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Research Article

Optimisation of Adhesive Made From Polyurethane and Polystyrene (PU/PS) Waste Plastics

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Abstract
The waste Polyurethane (PU) and Polystyrene (PS) plastics were blended to develop an adhesive. The developed adhesive was characterized and optimized for optimum performance. The scanning electron microscope of the new adhesive was carried out to understand the surface morphology of the new adhesive. The different blend of PU/PS were also optimized for physico-chemical parameters such as density, turbidity, viscosity, gel time, refractive index, melting point, moisture uptake and solubility in water. The physico-chemical parameters were in conformity with the literature. This show that this formulated adhesive can replace conventional adhesives with improved properties. This study also proffers solution to pollution problems arising from polyurethane and polystyrene wastes by converting this environmentally threatening wastes plastic into adhesive for surface application.
Keywords: Adhesive, optimisation, wastes, plastics, environment.

Introduction

The plastic is a versatile material which its usage has found application in many industries. According to Gidigbi *et al.,* (2020), its ability to resist chemical and microbe attack due to its polymeric arrangement of molecules; ease of production and cheap production cost has earned it a worthy replacement of iron and alloys in many industries. According to Peelman *et al.,* (2013), plastics find application in telecommunications; healthcare services, building sectors, water management, food and beverage industries. However; the very thing that qualifies plastics as a durable and ubiquitous also responsible for its environmental non-biodegradable thereby littered in environment and constituting hazard to human and animals' existence. According to Amin *et al.,* (2013), plastic waste pollutes the planet. It tends to form photo-degraded monomers under sunlight which thereafter contaminate the soil and oceans. Hamidu *et al.,* (2019) reported that the disposal of plastic waste is turning out to be an environmental menace. Disposal methods employed for polymeric wastes are land filling, mechanical, thermal, chemical and biological recycling. Suitable treatment of polymers is the primary factor in polymeric wastes management and considered important in the environmental, socio-economic and energetic, point of view.

According to Deng *et al.,* (2014), different techniques for managing the waste polymeric materials exist today, but major portion of the polymeric wastes are being subjected to landfill. Scarcity of land along with high volume to weight ratio of polymeric materials, poor biodegradability of common polymers together with formation of methane like explosive greenhouse gases, make land-filling an unattractive option which should be strictly regulated. Plastics production and waste continue to raise numerous problems and environmental threats. Besides the high percent of plastic waste which is landfilled in Nigeria, it is difficult to recycle plastic wastes due to its heterogeneity during collection (Brunori *et al.,* 2015). Incineration of plastic waste can be applied for energy recovery, but plastics combustion can generate emissions which contribute to global warming. Therefore, this study affirmed another route on how plastics waste especially that of Polystyrene and polyurethane will be utilized by converting it to useful materials.

Materials and Methods

Materials

Polystyrene waste, polyurethane waste, Urea, Sodium Dodecyl Sulphate, Toluene, measuring cylinder, pH meter, stirrer, desiccator, weighing balance and Distilled water.

Preparation of PU/PS waste plastics

Plastic wastes were collected from refuse heap in Jimeta metropolis in Adamawa State, Nigeria. The collected samples were washed to remove impurity present and oven dried at 55°C for 1h. The dried plastic was cut into small pieces for easy weighing.

Formulation of PU/PS blend and films

Adhesive from blend of polyurethane and polystyrene was prepared in accordance with the method reported by Osemeahon *et al.,* (2022). Different percentage blend of PU:PS polystyrene were prepared in 50ml of toluene at room temperature (30°C) . Subsequently, the mixture was stirred vigorously to achieve complete dissolution. The physical properties of the resin films were investigated.

Characterization of the formulated adhesive

Determination of density

The above property was determined according to AOAC (2000). The density of different resins was determined by taking the weight of a known volume of each resin inside a density bottle (20 cm^3) using weighing balance, the density was calculated using the mass volume relationship. Three readings were taken for each sample and the average value calculated.

