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Physicochemical Characterization of Polystyrene/Polypropylene oil blends as a Waste-Derived Binder for Sustainable Emulsion Paint Production

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ABSTRACT

The accumulation of polystyrene (PS) and polypropylene (PP) plastic waste presents a growing environmental challenge, particularly in regions with limited recycling infrastructure. This study investigated the conversion of waste PS and PP into pyrolysis oils for use as an alternative binder in emulsion paint formulation. Waste PS and PP were separately collected, washed, shredded, and pyrolyzed using a mini-pyrolysis plant, and the resulting oils were blended at ratios of 90:10, 80:20, 70:30, 60:40, and 50:50 (PS:PP). The physicochemical properties of the pure oils and their blends, including viscosity, density, pH, refractive index, turbidity, pour point, and dispersibility, were determined, and the chemical structures were confirmed by Fourier-transform infrared (FTIR) spectroscopy. Blending markedly improved the rheological and optical properties of the oils relative to the pure components, with viscosity rising from 4.21 cP (PS) and 3.01 cP (PP) to 18.00–36.00 cP across the blends. The 80:20 (PS:PP) blend displayed the most balanced profile, with the lowest turbidity (22.30 NTU), a refractive index of 1.5917, a density of 0.8978 g/cm³, and a pour point of −13°C, and its FTIR spectrum confirmed the coexistence of aromatic (PS-derived) and aliphatic (PP-derived) hydrocarbon structures. These findings demonstrate that pyrolysis oils derived from waste PS and PP, particularly at the 80:20 blend ratio, constitute a viable, environmentally sustainable alternative to petroleum-based binders in emulsion paint production.

Keywords:
Polystyrene;
Polypropylene;
Pyrolysis oil;
Waste-derived binder and
Emulsion paint

INTRODUCTION

Due to their widespread usage in consumer goods, building, and packaging as well as their resistance to natural degradation, plastic trash, especially that of polystyrene (PS) and polypropylene (PP), has grown to be a significant environmental concern (Ugwu and Obele, 2023; Bellon *et al.,* 2019). Improper disposal and treatment of these polymers particularly in developing nations with insufficient waste-management infrastructure contributes to soil and water contamination and the release of harmful compounds (Bellon *et al.,* 2019). According to (Ugwu and Obele, 2023), polystyrene is prized for its low weight, low thermal conductivity, and low cost. However, same characteristics also make it difficult to recycle and prone to accumulating in landfills and the environment. Another popular thermoplastic valued for its strength and adaptability, polypropylene, also makes a significant contribution to the buildup of plastic trash (Wang *et al.,* 2024). Both polymers are persistent in the environment and present long-term ecological hazards since they are not biodegradable (Chaukura *et al.,* 2016).

To address these issues, researchers have looked into a variety of recycling and upcycling techniques to turn PS and PP waste into products with added value. One such method is the use of these materials as binders in emulsion paint formulations, which is made possible by pyrolysis, thermal degradation, or solvent-based dissolution followed by emulsification (Das and Tiwari, 2018). Emulsion paints in particular dominate the decorative market due to their low volatile organic compound (VOC) content, ease of application, and quick drying time (Hess and Bongaerts, 2020). The global paint and coatings industry are multibillion-dollar sector essential to protecting, decorating, and preserving infrastructure (Grand View Research, 2023). Emulsion paint's performance, durability, and cost are largely determined by the binder, which is typically a synthetic polymer made from petrochemicals like polyvinyl acetate (PVA) or acrylics (Abubakar and Gidigbi, 2020). Replacing these with binders made from plastic waste has both financial and environmental advantages (Thiam and Fall, 2021).

According to research by Bellon *et al.,* 2019, waste PS and PP can be processed into resins or oils and added to paint formulations using solvents like gasoline, toluene, or D-limonene to dissolve and blend the polymers. This results in paints with good adhesion, water resistance, flexibility, and stability that sometimes with equal performance or better than conventional paints (Das and Tiwari, 2018). Despite this promise, there hasn't been a systematic investigation into the optimization of the binder as an important formulation parameter for emulsion paints made exclusively from these PS/PP pyrolysis-oil blends. In order to close this gap, waste PS and PP are pyrolyzed, the resulting oils are blended in five different ratios, their physicochemical and structural characteristics are determined to ascertain its suitability for emulsion paint production and further optimization.

