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Research Article

Characterization of Different Types of Polystyrene Waste Plastic Products as a Feasible Binder for Coating Industry

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Abstract
The waste polystyrene plastic products such as Plastic Petri Dish (PPD), Plastic Ruler (PR), Styrofoam (STYF) and Plastic Fruit Tray (PFT) were used for the production of resins at room temperature of 30^0C by dissolving in gasoline. All the formulated resins were stable as gel. Physical properties such as density, viscosity, turbidity, refractive index, moisture uptake, melting points etc. were evaluated. The data obtained varies for different polystyrene products, probably because of different additives added during their production processes. The physicochemical analysis figures obtained indicate that they present themselves as potential binders for coating industry, as the values from were in agreement with the similar adhesives in the literature used for the formulation of emulsion paint.
Keywords: Plastic Petri Dish, Plastic Fruit Tray, Resin.

Introduction

The accumulation of plastic waste products in our environment is of concern. The challenge of getting rid of plastic waste products has really been worrisome in recent decades. Plastic polymer products are not easily degraded. Besides, worldwide plastic production has surged for over past 50 years and will continue to grow (Barra and Leonard, 2018; Royer *et al.,* 2018; Drzyzga and Prieto, 2019).

Osemeahon *et al.,* (2013) and Fasina *et al.,* (2023) contended that it is only the good management of these undesirable materials that will alleviate negative effect of plastic waste as their affectations on human health, quality of life and the surroundings is grave. Paint is a colloidal mixture of chemical substances such that when spread on the surface it forms a thin protective layer that cohere with itself and adhere to the applied sub-surface for decorative and protective purposes (Arewa *et al.,* 2018). Paint comprises of a binder, pigment and solvent, which serves decorative and protective purposes. Among all these components paint binder consist a constituent of interest of which it is imported and thirty percent of the cost of production that adheres to surface of the substrate coated after the diluent have evaporated (Parker, 2019). Binder serves as a vehicle that suspends the pigments, additives and diluents (Gidigbi *et al.,* 2023). Even though oil paints have good performance and durable qualities, but its emission of volatile organic compounds (VOCs) scores it low (Gidigbi *et al.,* 2019).

Presently, in most of the third world countries, binders like polyvinyl acetate are being imported from oversea for paint formulation of emulsion paint. Locally sourced adhesives are lacking. As such, the conversion of plastic waste products to binder as a potential source of producing water resistant emulsion paint can help in eradication of waste plastic products from environment as well as convert waste to wealth. In case of polystyrene (PS), there are always additives in the matrix of both Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS) polymer. XPS is formed when PS crystals, without the blowing agents are extruded at high temperature. The closely packed particle of XPS gives it a smoother surface and a higher density than EPS of which it compactness is reduced by blowing agent. The blowing agent causes density reduction (Turner, 2020).

Residues in foamed PS include Fe_2O_3, used as a catalyst in the production of styrene. Zn stearate often used to make for even cell nucleation during the manufacturing of EPS (Varnagiris *et al.,* 2017). Additives are sometimes added as a thin surface texture for protection but most are usually mixed or precast into the raw material to ensure constant concentration. Additives are tailored towards specific needs and applications; to be specific, addition of graphite can advance insulation properties of construction boards, various pigments may be employed to give a range of diverse colors, and TiO_2 may be added to assist bacterial decomposition or as a pigment to provide a high refractive index (Varnagiris *et al.,* 2017). The stabilizer and antioxidant tris (4-nonylphenyl) phosphite, is sometimes added (Farelly and Shaw, 2017).

On the whole, the addition of these additives to the parent polymer material actually affects the properties of these daughter polymeric products, as such, enhances or limits its performance potentials. On this premise the examination of different types of waste polystyrene products to see how the physical property of the waste varies, we think is not out of place.

