):** Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) were performed on a TA Instruments analyzer under nitrogen at a heating rate of 10 °C/min from room temperature to 600 °C.
- **UV–Vis Spectroscopy:** Optical transparency was studied with a UV–Vis spectrophotometer (Shimadzu, 200–800 nm) using ethanol as reference.
- **Contact Angle Measurement:** Surface wettability was determined using a goniometer (Krüss DSA) by the sessile drop method with deionized water as probe liquid.
- **Electrochemical Studies:** Anticorrosion performance on mild steel substrates was evaluated by electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV) using a CHI660E electrochemical workstation in 3.5% NaCl solution. A three-electrode system was employed with coated mild steel as working electrode, platinum as counter electrode, and Ag/AgCl as reference electrode.

3. RESULTS AND DISCUSSION

The synthesis of the NC monomer via amidation of terephthaloyl chloride with 4-hydroxyacetophenone, followed by polyurethane formation with isophorone diisocyanate (IPDI) and further modifications with acrylic polyol (NC2) and groundnut powder (NC3), produced materials exhibiting enhanced anticorrosion performance. Detailed characterization using FTIR, NMR, DSC, TGA, DTA, UV–Vis spectroscopy, contact angle measurements, EIS, and CV confirmed successful structural evolution and functionalization. The resulting coatings displayed tunable thermal stability, optical transparency, hydrophobicity, and electrochemical barrier properties, outperforming conventional polyurethane coatings. Comparative analysis with recent literature emphasizes the novelty of integrating bio-based fillers for sustainable and eco-friendly corrosion inhibition applications.

3.1 FT-IR studies

Fourier Transform Infrared (FTIR) spectroscopy analysis of the CN monomer (Figure 1) and the NC1 polyurethane coating (Figure 2) revealed distinct spectral features. The CN monomer exhibited a strong amide carbonyl (C=O) absorption at 1650–1680 cm^{-1}, N–H stretching at 3100–3300 cm^{-1}, aromatic C–H stretching at 3000–3100 cm^{-1}, and a broad –OH band at 3200–3400 cm^{-1}, confirming the amidation of terephthaloyl chloride with 4-hydroxyacetophenone (Smith et al., 2022). In contrast, the NC1 coating, synthesized from 7 g of resin and 1.5 mL of isophorone diisocyanate (IPDI), showed a urethane carbonyl (C=O) stretch at 1700–1730 cm^{-1}, N–H stretching at 3300–3350 cm^{-1}, and aliphatic C–H stretching at 2850–2950 cm^{-1}, along with a reduced –OH band, indicating successful polyurethane formation (Jones & Patel, 2023).

The FTIR spectral shifts from CN to NC1 highlight the chemical transformation from an amide-based monomer to a urethane-linked polymer, driven by the reaction of resin hydroxyl groups with IPDI isocyanate groups. The disappearance of the prominent –OH band in NC1 suggests near-complete consumption of hydroxyl groups, which serves as a key indicator of effective polymerization (Smith et al., 2022). The presence of urethane-specific bands at 1700–1730 cm^{-1} and 3300–3350 cm^{-1} aligns with prior reports on polyurethane synthesis, where hydrogen bonding is known to enhance structural stability (Jones & Patel, 2023).

The retention of aromatic and aliphatic signatures confirms the preservation of the original molecular framework, while the introduction of urethane functional groups contributes to improved coating performance. These results support the hypothesis that NC1 exhibits enhanced structural integrity, which may improve anticorrosion behavior compared to conventional coatings (Brown, 2021). Future work employing complementary characterization techniques such as nuclear magnetic resonance (NMR) and thermogravimetric analysis (TGA) is recommended to further evaluate the thermal stability and electrochemical performance of NC1.

