

Research Article

Formulation of Adhesive from Polyurethane/Polystyrene Waste Plastics

Esther O. Fasina^{*a}, Sunday A. Osemehon^b, Joshua A. Gidigbi^c, and David Esenowo^d

^{a-d}Department of Chemistry, Faculty of Science, Modibbo Adama University, Yola, Adamawa State, Nigeria

^{*}Corresponding Author Email: estherfasina@gmail.com

Received: September 14, 2023

Accepted: September 29, 2023

Published: October 06, 2023

Abstract

Plastic debris represents a worldwide problem. Since they can affect all underground and surface water bodies with impermissible and negatively impacts risks on wildlife, ecological habitats and health of coastal communities. This study aimed at developing an adhesive from waste Styrofoam (polystyrene) and polyurethane. This is dual beneficial by reducing environmental pollution and creating wealth from waste. The polyurethane (PU) and Styrofoam (PS) were obtained from waste heap within Jimeta Metropolis Yola, Adamawa State. These plastic wastes were washed; dry under sun and processed into small pieces to enable uniform solubility. Subsequently, various blend of PU:PS were processed into adhesive by chemical interaction of toluene solvent. The assessment of the physicochemical parameters of the formulated adhesives affirmed conformity with the standard and literatures. Also, the formulated adhesive was tested for bond strength on five different surfaces namely; ceramic, aluminium sheet, wood, glass and plastic. The bond strength is: ceramic (3.64 MPa), aluminium sheet (1.540MPa), wood (3.010MPa), glass (3.150MPa) and plastic (2.316MPa) respectively. The formulated adhesive from these plastics depicted good bond strength on the different surfaces studied.

Keywords: Adhesive, blend, bond-strength, surface, plastics, waste.

Introduction

Plastic production and waste continue to raise numerous problems and environmental threats (Brunori *et al.*, 2015). Since a significant fraction of plastic waste finishes its life as refuse in the terrestrial and aquatic environment. It was found that marine environment is severely impaired such that each year water is polluted by equivalent of 100,000 truckloads of plastics. Plastic micro fragment could be swallowed by fish which are the link between plankton and vertebrates (Deng *et al.*, 2014). When these small fish are eaten by commercial fish such as tuna and sword fish, substances such as bisphenol A, styrene etc. could get into the body of fish which when eaten by human can generate disorder to human health because these plastics are neurotoxic and carcinogenic compounds (Deng *et al.*, 2014). Considering the severe impact of waste plastics on the environment and aquatic life it is necessary to find the alternative route to convert waste into useful materials.

Adhesive is any non-metallic substance applied to one or both surfaces of two separate items that binds them together and resist their separation (Garcia *et al.*, 2017). Substances such as glue, cement, mucilage, or paste, can also be classified as adhesive. The use of adhesives offers many advantages over binding techniques such as sewing, mechanical fastening, thermal bonding, etc. These include the ability to bind different materials together, to distribute stress more efficiently across the joint, the cost effectiveness of an easily mechanized process, an improvement in aesthetic design, and increased design flexibility (Adams, 2005). Production of polymers has always been coupled with the challenge of their further utilization after use. A slower development within the field of recycling creates a serious problem: tens of millions of tons of used polymeric materials are being discarded every year. It leads to ecological and consequently social problems (Gregoire and Igor, 2019).

The focus of this work is to source for an alternative raw material from plastic wastes that will reduce the present high cost of production. This will reduce the present environmental pollution caused by plastic waste. The development of adhesive from plastic waste will reduce the consequential effects on wildlife,

ecological habitats and health of coastal communities. This work will also introduce a novel adhesive to the adhesive industry and wealth generation from plastic wastes.

Materials and Methods

Materials

Polystyrene waste, polyurethane waste, stopwatch, Diphenyl amine, polyvinyl Acetate, Toluene, glycerol urea, sodium dodecyl sulphate and Distilled water, weighing balance, oven, viscometer, pH meter, stirrer, beakers, syringe and measuring cylinders.

Methods

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 dried. The dried plastic wastes were cut into small pieces to facilitate easy weighing.

