RESEARCH ARTICLE

Development of adhesive from polystyrene waste

Sunday A. Osemeahon[1], Usaku Reuben[2]*, Ezekiel Emmanuel[1]

[1]Department of Chemistry, Faculty of Physical Sciences Modibbo Adama University, Yola, Nigeria.
[2]Department of Science Laboratory Technology, Faculty of Life Sciences, Modibbo Adama University, Yola, P.M.B 2076 Yola, Adamawa state Nigeria.

Correspondence should be addressed to U.R; Email: usakureuben5@gmail.com

https://doi.org/10.53858/bnas02011324

ABSTRACT

Background: This study aimed to develop adhesive from waste polystyrene, which has the capacity to both reduce environmental pollution and create wealth from waste. **Methods:** Polystyrene waste was obtained from waste heap "bola" around Jimeta metropolis, Yola, Adamawa State, Nigeria. The polystyrene waste was washed and dried. The washed waste was used to formulate adhesive using various solvents such as toluene, gasoline, blend of gasoline and toluene, and blend of gasoline and acetone. The formulated adhesives were characterized by study some physical properties of the formulated adhesive, such as; viscosity, bond strength, pH, solid content, moisture content and drying time. **Results:** The adhesive formulated from the blend of toluene and acetone gave the best performance from the physical properties. The adhesive from blend of toluene and acetone as solvent was then selected for application on different surfaces such as plastic, plywood, aluminum, glass and ceramic. The Bond strength of the selected adhesive was measured on these surfaces as follows; plastic (6.74 MPa), ceramics (5.9 MPa), glass (5.9 MPa), plywood (7.04 MPa) and aluminum sheet (0.76 MPa). The pH of the adhesive was 6.58, viscosity;467, drying time; 2.44minutes, solid content (% SC); 90.62 % and the moisture content (% MC) of the adhesive was 9.38 %. The adhesive on optimization, established that increase in concentration of polyvinyl acetate impact greatly on the bond strength of the adhesive. Glycerol was used as plasticizer that improved the flexibility of the adhesive but it raises the moisture content (% MC) of the adhesive. **Conclusion:** It was concluded that creation of wealth while reducing environmental pollution, through production of environmentally friendly adhesive from waste plastics, is a viable task. This research hereby introduces a new adhesive to the adhesive industry.

Keywords: Polystyrene waste; environmental pollution; adhesive formulation; wealth creation.

Received: 07 February 2022, Revised: 07 March 2022, Published: 12 March 2022
Citation: Osemeahon, S.A., Reuben U., Emmanuel, E. (2022). Development of adhesive from polystyrene waste. *BIOMED Natural and Applied Science,* 2(1):13-24, https://doi.org/10.53858/bnas02011324

1.0 Introduction

Adhesives can be defined as a mixture in a liquid or semi-liquid state, capable to joining permanently surfaces, by an adhesive process. It involves two bodies being held in intimate contact such that mechanical force or work can be transferred across the interface. The forces involved in adhesion process include van-der Waals forces, chemical bonding, or electrostatic attraction [1].

The raw materials used as adhesives are mainly polymeric materials, both natural and synthetic. Taking into consideration the costs, natural products (such as starch, dextrin, casein, natural gums) are still important; however, synthetic ones have largely taken over the adhesive industry, both as modifiers of natural materials and, more importantly, as high-strength, moisture-resistant additives capable of being produced in many readily usable forms [2].

Wastes are the material that are not needed and are not usable economically with further processing. It may be in the form of solid, liquid, and gas. They originate from the human activities such as agriculture, industry, domestic activities etc. According to origin, waste is classified as domestic, industrial, commercial, clinical, construction, nuclear, and agricultural [3]. According to properties waste is classified as inert, toxic, and inflammable. If these wastes remain untreated, they lead to air, water, soil or solid waste pollution. Hence, solid waste management is very essential [4]

Most human activities generate waste [5]. Despite that, the production of wastes remains a major source of concern as it has always been since pre historic period [6]. In recent times, the rate and quantity of waste generation have been on the increase. As the volume of wastes increases, so also does the variety of the waste increases [7]. Unlike the pre historic period where wastes were merely a source of nuisance that needed to be disposed of. Proper management was not a major issue as the population was small and a vast amount of land was available to the population at that time. In those days, the environment easily absorbed the volume of waste produced without any form of degradation [4]

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 [8].

Polystyrene is a thermoplastic polymer made from styrene, a thermoplastic polymer material that can be repeatedly softened and hardened by alternately heating and cooling. [9] highlighted the environmental costs of plastic use in consumer World population, which surpassed 7 billion in 2011. This is forecasted to exceed 9 billion by 2050. It is feared that the growing demand for resources will facilitate an increase in resource consumption and waste generation thus contribute to deterioration of the natural environment climate change, and impact on future generations [10]. Development of adhesive from waste polystyrene will both reduce environmental pollution and create wealth from waste. This is the focus of this research.

2.0 Materials and Methods

2.1 Materials

Polystyrene wastes, stopwatch, gasoline, diphenylamine, polyvinyl Acetate, Toluene, glycerol, acetone and distilled water. The chemical BDH products used as were supplied. The equipment and apparatus that were used include: weighing balance (OLML-R51), Oven (Elba 9S4EX737 90cm), viscometer (AETEK DV1), pH meter 3510Bench pHmV), stirrer (EIE-223NL), beakers and measuring cylinders.

2.2 Treatment of raw Material

Polystyrene wastes were collected from refuse-heap around homes in Jimeta metropolis in Adamawa State, Nigeria. The collected polystyrene wastes were washed and dried. The dried polystyrene waste was then cut into small pieces for easy weighing.