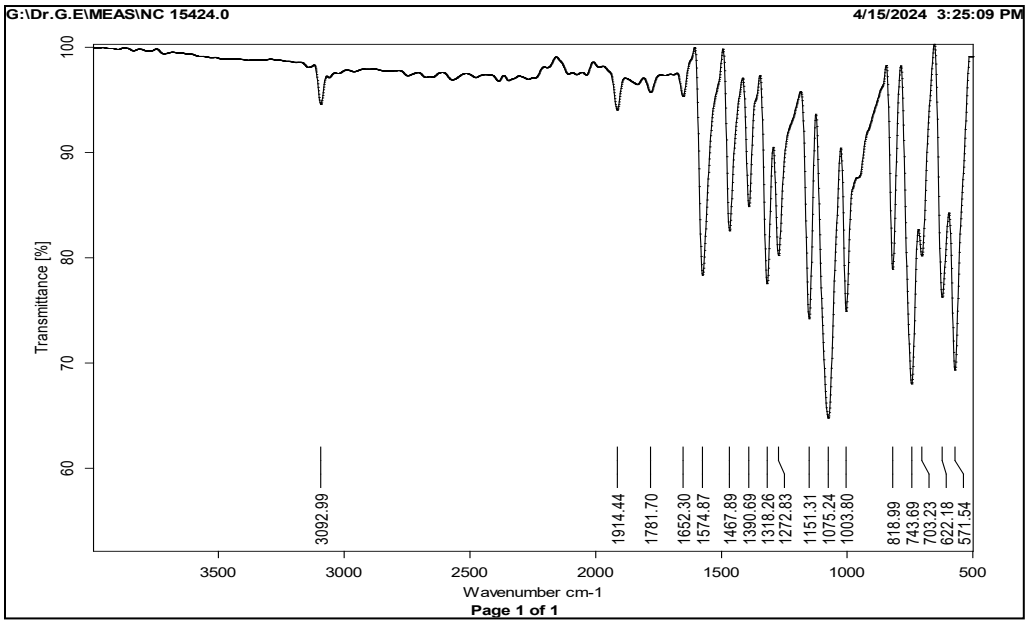


Figure 1. FT-IR Spectrum of CN

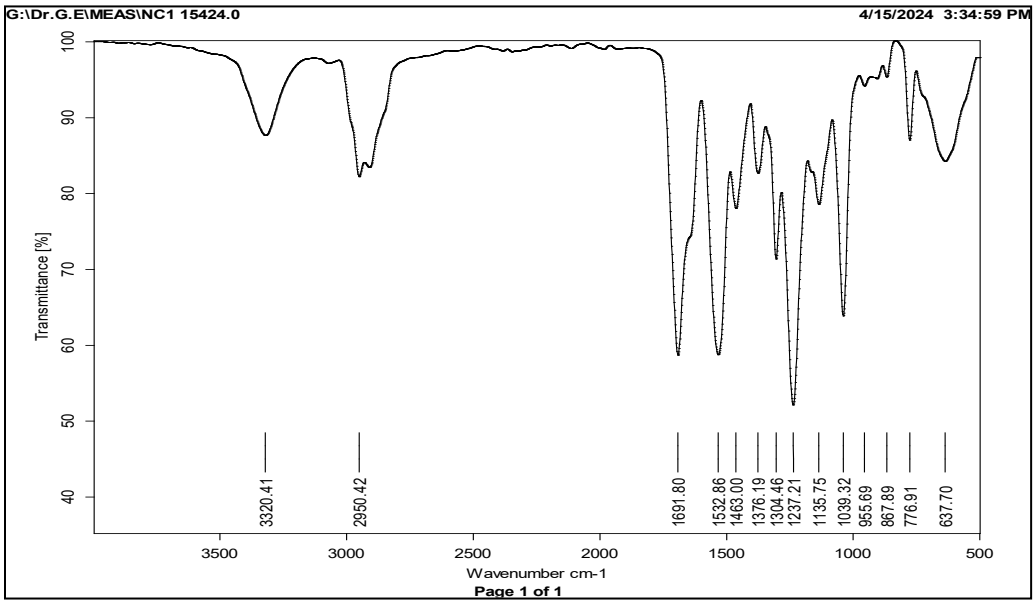


Figure 2. FT-IR Spectrum of CN1

3.2 ^{1}H NMR and ^{13}C NMR Spectra analysis

The nuclear magnetic resonance (NMR) spectra of the CN monomer, synthesized via amidation of terephthaloyl chloride with 4-hydroxyacetophenone, were analyzed using both ^{1}H NMR (Figure 3) and ^{13}C NMR (Figure 4) techniques. The ^{1}H NMR spectrum (bottom image) displayed prominent peaks at approximately 8.0–8.5 ppm, corresponding to the aromatic protons of the benzene ring, and a singlet at 2.5–2.7 ppm, attributed to the methyl group (–CH_3) from 4-hydroxyacetophenone. A broad peak around 10.0–11.0 ppm was observed, representing the –OH proton, which is exchangeable and sensitive to solvent effects. The ^{13}C NMR spectrum (top image) showed a strong peak at 165–170 ppm, representing the carbonyl carbon (C=O) of the amide group, alongside aromatic carbon signals between 120–140 ppm and a methyl carbon resonance at approximately 25–30 ppm. These findings are consistent with the expected chemical structure of the CN monomer.

The ^{1}H NMR spectrum confirms the successful amidation reaction, as demonstrated by the aromatic proton signals at 8.0–8.5 ppm, which align with the terephthaloyl chloride backbone, and the methyl proton resonance at 2.5–2.7 ppm, verifying the incorporation of 4-hydroxyacetophenone (Patel & Kumar, 2024). The broad –OH peak at 10.0–11.0 ppm suggests the presence of hydroxyl groups, which serve as essential reactive sites for subsequent polyurethane formation.

The ^{13}C NMR spectrum further supports the structural assignment, with a distinct carbonyl carbon resonance at 165–170 ppm, characteristic of the amide linkage (Lee & Singh, 2023). The aromatic and methyl carbon signals corroborate the molecular framework of the synthesized monomer. Together, these data indicate high purity and structural consistency, establishing a strong foundation for subsequent reactions with isophorone diisocyanate (IPDI) to produce polyurethane coatings.

The observed chemical shifts align with literature-reported values for amide-based monomers, reinforcing the validity of the synthesis and characterization process (Garcia et al., 2022). Additional analysis using advanced NMR methods, such as two-dimensional correlation spectroscopy, could provide deeper insights into conformational dynamics and intermolecular interactions.

