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Research Article

The Effect of Concentration on Physicochemical Properties of Resins Made From Some Waste Polystyrene Plastic Products as a Potential Binder for Coating Industry

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Abstract

Waste Plastic Petri Dish (PPD) and Styrofoam (STYF) were picked from the dumping sites and dissolved in a mixture of gasoline and acetone (80/20% vol./vol.) to form a gel at room temperature of 30^{0}C. 4%, 12%, 20%, 28% and 32% wt./vol. concentration of the solute to solvent ratio were prepared. Effect of concentration on some physical properties was examined. Analysis showed that their physicochemical properties such as density, viscosity, refractive index, of the binder formed rises gradually up to 20% concentration above which were sharper rise in values. Gel time fell with concentration whereas turbidity rose and peaks at 20%, before steady decline. Moisture uptake was next to zero. On the whole 20% concentration appears to be optimal concentration. The findings indicate that, depending on need, at different concentration, a cheap binder can be made out of these waste plastic materials.

Keywords: Plastic Petri Dish, Resin, Additives, Coating.

Introduction

One of the most important and widely used materials in the world today is plastics (Ali *et al.,* 2021). The properties of plastic materials such as low density, low toxicity, and low upkeep need, high resistance to degradation, transparency and low cost make them so all round good as well as attractive to everyone. However, after the useful life of plastic material to man, the continuous accumulation of its remains in the environment has become a nuisance to land, air, waters and man himself (Sharma, *et al.,* 2021). As such, the afterlife value of waste plastic is not only a big nuisance to the environment but also to man himself and the ecosystem. Therefore, effort to rid our environment of these waste is ongoing. Several researchers had made some significant contributions in the direction ridding the environment of this unwelcome visitor–plastic waste. This includes Mechanical recycle using to form composite with cement for application in the construction industry (Eskander *et al.,* 2021) chemical recycle (Singh *et al.,* 2017), conversion to fuel by pyrolysis (Jha and Kannan, 2020) polymer dissolution among several. In continuous quest for converting waste plastic products to useful industrial wealth, the option of employing different types of used polystyrene waste as binder for paint industry comes to focus. The addition of additives to the parent polymer material affects the properties of the daughter polymeric products (Lee *et al.,* 2020; Tan *et al.,* 2020; Turner, 2020). Even so, polystyrene is not left out. The effect of addition of these additives alters the properties of the produced polymer. This explains why the physicochemical properties of Plastic Petri-Dish (PPD) and Styrofoam (STYF) are not identical though made from predominantly the parent stock of polystyrene. This paper examines two different types of waste polystyrene products-plastic petri dish (PPD) and Styrofoam (STYF)-to see how the physical properties of the binder they form varies with concentration when dissolved in a mixture of gasoline and acetone.

Materials and Methods

Gathering and Cleaning of the Plastic Waste

The raw material for this study PPD and STYF came from the dumping sites around Girei Local Government Area of Adamawa State were visited to pick PPD and STYF as waste. It was then washed with raw water and followed by cleaning with distilled water. They were then allowed to dry for few days before being stored in a clean polythene bag for further use.

Dissolution of the Plastic Waste

10g of PPD and STYF materials were dissolved in 50 cm^{-3} of gasoline. The gel formed at room temperature of 30^{0}C was left for 24 hours. Afterward, 10 cm^{-3} of the gel was poured on a polythene bag spread on top of the laboratory platform and allowed to dry at room temperature for one week. The FTIR of the dry samples were run. Also, a known mass (1g, 3g, 5g, 7g and 9g) of each plastic waste product was added to a beaker containing 20 cm^{-3} of gasoline and 5 cm^{-3} of acetone in each of the five beakers respectively. The solution was left to dissolve effectively at room temperature for 24 hours. The mouth the beakers were tight covered with aluminum foil to reduce evaporation of solvent. The system was left for the plastic material to dissolve for 24 hours for complete dissolution. Then, the content of each beaker was put in a bottle with a lid and kept for various analyses to determine some physical properties (Fasina *et al.,* 2023; Osemeahon *et al.,* 2023).

Determination of Moisture Uptake and Gel time

The moisture uptake of the resin films was determined gravimetrically, according to the method described by Osemeahon and Dimas (2014) and Gidigbi *et al.,* (2019). The gel time was carried out according to method described by Archibong *et al*., (2021). Gel time was determined using gel-time meter. The temperature was set for 121°C in gel time meter and the container was filled with paraffin wax. The heating system as well as the stirrer was switched on. 10g of the resin was weighed in a test tube and vertically in hot paraffin bath with the help of a wooden holder. Resin level in the tube was taken such that it was placed within hot paraffin oil bath. A glass rod was placed in test tube and it was locked to the spindle drive with magnetic couple. The spindle was now rotated. When the top spindle rotates, magnetic coupling as well as the bottom fin also started rotating along with glass rod. As the resin started hardening, rotation of glass rod was repelled, which in turn stop rotation of bottom fin. Upper fin, still rotating freely, come into contact with static one, and the time was recorded as read from the stopwatch. The gel-time was determined.