2.3 Formulation of Adhesive

Gasoline selected solvent (50ml) was measured using a measuring cylinder into a clean and dry glass beaker and then 23g polystyrene was added slowly to the gasoline solvent in the beaker. The polystyrene was allowed to dissolve in the gasoline and then allowed to stay for 5 minutes. The resulting mixture was the Adhesive [11]. This process was repeated with different solvents namely; toluene, acetone, toluene + acetone, toluene + gasoline and + acetone. The polystyrene wastes used were white 'Styrofoam package' and different colors of takeaway plates.

2.4 Characterization of the Adhesive

2.4.1 Percentage Solid content

To determine the solid content of the formulated adhesive, about 50cm^3 of the adhesive was weighed and dried in the oven at a temperature of 200^{o}C for 1hour. The weight of the adhesive after drying was taken as dry weight. The percentage solid content was then computed using the mathematical formula [12];

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

 https://doi.org/10.53858/bnas02011324
ISSN: 2789-178X

2.4.2 Percentage Moisture content

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

$$\textbf{\% moisture content} = \frac{\text{Original weight - Dry weight}}{\text{Original weight}} \times 100$$

2.4.3 Viscosity

The viscosity of the developed adhesive was determined using a viscometer as described in [13], that, Dynamic (absolute) viscosity: Dynamic viscosity is also known as absolute viscosity and most often relates to non-Newtonian fluids. It refers to the fluid's internal resistance to flow when force is applied.

Kinematic viscosity: Kinematic viscosity is a measure of the viscosity of a (usually Newtonian) fluid in motion. It can be defined as the ratio of dynamic viscosity to density. Any viscometer that uses gravity in its measurement design is measuring kinematic viscosity.

Apparent (shear) viscosity: Apparent, or shear, viscosity refers to the relationship between viscosity and shear rate. In Newtonian fluids, this value doesn't change, but with non-Newtonian fluids, apparent viscosity is directly affected by the shear rate. It can be calculated by dividing shear stress by shear rate.

Relative viscosity: Relative viscosity is important for non-Newtonian fluids, specifically polymers. It refers to the relationship between molar mass (the mass of a chemical compound divided by total amount) and viscosity — higher molar mass means higher viscosity in the polymer. It is calculated by dividing the polymer viscosity by the viscosity of the pure solvent.

2.4.4 Drying time

The drying time of the adhesive was measured using the procedure described in [14]; 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.

2.4.5 **pH of the adhesive**

pH meter was used to determine the pH of the produced adhesive. The meter was cleansed with solvent to remove dirt and impurities on the electrodes. It was followed by stabilization in buffer solution of 4 and $9cm^3$ immersions in the sample. The meter was then recorded.

2.4.6 Determination of bond strength

The method of [15] was used. The surface of the substrate was pretreated by smoothening sand paper followed by air-blasting to remove accompanying dust. After the surface treatment, the substrate pair was joined following the application of the film of the adhesive on the measure area ($250mm^2$). The share strength was determined from the minimum amount of the load that would result in failure at adhesive joint and was calculated by the expression;

$$\text{Share Strength} = \frac{\text{Average Force (N)}}{\text{Surface Area (mm}^2\text{)}}$$

3.0 Results and Discussion

3.1. Adhesive from the polystyrene waste

The adhesive resulting from the polystyrene waste in various solvents are presented in Table 1. Adhesive using acetone as solvent could not give a homogeneous mixture which therefore makes it unfit for this study. The acetone produced a mixture with two phases; the solvent floating while the solute (polystyrene waste) settled at the bottom of the beaker. Other solvents used in this study as shown in Table 1, gave a homogenous mixture. These findings corroborate the views of [16].

Table 1: Comparative data of various solvent for adhesive formulation

Organic solvents used (50ml)	**Polystyrene waste used (g)**	**Nature of mixture**
Acetone	30.00	Heterogeneous liquid viscous in nature
Toluene	30.00	Homogenous liquid viscous in nature
Gasoline	30.00	Homogenous liquid viscous in nature
Gasoline + Acetone (50:50)	30.00	Homogenous liquid viscous in nature
Gasoline + Toluene (50:50)	30.00	Homogenous liquid viscous in nature
Toluene + Acetone (50:50)	30.00	Homogenous liquid viscous in nature

3.2 Percentage moisture content (%mc) of the formulated adhesive

Figure 1 presents the moisture content of the produced adhesives. Out of the 5 samples, the sample with toluene + acetone blended as solvent was found to be least with 8.97 % as compared to samples with; blend of acetone + gasoline (13.57 %), blend of gasoline + toluene as solvent (9.86 %), toluene (11.54 %) and gasoline as solvent (10.74 %). This show that adhesive with low moisture content has better property of bonding to substrate and might not degrade rapidly. And of all the samples, the sample with toluene + acetone blended was the least and best fit based on the urea formaldehyde adhesive used in particle board as reported by Ohoke et al. [12].