MATERIALS AND METHODS

Materials

The binders were made from waste polypropylene plastic and polystyrene plastic (packing materials). A turbidimeter, a mini-pyrolysis plant, an ABBE digital refractometer, a pH meter, a Mettler Toledo density kit, an FTIR spectrophotometer, and a viscometer were among the essential pieces of equipment.

Preparation of Binders

While polypropylene garbage was gathered from dustbins and landfills around the Federal Housing Estate, Bajabure, Girei Local Government Area, Adamawa State, Nigeria, located approximately between $9^0$20'N latitude and $12^0$30'E longitude. Polystyrene waste was gathered from electronic stores in Jimeta Modern Market located approximately at latitude 9.272^0N and longitude 12.438^0E in Yola North Local Government Area, Adamawa State, Nigeria. Before being added individually to a mini-pyrolysis plant with a reactor, condenser, and heat source, each waste stream was cleaned, dried, and shredded to enhance surface area. Each of the PS and PP pyrolysis oils that were produced were gathered and sealed for further examination. After that, the two oils were combined in PS:PP ratios of 90:10, 80:20, 70:30, 60:40, and 50:50 (ml/ml) and optimized.

Physicochemical Characterization of the Pyrolysis Oils

An NDJ-5S viscometer was used to measure viscosity in triplicate. Using a density bottle and the mass-volume relationship, density was calculated gravimetrically (AOAC, 2000). A pH meter that was standardized against buffer solution was used to monitor pH (Yuguda *et al.,* 2025). An ABBE digital refractometer was used to measure the refractive index in triplicate (Yuguda *et al.,* 2025). A HI88703 turbidimeter was used to test turbidity in triplicate, and the results were expressed in NTU. By combining 2 mL of the sample with 20 mL of distilled water and monitoring cloudiness or transparency, water solubility and dispersibility were evaluated (Osemeahon and Dimas, 2014). By heating a 10 mL sample and noting the lowest temperature at which flow occurred, the pour point was ascertained in accordance with ASTM D97. A 1750 FT-IR spectrophotometer was used to analyze the chemical structure of samples made as pellets (Jayamani *et al.,* 2020).

RESULTS AND DISCUSSION

Physicochemical Properties of Pure PS and PP Pyrolysis Oils

Table 1 shows that the physicochemical properties of the PP and PS pyrolysis oils were generally comparable with previous studies, although some differences were observed. The PP oil had a viscosity of 3.01 cP, within the range reported by Uebe et al. (2022), while its density of 0.7949 g/cm³ was slightly higher than the reported 0.753–0.769 g/cm³. Its pour point of −18 °C indicated good low-temperature flow, while the pH of 5.47 showed mildly acidic characteristics. The relatively high turbidity (75 NTU) and very low water dispersibility suggest the presence of impurities and predominantly hydrocarbon components. The PS oil recorded a viscosity of 4.21 cP and density of 0.9780 g/cm³, both higher than values reported by Miandad et al. (2017), who reported viscosity of 1.77–1.90 mPa·s and Its pour point of −11 °C was comparable to the lower range reported while its pH of 5.30 indicated mild acidity. Overall, the differences from previous studies may be attributed to variations in f eedstock composition, pyrolysis temperature, reactor conditions, and the composition of the recovered oils. When taken as a

whole, these factors offer a baseline knowledge of the physical characteristics of both feedstock oils, which is essential for determining whether or not they are suitable for paint formulation prior to mixing.