Determination of Density, Turbidity, Melting Point and Refractive Index

The density of the resins was determined by taking the weight of a known volume of resin inside a density bottle using Pioneer (Model PA64) weighing balance. Three readings were taken for each sample and average value calculated. The turbidity of the samples was determined by using LaMotte Smart Colorimeter ISO No. 9001.

The melting point of the film samples was determined using Stuart apparatus for measuring melting point (Model MFB600-010F).

The refractive index of the samples was determined with Digital Refractometer (Brix) DRE–B95. The above properties were determined according the standard methods (AOAC, 2000). Viscosity was determined by adopting Archibong *et al.,* (2021) method, using A & D Company Ltd. Vibro Viscometer SV-10. It was carried out at a temperature of 30°C.

Results and Discussion

The FTIR spectra of PPD and STYF mixed with GAS and ACE is illustrated in Figure 1 (a) and (b) respectively. The upper spectrograph, Figure 1a is PPD whereas the lower map Figure 1b is STYF. This shows the display of the vibrational spectrum of functional groups in the sample from 4000 cm^{-1} to 500 cm^{1}.

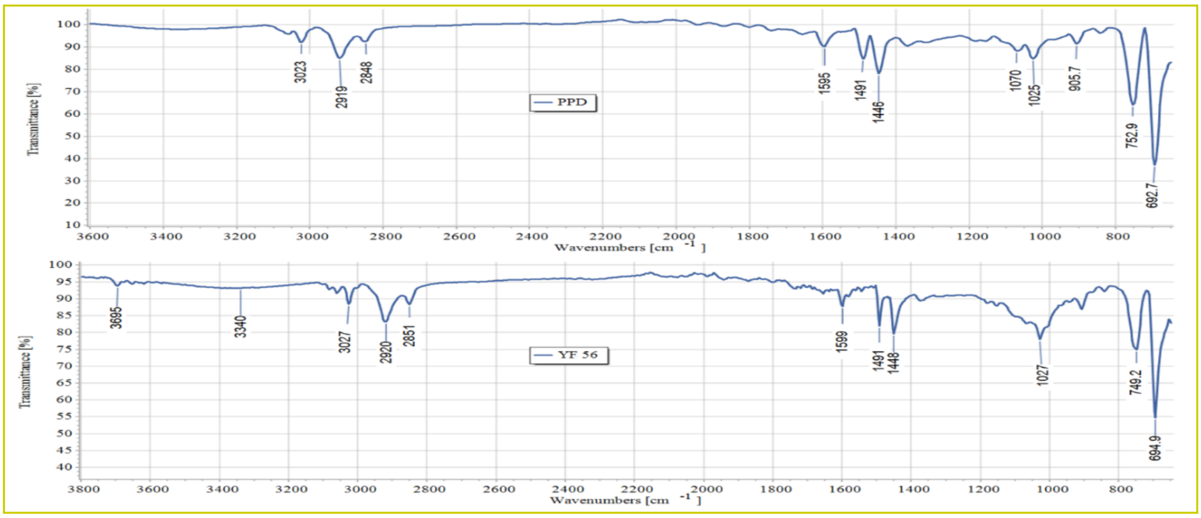

Figure 1 (a) and (b). The Fourier Transform Infra-Red Spectroscopy (FTIR).

Table 1. The comparison of the FTIR absorption bands for pure polystyrene, PPD and STYF.

Wave number (cm^{-1}) for pure PS	**PPD (cm^{-1})**	**Difference for PPD (cm^{-3})**	**STYF (cm^{-1})**	**Difference for STYF (cm^{-1})**	**Functional group indicative**
Stretching mode					
3354 (w)	3023 (w)	-331	3027 (w)	-327	C-H
2979 (m)	2919 (m)	-60	2920 (m)	-59	C-H
2917 (w)	2848 (w)	-31	2851 (w)	-66	C-H
Stretching in aromatic ring					
1645 (w)	1595 (w)	-50	1597 (w)	-48	C=C
1487 (m)	1491 (m)	+4	1491 (m)	+4	C-H
1445 (m)	1446 (m)	+1	1448 (m)	+3	CH_2+C=C
Out of plane bending					
1042 (m)	905.7 (m)	-136.3	1027 (m)	-136.3	C-H
877 (m)	752.9 (m)	-124.1	749.2 (m)	-127.8	C-H
748 (s)	692.7 (s)	+55.3	694.9 (s)	-55.3	C-H
vs = very strong; s = strong; w= -weak; m = medium					

