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Effect of Different Solvents on the Quality of Paint Binder Developed from Waste Polystyrene Materials

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ABSTRACT

Waste polystyrene materials (green, yellow and silver coloured disposable takeaway plates and styrofoam) were converted to a paint binder using gasoline, ethyl acetate, carbon tetrachloride (CCl_4), a mixture of gasoline and ethyl acetate, a mixture of gasoline and CCl_4, and a mixture of CCl_4 and ethyl acetate as solvents via solvent dissolution method. Some properties of the binders developed were investigated and found to vary from one solvent to another. The binder films formed with CCl_4 and ethyl acetate had high moisture uptake in the range of 4.3 to 5.5 and 3.2 to 5.5 respectively across the various waste polystyrene materials because of presence of cracks in their film while films from gasoline, gasoline and ethyl acetate show little absorption for moisture with range value of 1.5 to 2.0 and 1.1 to 1.3 respectively. Also, binder developed with 50:50 mixtures of gasoline and ethyl acetate showed significant increase in percentage elongation at break, from 43 to 47% across the various samples used. Therefore, gasoline and ethyl acetate mixture was the choice solvent for the dissolution of waste polystyrene as a binder for emulsion paint production.

Keywords: Binders, solvent, waste polystyrene, paint.

INTRODUCTION

Painting and coating are of immerse importance to human activities. Binder is the most important component of paint. It serves to provide adhesion to a substrate, form a continuous film and bind the pigments and additives into the paint. Water-based paint or emulsion paint and the oil-based paint are the types of paint. Whereas the oil-based paint exhibits excellent properties such as good chemical, water, weather and heat resistance, adhesion, full gloss and flexibility [1], it has limited usability due to the presence of organic solvents also referred to as volatile organic compound in oil paints which cause environmental health hazard. These restrictions are now driving industries towards the production of paints with little or no volatile organic compound [2].

Water based paint though environmentally friendly, easy to handle, quick drying and economical is now gaining popularity with public efforts to avoid paints with harmful solvents [3]. They however have limited application due to their low gloss and water resistivity properties as compared to the oil-based coatings. This necessitates the quest for alternative raw materials and new formulations to improve the overall quality of water-based paints while reducing the use of volatile organic compounds in surface coating [4].

Polystyrene is an important polymer of immense use industrially, as it is highly resistance to shock, chemical and weather conditions. It dissolves in many solvents and in use in large quantity in many sectors like food and packaging industries. Since these products are non-biodegradable, once used and discarded, they become a major waste disposal problem. It has been shown that waste polystyrene can be recycled by dissolution in suitable solvents to produce a polystyrene binder with excellent and improved properties such as flexibility gloss, good water and chemical resistance property. To achieve this, finding the right solvent or solvent mixtures for its dissolution is of paramount importance. [5]

Determination of polymer dissolution in different solvents is an important area of interest in polymer science and engineering because of its many applications in industries such as micro lithology, membrane science, drug delivery and plastic recycling [6]. The dissolution of a polymer in a solvent occurs in two major ways, namely: solvent diffusion and chain disentanglement. The type of solvent used in polymer dissolution affects its mechanical properties such as elongation at break, viscosity, surface tension and conductivity [7].

Previous studies have tried to investigate the use of single solvents for the dissolution of waste polystyrene materials [15, 16], but none has looked into the use of mixture of solvents for the dissolution of waste polystyrene materials for the formulation of paint binders and their effect on the quality of paint binders produced. This study examined the effect of three solvents namely gasoline, ethyl acetate and carbon tetrachloride and three mix solvents gasoline and ethyl acetate, gasoline and carbon tetrachloride and carbon tetrachloride and ethyl acetate on the physical property of polystyrene solution for use as a binder in emulsion paint formulation.

MATERIALS AND METHODS

Waste polystyrene materials were collected around homes and refuse dumps within Girei Local Government area of Adamawa state Nigeria. The waste polystyrenes collected were green, yellow and silver takeaway plates and Styrofoam. Gasoline was obtained from a filling station in Yola. Carbon tetrachloride (CCl_4) and ethyl acetate reagent grade products from the British Drug House (BDH) were received from Chemistry Laboratory Modibbo Adama University, Yola.

Preparation of waste polystyrene (PS) binder

Solid PS wastes were cleaned efficiently with water and dried. Liquid PS was obtained by dissolving 40 g of each of the polystyrene wastes in 200 ml of each of the solvents (gasoline, CCl_4, ethyl acetate, mixture of ethyl acetate and gasoline, a mixture of gasoline and CCl_4, and a mixture of CCl_4 and ethyl acetate) The mixture was continuously stirred until a homogeneous solution was formed [8]. This procedure was repeated on the green takeaway, the yellow take-away, the silver coloured take-away and styrofaom.

Characterization of binders from waste polystyrene materials

Film preparation

Film of different binders obtained from various waste polystyrene materials dissolved in the various solvents was cast on a glass petri dish (properly lined with aluminum foil) using solution casting methods. The binders were allowed to cure at 30 °C [9].