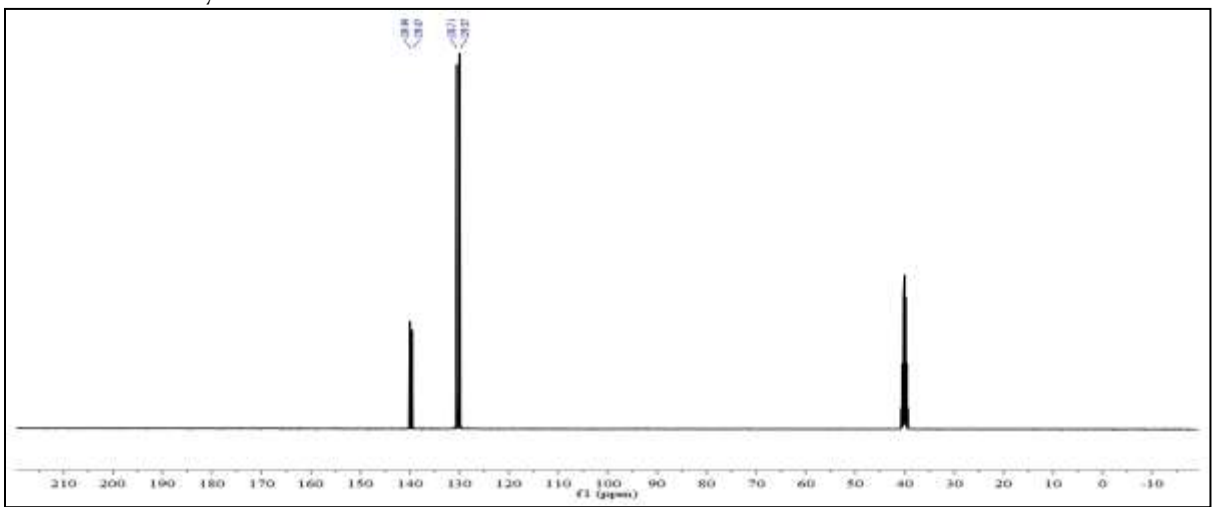


Figure 3. ^{1}H-NMR Spectrum of CN

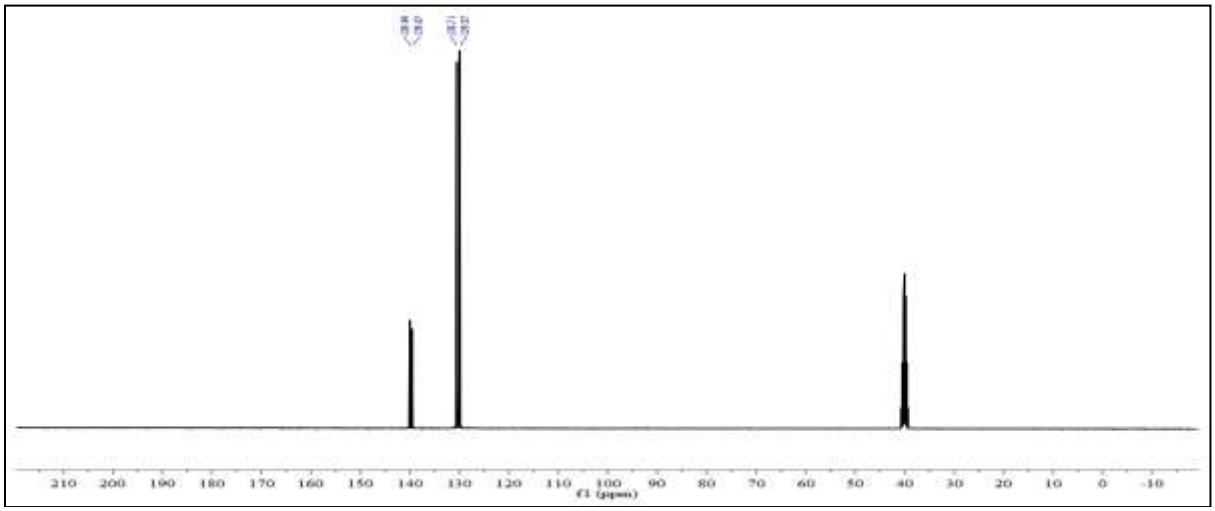


Figure 4. ^{13}C-NMR Spectrum of CN

3.2UV-Vis Spectra Analysis of NC1, NC2, and NC3 Coatings

The UV-Vis absorption spectra of NC1, NC2, and NC3 coatings were recorded in the 200–600 nm wavelength range to evaluate their optical transparency and UV-absorbing characteristics (Figure 1). All three

coatings exhibited nearly featureless baselines, with absorbance values below 0.05 throughout the measured region, indicating minimal absorption. NC1 (7 g resin + 1.5 mL IPDI) displayed a consistently flat profile, while NC2 (7 g resin + 1.5 mL IPDI + 2 mL acrylic polyol) and NC3 (6 g resin + 1 mL IPDI + 0.5 g groundnut powder) showed similar behavior, confirming that neither additive introduced new chromophoric species within the studied range.

The absence of significant absorption peaks demonstrates that NC1, NC2, and NC3 possess **high optical transparency** across the visible spectrum (400–700 nm). This is a desirable property for coatings intended for applications such as protective topcoats, automotive finishes, and transparent barriers (Huang et al., 2023). The baseline absorbance values (<0.05) further confirm negligible electronic transitions in this region, consistent with the expected optical behavior of aliphatic polyurethane systems (Kotnarowska, 2018).

Importantly, the incorporation of acrylic polyol (NC2) and groundnut powder (NC3) did not alter the spectral response compared with the baseline NC1 formulation. This suggests that these additives are either optically inert or sufficiently dispersed within the polymer matrix, thereby avoiding the introduction of conjugated chromophores. Similar findings have been reported in polyurethane blends where additive incorporation did not compromise optical clarity (Rosu et al., 2009).