The spectrum ranging from 3200 to 2800 cm^{-1} signifies the area of the C–H stretching modes. The peaks at 3082, 3060 and 3026 cm^{-1} correspond to engagements from the aromatic C–H stretching vibrations, while the absorption bands at 2923 and 2848 cm^{-1} come from the asymmetric and symmetric respectively, stretching vibrations of methylene groups –CH_2. The pattern of the overtone and combination bands in the region 2000–1665 cm^{-1} reflects what was expected for single-substituted aromatic rings (1947 cm^{-1}; 1889 cm^{-1}; 1807 cm^{-1}; 1749 cm^{-1} and 1668 cm^{-1}) (Ashenhurst, 2022).

The carbon–carbon stretches in the aromatic ring are observed at 1601 and 1583 cm^{-1} and both represent in-plane ring breathing modes. The absorptions at 1493 cm^{-1} and 1452 cm^{-1} are also due to carbon–carbon stretching vibrations in the aromatic ring. This may be as a result of both the ring breathing of the benzene ring, and the deformation quivering of –CH_2. The intermediate part of the spectrum, from 1300 cm^{-1} to 900 cm^{-1} approximately, is usually called the fingerprint region. In-plane bending bands show up in this region, sometimes these bands are often very weak in most aromatic compounds. The in-plane C–H bending of the benzene ring are observed at 1069 and 1028 cm^{-1}. The pattern of the out-of-plane C–H bending bands in the region 900–675 cm^{-1} is also characteristic of the aromatic substitution pattern, being intense at 697 and 757 cm^{-1} respectively (Olmos *et al.,* 2014).

In comparison of the FTIR of the synthesized Polystyrene (Olmos *et al.,* 2014) and waste polystyrenes (PPD and STYF) from this study, a shift in peak was observed from 2917 cm^{-1}, of which synthesized polystyrene absorbs energy (Olmos *et al.,* 2014), respectively, to 2920 cm^{-1} and 2919 cm^{-1}; from 3060 cm^{-1} to 3027 cm^{-1} and 3023 cm^{-1} of aromatic stretch; from 2923 cm^{-1} to 2920 cm^{-1} and 2919 cm^{-1}; from 2848 cm^{-1} to 2885 cm^{-1} whereas the same value is obtained for PPD for symmetrical stretch of the carbon–hydrogen (-C-H) bonds.

Similarly, in the region of carbon–carbon stretch in the aromatic weak carbon-carbon double bond (>C=C<) in the benzene ring and the deformation vibration of --CH_2, STYF and PPD films from waste polystyrene materials, a shift from pure polystyrene that absorbs at 1601 cm^{-1} to 1599 cm^{-1} and 1595 cm^{-1} respectively. This might have been the vibrations of the benzene ring (Olmos *et al.,* 2014). In the same vein, 1452 cm^{-1} moved to 1448 cm^{-1} and 1446 cm^{-1} for STYF and PPD respectively. The absorption peaks at the 1491 cm^{-1} common to both STYF and PPD of which is completely absent in the pure polystyrene might have been due to the effect of the C-C vibration in the solvent.

Also, in the finger print region of the spectra, the absorption peak of 1028 cm^{-1} of pure polystyrene for STYF and PPD is 1027 cm^{-1} and 1025 cm^{-1} respectively. Finally, in the out-of-plane region of 900 cm^{-1} to 675 cm^{-1}, ortho-distributed benzene with which has a very strong absorption peak in pure 757 cm^{-1} and 697 cm^{-1} respectively having 749.2 cm^{-1} and 682.7 cm^{-1} as well as 752.9 cm^{-1} and 682.7 cm^{-1} for STYF and PPD respectively. In view of the above, the minor change in in the absorption peaks might have been as a result of the effect of the additives added to the dissimilar types of polystyrene products to achieve the desired application of the polymeric stuff or the effect impurities contacted at the dumping site, or both.

Effect of PPD and STYF Concentration on Density

The effect of PPD concentration on density of binder solution is shown in Figure 2. The density is observed to increase with increasing addition of PPD solute. This result may be due to the inherently structure of the polymer of the plastic chain, which is prone to formal less compact cross-linked structure. It can also be as a result of differences in molecular feature as the concentration of PPD increases which influences the packing nature of resin molecules. Physical properties of the polymer depend on chain length and content of the soft and hard segments. The density increase is due to both mass transport and polymerization reaction and distortions in the exposed material (Galli *et al.*, 2021).