Determination of viscosity and gel time

Viscosity measurements were carried out using Brookfield DV-E viscometer. Five different readings were taken for each sample and the average value calculated. The gel point of the resin was determined by measuring the viscosity of the resin with time until a constant viscosity profile is obtained [10].

Determination of solubility

Solubility of the resins in water was determined by mixing 1 ml of the resin with 5 ml of distill water at room temperature (30 ^{O}C) [10].

Determination of moisture uptake

The resin films moisture uptakes were determined gravimetrically. Known weight of a cured sample was introduced into a desiccator containing a saturated solution of sodium chloride. The increase in weight (wet weight) of the sample was monitored until a constant weight is obtained. The difference between the wet weight and dry weight of the sample was recorded as the percentage moisture uptake by resin [10].

Elongation at break

The elongation at break was measured using Inston Tensile Testing Machine (Model 1026) based on ASTM D638. Resin films of dimension 50 mm long, 10 mm wide and 0.15 mm thick was brought to rapture at a clamp rate of 20 mm/min and a full load of 20 kg. A number of five runs were carried out for each sample and the average elongation evaluated and expressed as the percentage increase in length [10].

Determination of density, turbidity, melting point and refractive index

Density was measured by taking the weight of a known volume of resin inside a density bottle using metler (Model, AT400) weighing balance. Average value of five readings was taken for each sample. Turbidity of the resin samples was measured using Hanna microprocessor turbidity meter (Model, H193703). Melting points of the film samples were determined by using Galenkamp melting point apparatus (Model, MFB600-010F). The refractive indices of the resin samples were determined using Abbe refractometer. The above properties are determined according to standard method [11].

RESULTS AND DISCUSSION

The effect of different solvents on the solubility of different waste polystyrene materials

The ability of the waste polystyrene (green, yellow, silver take away plates and styrofoam) to dissolve in six different solvents was examined. These solvents include gasoline, carbon tetrachloride, ethyl acetate, a mixture of gasoline and carbon tetrachloride, a mixture of gasoline and ethyl acetate and a mixture of ethyl acetate and carbon tetrachloride. The solvents were found to dissolve expanded polystyrene sufficiently well as detailed in Table 1. The waste polystyrene materials dissolved in all the solvent because gasoline, ethyl acetate and carbon tetrachloride have a solubility parameter of 17.0, 18.2, and 17.58 respectively which is close to the solubility parameter of polystyrene which is 19.2 [12]. Moreso carbon tetrachloride and ethyl acetate dissolved the polystyrene waste faster because their chi parameter X (a factor which shows the degree of solvent polymer compatibility) is less than 0.5 while gasoline has a chi parameter which is greater than 0.5 [13]. Table 1 shows the physical observations with the various solvents.

Characterization of the binder from different waste polystyrene materials

Effect of solvents used on the turbidity of waste polystyrene binders

Figure 1 shows the effect of the different solvents used on the turbidity of the binder formulated from four different waste polystyrene materials namely green, yellow and silver take away plates and Styrofoam. Waste polystyrene binders formulated with gasoline, CCl_4 and ethyl acetate solvents show high turbidity on all the samples except binder from waste silver takeaway plate. While the mixed solvents of gasoline and CCl_4, gasoline and ethyl acetate and ethyl acetate and CCl_4 show low turbidity on all samples. This decrease in turbidity could be as a result of independent reactions between the solvent mixtures rather than the reaction between the solvent mixture and the solute [14]. The low turbidity as seen in silver takeaway plate binder across all solvents could be as a result of the light-coloured pigment in the silver polystyrene material [2]. The lower turbidity for silver take-away plate binder in the mixed solvents is in consistency with the proposed reaction between solvents mixtures as earlier stated by Kaur and Juglan [14].

Effect of solvents used on the viscosity of waste polystyrene binders

Figure 2 shows the effect of the different solvents used on the viscosity of the binders produced with four different polystyrene waste materials. Carbon tetrachloride gave the highest viscosity while the mixture of CCl_4 and ethyl acetate gave the lowest viscosity. Binders formed from CCl_4 gave high viscosity value than those formed from ethyl acetate and gasoline. This is because the solvent CCl_4 has a viscosity of 0.84 compared to gasoline and ethyl acetate which have a viscosity of 0.6 and 0.49 respectively [15]. Moreso, since viscosity is affected by mass (concentration), CCl_4 has a molecular weight of about 153.82 and a density of 1.57 higher than that of gasoline and ethyl acetate with molecular weights of 100 and 88.12 and densities 0.79 and 0.90 respectively, hence binders formed from CCl_4 showed higher viscosity. This agrees with the previous works of Osemeahon, et al [16] that the properties of solvents have an effect on the binders formed.