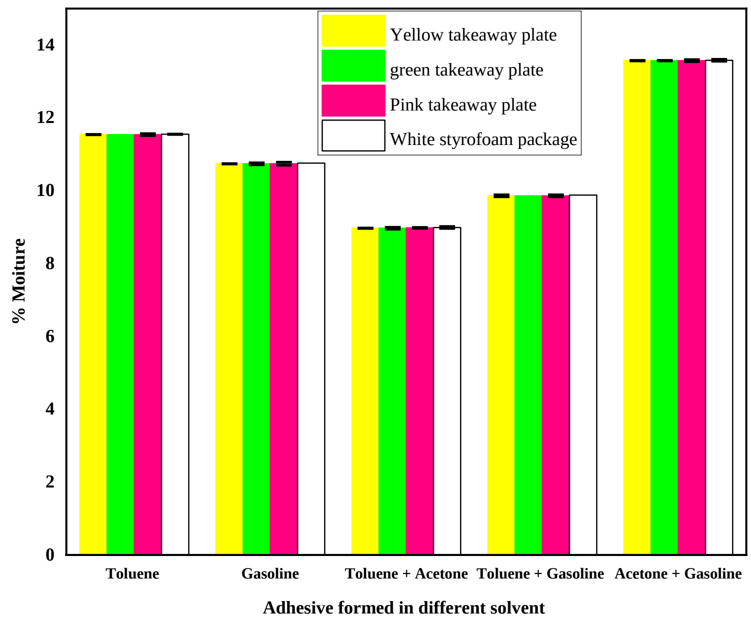

Figure 1: Moisture content of the formulated adhesive

3.3 Percentage solid content (%SC) of the formulated adhesives

Figure 2 presents the solid content for the formulated adhesives using different solvents. The results show that the formulated adhesives have solid content ranging from 86.42 % to 91.12%. From these analyses, the solid content of all samples falls within the range for solid content of adhesive used in particleboard production [17]. This implies that all the samples of the formulated adhesives could be used for composite material production if other quality parameters are met [17,18,19]. The color (green, yellow and pink) of the takeaway plate as shown in Figure 2 appears to have no effect on the solid content of the formulated adhesives.

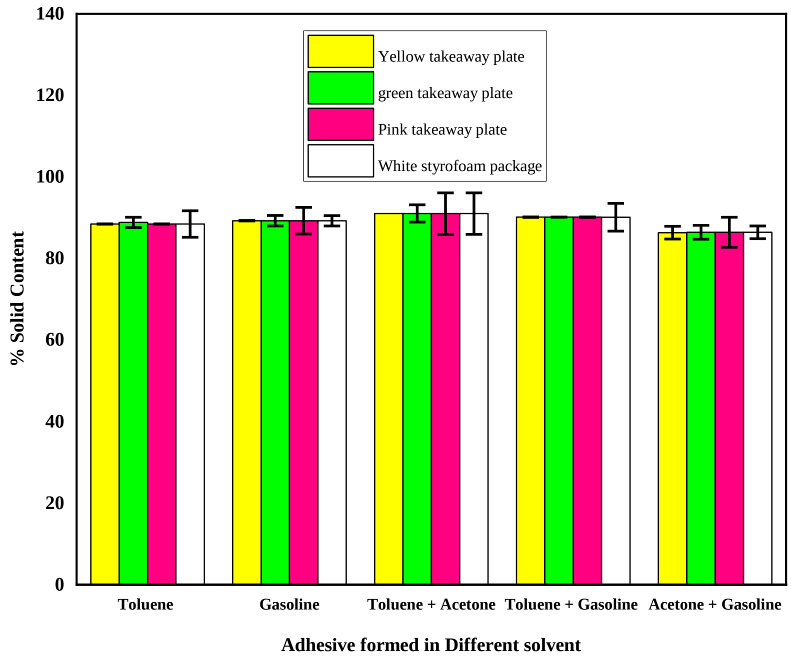

Figure 2: percentage solid content of the formulated adhesives

3.4 pH of the formulated adhesives

Figure 3 presents results of pH obtained from the various formulations. The pH of the samples ranges from between 6.86 to 8.03. The difference in pH could be attributed to the solvents used in each sample. The pH values obtained above were within the reported values of urea formaldehyde resin used in particleboard production [20]. It is believed that either high or low pH of an adhesive could influence its bond durability and performance especially under wet conditions [21]. There is concern that adhesive in which pH is either too low or too high may impact the service life of the adhesive. The result of this finding shows that the pH is neither too low nor too high.