Generally, the density of the resin increases with increase on the PPD concentration. Density depends on free volume and packing efficiency of molecular chain (Kazys and Rekuviene, 2011). From Figure 2 there is a sharper increase in density of PPD resin as the concentration increases from 20% to 28%. The sharp increase in density may be due to molecular features and morphology of the polymer and increase in polydispersity index which leads to increase in density (Archibong, *et al.,* 2018). Also, the increase in density could be owing to the effect of polymerization proceeding with crystallization simultaneously from lower concentration of the solute to a higher concentration. The reduction in the micro voids as the concentration increases accounts for the increase in density.

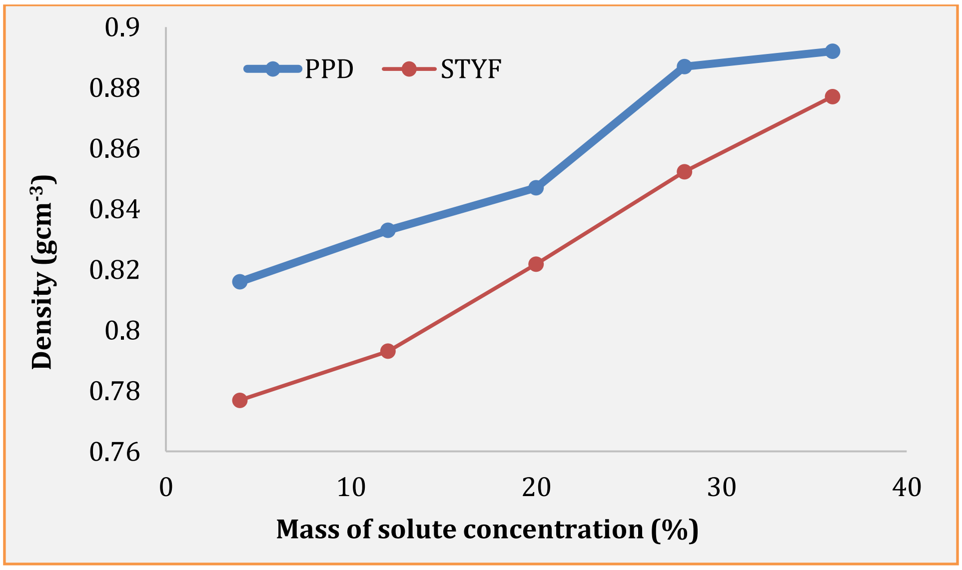

Figure 2. Effect of the PPD and STYF concentration on density.

Effect of the PPD and STYF concentration on viscosity

Viscosity is of grave importance in as much as the study of flow of fluids and gels is concerned. Viscosity deals with the flow of matter under stress. The key to the design of a processing operational system that depends on the way products flow must consider the viscosity of the product. For example, flow products through a pipe, stirring in the mixer and packaging into the container is done with consideration to the rate of flow.

Many of the sensory attributes of emulsion structures are directly related the flow properties such as creaminess, thickness, smoothness, spread-ability, pour-ability, flow-ability, brittleness and hardness. Control of morphology and viscosity of lattices particles has been a well-practiced art within industry for some now given its great importance in determining the physical and mechanical properties of polymer system (Osemeahon and Dimas, 2014).

The viscosity is observed to rise gradually until it reaches 20% concentration, afterwards a very sharp rise is observed. An important rheological property of fluids is viscosity. Viscosity is the fundamental property that can be defined as resistant to flow and is related to the characteristics of composite material. It is widely used in many industries to characterize polymers (Archibong, *et al.,* 2021).

Difference in viscosity arises as a result of the increase in flux density of PPD and STYF waste polymer. This in turn alters the number of chain per unit volume as the concentration of rises. This explains the reason why there is a steady rise from 4% concentration to 20%. As the PPD and STYF load increases, the molecular flux of the polymer density rises. Beyond 20% concentration a very sharp rise in viscosity is recorded.