Adhesive Formulation

The adhesive from blend of polyurethane and polystyrene was prepared in accordance with the method reported by Bomba *et al.*, (2014) and Osemeahon *et al.*, (2022). Toluene solvent (50 ml) was measured using a measuring cylinder into a clean and dried glass beaker and then few blend ratio of PU:PS (30:70; 20:80 and 10:90) % were added slowly to the solvent in the beaker. Homogeneity and consistency decreased with increase in the amount of PU incorporated in the PS resin. At higher PU proportions lumps were formed which created inconsistency and disrupt homogeneity in the composite resins. On the introduction of PU into the PS, the plastics waste was allowed to dissolve completely in the solvent. The resulting mixture is the adhesive which is transferred into a clean air tight container and stored for further usage.

Characterisation of the Formulated Adhesive

Fourier Transform Infrared (FTIR) of PU/PS

The FTIR of the blended polyurethane and polystyrene will be carried out using the method described by Gidigbi *et al.*, (2023).

pH of the Adhesive

The pH of the adhesive will be determined by the method described by Lucas *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 (Osemeahon *et al.*, 2022). 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:

$$\% \text{ Solid content} = \text{Dry weight} / \text{Original weight} \times 100$$

Moisture Content of the Adhesive

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 (Osemeahon *et al.*, 2022).

The percentage moisture content of the adhesive was then computed using the mathematical formula:

$$\% \text{ Moisture content} = \text{Original Weight} - \text{Dry weight} / \text{Original weight} \times 100$$

Viscosity of the Adhesive

The viscosity of the adhesive was carried out by using BROOKFIELD DV-E Viscometer, model (LUDE). This was done by setting the spindle at the center and inserting the spindle into a 500ml of the formulated adhesive. The spindle speed used was 63 and at 12% all readings were taken after the spindle has rotated for five times.

Drying Time

The drying time of the adhesive was measured using the procedure described by Gunorubon (2012). Formulated adhesives were applied on pieces of filter paper, allowed to air dry and the drying time measured. The stop watch was used to record the time taken for each adhesive to dry. The experiment was repeated three times and the average value was recorded as drying time.

Determination of Bond Strength

Stress-strain behavior of samples was examined using a universal testing machine (UTM) (M500-50CT) with a strain rate of 5 mm/min at 23°C according to ASTM (2013). For this purpose, sample specimens of dimension $40 \times 10 \times 1 \pm 0.05$ mm³ and a crosshead speed of 20 mm/min was used during the test. The data given are the average of three measurements. During this process, the sample object is gripped in the machine's jaws and load is applied to the specimen through controlling a screw mechanism. The tensile bond strength test reveals the response of the object under the stress and the changes experienced by the object during test. Surfaces used are: plastic, aluminum sheet, ceramic, plywood and glass.

Results and Discussion

FTIR Analysis of the Formulated PU/PS Adhesive

The FTIR spectra of PS/PU (Figure 1) composite revealed absorption peaks at 3349 cm⁻¹ and 1662 cm⁻¹, which were attributed to N-H stretching and -C(=O)-N groups vibrations respectively. These peaks indicated the amine and amide group of the PU in the composite (Derikvand and Pangh, 2015). The peaks in the spectra within 3200–2800 cm⁻¹, 1700–1300 cm⁻¹, and 1200–600 cm⁻¹ can be attributed to aliphatic/aromatic C-H stretching, aliphatic C-H bending/C=C stretching/aromatic C=C-C stretching, and aromatic C-H/C-Substituent bending vibrations (on monosubstituted benzene rings). The changes in peak intensities can be attributed to changes in conformation of polystyrene molecules in the composite due to the incorporation of PU. Grafting reaction of styrene molecules with PU particles in Scheme 1 as similarly proposed by Osemeahon *et al.*, (2022), is expected to enhance stable dispersion of PU particles in the PS/PU composite.