Table 1: The effect of different solvents on the solubility of different waste polystyrene materials

Solvent	**Observation**
Gasoline	Dissolves completely with stirring after 2 hours
Ethyl Acetate	Dissolves all polystyrene waste material forming a homogeneous mixture in less than 10 minutes
Carbon Tetrachloride (CCl_4)	Dissolves all polystyrene waste material forming a homogeneous mixture in less than 10 minutes
Gasoline + Ethyl Acetate	Dissolves completely after stirring for 30 min
Gasoline + CCl_4	Dissolves completely after stirring for 30 min
Ethly Acetate + CCl_4	Dissolves all polystyrene waste material forming a homogeneous mixture in less than 10 minutes

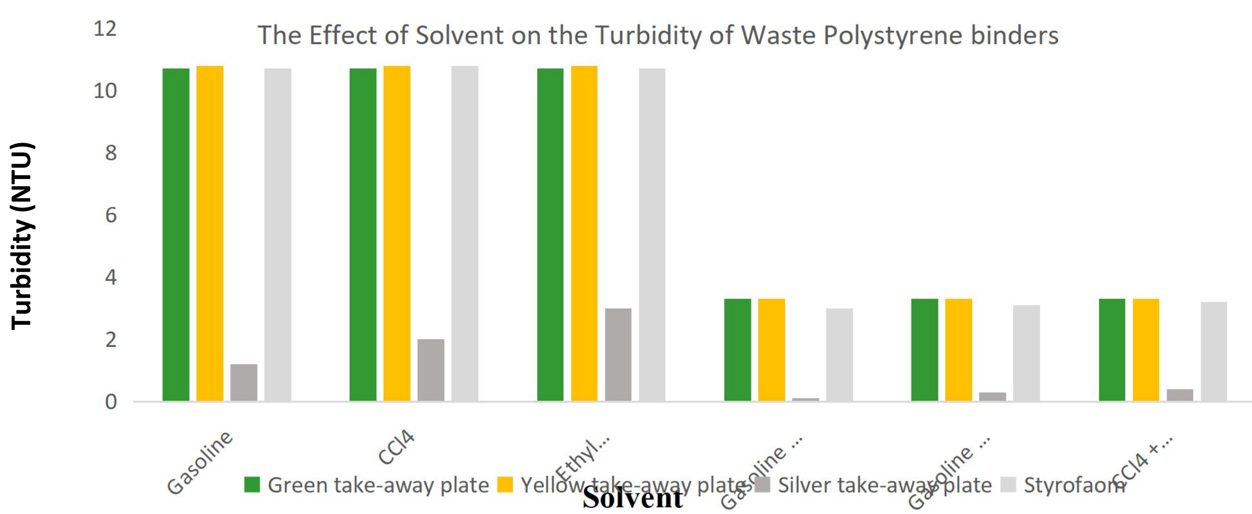

Figure 1. The effect of solvent on the turbidity of waste polystyrene binders

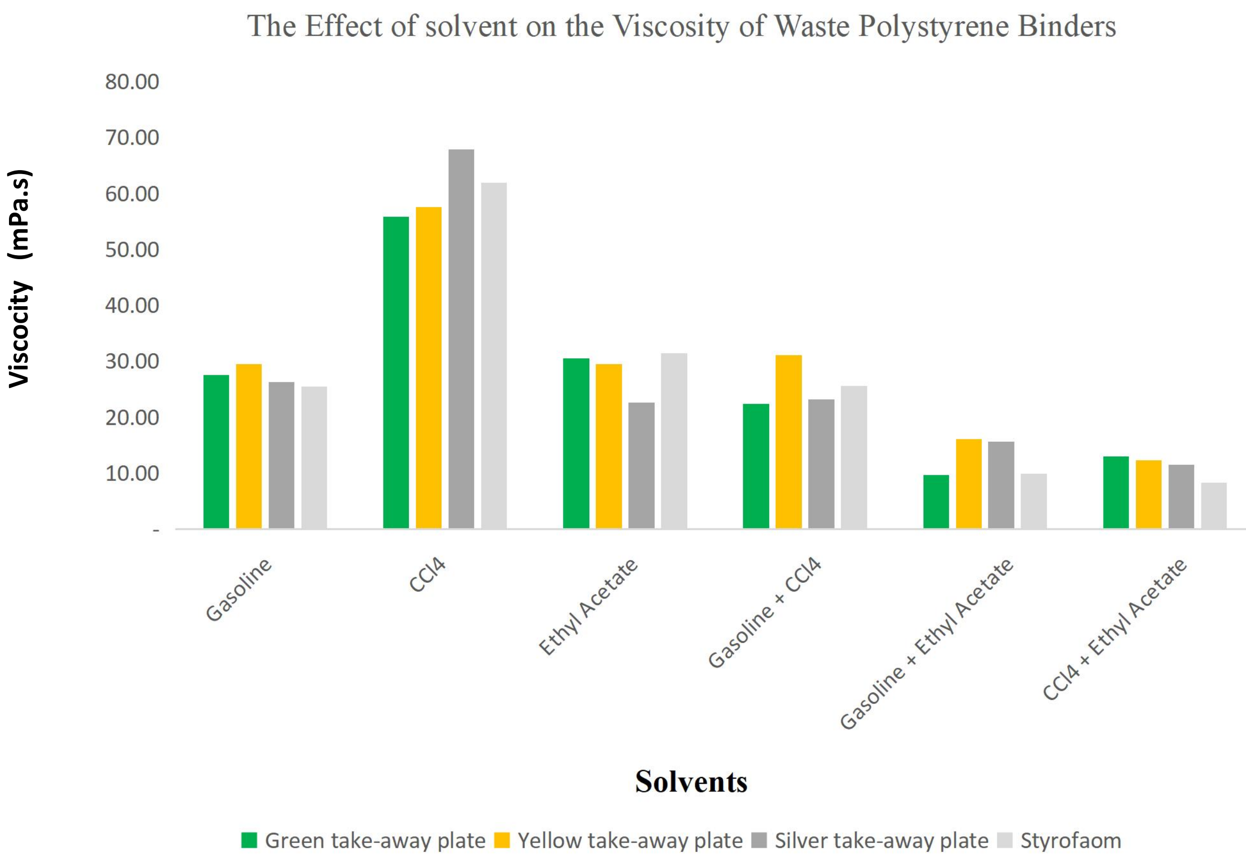

Figure 2. The effect of solvent on the viscosity of waste polystyrene binders

Effect of solvents used on the density of waste polystyrene binders

Figure 3 shows the effect of the different solvents used on the density of the binder formed from four different types of polystyrene wastes. From the Table, it was observed that binder formulated with the solvent – CCl_4 gave the highest density. CCl_4 has the highest density of the solvent used. As expected, the density of the solvent used has an effect on the density of binder formed.

Previous studies collaborate this result as they have reported that the density of the solvent affects the density of binder formed [12, 17]. The mixture of gasoline and ethyl acetate gave a density of 0.8-1.05 which agrees with the SON standards for paint resins. Although CCl_4 has high density it cannot be used for production of the binder due to its high volatility and environmental unfriendliness.

Effect of solvents used on the refractive index (RI) of waste polystyrene binders