Melting point

The melting point of the different resins of the adhesive was determined using Stuart melting point machine (Model SMP 10). Triplicate determinations were made and average values were taken.

pH of the adhesive

The pH of the adhesive will be determined by the method described by Hamidu *et al.,* (2019). The pH meter will be cleansed with solvent to remove dirt and impurities on the electrodes. It was followed by stabilization in buffer solution and immersion in the sample. The meter started reading immediately when it was immersed until it attained stability at the optimal value which was recorded. The test was done in triplicate to ensure precision.

Solid content of the adhesive

The percentage solid content of the produced adhesive was determined using laboratory crucibles. A known quantity of the sample was weighed and oven dried at a temperature of 200°C. After 2 hours; the sample drying was discontinued and removed from the oven to cool after which it was weighed as dry weight.

The percentage solid content was then computed using the mathematical formula:

% Solid content = Dry weight/ Original weight x 100

Determination of moisture uptake

The moisture uptake will be determined according to the method described by Gidigbi *et al.,* (2023). A known weight of each of the samples of adhesive was introduced into desiccators containing a saturated solution of sodium chloride. The wet weight of each sample was then monitored until maximum weight is obtained. The difference between the wet weight and the dry weight of each sample was then recorded as the moisture intake by adhesive.

Water solubility

Water solubility of the adhesive was determined by mixing 1ml of the resin with 5ml of distilled water at room temperature (30^0C). A clear transparent solution indicates water solubility while a cloudy solution or white precipitate results in the case of insolubility in water (Osemeahon and Dimas, 2014).

Viscosity of the adhesive

The viscosity of the adhesive was carried out by using BROOKFIELD DV-E Viscometer, model. This was done by setting the spindle at the center and inserting the spindle into a 500ml of the formulated adhesive. The spindle speed was used at 12%, all readings were taken after the spindle has rotated for five times.

Results and Discussion

Surface morphology of the new adhesive

The surface morphology images of PU/PS adhesive were observed by SEM. The micrographs depict evidence of pores on the surface of the adhesive resin which are infinitesimal. The result observed can be connected to the presence of polyurethane which has served as filler and has occupied the pore spaces which might have initially appeared in the polystyrene due to the presence of inefficient packing of bulky phenyl groups of polystyrene chains. The introduction of PU particles into the adhesive resin has proofed to have occupied the pores available in the polystyrene chains thereby promoting the packing of PU/PS adhesive resulting in a more crystalline network structure of the adhesive matrix (Fried, 2003).

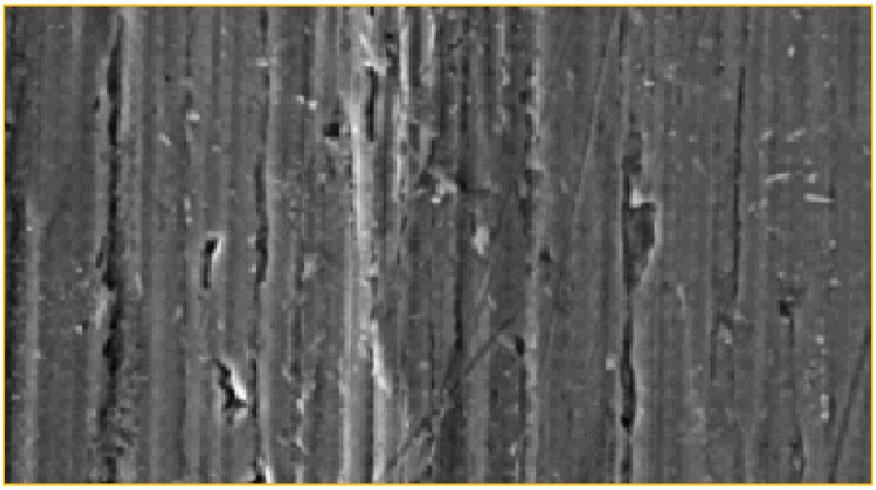

Figure 1. Surface morphology of PS/PU.