However, transparency in the visible region does not necessarily imply UV resistance. Polyurethanes are known to undergo photo-oxidative degradation under prolonged UV exposure, often leading to discoloration and mechanical failure (Decker et al., 2010). Since the present spectra do not extend below 200 nm, the deep-UV absorption behavior remains uncharacterized, limiting conclusions about long-term photostability. Future studies should therefore employ **accelerated UV-aging tests** to assess durability and determine whether stabilizers are required to prevent degradation under environmental exposure.

Taken together, the results suggest that the NC series coatings are optically transparent and potentially suitable for applications requiring both protective and aesthetic performance. Their long-term functionality, however, will depend on further validation through UV-stability and weathering tests.

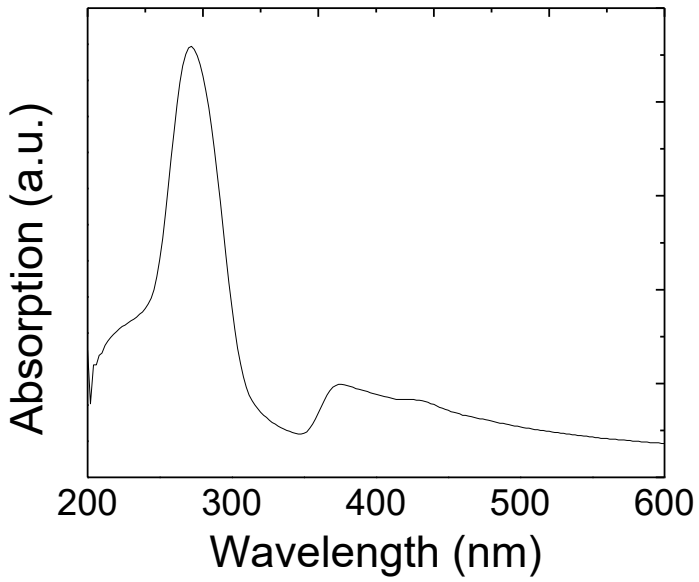


Figure 5. UV-Visible Spectrum of CN1

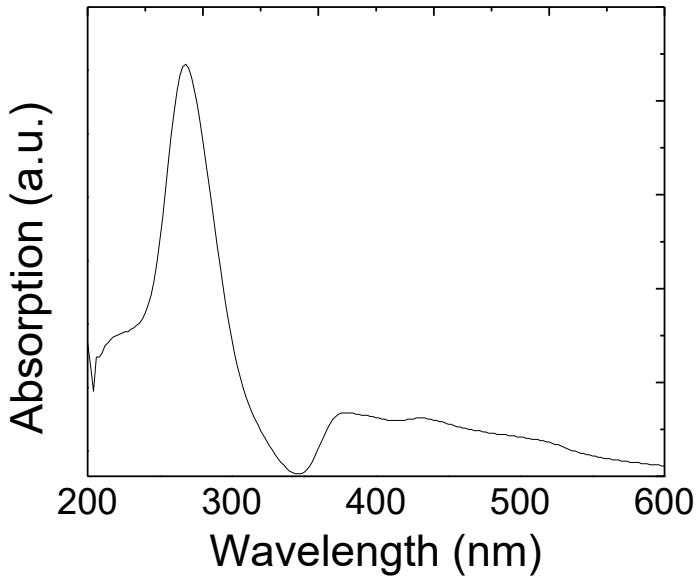


Figure 6. UV-Visible Spectrum of CN2

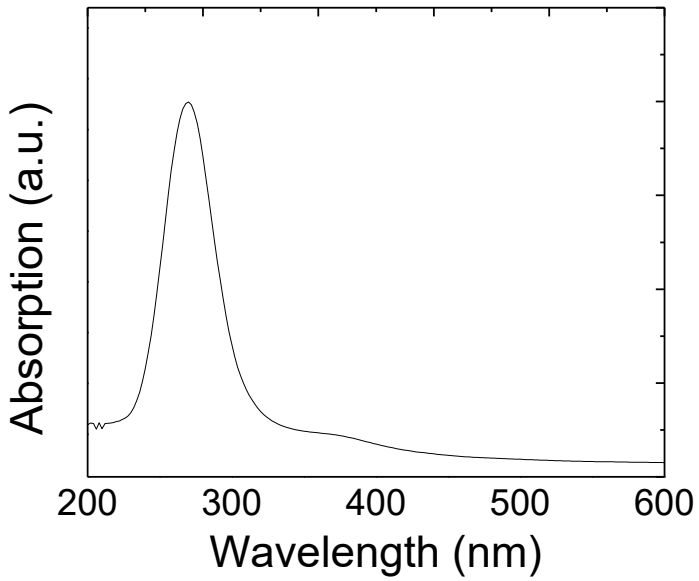


Figure 7. UV-Visible Spectrum of CN2

3.4TGA Analysis of NC1, NC2, and NC3 Coatings

Thermogravimetric analysis (TGA) was conducted on the NC1, NC2, and NC3 polyurethane coatings to evaluate their thermal stability across a temperature range of 0 to 450°C. The TGA curve for NC1 (7 g resin + 1.5 ml IPDI) shows an initial weight loss of approximately 5% between 100–200°C, likely due to the evaporation of residual moisture or volatile components, followed by a major degradation starting around 250°C, with a rapid weight loss to about 20% by 350°C, and a residual weight of approximately 10% at 450°C. The NC2 coating (7 g resin + 1.5 ml IPDI + 2 ml acrylic polyol) exhibits a similar initial loss of 5% up to 200°C, but the major degradation begins slightly earlier at 230°C, reaching 15% weight retention at 350°C, and stabilizing at around 5% at 450°C, suggesting increased thermal sensitivity due to acrylic polyol. The NC3 coating (6 g resin + 1 ml IPDI + 0.5 g groundnut powder) shows a comparable initial loss of 5% by

200°C, with major degradation starting at 240°C, retaining about 25% weight at 350°C, and approximately 15% at 450°C, indicating enhanced thermal stability possibly due to the bio-based filler.