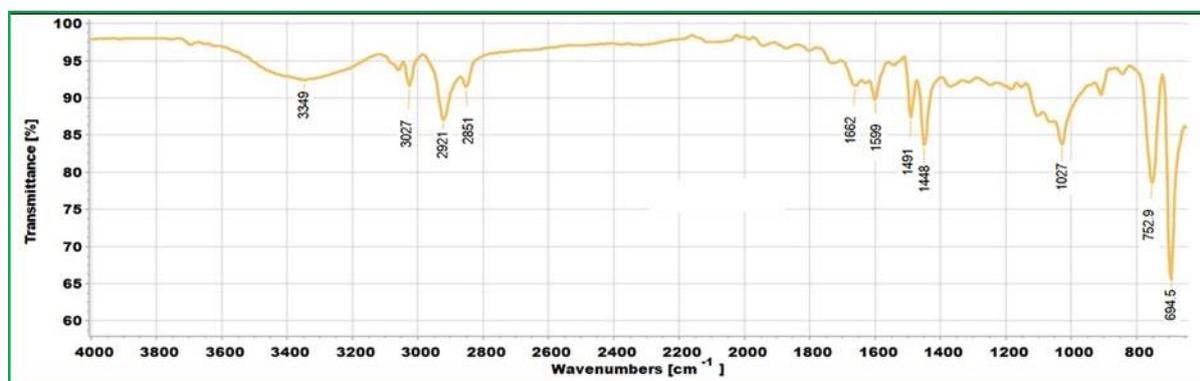


Figure 1. FTIR spectra of PU/PS.

Table 1. Physico-chemical properties of the 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 |
| Turbidity | 5180 NTU |
| Refractive Index | 1.51 |
| Melting Point | 170°C |
| Solubility | Soluble |

Characterisation of formulated Adhesive Bond Strength on Surface Materials

Bond strength of formulated adhesive on aluminum sheet substrate

The bar chart in figure 2 shows the effect of formulated adhesive on Aluminum surface. As shown in the chart, the highest peak is 1.540MPa while the lowest peak is 0.513MPa. The bond strength of this study

1.54MPa is less than the bond strength 52MPa for Aluminum as reported by (Hamidu, *et al.*, 2009). The reason for this may be that the adhesive is not suitable on Aluminum substrate as not all adhesives perform best when bonded to a particular surface (Constable *et al.*, 1998). The low bond strength may also be attributed to lack of difference in the surface energy of the substrate since the same substrate surface was used. This can be explained by the fact the difference in surface energy allows penetration of the polymer into the craters and pores in rough metals substrate, enhancing the bond strength through mechanical interlock mechanism. Since adsorption promote mechanical interlock (Kim *et al.*, 2010), the low bond strength suggests that there is poor adsorption between the adhesive and the substrate.

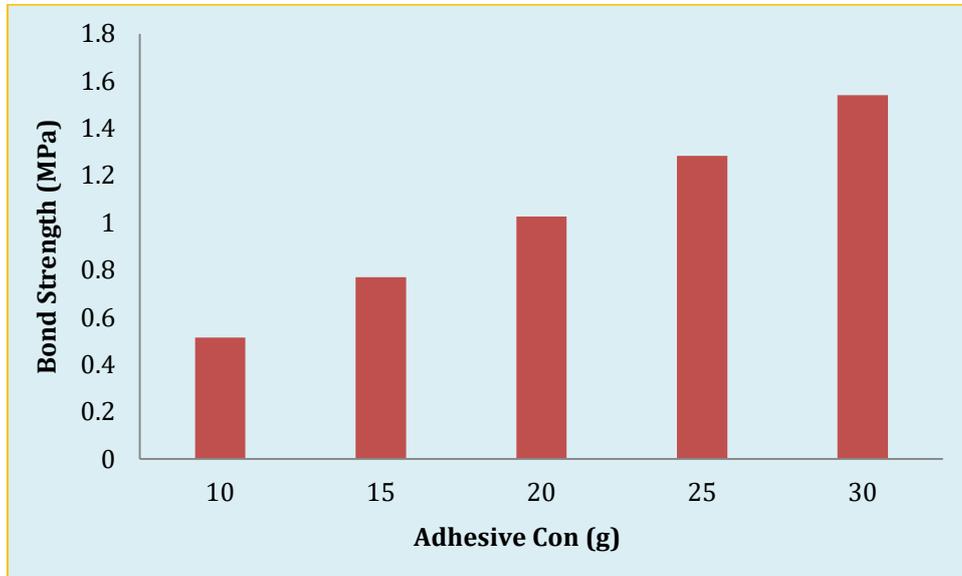


Figure 2. Bond strength of formulated adhesive on aluminum sheet substrate.

Bond strength of formulated adhesive on plastic substrate

The result of this study in figure 3 shows bond strength of the formulated adhesive when tested on plastic surface. The bond strength 2.32MPa represent the highest peak and is slightly greater than the value 2.03MPa of the adhesive as reported by (Issam, 2009). The reason for this high bond strength may be due to the adhesive viscosity which enhanced flexibility in the resin resulting in easy spreading of the adhesive onto the resin (Kaaden *et al.*, 2002). Higher electronegativity difference among linked atoms could also account for the high bond strength. Studies revealed that the higher the electronegativity difference, the higher the bond polarity and thus the bond strength. The high bond strength could also be traced to decrease in bond length which decreases as the atoms size decreases, the bond dissociation energy increases resulting in increase in bond strength.