Table 1: Physicochemical Properties of Pure PP and PS Pyrolysis Oils

Property	PP	PS
Viscosity (cP)	3.01	4.21
Turbidity (NTU)	75.00	57.00
Refractive index (Bx)	1.1492	1.4512
pH	5.47	5.30
Density (g/cm³)	0.7940	0.9780
Pour point (°C)	−18	−11
Dispersibility	Very low	Moderate

Physicochemical Characterization of PS/PPPyrolysis Oil Blends as Potential Paint Binders

The result in Table 2 shows the physicochemical properties of PS/PP pyrolysis oil blends at ratios of 90:10, 80:20, 70:30, 60:40, and 50:50 (ml:ml). The properties evaluated include viscosity, turbidity, refractive index, pH, pour point, density, and dispersibility. Results reveal that blending PS and PP pyrolysis oils significantly influenced their physicochemical properties. Viscosity varied non-linearly from 18.00 to 36.00 cP, indicating that the properties of the different hydrocarbon fractions and their interactions influenced the blends, consistent with observations for mixed-plastic pyrolysis oils (Palmay et al., 2022). Density decreased from 0.9199 to 0.8623 g/cm³ as PP content increased, consistent with the generally lower density of PP-derived oils. The pour point decreased from −11 to −16 °C, indicating improved low-temperature flow with increasing PP content. This behaviour may be associated with the contribution of lighter paraffinic and olefinic hydrocarbons present in PP-derived pyrolysis oils, which have been reported to have low pour points (Das & Tiwari, 2018). The blends were acidic, with pH values of 3.77–4.24, while turbidity ranged from 22.30 to 36.60 NTU, with the 80:20 blend showing the lowest turbidity. Refractive index varied from 1.5139 to 1.5917, indicating differences in the relative aromatic and aliphatic/unsaturated hydrocarbon compositions of the blends (Jaafar et al., 2022). All blends showed low water dispersibility, consistent with their predominantly hydrocarbon nature. Therefore, decreasing PS content generally decreased viscosity and density, while increasing PP content also decreased density and improved low-temperature flow. The 80:20 blend, with 28.00 cP viscosity, 22.30 NTU turbidity, 1.5917 refractive index, and −13 °C pour point, showed a favourable combination of properties for further evaluation as a binder precursor.

Table 2: Summary of Physicochemical Properties of PS/PP Pyrolysis Oil Blends

Blend (PS:PP)	Viscosity (cP)	Turbidity (NTU)	Refractive index	pH	Pour point (°C)	Density (g/cm³)	Dispersibility
90:10	36.00	27.00	1.5917	4.03	−11	0.9199	Low
80:20	28.00	22.30	1.5917	3.77	−13	0.8978	Low
70:30	18.00	22.80	1.5917	3.87	−14	0.8909	Low
60:40	20.00	26.00	1.5139	3.92	−15	0.8755	Very low
50:50	30.00	36.60	1.5895	4.24	−16	0.8623	Very low