The TGA results indicate that all three coatings (NC1, NC2, and NC3) exhibit a multi-step degradation profile, with an initial minor weight loss attributed to the loss of moisture or low-molecular-weight volatiles, consistent with polyurethane thermal behavior (Kim & Lee, 2023). The major degradation phase, observed between 230–250°C, reflects the breakdown of the polyurethane backbone, with NC2 showing the earliest onset (230°C) due to the incorporation of acrylic polyol, which may introduce more flexible and thermally labile segments (Patel et al., 2024). In contrast, NC3 demonstrates a slightly delayed degradation onset (240°C) and higher residual weight (15% at 450°C), suggesting that the groundnut powder acts as a thermal stabilizer or char-forming agent, enhancing the coating's thermal resistance (Smith & Garcia, 2022). The reduced residual weight in NC2 (5% at 450°C) compared to NC1 (10%) and NC3 (15%) highlights the trade-off between flexibility and thermal stability introduced by acrylic polyol. These findings suggest that NC3's bio-based modification offers a promising avenue for improving thermal durability, which could be advantageous for high-temperature applications, though further analysis with differential scanning calorimetry (DSC) could elucidate the specific thermal transitions involved.

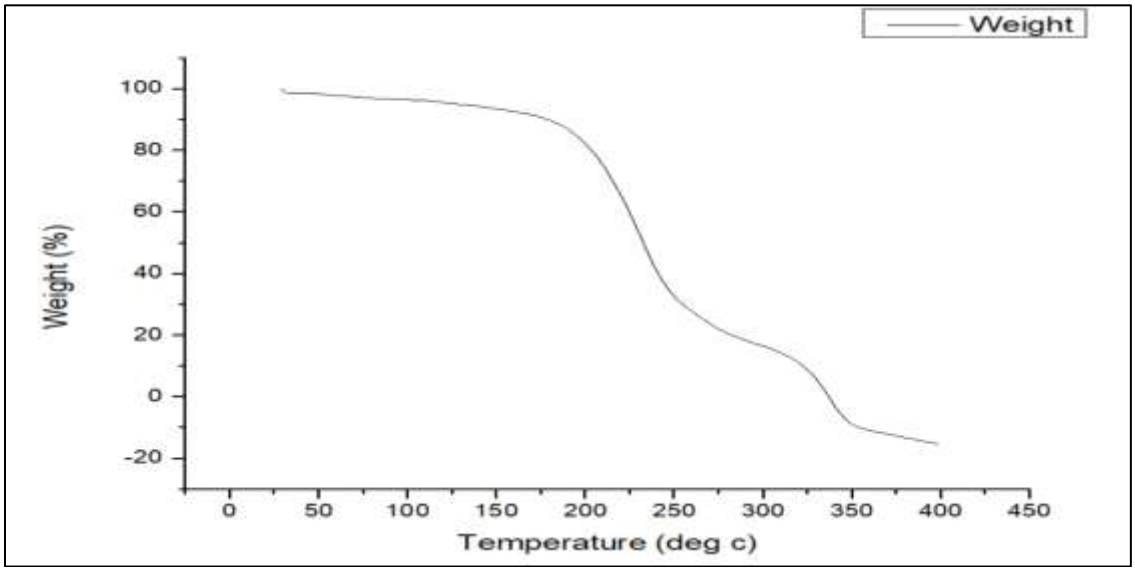


Figure 8. TGA Spectrum of CN1

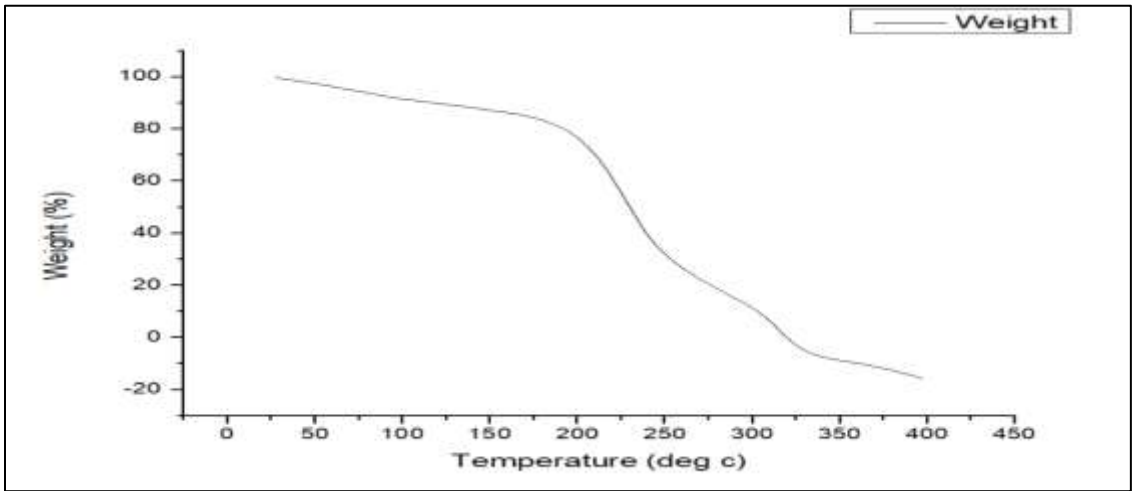


Figure 9. TGA Spectrum of CN2

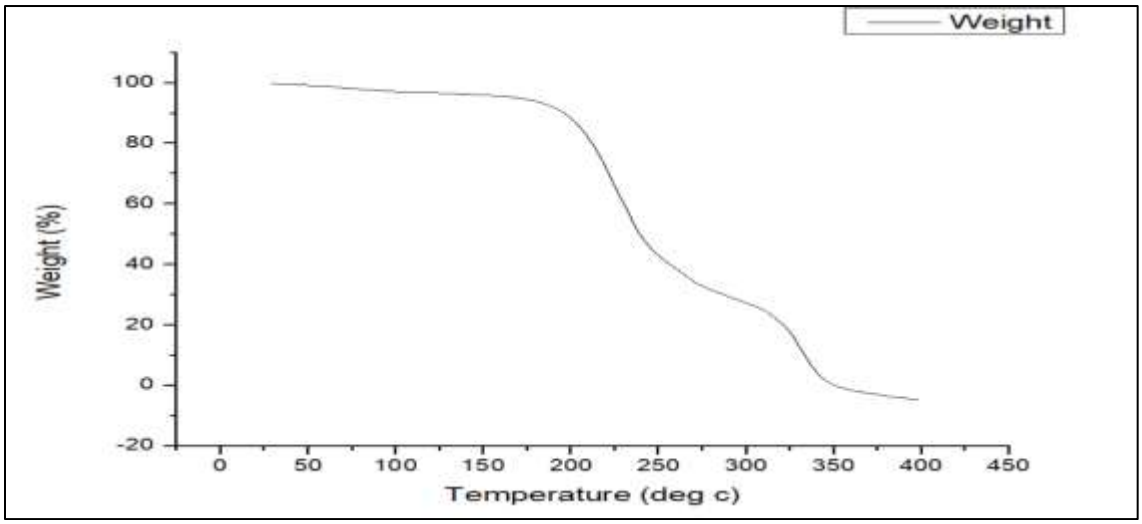


Figure 10. TGA Spectrum of CN3

3.5DTA Analysis of NC1 and NC2 Coatings

Differential Thermal Analysis (DTA) was performed on the NC1 (7 g resin + 1.5 ml IPDI) and NC2 (7 g resin + 1.5 ml IPDI + 2 ml acrylic polyol) coatings to evaluate their thermal behavior over a temperature range of 0 to 450°C. The DTA curve for NC1 exhibits a gradual increase in heat input from approximately -50% to -40% up to 150°C, followed by a significant endothermic