As such, it is the intent of this paper is to examine four types of waste polystyrene products so as to develop potential binders from these waste materials for paint making industry. The assumption is that these products Plastic Petri-Dish (PPD), Plastic Ruler (PR), Styrofoam (STYF) and Plastic Fruit Tray (PFT) are made up of a high proportion Polystyrene with different additives.

Materials and Methods

Identification of Soluble Plastic Materials

Some of the dumping site and Clinics around Girei LGA of Adamawa State, Nigeria were visited to pick various plastic materials for possible dissolution in given solvents. The solubility of the plastic material so picked was tested with several solvents for possible dissolution. The four earlier mentioned had likeliness to dissolve in gasoline mixed with acetone as well as in gasoline alone at room temperature were identified from preliminary test.

Dissolution of Plastic Material

A known 5 gram of each plastic waste product was dissolved in 20 cm^{-3} of gasoline (GAS) plus 5 cm^{-3} of acetone (AC). Also, 5g of plastic material was dissolved in 25 cm^{-3} of gasoline (GAS) differently as solvent to get a gel at room temperature of which can serve as a binder for paint production. The same procedure was repeated for each of the polystyrene waste product (Osemeahon and Dimas, 2014; Osemeahon *et al.,* 2023).

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 will be taken for each sample and average value calculated. The turbidity of the samples will be determined by using LaMotte Smart Colorimeter ISO No. 9001 (AOAC, 2000). The melting point of the film samples will be determined using Stuart apparatus for measuring melting point (Model MFB600-010F).

The refractive index of the samples will be determined with Digital Refractometer (Brix) DRE–B95. The above properties will be determined according the standard methods (AOAC, 2000).

Viscosity was determined by adopting Archibong *et al*., (2021) method, using NDJ-55 208 N2269 Searchtech Instrument, British Standard Viscometer. Spindle number was selected and the speed of motor was set. The temperature of the solution was measured using temperature probe. The spring cap was removed and the spindle was fixed. It was immersed up to the mark in the resin and the motor switched on. Spindle rotates inside the solution and produces shear, which gives value of viscosity. It was carried out at a temperature of 30°C. The gel time will be carried out according to method described by Archibong, *et al*., (2021).

Determination of Moisture Uptake

The moisture uptake of the resin films will be determined gravimetrically, according to the method described by Osemeahon and Dimas (2014). Known weights of the samples will be introduced into desiccators containing a saturated solution of sodium chloride. The increase in weight (weight difference between the wet weight and dry weight of the sample was recorded as the moisture uptake by the resin. The triplicate determinations were made for each sample and the average value recorded.

Results and Discussions

Cleaning of the Plastic waste

Figure A and B shows the image of dirty PPD from one of the dumping site in Girei Local Government Area as well as the cleaned PPD as a model sample of plastic waste.

Figure A. Dirty Plastic Petri Dishes (PPD) **Figure B. Cleaned Plastic Petri Dishes (PPD)**

Density

Density is a physical property that expresses the ratio of mass to volume. Density depends on the atomic mass of the element or compound (Osemeahon and Dimas, 2014). Since different substances have different density, this parameter plays critical role in polymer engineering process. So, density measurement helps in the proof of identity and categorization of several substances. Density is factor that influences the production cost, profitability and transportation of finished products in the manufacturing processes (Kazys and Rekuviene, 2011).

The density of a binder influences properties such as the dispersion and stability of the pigment. Also, it can be used to determine the critical factor in the paint production of which is the pigment volume concentration (PVC), spreading capacity and consistency of the paint (Osemeahon *et al.,* 2015).

From Table 1, it may be the molecular features and morphology which influences the packing nature of the binder and the morphology of the binder that influenced the density. The highest value was A which is PPD + AC + GAS with the value of 0.8851 and least in H which is PFT + AC + GAS with the value of 0.8359. The rest of the values fell between these two extremes. These results are unconnected with the packing nature of resins (Osemeahon *et al.,* 2013).

Table 1. Density of the binder samples.