Effect of concentration of plastic wastes on viscosity of the formulated adhesive

The viscosity properties of adhesives define characteristics such as: processability, application, wettability, etc. As shown in figure 2, increase in concentration of the PU increases the viscosity of the adhesive. Difference in viscosity is due to increase in concentration which arises as a result of variation in the respective chain length. As the plastic loading increases, the molecular weight of the polymer in the solvent also increased, this increase in the molecular weight gave rise to increase in the viscosity due to increase in polymer density (Osemeahon and Dimas, 2014). Adhesives exhibit very different rheological properties before and after curing. The rheology of adhesives is a very important issue concerning adhesives during dispensing. Prior to curing, adhesives should act as fluids, capable of being transported to the adherend surface and should copy the surface morphology via sufficient wetting of the surface.

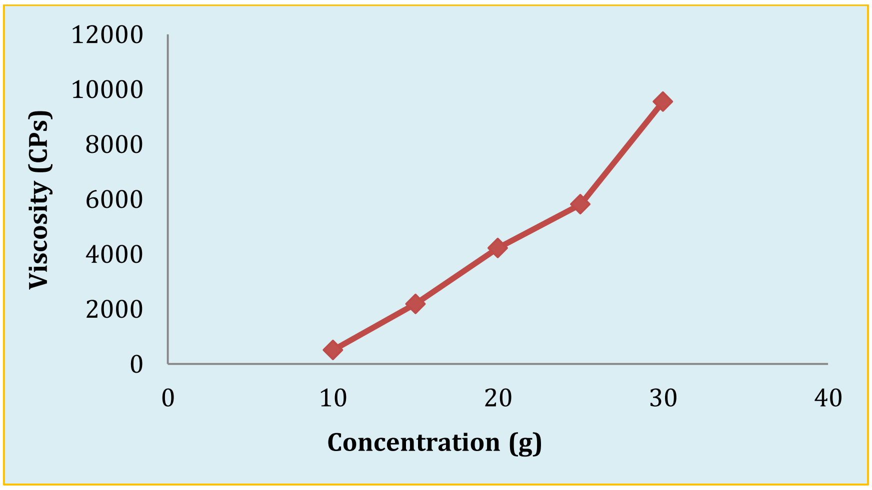

Figure 2. Effect of concentration of plastic wastes on viscosity of adhesive.

Effect of concentration of plastic wastes on pH of the formulated adhesive

In figure 3, the experimental data displayed the pH of the adhesive. The increase in the plastic loading only resulted in infinitesimal change in the pH of the adhesive. Adhesive that is slightly acidic tends to have a longer shelf life and does not foam unlike the adhesive that is alkaline (Elbadawi *et al.,* 2015). The pH remains almost unchanged despite the corresponding increase in the plastic concentration. This result insinuate that increase in the concentration of the solute have impact only on the viscosity and the bond strength but does not impact on the pH of the solvent (Tankut, 2016). The pH level obtained in this study is suitable for the production of durable adhesive.

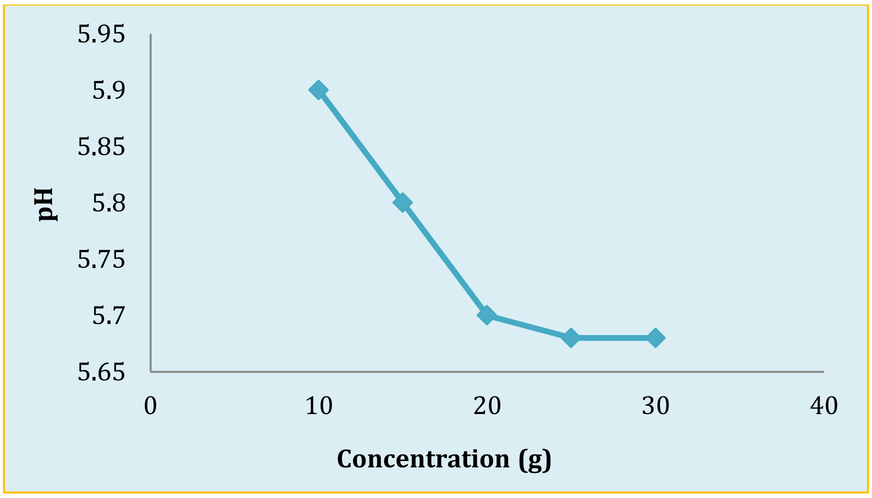

Figure 3. Effect of Concentration of plastic wastes on pH.