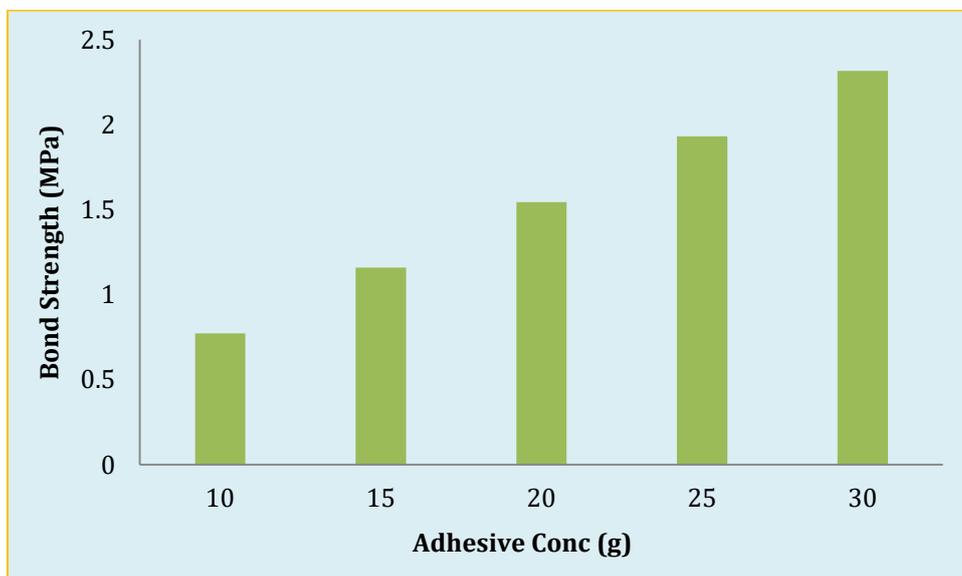


Figure 3. Bond strength of formulated adhesive on plastic substrate.

Bond strength of formulated adhesive on ceramic substrate

The bond strength reported in figure 4 depicts the bond strength of the adhesive when measured on ceramic surface. The highest peak 3.64MPa observed in this study revealed good performance of the adhesive on the ceramic substrate. The high bond strength could be linked to the presence of triple or double bonds which may be present between the bonded atoms. Findings revealed that the strength of a bond between two atoms increases as the number of electron pairs in the compound increases. Thus, triple bonds are stronger and shorter than double bonds between the same atoms, likewise double bonds are stronger and shorter than single bonds between the same two atoms. The bond strength 3.64MPa in this study is slightly higher than the bond strength 3.5MPa reported by (Rhazi *et al.*, 2017). The better bonding performance may also be as a result of the viscosity of the adhesive which allowed easy handling, smooth spreading and sufficient penetration of the adhesive into the ceramic surface (Li *et al.*, 2015).