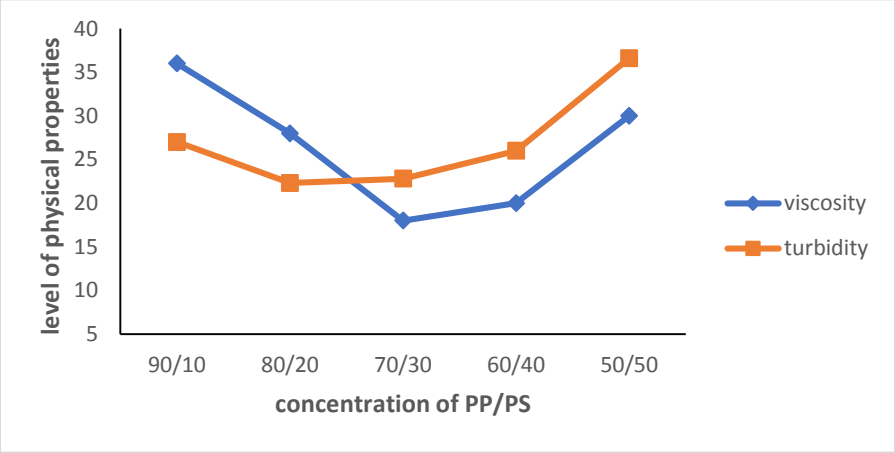


Fig 3.1 Effect of blended PS/PP pyrolysis oil on viscosity and turbidity

3.2.1 Viscosity

The viscosities of all five PS/PP blends as shown in Table 2 and fig 3.1 were significantly higher than those of either pure oil, ranging from 18.00 cP (70:30) to 36.00 cP (90:10), indicating interactions between compounds derived from PS and PP upon blending. These interactions may result from aromatic–aliphatic intermolecular associations that raise the effective hydrodynamic volume of the mixed system (Mangesh *et al.*, 2020). The non-linear viscosity trend where the 70:30 blend has the lowest viscosity and the 90:10 blend the highest can be explained by changes in the internal structure of the polymer mixture. As the blend ratio changes, the dispersed polymer droplets can interconnect to form a co-continuous network, which significantly alters the overall flow behavior (Cardinaels *et al.*, 2023). All five blends fall well below the paint industry's viscosity threshold of roughly 100cP needed for spray, brush, or roller application despite having higher viscosities than the pure oils (ASTM D2196, 2018). This suggests that viscosity enhancement, such as solvent evaporation, blending with higher-viscosity resins, or adding rheology modifiers, would be necessary prior to direct use as a paint binder (Schoff, 2021).

Turbidity

In Table 2 and fig 3.1, the values of turbidity ranging from 22.30 NTU (80:20) to 36.60 NTU (50:50), all five blends demonstrated significantly lower turbidity in comparison to the parent oils (75.00 NTU for PP and 57.00 NTU for PS). This suggests that blending enhances optical homogeneity when compared to either component alone, which is consistent with the improved optical properties reported for blended PS/PP pyrolysis oils by Osemeahon *et al.* (2026b). According to Wang et al. (2019), binders with lower turbidity are known to be more compatible with pigments, fillers, and other

additives. The 80:20 and 70:30 blends had the lowest turbidity values, indicating superior optical clarity and the highest degree of miscibility within this compositional range. Phase-separation processes observed for PS/PP systems, where compositional divergence beyond a key blend ratio promotes phase-boundary development and increased light scattering, are consistent with the rapid increase in turbidity at the 50:50 ratio (Osemeahon *et al.*, 2026a).

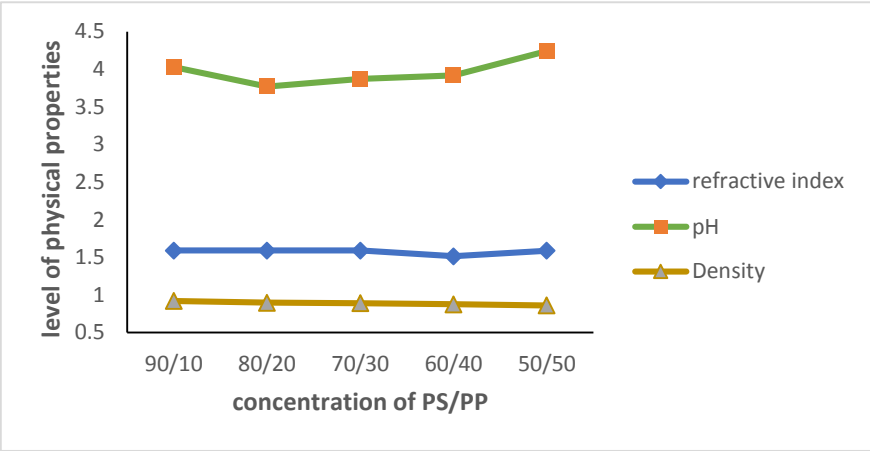


Fig 3.2 Effect of blended PS/PP pyrolysis oil on refractive index, pH and density