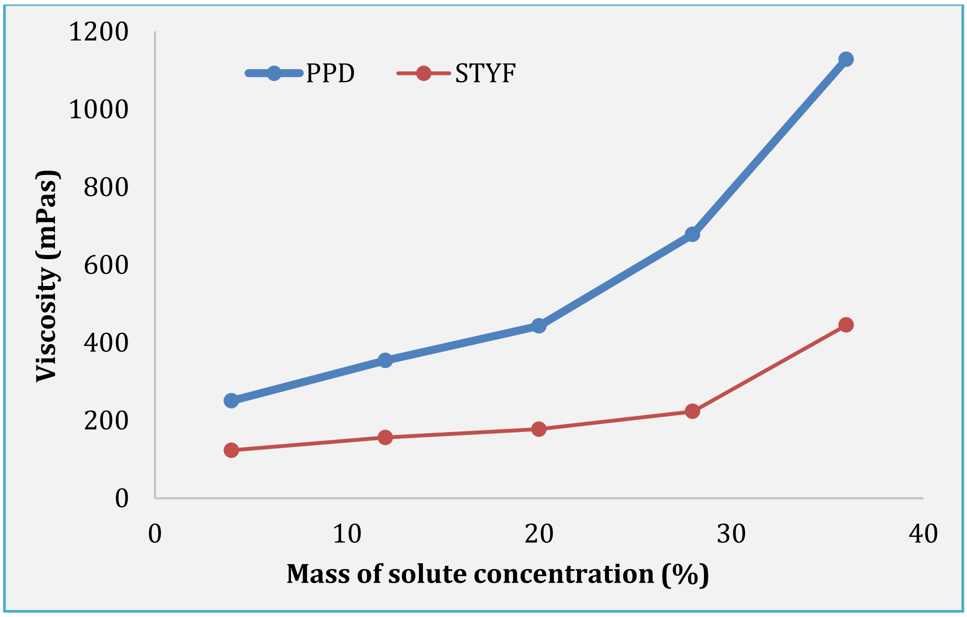

Figure 3. Effect of PPD and STYF concentration on viscosity.

Effect of STYF and PPD Concentration on Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in the direction or flux through the sample. When we have homogeneity and few particles, there will be less scattering; hence, higher scattering is observed when there is a non-homogeneous system with lots of particles (Archibong *et al.,* 2018). Turbidity is a measure of amount of cloud in a fluid of which can be measured in Nephelometric Turbidity Unit (NTU) or Jackson Turbidity Unit (JTU) (Mohammed, 2015). Turbidity of the binder is an important property to the Chemist in the coating industry (Osemeahon *et al.,* 2015). The property is very important because it is related to the gloss property of the binder. The measurement of the turbidity of the binder was performed in order to characterize the optical properties of the resin as related to the gloss property. The refractive index gives a suggestion of the turbidity. Light collaboration with the colloidal system is termed turbidity. In homogenous system with few particles, there will less scattering of light and less turbidity value. Higher scattering of light will be obtained when we have a non-homogenous system with a lot of particles. Turbidity is relatively low at 4% concentration for both samples. However, as the concentration of the of STYF and PPD concentration increases, the binder becomes more colloidal because of the more polymer strain influx density. Particles absorb and reflect light. At higher concentration of PPD and STYF, it can be seen that as the resin becomes denser, less light passes through the solution, therefore turbidity values declines (Osemeahon *et al.,* 2013). For both PPD and STYF the optimal turbidity values were recorded at 20% concentration.

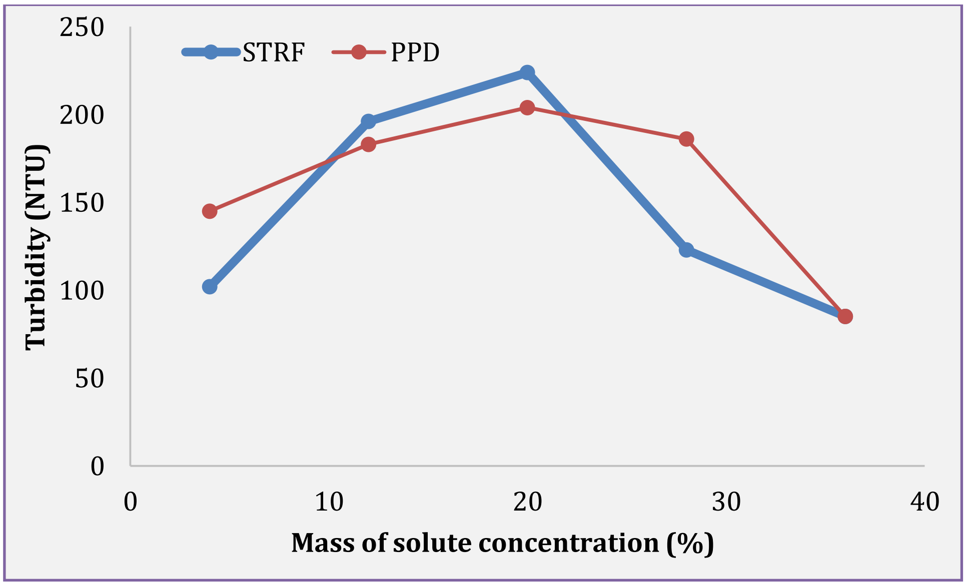

Figure 4. The Effect of PPD and STYF concentration on turbidity.