Figure 4, shows that waste polystyrene binder formed in gasoline gave a RI value of 1.47 which is in agreement with previous works done by Osemeahon, et al [16] and Uthman [18]. While the mixture of gasoline and ethyl acetate gave a binder the highest RI value of 1.48. This shows that emulsion paint with high gloss can be produced from waste polystrene binder formed from a mixture of ethyl acetate and gasoline. CCl_4 gave results with the lowest RI values. This could be as a result of its high density and high vapour pressure. Although CCl_4 has a Chi parameter of less than 0.5, but because of its high vapor pressure, it is unsuitable for the production of a paint binder [12, 17].

Effect of solvents used on the gel time of waste polystyrene binders

Figure 5 indicates that waste polystyrene binder obtained from gasoline solvent gave a slower gelation time compared to other binders from CCl_4 and ethyl acetate. This may be attributed to the fact that gasoline consists of a mixture of hydrocarbons while the other CCl_4 and ethyl acetate are made up of simple chemical substance [8]. Hence the combined properties of each component in the mixture such as boiling point, molecular weight and molecular structure are a contributing factor [13, 16]. CCl_4 and ethyl acetate gave the lowest gelation time because of its high vapour pressure as stated earlier [12]. The mixture of gasoline and ethyl acetate gave an optimal gel time of 72 hours suitable for the production of paint binders.

Effect of solvents used on the moisture uptake of waste polystyrene binders

Figure 6 shows that waste polystyrene binders in all solvent gave a moisture uptake of <5.00%. This implies a minimal risk of film degradation due to moisture. This is in agreement with the work of Osemeahon, et al [16]. This observation can be attributed to the hydrophobic nature of the polystyrene polymer used in the formulation of the binders. Binders formed from gasoline have the lowest moisture uptake compared the binders formed from CCl_4 and ethyl acetate. This is because binder film formed from gasoline is smoother than that formed from CCl_4 and ethyl acetate which has cracks on them that enhanced water penetration into the film. The mixture of gasoline and ethyl acetate also gave the lowest moisture uptake compared to all the solvents which makes it optimal solvent for binder formation in terms of moisture uptake.