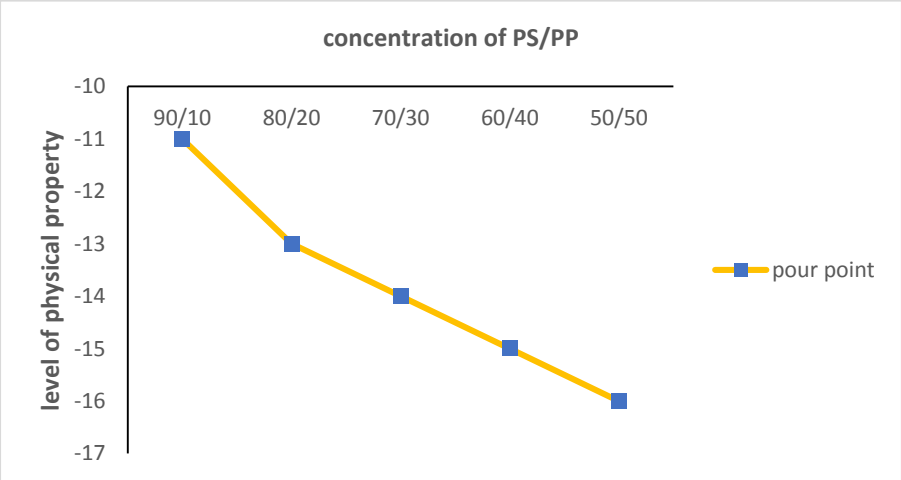


Fig 3.3 Effect of blended PS/PP pyrolysis oil on pour point

Refractive Index

Excellent optical consistency and miscibility within this compositional range were demonstrated by the 90:10, 80:20, and 70:30 blends' same refractive index of 1.5917 as shown in table 2 and fig 3.2, which is consistent with the aromatic PS fraction dominating the blend's optical character (Osemeahon *et al.*, 2025). The 60:40 blend showed a significant divergence (1.5139), which could indicate a phase-inversion point or crossover between homogeneous and two-phase microstructure. The 50:50 blend then recovered to 1.5895, indicating partial re-mixing at equal proportions. All measured blend refractive indices are compatible with typical inorganic pigments like TiO_2 (refractive index ≈ 2.70) and fall within the 1.48–1.65 benchmark range for regular paint binders (Osemeahon *et al.*, 2025). Because of their homogeneous and consistent optical quality, the 90:10, 80:20, and 70:30 mixes are the most advantageous.

pH

Table 2 shows an increase in pH from 3.77 (80:20) to 4.24 (50:50), all blend formulations showed lower pH values than either pure component, which is in line with

findings that plastic pyrolysis oils usually contain organic acids produced by cracking and rearrangement reactions during thermal deterioration (Masakhoh, 2026). Because acidic binders can increase metal substrate corrosion and destabilize pigment dispersion, as well as partially dissolve amphoteric pigments like TiO_2, reducing their light-scattering efficiency (SpecialChem, 2025), this strong acidity has implications for substrate compatibility. For all blends to reach pH levels suitable for commercial paint-binder application, alkaline buffering and compatibilizers are consequently necessary (Mshelia *et al.*, 2025).

Density and Pour Point

From 0.9199 g/cm³ (90:10) to 0.8623 g/cm³ (50:50), density declined gradually and linearly as PP content rose as shown in Table 2, fig 3.2. This linear trend suggests that density in this system is primarily controlled by a volume-weighted average of the component attributes (Hegedüs *et al.*, 2024). All blend densities are slightly lower than traditional alkyd or acrylic binders and are within the normal range described for plastic-derived pyrolysis oils, which may provide useful advantages in terms of less weight per liter of paint (Rahmanian *et al.*, 2024). As PP concentration increased, the pour point also gradually dropped from −11°C (90:10) to −16°C (50:50), remaining on par with or superior to traditional solvent-based alkyd binders and significantly better than water-based emulsions, which freeze close to 0°C (Osemeahon *et al.*, 2025).

Dispersibility

While pure PP oil and all five PS/PP blends showed low to very low dispersibility, pure PS oil showed moderate dispersibility (Table 1 and Table 2). This qualitative uniformity across blend ratios indicates that the limitation is intrinsic to the non-polar hydrocarbon character of both parent oils, which lack the polar functional groups required for efficient wetting and pigment stabilization (Hegedüs *et al.*, 2024). Dispersant addition or polar co-binder blending will be a necessary formulation requirement for any chosen blend because dispersibility is consistently low regardless of PS:PP ratio, making it an ineffective criterion for blend selection (Osemeahon *et al.*, 2025).