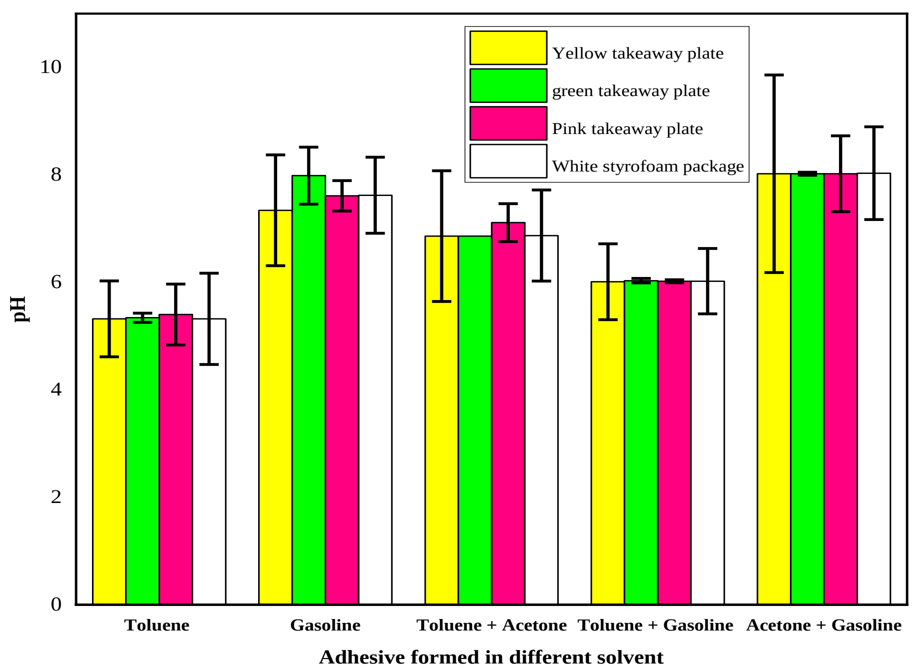

Figure 3: pH of the Formulated Adhesives

3.5 Viscosity of the formulated adhesives

Figure 4 presents viscosity for the formulated adhesives. The viscosity data obtained for the adhesives with various solvents are: sample 1(toluene as solvent); 450cPs, sample 2(gasoline as solvent); 460 cPs, sample 3(blend of Toluene + Acetone as solvent); 467cPs, sample 4(blend of Toluene + Gasoline as solvent); 476 cPs and Sample 5 (blend of Acetone + Gasoline as solvent); 475 cPs. Color of the samples (takeaway plate) had no appreciable effect on the viscosity of the adhesives while the difference in viscosity amongst the samples could be attributed to the solvents used in each case except for the different product of polystyrene waste used (Styrofoam package) which showed slight difference in viscosity from those of the same solvent. Viscosities obtained in this experiment falls within the range of viscosity of urea formaldehyde used as binder in panel and other composites materials production [21,17] and also within range of viscosities for pressure sensitive adhesives [22].

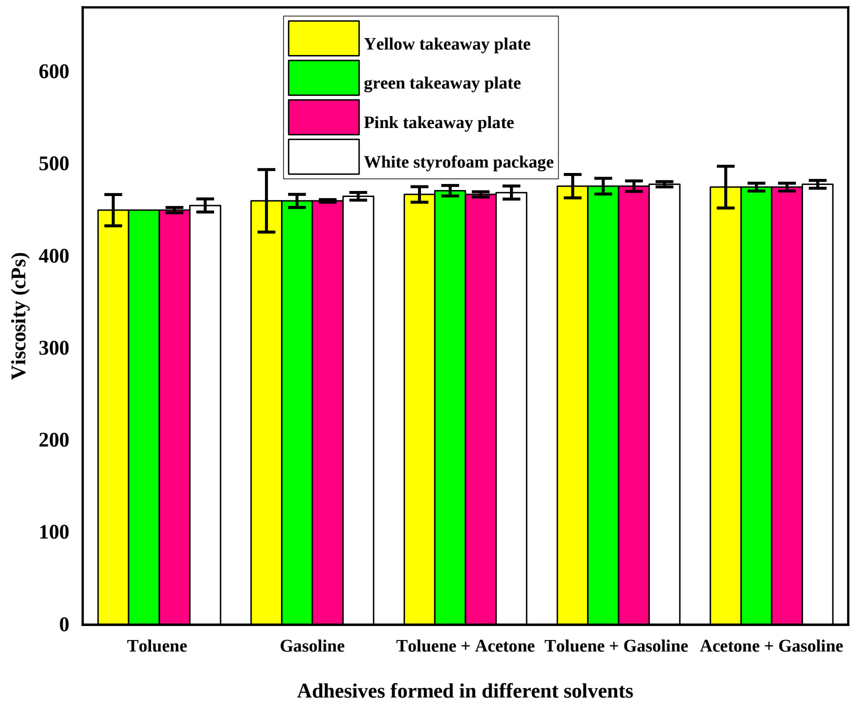

Figure 4: Viscosities of the Formulated Adhesive

3.6 Drying time of the formulated adhesives

Figure 5 present the time taken for the developed adhesive to dry on substrate. The experimental data obtained for the drying time of the formulated adhesives are: 4.30 minutes for toluene, 4.15minutes for gasoline, 2.44 minutes for blend of Toluene +Acetone, 1.55 minutes for blend of Toluene + Gasoline, and 3.19 minutes for blend of Gasoline + Toluene as solvent. The adhesives with drying time 1.55minutes and 2.44 minutes falls within the drying time of adhesive for particleboard production (Lucas *et al*., 2019) [10] while those with drying time ranging from 3.19 minutes to 4.30 minutes fall within the range of drying time for wood adhesive [16] but less than the drying time of cassava starch-based adhesive reported by Melo et al. [17].

3.7 Bond strength

Bond strength or shear strength generally involves determining the stress required to rupture a bond formed by an adhesive between two surfaces. The bond strength being the interfacial strength between adhesive and substrate is usually the most important consideration when designing a strong adhesive [23]. The interfacial strength of the formulated adhesive was measured on different surfaces. These surfaces include; plastic, plywood, ceramics, glass and Aluminum sheet.