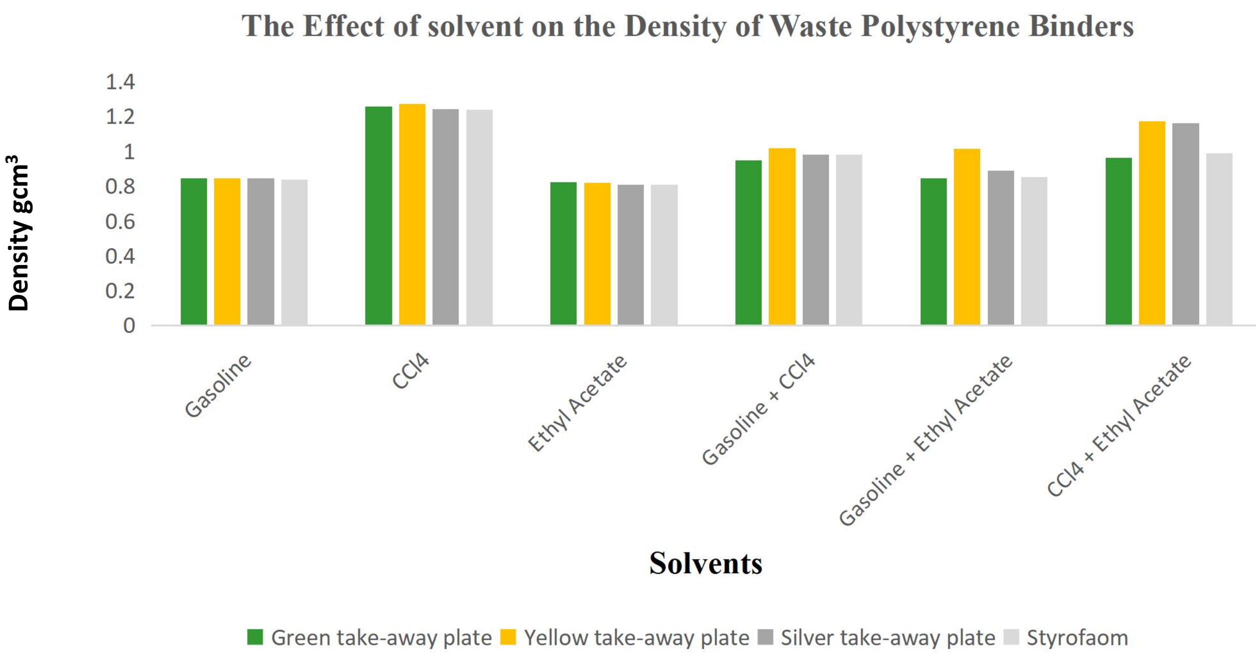

Figure 3: The effect of solvent on the density of waste polystyrene material

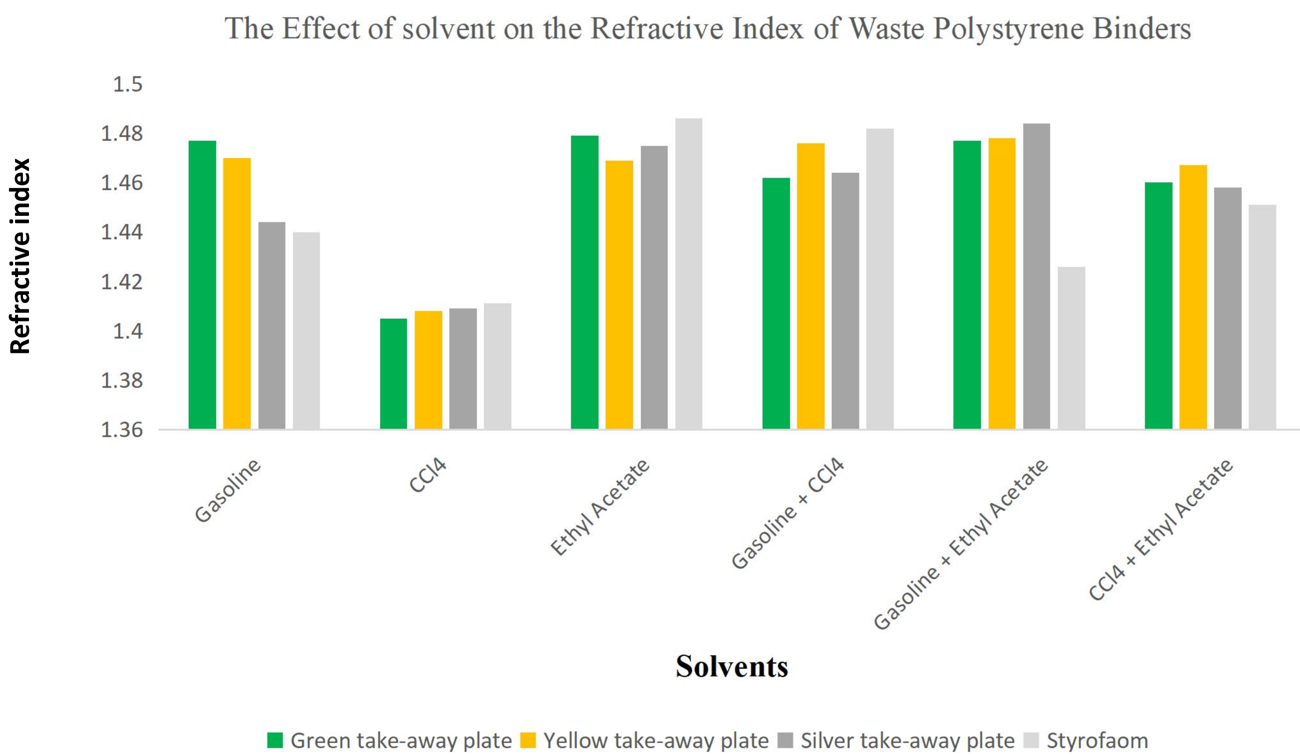

Figure 4: The effect of solvents used on the refractive index of waste polystyrene binders