The Effect of Concentration on Refractive Index

Refractive Index is a fundamental physical quantity of a material which is expressed as a function of the incidence angle of light or electromagnetic wave propagates through an optical medium and refractive angle of material on the surface roughness and geometrical shadowing (Archibong *et al.,* 2021). Gloss is a measure of the ability of the surface to reflect light. Gloss comes about by the reflection and absorption of light and is a necessary coating property when the aesthetic or decoration of the surface becomes the desired (Osemeahon and Dimas, 2014). Glossiness of the paint shows how it reflects light and shininess. The glossiness/shininess of paint is direct reflection of the refractive index of the binder. As such, refractive index of the binder is a crucial factor in the ultimate gloss property of the formulated paint.

The effect of PPD and STYF concentration on refractive index is shown in Figures 5. It is observed that the refractive index increases with the increase in the STYF and PPD concentration which is in agreement with the work of (Osemeahon *et al.,* 2013; Osemeahon and Dimas, 2014). STYF has a lower refractive index than PPD. They may also have been an alteration in the crystallinity of the system with increasing temperature due to decrease in the number of various chain lengths that make up the polymeric system (Archibong *et al.,* 2021). The refractive index changes come from the change in concentration gradient that causes the vibration of polymer chain from dark to bright areas, where the polymer chains advance. Consequently, the refractive index modulation in photopolymers originates from two main factors: a density upsurge and a separation of index contrasting species resin matrix.

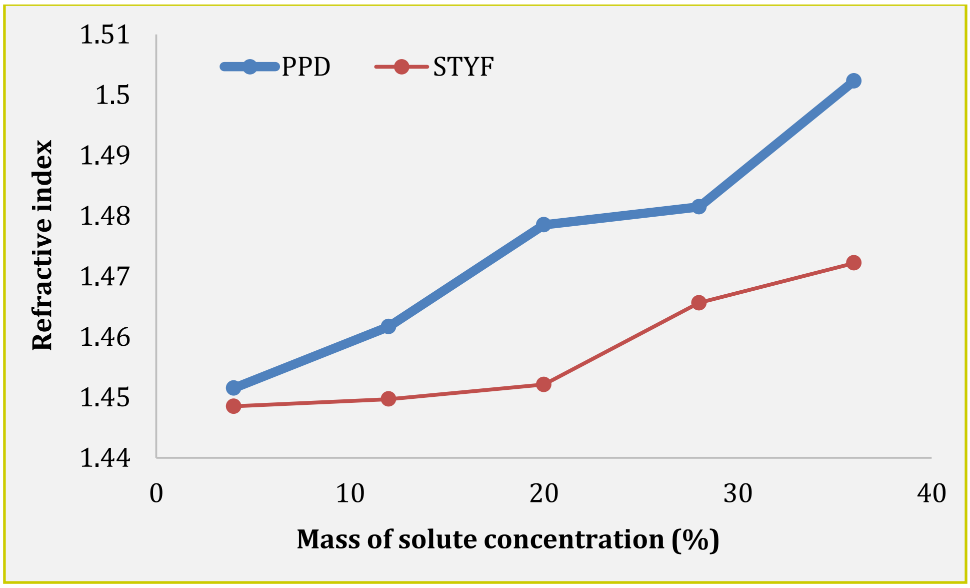

Figure 5. The Effect of PPD and STYF concentration on refractive index.

Moisture Uptake

The quality of a polymeric binder has much to do with moisture transport property of the paint as one of the major constituent. The greatest weakness of the water based coating has been the susceptibility to durability issue concerning water resistance. Often, some functional group on the polymer chain or the copolymer chain forms hydrogen or ionic bond with hydrophilic tendency. Unless the hydrophilic attraction is balanced equally with that of the hydrophobic, the coating will either be water sensitive or the formulation will not have colloidal stability. Hydrophobic components in the binder give the best combination of improving water resistance of water-borne coating. A detailed knowledge of moisture transport is also essential for understanding the resistance of a material against attacks from its environment (Bharat and Swamy, 2009; Osemeahon and Dimas, 2014).

One of the main drawbacks of urea formaldehyde resin is its high water take and this has to be improved in order for the resin to satisfy the coating industry. Water deteriorates thermo-mechanical properties and adhesion. It induces chemical degradation of the network and also generates stresses, because of swelling and hence blistering of the coating film. The water absorption ratio of latex films is an important parameter for characterization of hydrophobicity of the binder (Gonzalez, *et al.,* 2012; Gidigbi *et al.,* 2023). The moisture uptake is seen to decrease with increasing concentration of PPD and STYF. This is expected as the increasing concentration PPD and STYF causes the polymer to form a tighter network and therefore the increasing density reduces the moisture uptake.