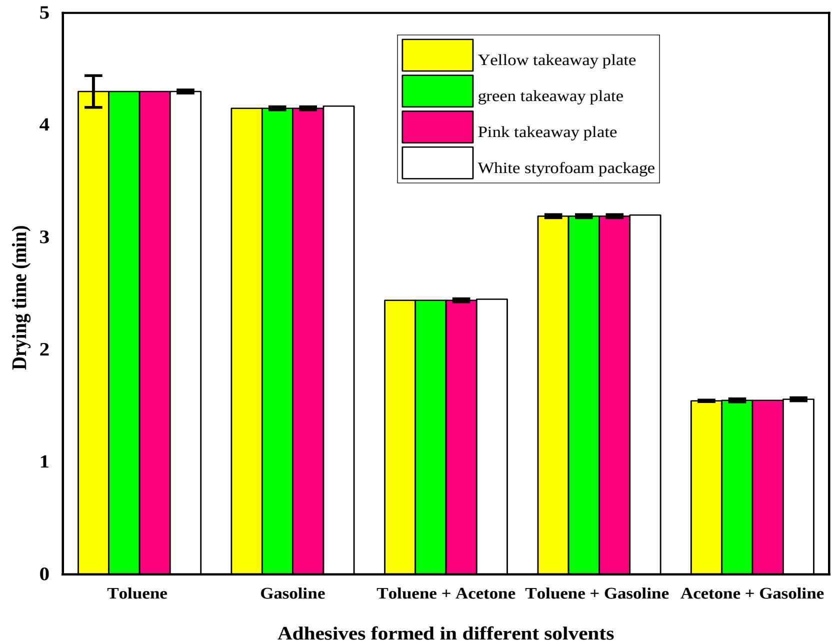

Figure 5: Drying time of the formulated adhesive

3.7.1 Bond strength of the formulated adhesive on plywood

The bar chart in Figure 6, showed the effect of solvent on the bond strength of the formulated adhesive. The color of the solute appears to have no significant effect on the bond strength of the adhesive when measured on plywood. As shown in Figure 6, the solvent mixture, Toluene + Acetone, exhibited the highest interfacial strength on plywood which is higher than the shear strength for adhesive formulated from soybean for plywood as reported by [24] but correspond to the shear strength reported by Ahmed *et. al.,* (2010) [20] for adhesive of timber. Styrofoam package (solute) appears to have an edge over the other solutes regardless of the solvent used. The bond strength resulting from other solvents as shown in Figure 6, is within range of adhesive for particle board production [25].

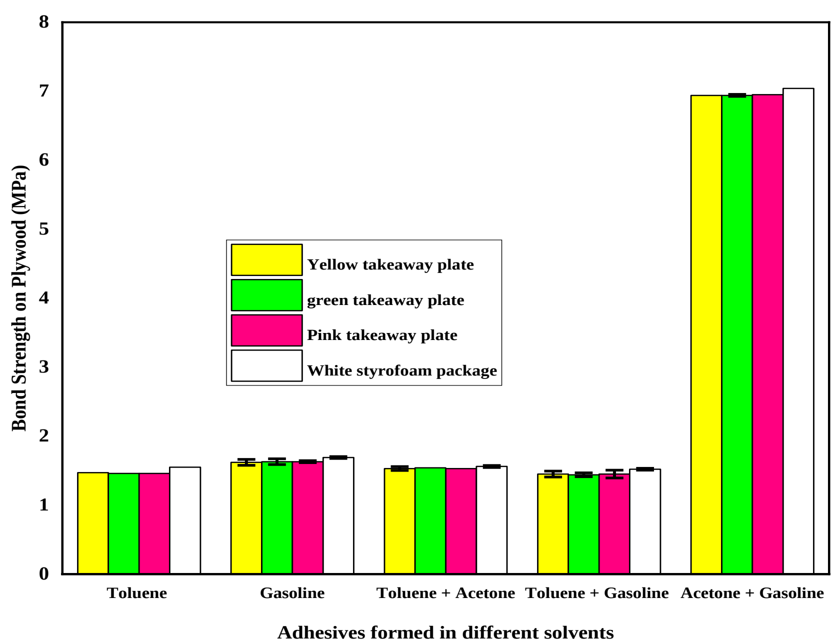

Figure 6: Bond strength of the formulated adhesive on plywood using different solvent

3.7.2 Bond strength of the formulated adhesive on ceramics

The bond strength reported in Figure 7, revealed that the solvent (Toluene + Acetone) with the highest peak gave a better performance of shear strength amongst the other solvents used when measured on ceramics. A ceramic is any of the various hard, brittle, heat-resistant and corrosion-resistant materials made by shaping and then firing a nonmetallic mineral, such as clay, at a high temperature. The color of the polystyrene waste had no noticeable effect on the bond strength of the formulated adhesive when measured on ceramic tile. The bond strength of the best performing adhesive on ceramic for this study is less than the value for ceramic adhesive reported by Thornton, [26]. However, the bond strength (solvent with the highest peak) for the formulated adhesive is in close range with the bond strength (3.5MPa) reported by [27].

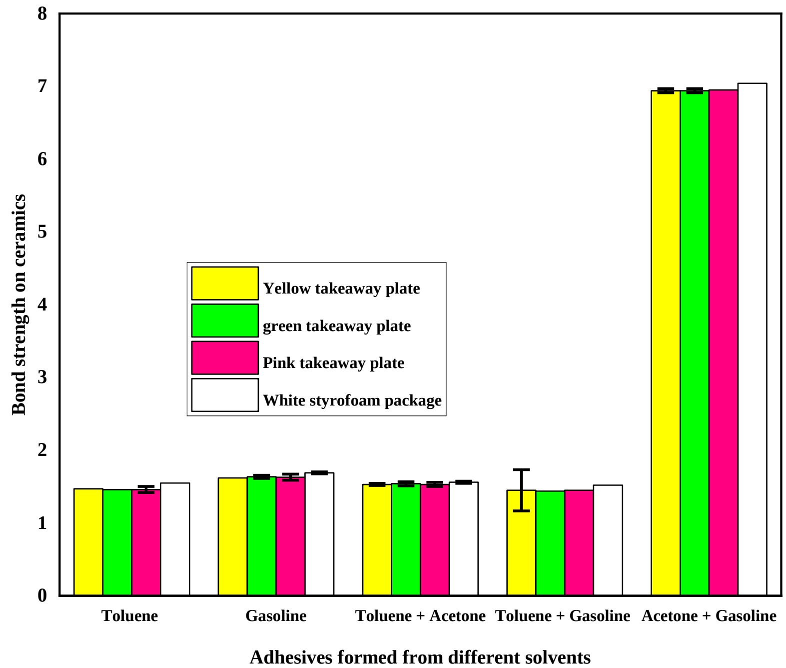

Figure 7: bond strength of the formulated adhesive on ceramics using different solvent

3.7.3 Bond strength of the formulated adhesive on glass substrate

The bond strength of the formulated adhesive on glass substrate reported is represented in Figure 8. As shown in the figure, the bond strength of the formulated adhesive for this study was measured on glass. Solvent Mixture (Toluene +Acetone) showed a better performance with glass followed by gasoline. The different colors of polystyrene waste most especially the takeaway plate showed no appreciable effect on the bond strength of the formulated adhesive when tested on glass, as all the different colors of takeaway plate in same solvent have the same peak except for the 'Styrofoam package' which showed slight difference in performance. The reasons for difference could be due to the mechanical properties of panels manufactured with low density styrofoam type were higher than those of panels manufactured with high density styrofoam type. The lowest thermal conductivity among the wall panels was found for poplar panels manufactured with high density Styrofoam. The bond strength (highest peak) of this study is less than the value for single component epoxy adhesive and structural acrylic adhesive for glass as reported as 3.1 MPa by Elbadawi et al., [28].