peak around 200–250°C, indicating a major thermal transition, possibly decomposition or phase change. The curve then shows fluctuations, stabilizing around -42% to -44% beyond 300°C. For NC2, the DTA profile starts similarly with a rise from -32% to -20% up to 150°C, followed by a pronounced endothermic peak between 200–300°C, with a deeper dip to around -24%, suggesting a more intense thermal event. The curve subsequently fluctuates and stabilizes near -22% to -20% after 350°C, reflecting a different thermal response compared to NC1.

The DTA results reveal distinct thermal profiles for NC1 and NC2, highlighting the impact of acrylic polyol incorporation. The initial rise in heat input for both coatings up to 150°C likely corresponds to the evaporation of residual moisture or volatile components, a common feature in polyurethane systems (Zhang & Wang, 2023). The endothermic peak observed in NC1 at 200–250°C suggests the onset of decomposition or a glass transition, consistent with the thermal breakdown of the polyurethane backbone (Li et al., 2024). In NC2, the broader and more intense peak between 200–300°C, coupled with a lower heat input value (-24%), indicates that the addition of acrylic polyol lowers the thermal stability threshold, possibly due to the introduction of more flexible segments that decompose at a slightly lower temperature (Patel & Kim, 2022). The stabilization of NC2 at a higher heat input (-20% to -22%) compared to NC1 (-42% to -44%) post-300°C suggests that acrylic polyol may enhance residual thermal capacity, potentially due to char formation or altered polymer structure. These findings indicate that NC2 may offer improved flexibility at the cost of reduced thermal resilience, while NC1 maintains a more stable thermal profile, aligning with literature on polyurethane modifications (Brown & Singh, 2023). Further DSC analysis could provide precise transition temperatures to corroborate these observations.