The smaller inter-molecular lower void space within the polymer matrix, hence give rise to reduced moisture uptake (Archibong, *et al.,* 2021). The lower sensitivity to moisture is due the plastic nature of PPD and STYF (Osemeahon and Dimas, 2014). This will address one of the shortcomings of emulsion paint formulation which is susceptibility to sagging in water and moisture conditioned environment.

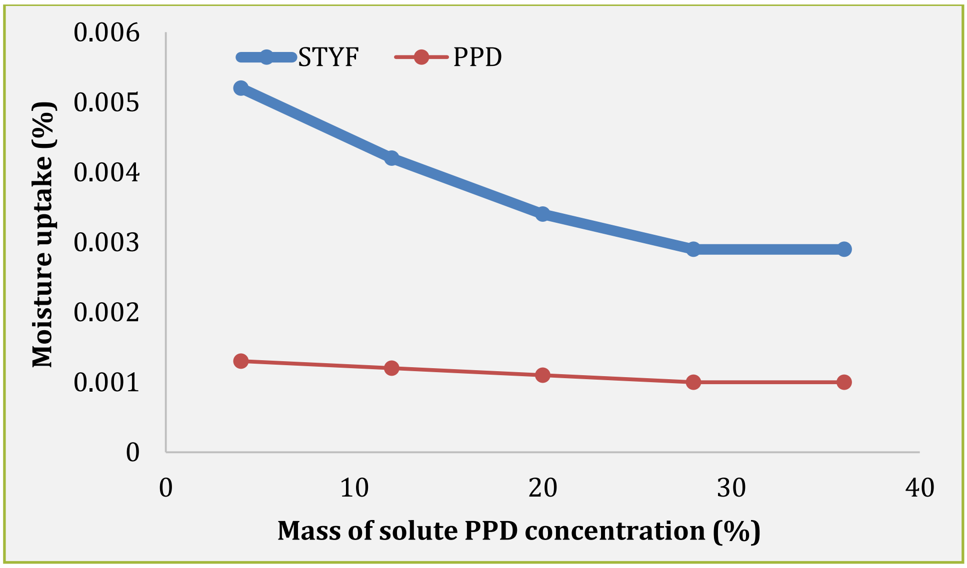

Figure 6. The effect of PPD and STYF concentration on moisture uptake.

Gel Time

Gel time is the time it takes for mixed resin system to become highly viscous or gel that it can no longer be considered workable or able to handle without impending curing process. Gelation is the change in the macromolecular structure of resin, which is usually expressed as an increased viscosity and leads finally to the loss of flow-ability. It is a two-step process: the initial period of slow viscosity growth and period of fast structuration (Gidigbi *et al.,* 2023). The early period slow viscosity increase is the 'pot life' of which is the maximum length of time the system remains in sufficiently fluid condition before being applied to a substrate. It is also the peak at which the network formation commences.

The dry time of any paint is the direct function of its binder's gel time among other factors. The gel time also plays a key role in guiding the paint formulator to ascertain the maximum storage period of his product. Besides, the time it would take before the coating adheres effectively to the applied substrate (Osemeahon and Dimas, 2014; Osemeahon, *et al.,* 2023).

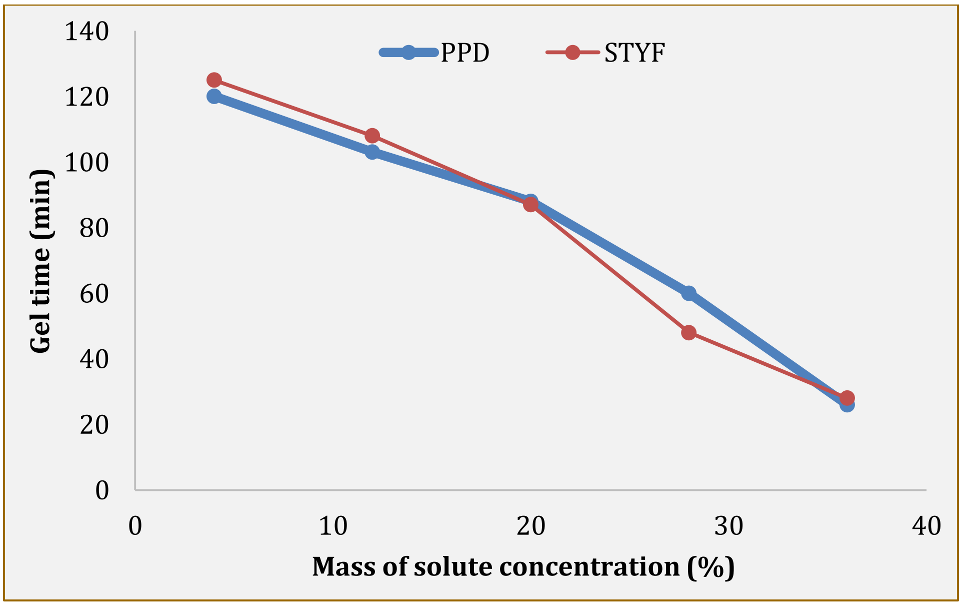

Figure 7. The effect of PPD and STYF concentration on gel time.