3.7.4 Bond strength of the formulated adhesive on aluminum sheet substrate

The bond strength of the formulated adhesive on Aluminum substrate using is reported in **Figure 9**. As shown in the figures, the bond strength of these adhesives was measured on an Aluminum sheet. Adhesive with the blend of Toluene+ Acetone as solvent was observed to be the better performing solvent while gasoline is the lowest. The 'styrofoam package' showed higher bond strength in each of the solvents as shown in Figure 7. The bond strength of this study (0.75MPa) is less than the bond strength (52MPa) for Aluminum adhesive reported by Hamidu et al., [29].

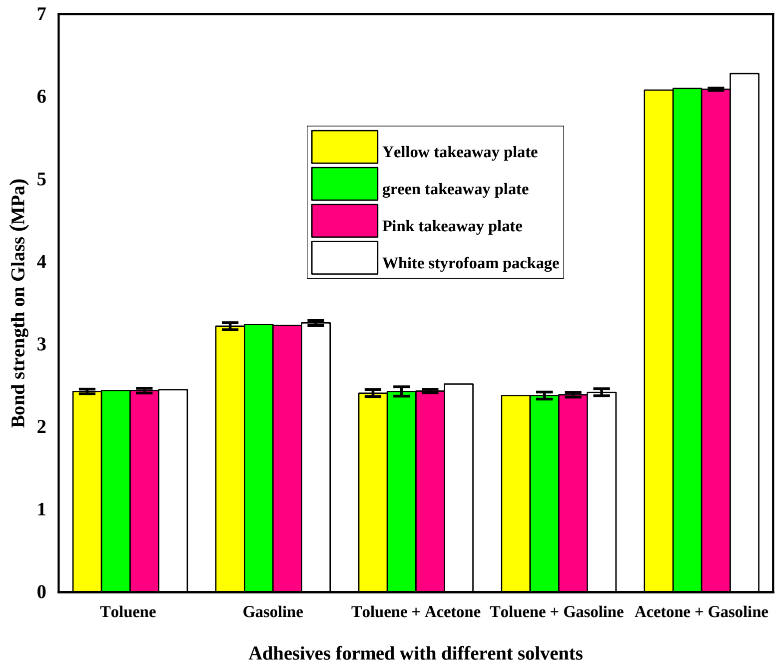

Figure 8: bond strength of the formulated adhesive on glass substrate

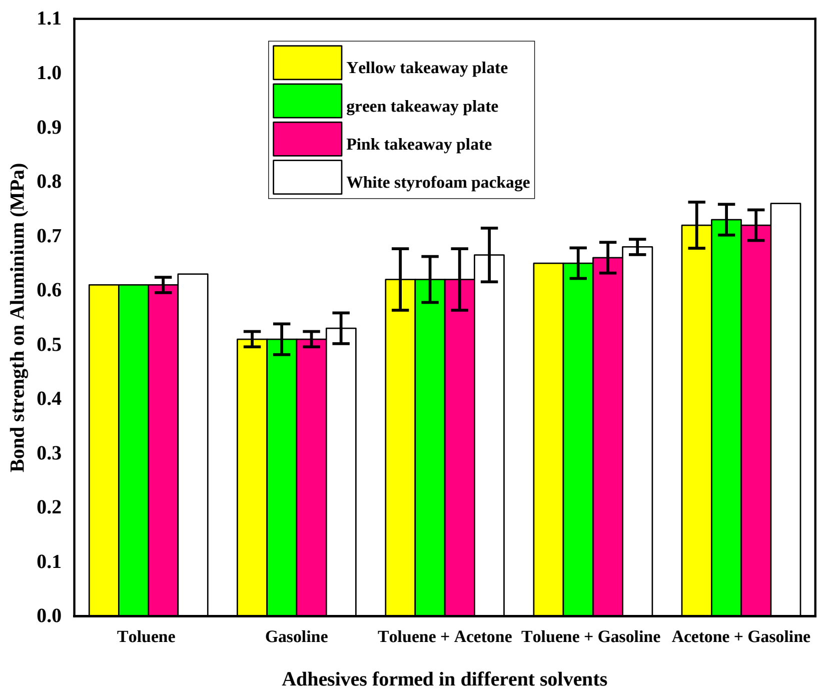

Figure 9: Bond strength of the formulated adhesive on Aluminum using different solvent

3.7.5 Bond strength of the formulated adhesive on plastic substrate

The bond strength of the formulated adhesive on plastic substrate using is reported in **Figure 10**. Gasoline had the least peak regardless of the polystyrene waste used while solvent mixture (toluene + acetone) had the highest peak regardless of the nature and color of the polystyrene waste used for this study. Apparently, the color of the polystyrene waste had not shown any noticeable impact on the bond strength of the adhesive when it was measured on plastic. The bond strength (2.98 MPa) representing the lowest peak as shown in Figure 9 , is slightly greater than the value of the bond strength (2.03 MPa)

 https://doi.org/10.53858/bnas02011324
ISSN: 2789-178X

of the adhesive reported by [30]. The bond strength of the formulated adhesive represented by the highest peak is (6.74MPa).