Sample	Density (gcm^{-3})	Standard
A	0.8851	0.865 (gcm^{-3}) Osemeahon and Dimas, (2014)
B	0.8751	
C	0.8797	
D	0.8719	
E	0.8735	
F	0.8567	
G	0.8678	
H	0.8359	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Viscosity

Rheological properties such as viscosity can be directly correlated to the evolving physical and mechanical properties during resin cure (Osemeahon, 2011). Viscosity is a fundamental rheological parameter of macromolecular compounds. The property, viscosity describes the resistance to flow of polymeric materials of which it widely used in many fields of industry. Correct measurement of viscosity can help to characterize the polymer and to determine the relative molecular mass. Understanding the viscosity of the binder is quite important because it controls factors such as flow rates, levelling and sagging, thermal and mechanical properties, dry rate of paint film and adhesion of the coating to the substrate (Osemeahon *et al.,* 2013).

From Table 2 the viscosity of the PR + GAS had the highest viscosity of 665 mPas whereas STYF + GAS had the lowest viscosity. It is a common observation that the type of solvent affects viscosity of the resin. This may be as a result of the type of plasticizer use in the plastic and the variation in the chain length of different length of the plastics. Therefore, increase in molecular weight gives the rise to increase in viscosity (Afzal *et al.,* 2013).

Table 2. Viscosity of binder samples.

Sample	Viscosity (mPas)	Referred standard
A	442.5	250 mPas Osemeahon *et al.,* (2013)
B	378.8	
C	314.0	
D	665.0	
E	275.0	
F	177.4	
G	236.0	
H	345.0	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Turbidity

The reason for determining the turbidity of a resin is in order to characterize the optical properties of the binder as it relates to the gloss performance. Turbidity has to do with the light scattering. Refractive Index gives indication of the turbidity. For the homogenous clear solution, there are few particles that scatter light. On the other hand, non-homogenous system with a lot of particles, a rise in turbidity is expected. For PFT of which the color is black, all the colors of the white light were absorbed. As such, their opaque nature of the plastic waste product made it impossible to determine their turbidity. Other transparent ones has the values indicated in the Table 3. The rise in turbidity may be due to the progressive changes in the crystalline orientation and morphological changes responsible for the light scattering. Turbidity also gives a signal of the average molecular weight of a polymeric material (Saljaba *et al.,* 2018).

Table 3. Turbidity of binder samples.

Sample	Turbidity (NTU)
A	139.3
B	204.3
C	126.0
D	104.3
E	54.0
F	224.0
G	0.0
H	0.0

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

The Refractive Index

Table 4. The refractive index of binders.

Sample	Refractive index	Standard
A	1.4620	1.47 Osemeahon *et al.,* (2013)
B	1.4845	
C	1.4783	
D	1.4948	
E	1.4546	
F	1.4724	
G	0.0000	
H	0.0000	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Reflectiveness is known to be a good property of the paint has been reported to have something to do with the refractive index (Osemeahon *et al.,* 2015). Gloss plays a significant role in the performance of coating material. The gloss of paint changes with or without pigment is a function of refractive index of the surface angle of incidence of the surface, the nature of the beam of light, the angle of incidence of the beam (Osemeahon *et al.,* 2013). The binder plays a role in exhibiting the reflective property of paint. The refractive index of the binders prepared from waste plastic relatively high in comparison to the acceptable level of 1.4000 (minimum) (Osemeahon *et al.,* 2015).

From Table 4, Sample E which is STYF/GAS/AC recorded the least value of 1.4546 whereas D which is PR/GAS had a highest refractive index of 1.4948. The refractive index for sample G and H could not be determined because of their opaque nature in which all the colors of white light were absorbed.

Moisture Uptake

Moisture absorption causes chemical degradation to polymer network and generates stress because of swelling and hence blistering of the coating film. It weakens the thermo-mechanical properties as well as adhesion (Gonzalez *et al.,* 2012). It is that property responsible for alligatoring, brooming, blistering etc. of paint film, and affecting its mechanical grid in the way that it might lead to paint failure (Osemeahon *et al.,* 2015).