Overall Blend Selection

There was no blend combination that was consistently better in every way. The most promising options for paint-binder development were the 80:20 and 70:30 blends, which had the lowest turbidity, the most reliable, favorable refractive indices, a moderate pH, and an acceptable pour point. While the 50:50 blend provided the best low-temperature flow and the highest pH but the most noticeable phase separation, the 90:10 blend provided the highest viscosity and density, closest to conventional resin standards, but increased turbidity. The 80:20 blend is suitable for paint formulation and subsequent optimization based on the balance of these factors.

FTIR Analysis of the PS/PP (80:20) Blend

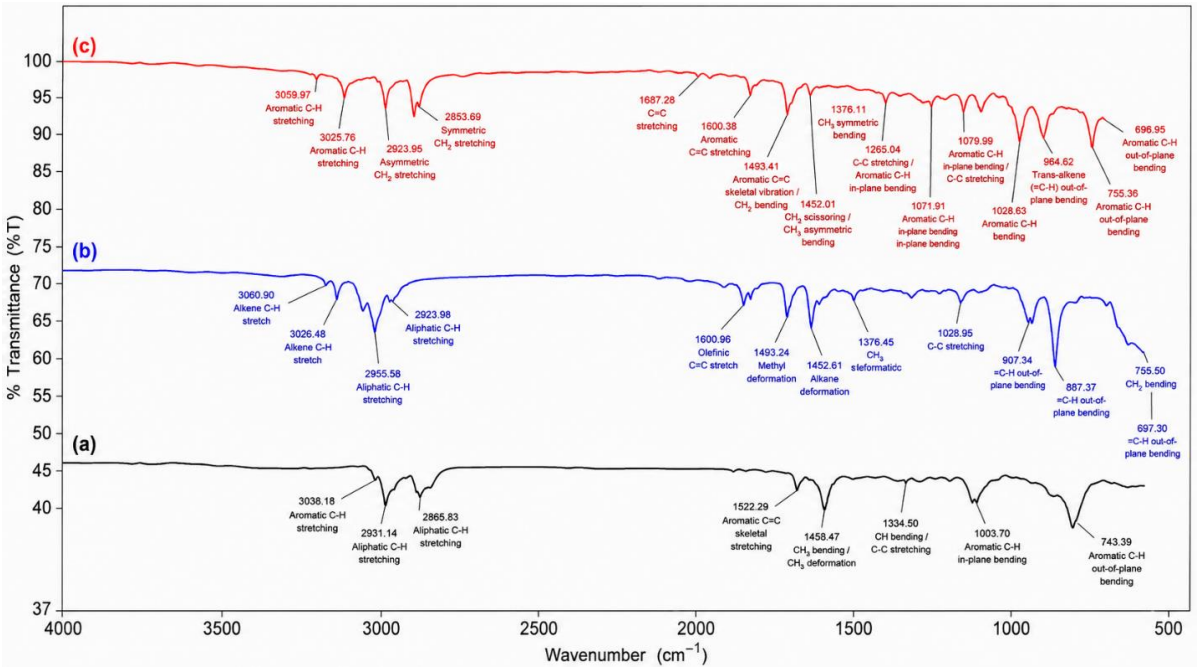


Fig 3.3: FTIR spectrum of (a) PS, (b) PP and (c)PS/PP (80:20) blend

In fig 3.3, (a) is the polystyrene pyrolysis oil FTIR spectrum. It confirms that it is predominantly aromatic in nature, with aromatic hydrocarbons being the major constituents (Nisar *et al.,* 2020; Chandrasekaran *et al*., 2022)**.** The strong bands observed at 3038.18, 1522.29, 1204.50, 1003.70, and 743.39 cm^{-1} are characteristic of benzene-ring vibrations and indicate the presence of styrene and other alkyl-substituted aromatic compounds formed during the depolymerization of polystyrene. The bands at 2931.14, 2865.83, and 1458.47 cm^{-1} indicate the presence of aliphatic CH_2 and CH_3 groups, arising from secondary cracking reactions that generate alkyl-substituted aromatic hydrocarbons (Dement'ev *et al.,* 2019)**.** Polystyrene pyrolysis oil is composed almost entirely of hydrocarbon species and contains negligible oxygenated compounds due to the absence of O-H and C=O bands.