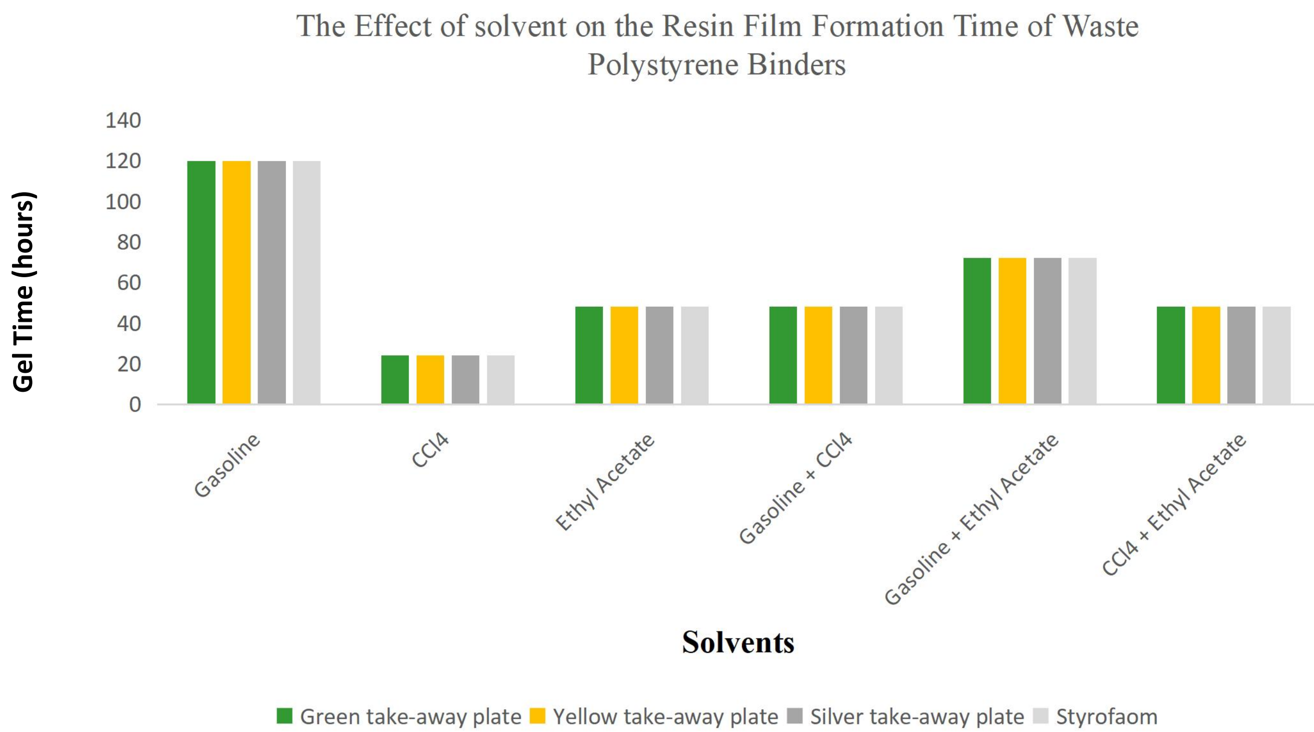

Figure 5: The effect of solvent on the gel time of waste polystyrene binders

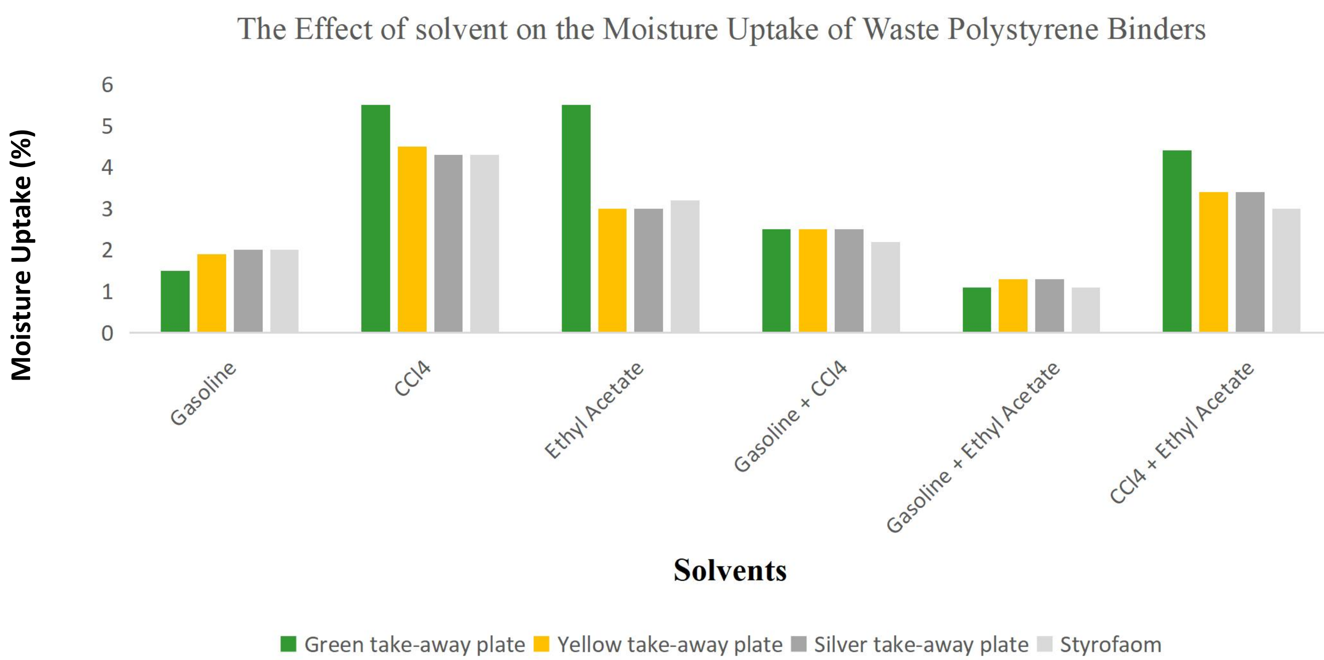

Figure 6: The effect of solvent on the moisture uptake of waste polystyrene binders