Water borne paints are susceptible to a lot of issues including durability as well poor water resistance. This is usually because functional groups in the polymer and copolymer matrix undergo hydrogen and ionic bonding. Exception would be when the hydrophilic property is balanced with that of hydrophobic properties. The polymer will either be water sensitive or the formulation will not have colloidal stability. From Table 5 the binders have strong resistance to moisture penetration in its matrix.

Generally, the percentage moisture uptake recorded is of insignificant value. Some of the values obtained might have been due to the procedural error, as plastics do not absorb water in their matrices. The moisture uptake was highest in Sample A which is PPD/ GAS and lowest in F which is STYF/ GAS. It appears as if the carboxylic group in the acetone attracted more water.

Table 5. Moisture uptake of binders.

Sample	% Moisture uptake	Standard reference
A	0.0042	3.10 (max)
B	0.0034	
C	0.009	
D	0.0208	
E	0.0022	
F	0.0011	
G	0.0012	
H	0.0031	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Gel Time

Gelation is the time required for a polymeric material to reach infinite viscosity. Gel time or the pot life is the measure of the maximum length of time the fluid system of binder remains for it to be applied to the substrate. It has also noticeable to be the point at which a polymeric substance can attain infinitesimally large molecular weight (Idowu-Oyewole *et al.,* 2016). It marks the attainment of certain critical conversion responsible for the transition from liquid to solid state of the curing process (Osemeahon and Dimas, 2014). At this point the macromolecular structure of the resin changes and loss flow-ability as a result of the commencement of the network formation. In the gelation process, first the viscosity increases slowly, then comes the time of fast structuration at which the resin will no longer flow.

The function of a binder's gel-time among other factors determines the dry time of paint. Technically the gel helps the paint maker defines the how long it will take for his product to dry. It also defines the adhesion of the paint to the coated surface (Menkiti and Onukwuli, 2011). From Table 6 the gel time of all the binders were at the range of 80 and 90 minutes. These values are encouraging as they would give a paint that cure fast if used for formulation.

Table 6. Gel time of the binders.

Sample	Gel time (minutes)	Standard reference
A	84.0	120 minutes Osemeahon *et al.,* (2013)
B	88.0	
C	82.0	
D	80.3	
E	88.0	
F	87.0	
G	81.3	
H	83.7	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Melting Point

Melting point is associated with thermal property, molecular weight, level of crosslinking and degree of rigidity (Osemeahon and Dimas, 2014). In coating industry, the melting point of binder is related to its thermal resistance as well as it brittleness. The thermal property, degree of cross linking, level of rigidity and molecular weight of the polymer are related to its melting point. Generally, the melting point of a compound increases with its molar mass, intermolecular Van der Waals interactions and also the intrinsic structures that affect the rigidity. From Table 7, PPD and PR and PFT earlier indicated a high melting point range of 184^0C to 186^0C.

Table 7. Melting point of the binders.

Sample	Melting point ^{0}C	Referred reference
A	184.7	130 ^{0}C Osemeahon *et al.,* (2013)
B	183.3	
C	186.7	
D	181	
E	185.7	
F	179.7	
G	179.9	
H	185.3	

A = PPD + AC + GAS; B = PPD + GAS; C = PR + AC + GAS; D = PR + GAS; E = STYF + AC + GAS; F= STYF + GAS; G = PFT + GAS; H = PFT + GAS + AC

Conclusion

The study showed that a locally sourced waste plastic polystyrene product such as PPT, PR, STRF and PFT has potential to be formulated and used as a substitute for emulsion paint binders in view of the physicochemical analytical data they generate. However, PFT, in view of its opaque nature may only be suitable where black color is a requirement as it absorbs all other colors of light. With this in view, it is hopeful that these waste plastics can be turned to wealth as well as makes our environment beautiful and cleaner for a healthy living.

Declarations

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