(b) is the polypropylene spectrum. The FTIR spectrum of polypropylene pyrolysis oil shows that the product is predominantly composed of aliphatic and olefinic hydrocarbons (Negi *et al.,* 2023). Absorption bands at 2955.58 and 2923.96 cm^{-1} are assigned to asymmetric stretching vibrations of CH_3 and CH_2 groups, confirming the presence of saturated hydrocarbon chains (Tsog *et al.,* 2024). Weak bands at 3060.90 and 3026.48 cm^{-1}, together with the absorption at 1600.96 cm^{-1}, correspond to olefinic C–H and C=C stretching vibrations, indicating the formation of unsaturated hydrocarbons during thermal cracking (Mua and Tsamo, 2025). Bands at 1493.24, 1452.61, and 1376.45 cm^{-1} are attributed to CH_2 and CH_3 bending vibrations, with the prominent band at 1376.45 cm^{-1} being characteristic of the methyl groups abundant in polypropylene-derived products (Liu *et al.,* 2025).

The 80:20 PS/PP pyrolysis-oil(c) blend's FTIR spectra showed that olefinic, aliphatic, and aromatic hydrocarbon structures coexisted. Aromatic C–H stretching was identified in absorption bands at 3059.97 and 3025.76 cm^{-1}, whereas asymmetric and symmetric stretching of aliphatic CH_2 groups was identified in bands at 2923.95 and 2853.69 cm^{-1}. Aromatic C=C skeletal stretching was identified as the band at 1600.38 cm^{-1}, whereas conjugated C=C bonds were identified as the band at 1687.28 cm^{-1}. Strong bands at 755.36 and 696.95 cm^{-1} verified monosubstituted benzene rings typical of styrene and alkylbenzene derivatives, while peaks at 1493.41, 1452.01, and 1376.11 cm^{-1} corresponded to aromatic skeletal vibrations and CH_2/CH_3 bending modes characteristic of polypropylene-derived products. The blended oil differs from the individual polymer pyrolysis oils due to the simultaneous presence of aromatic and aliphatic structures, indicating a chemically balanced composition appropriate for binder applications (Maafa, 2021). The coexistence of both functional-group types suggests that the 80:20 blend combines the structural advantages of both parent polymers; this is consistent with the synergistic behavior frequently seen in polymer blends where combining components with different molecular characteristics produces materials with more balanced properties than the individual components (Fredi and Dorigato, 2024). Aromatic hydrocarbons contribute rigidity, hardness, and gloss retention, while aliphatic hydrocarbons contribute flexibility and moisture resistance.

CONCLUSION

This study shows that waste polystyrene and polypropylene can be transformed into pyrolysis oils that can be used as substitute binders in the manufacturing of emulsion paint. In comparison to the individual oils, blending the two pyrolysis oils greatly increased their density, optical clarity, refractive index, and general suitability for coating applications. With the lowest turbidity (22.30 NTU), a refractive index of 1.5917, an acceptable density (0.8978 g/cm^3), a satisfactory pour point (−13°C), and favorable FTIR characteristics combining aromatic and aliphatic hydrocarbons, the 80:20 PS/PP blend demonstrated the most balanced combination of desirable properties among the formulations examined. Overall, the study supports both increase in value of plastic waste and circular economy practices in the coatings industry by confirming that pyrolysis oils derived from mixed PS/PP plastic waste, especially at the 80:20 blend ratio, represent a promising, environmentally sustainable alternative to traditional petroleum-based binders in emulsion paint production.

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