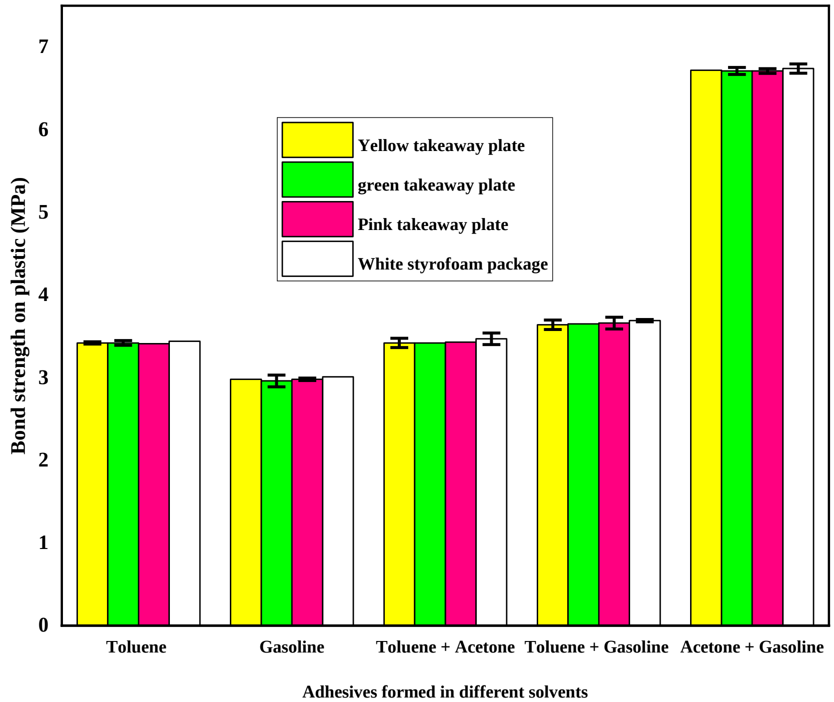

Figure 10: Bond strength of the formulated adhesive on plastic using different solvent

4.0 Conclusion

Wealth can be created through developing a cost effective and environmentally friendly adhesive. Adhesive was formulated from polystyrene and a mixture of toluene and acetone as solvent, using additives as stabilizer. The color of takeaway plate had no effect on the adhesive while white 'Styrofoam package' which is another polystyrene product showed a slightly better performance when used as adhesive than takeaway plate. This study may introduce new cost effective and environmentally adhesive to adhesive industries.

Authors Contributions: Concept :Sunday A. Osemeahon, design: Sunday A. Osemeahon, definition of intellectual content: Ezekiel Emmanuel, literature search: Ezekiel Emmanuel, clinical studies, experimental studies: Not applicable, data acquisition: Ezekiel Emmanuel, software: Ezekiel Emmanuel, writing : Usaku Reuben, supervision: Sunday A. Osemeahon, funding acquisition: Sunday A. Osemeahon, data analysis: Usaku Reuben, statistical analysis, manuscript preparation: Usaku Reuben, manuscript editing and manuscript review: Sunday A. Osemeahon.

Competing Interests: The authors have no conflict of interest in any form.

Funding: This research received no external funding"

Acknowledgements: This work was supported by Modibbo Adama University, Yola. The authors would like to give thanks to the support of the laboratory technologists of chemistry department, Modibbo Adama University, Yola. Thanks to all the participating chemical workers and other technologists in the sisters' departments who provided assistance for our survey and collection of samples.

Ethics Approval Statement: Not applicable

References

1. Garcia, M., Aldana A., Tartara L., Alovero F., Strumia M., Manzo R., Martinelli M, Jimenez-Karus A. Bioadhesive and biocompatible films as wound dressing materials based on a novel dendronized chitosan loaded with ciprofloxacin. Carbohydrate Polymers. 2017; **175:75**-86

2. Dinte E, Sylvester B. Adhesives: applications and recent advances. Applied adhesive bonding in science and technology. 2018 Feb 21:119-34.

3. Vineeth SK, Gadhave RV. Sustainable raw materials in hot melt adhesives: a review. Open Journal of Polymer Chemistry. 2020 Aug 25;10(03):49

4. Williams, P. T. (2005). *Waste Treatment and Disposal*. London, New York: John Wiley & Sons. https://doi.org/10.1002/0470012668

5. Wilson, D. C. (2007). Development drivers for waste management. *Waste Management & Research the Journal of the International Solid Wastes & Public Cleansing Association Iswa, 25*(3), 198-207.https://doi.org/10.1177/0734242X07079149

6. Vergara, S. E., & Tchobanoglous, G. (2012). Municipal Solid Waste and the Environment: A Global Perspective. *Environment and Resources, 37*(37), 277-309. https://doi.org/10.1146/annurev-environ-050511-122532

7. Brunner, P. H., & Rechberger, H. (2014). Waste to energy—key element for sustainable waste management. *Waste Management, 37*, 3-12. https://doi.org/10.1016/j.wasman.2014.02.003

8. Golshan, P., Bomba, J., Böhm, M., and Boška, P. (2015). Influence of Temperature on the Strength of Bonded Joints. *BioResources, 10*(3). doi: 10.15376/biores.10.3.3999-4010

9. Thornton, R. H., (1962) bond strength and elastic properties of ceramic adhesive. Journal of the American ceramic society. V(45) 201- 209

10. Ogwo, R. R. de, Stangerlin, D. M., Santana, R. R. C., & Pedrosa, T. D. (2014). Physical and mechanical properties of particleboard manufactured from wood, bamboo and rice husk. *Materials Research, 17*(3), 682–686. doi: 10.1590/s1516-14392014005000052

11. Narendra, R. V., Abraham, B. T., &Thachil, E. T. (2014). Utilization of waste expanded polystyrene: Blends with silica-filled natural rubber. *Materials & Design, 40*, 221–228. doi: 10.1016/j.matdes.2012.03.042

12. Ohoke, F. O and Igwebike-Ossi, C. D. (2015). Formulation and Performance Evaluation of Wood Adhesives Produced with Rice Husk Ash as New Filler. American Journal of Applied chemistry. 3 (2): 33-39.