Effect of concentration of plastic wastes on the drying time of the formulated adhesive

In figure 4 the data obtained revealed that increase in concentration of the polymer impacted slight increase in the drying time of the adhesive. This can be attributed to the fact that the solid content of the adhesive has been raised as a result of the increase in the concentration of the plastic waste which also greatly contributed to the viscosity of the adhesive. The result obtained in this study is in agreement with the work of Mavani *et al.,* (2007), which concludes that decrease in viscosity will bring about a corresponding decrease in the gelling time of the adhesive.

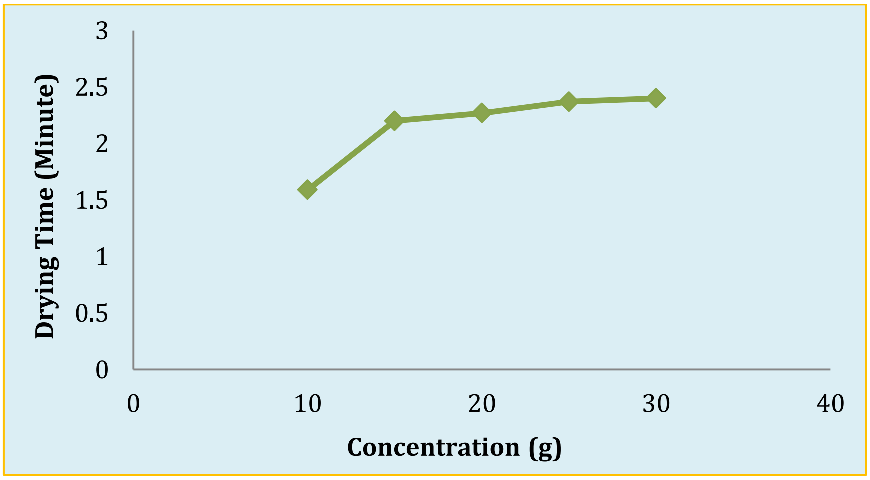

Figure 4. Effect of Concentration of plastic wastes on drying time of adhesive.

Effect of concentration of plastic wastes on the moisture content of the formulated adhesive (MC%)

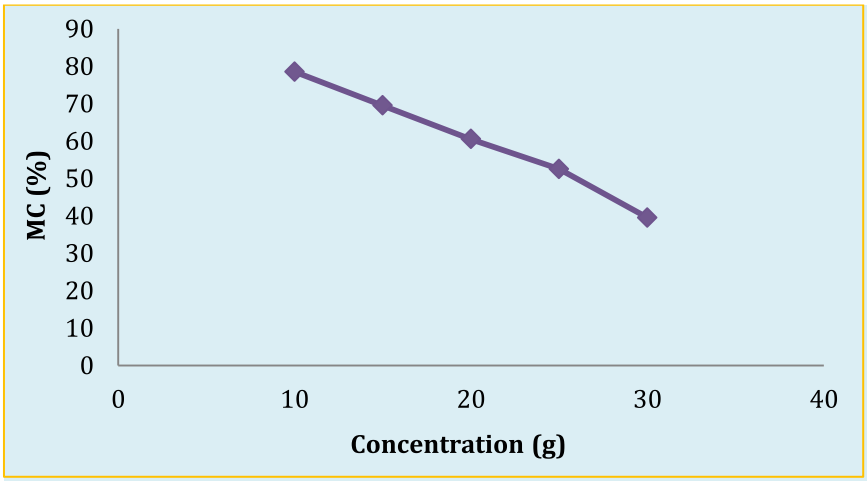

Figure 5. Effect of Concentration of plastic wastes on Moisture Content of adhesive.