Gelation is characterized by the incipient formation a material of an infinite molecular weight and indicates the conditions of the processability of the material. Prior to the gelation, the system is soluble, but after gelation, both soluble and insoluble materials are present. As gelation is approached, viscosity increased dramatically and the molecular weight goes to infinite. The reacting between monomers leads to the formation network, hence gelation. Both molecular weight and polydispersity increase until one single macromolecular whole is formed. At this point the behavior of the system changes form liquid-like to rubber-like, thus the reactive system becomes a gel (Gonzalez *et al.*, 2012).

This behavior can be attributed to increase cross-linking density which leads to increase in viscosity and reached a stage where the nucleation process for the formation of a single macrostructure begins to increase the viscosity build up (Menkiti and Onukwuli, 2011). The longer the gel time of the binder, the longer it will take the paint formulated with the binder to dry. From the observation it appears the optimal gel for this grade of binder would be at a concentration of 20% for both PPD and STYF.

Effect of PPD and STYF Concentration on Melting Point

The melting point of the polymer has a direct effect on its thermal property (Osemeahon *et al.,* 2007; Osemeahon *et al.,* 2023). It is related to its molecular weight, degree of rigidity and the level of cross-linking. Generally, the melting point of a compound increases with its molar mass, inter-molecular Van der Waals interaction and also the intrinsic structures that affect the rigidity. In the coating industry, the melting point of a binder is related to its thermal resistance as well as the brittleness (Afsoon, *et al.,* 2011). Figure 8 exhibits the effect of PPD and STYF plastic waste products on the concentration of the melting point of the resins from 0 to 36%. The result shows a gradual increase of melting point with increase in concentration. The increase can be attributed to increase in molecular mass as well as the increase in the cross-linking density.

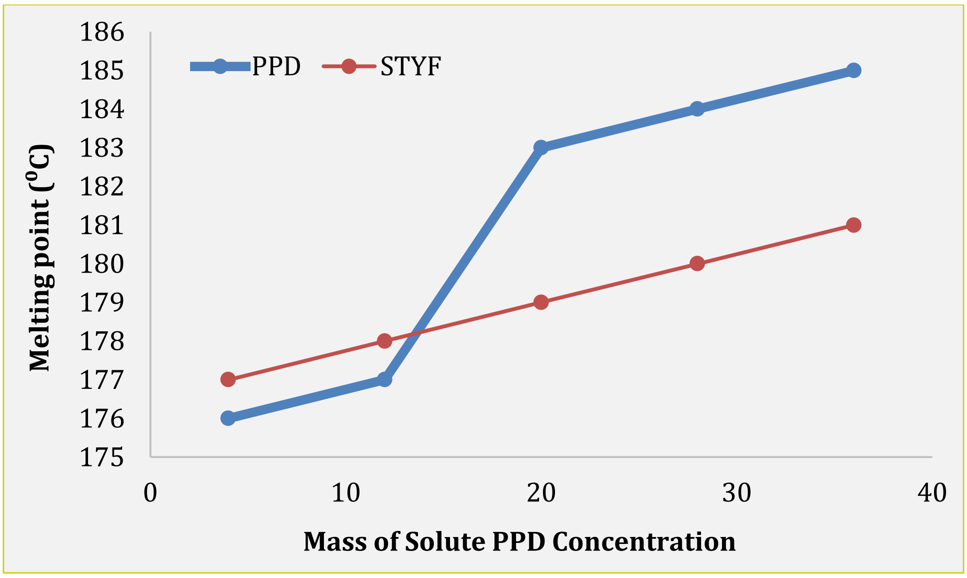

Figure 8. The effect of concentration of PPD and STYF on melting point.

Conclusion

The study showed that locally sourced waste plastic polystyrene products such as PPD, and STYF have potentials to be formulated and used as a substitute for emulsion paint binders in view of the physicochemical analytical data they generate. With this in view, it is hopeful that these waste plastics can be turned to wealth as well as makes our environment cleaner for a healthy living.

Declarations

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Author Contributions: The authors confirm sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Conflict of Interest: The authors declare that they have no conflict of interest.

Consent to Publish: The authors agree to publish the paper in International Journal of Recent Innovations in Academic Research.

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Research Content: The research content of manuscript is original and has not been published elsewhere.

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