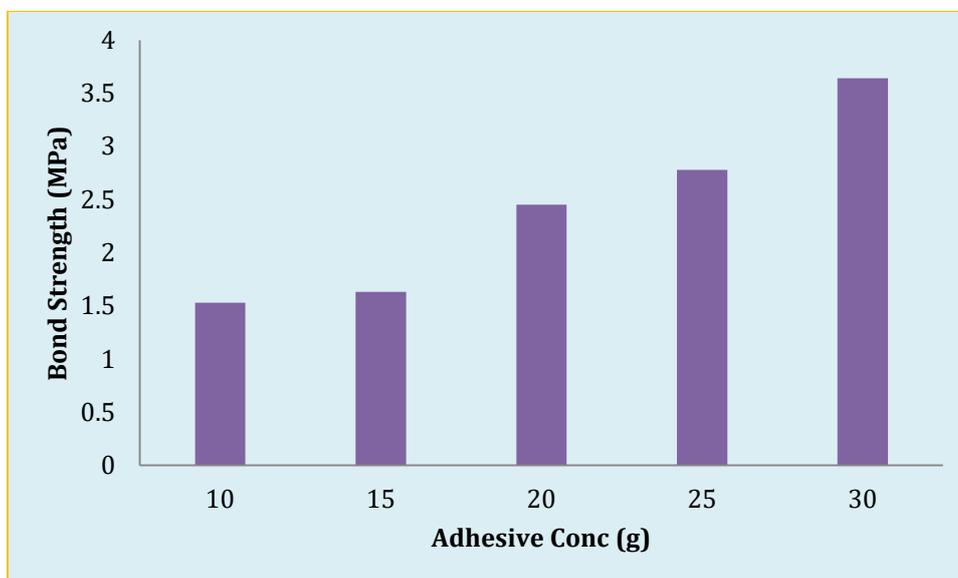


Figure 4. Bond strength of formulated on ceramic substrate.

Bond strength of formulated adhesive on glass substrate

The bond strength of the formulated adhesive was measured on glass surface. The effect of the adhesive on glass is revealed in figure 5. The bond strength 1.15MPa depicted as the highest peak in the chart is less than the value 3.15MPa for single component epoxy adhesive and structural acrylic adhesive for glass as reported by (Elbadawi *et al.*, 2015). This result may be attributed to the fact that not all adhesives perform best when bonded to a particular surface (Constable *et al.*, 1998). Hence both physical and chemical characteristics of surfaces are imperative in adhesion. Similarly, Karachalios (2013) reported that different surfaces yield different failure modes and shear strength values.

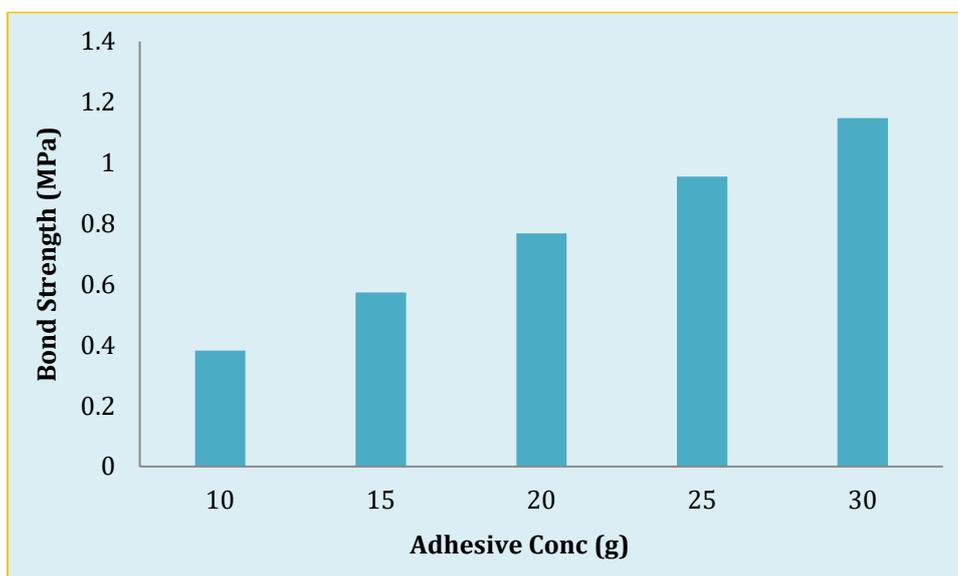


Figure 5. Bond strength of formulated adhesive on glass substrate.

Bond strength of formulated adhesive on wood substrate

The bond strength of the formulated adhesive was carried out on wood surface. The effect of the adhesive is presented in figure 6. The value 3.01MPa in this study is higher than the value 1.8MPa for timber as reported by (Yang *et al.*, 2002) but less than the shear strength reported by (Osemeahon *et al.*, 2022). The apparent bond strength displayed in figure 5 may be hypothesized to the ability of the adhesive to influence gelatinization and retrogradation characteristics within the resin (Tankut *et al.*, 2016), which allow good mobility of the adhesive hence sufficient penetration into the substrate. The result may also be connected to the rough surface of the wood which is able to supply mechanical interfacial locks between the adhesives and the substrate, resulting in the improvement of the shear strength of adhesive joints.