Effect of solvents used on the elongation at break of waste polystyrene binders

Figure 7 shows the effect of solvent on elongation at break of waste polystyrene binder in the solvents and solvent mixtures used. Binders formed from gasoline gave a high elongation value only lower than binders formed from the mixture of gasoline and ethyl acetate which has the highest elongation value than all the other solvents. The higher elongation value obtained from the mixture may be as a result of complex solvent – solvent reaction in the mixture rather than the individual solvent composition [14]. This implies that mixture solvent of gasoline and ethyl acetate will be the optimal solvent for the production of paint binders using waste polystyrene material.

Effect of solvents used on the melting point of waste polystyrene binders

Figure 8 shows the effect of solvents on the melting point of waste polystyrene material. Melting point of waste polystyrene materials was seen to be in close range, with no much effect of solvent seen. This is due to the fact that upon drying, nearly all solvents have been evaporated leaving behind the waste polystyrene material. Hence the melting point of the binder film formed tends towards the melting point of the waste polystyrene material.

A detailed comparison of some physical properties of the waste polystyrene film with films from other paint binders is given in Table 2.

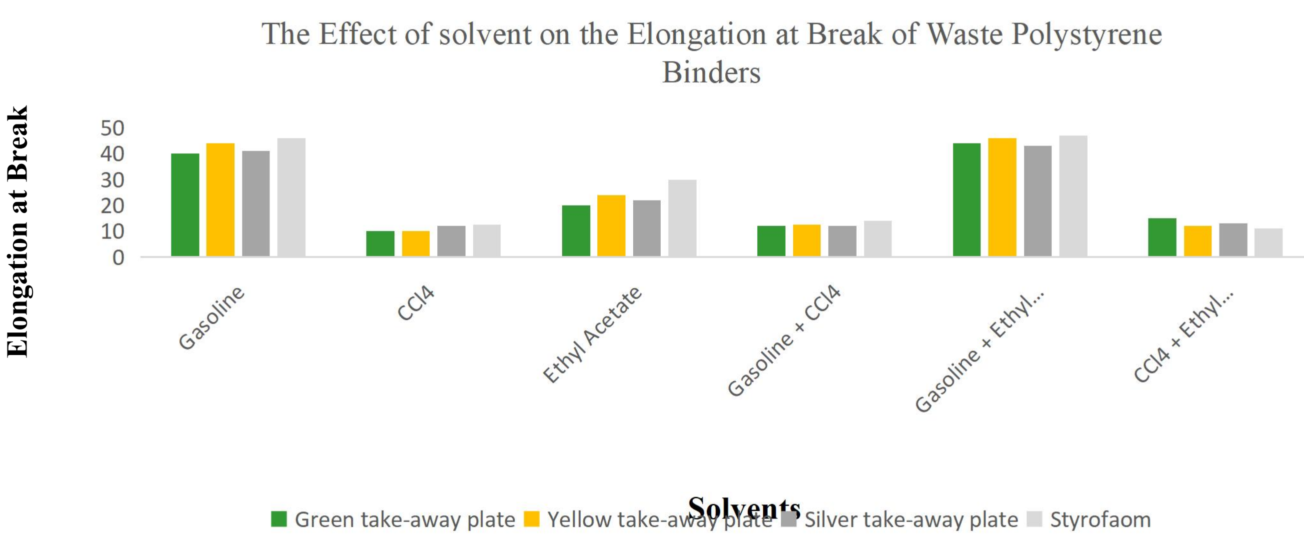

Figure 7: The effect of solvent on the elongation at break of waste polystyrene binders