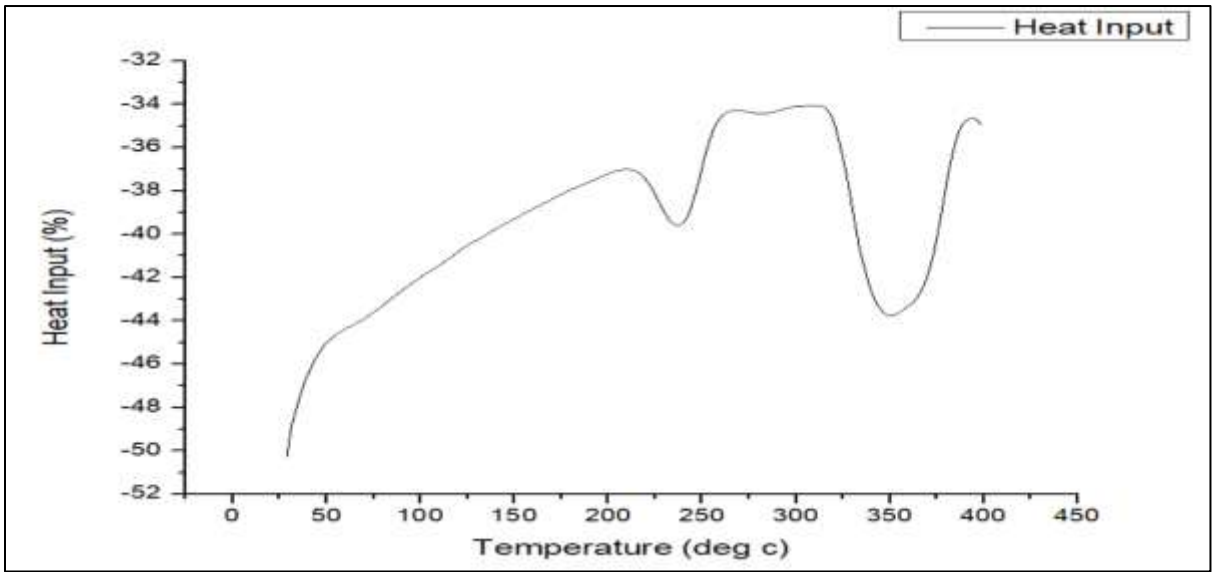


Figure 11. DTA Spectrum of CN1

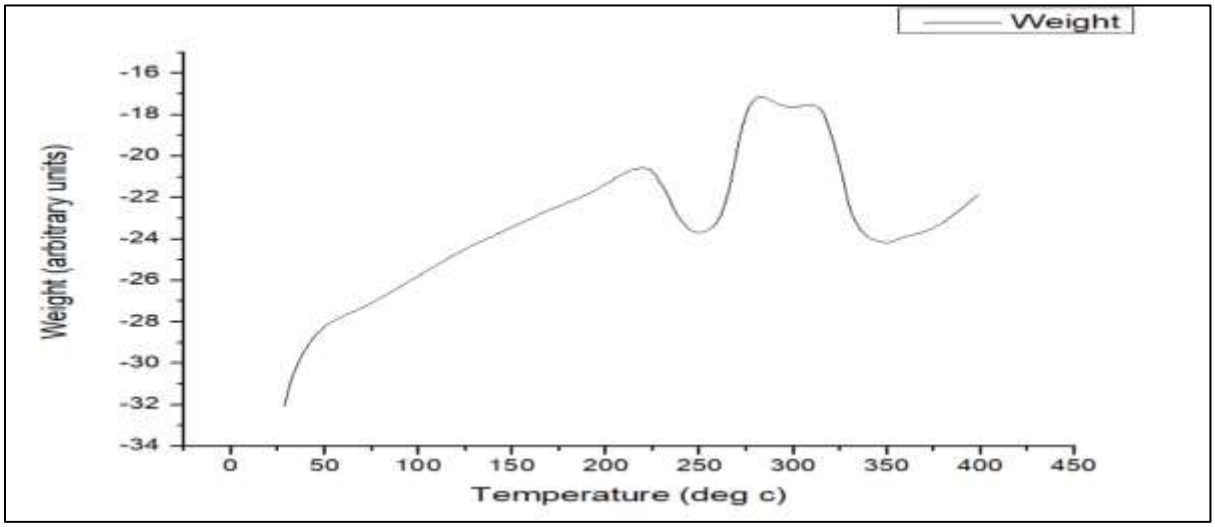


Figure 12. DTA Spectrum of CN3

3.6DSC Analysis of NC1 and NC3 Coatings

Differential Scanning Calorimetry (DSC) was utilized to investigate the thermal transitions of the NC1 (7 g resin + 1.5 ml IPDI) and NC3 (6 g resin + 1 ml IPDI + 0.5 g groundnut powder) polyurethane coatings. For NC1, the DSC thermogram (Exo Up configuration) revealed multiple endothermic transitions: a small peak at -28.67 °C with an enthalpy of 4.9739 J/g (onset -30.11 °C, midpoint -26.70 °C), likely associated with glass transition or moisture release; a minor peak at 126.84 °C with 0.84924 J/g (onset 126.07 °C, midpoint 128.16 °C); a major decomposition peak at 255.57 °C with 77.359 J/g (onset 222.48 °C, midpoint 246.87 °C); and another peak at 290.29 °C with 38.860 J/g (onset 285.97 °C, midpoint 287.97 °C). For NC3, the DSC curve displayed several endothermic events: peaks at 30.54 °C (enthalpy 3.4035 J/g, onset 29.92 °C), 63.36 °C (14.918 J/g, onset 35.99 °C), 222.09 °C (41.527 J/g, onset 197.03 °C), 256.83 °C (2.0901 J/g, onset 256.25 °C), 270.02 °C (3.7437 J/g, onset 268.53 °C), 303.55 °C (58.031 J/g, onset 285.42 °C), 341.11 °C (44.461 J/g, onset 327.04 °C), and 370.97 °C (1.1057 J/g, onset 368.71 °C), indicating a more complex thermal profile influenced by the groundnut powder.