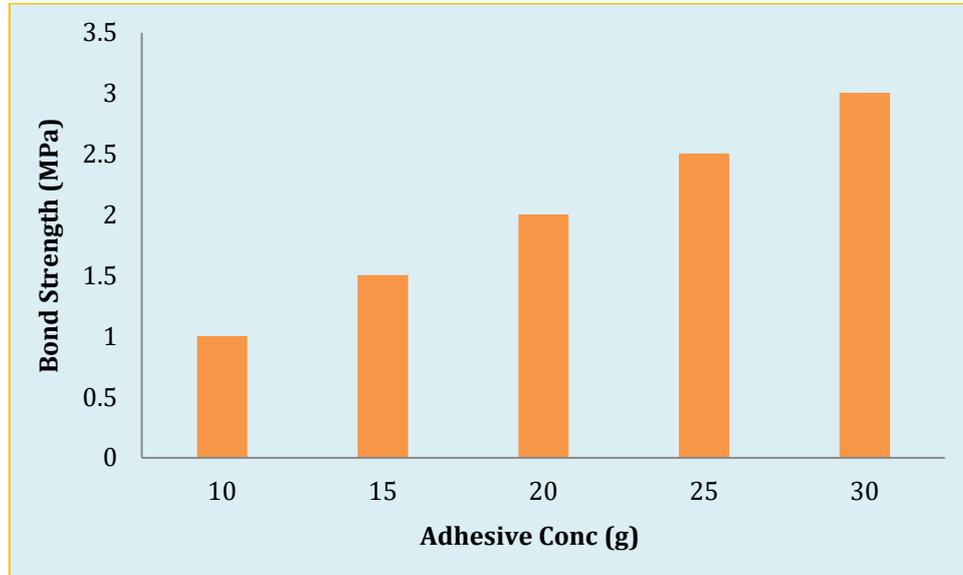


Figure 6. Bond strength of formulated adhesive on wood substrate.

Conclusion

Adhesive was successfully formulated from polyurethane and polystyrene (Styrofoam) waste. The optimal composition for developing adhesive from these plastic wastes are 90% of PS and 10% of PU in a 50ml toluene solvent. The physico-chemical properties of the formulated adhesive affirmed that the adhesive has similar properties with the conventional adhesive.

The bond strength assessment on the materials' surfaces revealed that the formulated adhesive has better performance on the wood surface; ceramic and plastics surfaces. Therefore, this adhesive can perform better than conventional adhesive.

Declarations

Acknowledgements: The authors wish to appreciate Professor Sunday Osemeahon of Chemistry Department, MAU Yola for his invaluable contribution during the course of experiment and writing.

Conflict of Interest: The authors declare no conflict of interest.

Funding: The authors received no funding for the work.

Ethical Approval: Not Applicable.

Informed Consent: Not Applicable.

Author Contributions: Fasina, E.O. carried out laboratory work. Osemeahon, S.A. conceived the idea and research design. Gidigbi, J.A. drafted the manuscript, while Esenowo, D. proofread the manuscript and offer pragmatic suggestions.

References

1. Adams, R. 2005. Adhesive Bonding: Science Technology and Applications. Cambridge: Woodhead Publishing Limited.
2. ASTM. 2013. Standard practice for effect of moisture and temperature on adhesive bonds (D1151-00). American Society of Testing and Materials, Philadelphia, PA, pp. 73-75.
3. Bomba, J., Šedivka, P., Böhm, M. and Devera, M. 2014. Influence of Moisture Content on the Bond Strength and Water Resistance of Bonded Wood Joints. BioResources, 9(3): 5208-5218.