The result of the experiment for the effect of moisture content is presented in figure 5. Moisture content is the amount of water in a product. Moisture content will decrease when there is increase in the solid content of the adhesive. As more polymeric material is been loaded into the system, the moisture content decreases. Study reveals that moisture content affects physical, mechanical, thermal and structural properties of polymer materials. The moisture uptake and dry time reduces with increasing viscosity (Osemeahon *et al.,* 2009).

Effect of concentration of plastic wastes on solid content of the formulated adhesive (SC%)

The result of this study represented by figure 6 showed the solid content of the formulated adhesive. The result revealed that the solid content significantly increases as the rate of loading of the plastics increased. The increase in the solid content can be explained in terms of the increase in the molecular weight of the particle phase of the adhesive which keep increasing as more load is been introduced into the system. The gel time of adhesive is reported to decrease with decreasing viscosity (Mavani *et al.,* 2007). This can be explained by the fact that more water in the system dilutes the curing reactions and acts as energy barrier to resin curing. A longer gel time will result when the solid content is less. Cure rate therefore decreases with decreasing solid content.

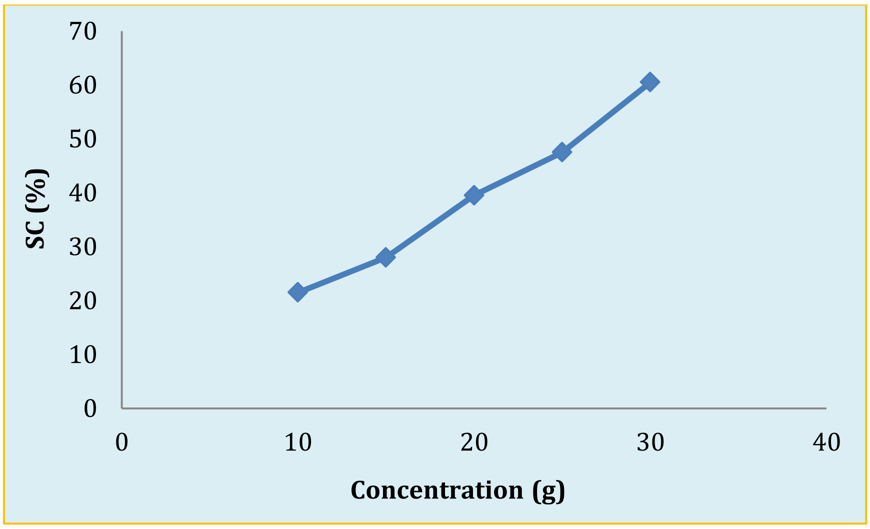

Figure 6. Effect of Concentration of plastic wastes on Solid Content of adhesive.

Water solubility of PU/ PS

Table 1. Water solubility of PU/PS.

PU/PS Concentration (g)	Solubility
10	soluble
15	soluble
20	soluble
25	soluble
30	soluble

Physico-chemical properties of the formulated Adhesive

Table 2. Physicochemical Parameter of the new formulated adhesive.

Properties	Values (Units)
Viscosity	6850
pH	5.68
Drying time	148.8s
Moisture content	39.5%
Solid content	60.5%
Density	0.9g/cm^3
Melting Point	170^{0}C
Solubility	Soluble

Conclusion

The adhesive from waste PU/PS plastics was successfully formulated and physico-chemical parameters of the formulated PS/PU were assessed. Also, ratio of PU to PS in the adhesive was also optimized in order to achieve maximum adhesive quality and strength. The result revealed that 10% of PU to 90% PS formed a good adhesive with strong surface bond. The adhesive formulated showed improved physico-chemical properties over the conventional adhesive, therefore it can be used in the place of conventional adhesive.

Declarations

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