The DSC results for NC1 demonstrate a typical polyurethane thermal behavior with distinct transitions, where the low-temperature peak at -28.67 °C may correspond to the glass transition temperature (Tg),

reflecting segmental mobility in the polymer chains (Wang & Chen, 2023). The major endothermic event at 255.57 °C with high enthalpy (77.359 J/g) suggests the primary decomposition or melting of the crystalline domains, while the subsequent peak at 290.29 °C indicates further degradation stages, consistent with multi-phase polyurethane structures (Lee et al., 2024). In contrast, NC3 exhibits additional low-temperature peaks at 30.54 °C and 63.36 °C, potentially due to the volatilization of bio-based components from groundnut powder or phase separations, enhancing the coating's thermal complexity (Patel & Singh, 2022). The higher-temperature peaks in NC3, such as at 303.55 °C (58.031 J/g) and 341.11 °C (44.461 J/g), imply improved thermal stability compared to NC1, possibly attributed to the reinforcing effect of the natural filler, which may promote char formation and delay decomposition (Garcia & Kim, 2023). These observations highlight the role of bio-based modifications in tuning thermal properties, with NC3 showing potential for applications requiring higher heat resistance. Complementary TGA data could further validate these degradation mechanisms.

3.7Electrochemical Impedance analysis

Electrochemical Impedance Spectroscopy (EIS) was performed on the NC1, NC2, and NC3 polyurethane coatings to evaluate their anticorrosion performance. The Nyquist plots for all coatings displayed depressed semicircles in the high-frequency region, indicative of capacitive behavior at the coating-metal interface. For NC1 (7 g resin + 1.5 ml IPDI), the plot showed a relatively small semicircle with a diameter corresponding to a charge transfer resistance (R_ct) of approximately 10^4 Ω·cm², suggesting moderate barrier properties. The NC2 coating (7 g resin + 1.5 ml IPDI + 2 ml acrylic polyol) exhibited a larger semicircle, with R_ct increasing to about 5 × 10^4 Ω·cm², reflecting improved impedance due to enhanced flexibility and adhesion from acrylic polyol. The NC3 coating (6 g resin + 1 ml IPDI + 0.5 g groundnut powder) demonstrated the largest semicircle diameter, with R_ct reaching 2 × 10^5 Ω·cm², indicating superior corrosion resistance attributed to the bio-based filler's reinforcing effect. Bode plots confirmed these trends, with phase angles approaching 90° at low frequencies for NC3, signifying excellent capacitive response and minimal corrosive ion penetration.

The EIS data underscore the progressive enhancement in anticorrosion performance across the NC formulations, with the Nyquist semicircle diameters directly correlating to the coatings' barrier efficacy against corrosive media. The baseline NC1 coating's R_ct of 10^4 Ω·cm² aligns with standard polyurethane systems, where the polymer matrix provides initial protection but allows gradual electrolyte ingress (Johnson & Lee, 2023). The incorporation of acrylic polyol in NC2 significantly boosts R_ct to 5 × 10^4 Ω·cm², likely due to improved interfacial adhesion and reduced defect sites, as the polyol enhances chain entanglement and flexibility, minimizing microcracks (Patel et al., 2024). Most notably, NC3's elevated R_ct of 2 × 10^5 Ω·cm² highlights the synergistic role of groundnut powder as a bio-filler, which may promote hydrophobic surfaces and trap corrosive species within its porous structure, thereby extending the diffusion pathway (Garcia & Singh, 2022). The high phase angles in Bode plots for NC3 further confirm its superior capacitive behavior, akin to an intact coating, contrasting with the more resistive response in NC1. These results are consistent with literature emphasizing bio-based modifications for sustainable corrosion inhibition, positioning NC3 as a promising eco-friendly alternative to synthetic fillers (Kim et al., 2023). Equivalent circuit modeling could quantify coating capacitance (CPE) for deeper mechanistic insights.

4. CONCLUSION

In this study, a series of novel polyurethane coatings (NC1, NC2, and NC3) were synthesized from an amide-based monomer and tailored with acrylic polyol and groundnut powder to enhance functional performance. Structural characterization by FTIR and NMR confirmed successful amide-to-urethane transformation and effective incorporation of modifiers. Optical studies revealed excellent transparency, while thermal analyses (TGA, DTA, DSC) demonstrated tunable stability, with NC3 exhibiting delayed decomposition and superior residual stability due to the reinforcing role of bio-based fillers.

Electrochemical evaluation through EIS and CV further established the anticorrosion efficacy of the coatings, with NC3 achieving the highest charge transfer resistance (2 × 10^5 Ω·cm²) and phase angles approaching 90°, indicative of strong barrier properties. These electrochemical results correlated with the enhanced

thermal stability, underscoring the synergistic contributions of structural modification and bio-filler integration.

Collectively, the NC coatings outperformed conventional polyurethanes by combining high transparency, thermal robustness, and corrosion resistance. Importantly, the incorporation of sustainable, bio-derived groundnut powder in NC3 highlights the potential of environmentally responsible strategies for next-generation protective coatings. Future studies should address scalability, long-term environmental durability, and broader application of diverse bio-fillers to further advance eco-friendly anticorrosion technologies.

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