13. Lucas A.J.H , Umar, O.A, Odeh, O. A.,Idris M. M. (2019). Formulation and Characterization of Adhesive Produced From Polystyrene Waste Using Response Surface Optimization*Path of Science.*

14. Derikvand, M., and Pangh, H. (2015). A Modified Method for Shear Strength Measurement of Adhesive Bonds in Solid Wood. *BioResources, 11*(1). doi: 10.15376/biores.11.1.354-364

15. 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

16. Zhu, L. B., Han, B., Gu, J. Y., Zhang, Y. H., Tan, H. Y., and Zuo, Y. F. (2010). Preparation of Water-Resistance Plywood with UF Resin Modified by EmulsifiablePolyisocyanate. *Applied Mechanics and Materials, 26-28*, 1056–1060. doi: 10.4028/www.scientific.net/amm.26-28.1056

17. Melo, R. R. de, Stangerlin, D. M., Santana, R. R. C., and Pedrosa, T. D. (2014). Physical and mechanical properties of particleboard manufactured from wood, bamboo and rice husk. *Materials Research, 17*(3), 682–686. doi: 10.1590/s1516-14392014005000052

18. Arendt, W. D., McBride, E., and Conner, M. M. (2014). Use of Dibenzoate Plasticizers in Pressur Sensitive Adhesives. Retrieved fromhttps://www.pstc.org/i4a/pages/index.cfm?pageID=4491

19. Baraya K. A., Boryo, D. E. A., Chindo, I. Y. and Hassan, U. F. (2020). Formulation and Characterization of Green Adhesive Using Agricultural and Plastic Waste Materials as Composites. *IOSR Journal of Applied Chemistry (IOSR-JAC)*

20. Gunorubon, A. J.,(2012). Production of cassava starched-based adhesive. Research journal in engineering and applied Sciences. 1(4)219-214

21. Ahmad, Z., Ansell M., and Smedle, D. (2011). Bonding Strength Properties of Adhesively-TimberJoint with Thixotropic and Room TemperatureCured Epoxy Based Adhesive Reinforced with Nano- and Micro-particles. Journal of Materials Science and Engineering

22. Yang, I, and Kuo, (2002) physical properies of hybrid poplar flakeboard bonded with alkaline phenolic soy adhesives. *Retrospective Theses and Dissertations*. 412. https://lib.dr.iastate.edu/rtd/412

23. Permabond, J. (2021, February 3). *Strong Adhesive Manufacturing Initiative*. Retrieved from https://www.permabond.com/resource-center/strongest-adhesive

24. Piekarczyk, M. and GrecR.(2012). Application of adhesive bonding in steel and aluminium Structures. Archives of civil engineering, LVIII, 3. DOI: 10.2478/v.10169-012-0018-8

25. Garcia, M., Aldana A., Tartara L., Alovero F., Strumia M., Manzo R., Martinelli M, Jimenez-Karus A. Bioadhesive and biocompatible films as wound dressing materials based on a novel dendronized chitosan loaded with ciprofloxacin. Carbohydrate Polymers. 2017;**175**:75-86

26. Li R, Guo X, Ekevad M, Marklund B, Cao P. Investigation of glueline shear strength of pine wood bonded with PVAc by response surface methodology. BioResources. 2015 May 5;10(3):3831-8.

27. Rhazi N, Oumam M, Sesbou A, Hannache H, Charrier-El Bouhtoury F. Physico-mechanical properties of plywood bonded with ecological adhesives from Acacia mollissima tannins and lignosulfonates. The European Physical Journal Applied Physics. 2017 Jun 1;78(3):34813.

28. Elbadawi M, Osman Z, Paridah T, Nasroun T, Kantiner W. Properties of particleboards made from acacia seyal var. Seyal using uf–tannin modified adhesives. Cellulose chemistry and technology. 2015 Mar 1;49(3-4):369-74.

29. Hamidu LA, Aroke UO, Osha OA, Muhammad IM. Formulation and Characterization of Adhesive Produced from Polystyrene Waste Using Response Surface Optimization. Traektoriâ Nauki= Path of Science. 2019;5(8):2001-9.

30. Ong HR, Prasad DR, Khan MR, Rao DS, Nitthiyah J, Raman DK. Effect of jatropha seed oil meal and rubber seed oil meal as melamine urea formaldehyde adhesive extender on the bonding strength of plywood. Journal of Applied Sciences. 2012;12(11):1148-53.

Submit your article to AROC JOURNALS
-AROC in Pharmaceutical and Biotechnology
-AROC in Agriculture
-AROC in Bioinformatics
-AROC in Food and Nutrition
-AROC in Natural Product Research
-BIOMED Natural and Applied Science
Via https://arocjournal.com/

Copyright © 2022 Osemeahon et al. This is an open access article distributed under the terms and conditions of the Creative Commons Attribution License (CC BY) which allowed unrestricted download, distribution and reused as long as the original authors are properly cited.