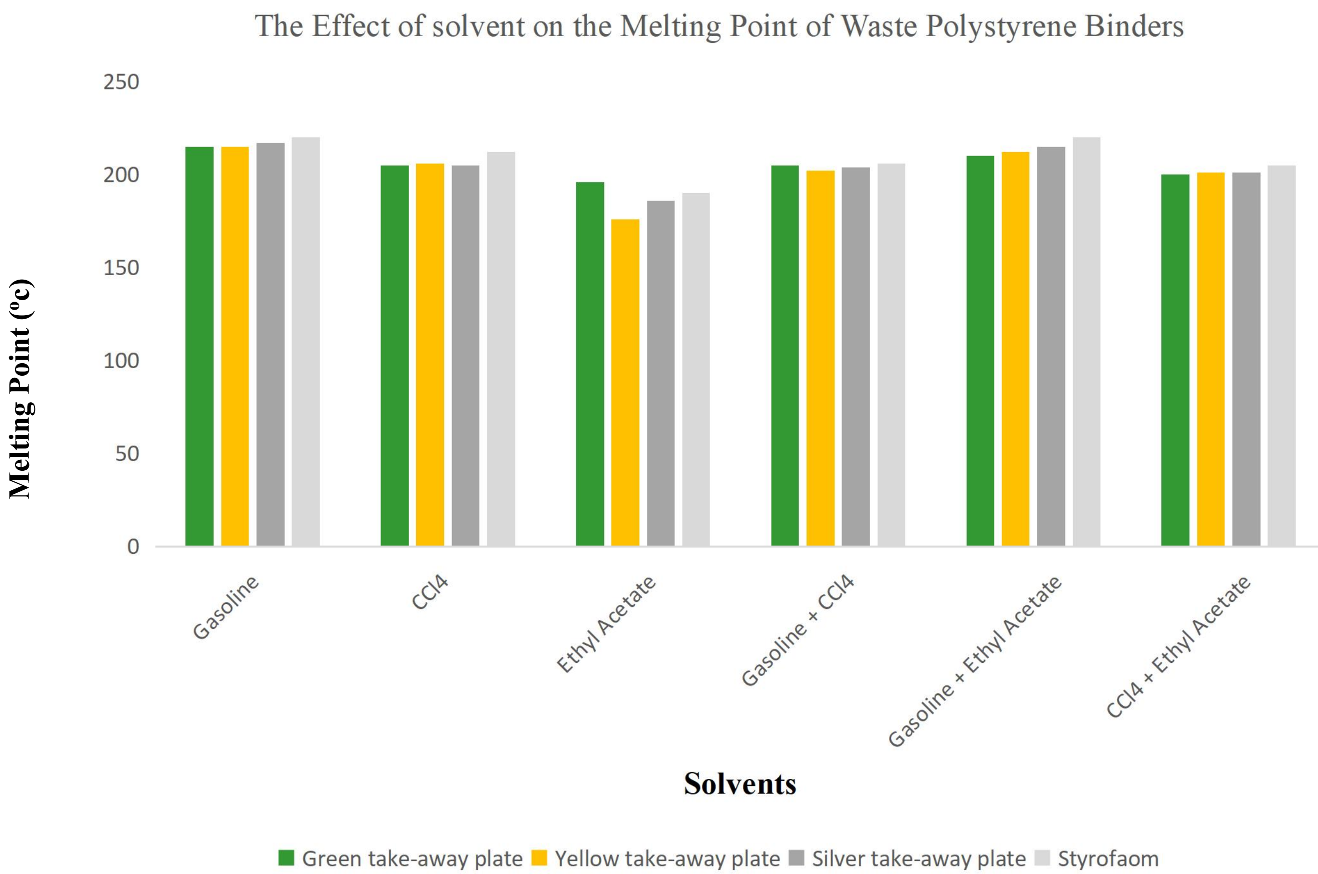

Figure 8: The effect of solvent on the melting point of waste polystyrene binders.

Table 2: Comparisons of some physical properties of the waste polystyrene film with films from other paint binders

Types of Resin	Physical Properties									
	Appearance	Density (g/cm^3)	Refractive Index	Melting Point (C°)	Moisture Uptake (%)	Viscosity (mPa.s)	Turbidity (NTU)	Elongation on Break (%)	Gel Time (Hours)	Literature
Waste Polystyrene	Creamy white	0.85	1.43	220	1.1	9.92	310	47	72	This work
TMU/PS	ND	1.10	1.43	262	1.01	19.70	878	450	2	[19]
Commercial UF	ND	ND	ND	ND	2	451	ND	ND	54.2	[20]
TMU/NR	ND	0.57	1.35	260	ND	220	ND	340	ND	[21]
UF/CS	ND	1.17	1.42	130.00	0.6	11.1	ND	160	ND	[22]
XASO	Dark	0.91	1.47	ND	ND	900	ND	ND	ND	[23]
Innovative UF	ND	ND	ND	ND	0.25	ND	ND	ND	ND	[24]
MAGPP/ER	ND	ND	ND	200	ND	ND	ND	11.6	ND	[25]
EBDE	ND	1.04	ND	179	ND	38.0	ND	ND	ND	[26]
AESO	Clear	ND	ND	ND	ND	13,000	ND	ND	ND	[27]
RSOMAR	ND	0.95	ND	ND	ND	3.11	ND	ND	24	[28]

UF – Urea Formaldehyde
CS – Cassava Starch
XASO - Ximenia americana Seed Oil
ER - Epoxy Resin
EBDE - Epoxy-based Divinyl Ester
NR – Natural Rubber
MAGPP – Maleic anhydride Grafted Polypropylene
AESO – Accrylated Epoxidized Soybean Oil
RSOMAR – Rubber Seed Oil Modified Alkyd Resin

CONCLUSION

The use of waste polystyrene in the production of paint binders has been established and has been shown to be feasible given the quality of binders and frequency of production of such waste materials. The binder produced from waste polystyrene exhibited favorable results in some properties such as viscosity, density, turbidity, refractive index, and drying time. The quality of paint binder produced however, has been shown to be dependent on the solvent used. The binder produced using a mixture of gasoline and ethyl-acetate had better binding property, this made the mixture (gasoline and ethyl-acetate) a solvent of choice for making paint binder using waste polystyrene.

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