4. Brunori, C., Cafiero, L., De Carolis, R., Fontana, D., Guzzinati, R., Pietrantonio, M., et al. 2015. Innovative technologies for metals recovery and plastic valorization from electric and electronic waste: An integrated approach. *Environmental Engineering and Management Journal*, 14(7): 1553-1562.
5. Constable, J.H., Kache, T., Tiechmann, H., Muhle, S. and Gaynes, M.A. 1998. *Proceedings of the 3rd International Conference on Adhesive Joining and Coating Technology in Electronic Manufacturing*, 76NY: Binghamton.
6. Deng P., Xu Z. and Kuang Y. 2014. Electrochemical determination of bisphenol A in plastic bottled drinking water and canned beverages using a molecularly imprinted chitosan-graphene composite film modified electrode. *Food Chemistry*, 157: 490- 497.
7. Derikvand, M. and Pangh, H. 2015. A Modified Method for Shear Strength Measurement of Adhesive Bonds in Solid Wood. *BioResources*, 11(1): 354-364.
8. Elbadawi, M., Osman, Z., Paridah, T., Nasroun, T. and Kantiner, W. 2015. Mechanical and Physical Properties of Particleboards made from Ailanthus Wood and UF resin Fortified by Acacias Tannins Blend. *Journal of Materials and Environmental Sciences*, 6(4): 1016–1021.
9. García, M.C., Aldana, A.A., Tártara, L.I., Alovero, F., Strumia, M.C., Manzo, R.H. and Jimenez-Kairuz, A.F. 2017. Bioadhesive and biocompatible films as wound dressing materials based on a novel dendronized chitosan loaded with ciprofloxacin. *Carbohydrate Polymers*, 175: 75-86.
10. Gidigbi, J.A., Abubakar, A.B., Ngoshe, A.M. and Okomah, Y.E. 2023. Formulation of emulsion paint using benign HGSO/PVAc copolymer as a binder. *International Journal of Chemistry and Materials Research*, 11(1): 1-7.
11. Gregoire, N. and Igor, C. 2019. Accelerating Transition into circular economy in Plastics. *Field Action Science Reports*, 44-53.
12. Gunorubon, A.J. 2012. Production of cassava starched-based adhesive. *Research Journal in Engineering and Applied Sciences*, 1(4): 219-214.
13. Hamidu, L.A., Aroke, U.O., Osha, O.A. and Muhammad, I.M. 2019. Formulation and Characterization of Adhesive Produced from Polystyrene Waste Using Response Surface Optimization. *Path of Science*, 5(8): 2001-2009.
14. Issam, A.M., Poh, B.T., Abdul Khalil, H.P.S. and Lee, W.C. 2009. Adhesion properties of adhesive prepared from waste polystyrene. *Journal of Polymers and the Environment*, 17: 165-169.
15. Kaaden, C., Powers, J.M., Friedl, K.H. and Schmalz, G. 2002. Bond strength of self-etching adhesives to dental hard tissues. *Clinical Oral Investigations*, 6(3): 155-160.
16. Karachalios, E.F., Adams, R.D. and da Silva, L.F. 2013. Single lap joints loaded in tension with high strength steel adherends. *International Journal of Adhesion and Adhesives*, 43: 81-95.
17. Kim, W., Yun, I., Lee, J. and Jung, H. 2010. Evaluation of mechanical interlock effect on adhesion strength of polymer-metal interfaces using micro-patterned surface topography. *International Journal of Adhesion and Adhesives*, 30(6): 408-417.
18. Li, R., Guo, X., Ekevad, M., Marklund, B. and Cao, P. 2015. Investigation of glueline shear strength of pine wood bonded with PVAc by response surface methodology. *BioResources*, 10(3): 3831-8.
19. Lucas, A.J.H., Umar, O.A., Odeh, O.A. and Idris, M.M. 2019. Formulation and Characterization of Adhesive Produced from Polystyrene Waste Using Response Surface Optimization. *Path of Science*, 5(8): 2001-2009.
20. Osemeahon, S.A., Reuben, U. and Emmanuel, E. 2022. Development of adhesive from polystyrene waste. *BIOMED Natural and Applied Science*, 2(1): 13-24.
21. Rhazi, N., Oumam, M., Sesbou, A., Hannache, H. and Charrier-El Bouhtoury, F. 2017. Physico-mechanical properties of plywood bonded with ecological adhesives from *Acacia mollissima* tannins and lignosulfonates. *The European Physical Journal Applied Physics*, 78(3): 34813.
22. Tankut, N., Bardak, T., Sozen, E. and Tankut, A.N. 2016. The effect of different nanoparticles and open time on bonding strength of poly (vinyl acetate) adhesive. *Measurement*, 81: 80-84.

23. Yang, I., Kuo, M. and Myers, D.J. 2005. Physical properties of hybrid poplar flakeboard bonded with alkaline phenolic soy adhesives. *Journal of the Korean Wood Science and Technology*, 33(5): 66-75.

Citation: Esther O. Fasina, Sunday A. Osemeahon, Joshua A. Gidigbi, and David Esenowo. 2023. Formulation of Adhesive from Polyurethane/Polystyrene Waste Plastics. *International Journal of Recent Innovations in Academic Research*, 7(10): 10-17.

Copyright: ©2023 Esther O. Fasina, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.