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Development of Adhesive Materials from Polystyrene Foam Waste

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Abstract—Polystyrene is a type of plastic that is difficult to decompose naturally, leading to waste that contributes to environmental pollution. This study developed adhesive materials based on polystyrene waste to reduce environmental impacts while addressing the need for eco-friendly adhesives. The adhesives were prepared by dissolving polystyrene foam waste in gasoline and acetone with various compositions. The solvents with a composition ratio of gasoline and acetone of 100:0; 90:10; 80:20; 70:30; 60:40; and 50:50 were coded as A, B, C, D, E, and F. Tests were carried out to determine the solubility of polystyrene foam in various solvent compositions and the mechanical properties of samples, including shear force, shear strength, and strain (elongation). Paper, cardboard, and wood were used as gluing materials. The adhesive strength was also compared with that of commercial adhesives. The adhesive samples were then characterized using Fourier-Transform Infrared Spectroscopy (FTIR). The shear strength results obtained for samples code A, B, C, D, E, and F were 119.95 kPa, 103.68 kPa, 96.64 kPa, 124.56 kPa, 150.08 kPa, and 157.80 kPa, respectively. The findings showed that the adhesive sample coded F synthesized using a solvent composition of 50: 50 gasoline: acetone exhibited superior adhesive ability than other variations. This sample can potentially serve as a substitute for commercial adhesives that are suitable for bonding various materials.

Keywords—*Adhesive; Environment; Polystyrene foam waste; Recycling and reuse; Shear strength.*

1. INTRODUCTION

Polystyrene is a type of plastic often used in various applications, especially polystyrene foam or Styrofoam, also known as Expanded Polystyrene (EPS). Polystyrene foam is widely used in plastic bags, food and beverage containers, electronic goods packaging, etc. This is due to its flexible, heat-resistant, and opaque properties [1]. However, these properties also make polystyrene foam one of the most challenging plastic wastes to manage, causing significant environmental waste accumulation. Polystyrene foam waste contributes significantly to plastic pollution because it is not easily decomposed naturally. Thus, it seriously impacts terrestrial and aquatic ecosystems [2,3].

The issue of plastic waste cannot be solved effectively through landfilling because safe disposal facilities are scarce, particularly in developing countries. Incinerating plastic waste contributes to the emission of toxic and greenhouse gases that cause climate change and release carcinogens [4]. In addition, it is essential to consider the potential negative impacts of processing polystyrene foam waste and its derivatives, such as styrene. If not properly managed, these substances can harm health and the environment [5].

As awareness of environmental sustainability grows, there is a growing focus in research on developing eco-friendly adhesive manufacturing processes by utilizing plastic waste, including polystyrene foam [6]. Recycled polystyrene foam waste can be managed sustainably to create value-added chemicals and fuels [7]. In addition, waste polystyrene foam beads can be integrated into concrete to produce lightweight materials suitable for various applications, such as low thermal conductivity walls, bridge decks [8-10], lightweight composite materials [11], carbonaceous materials [12], and adhesives [13].

Adhesive materials can be synthesized from polystyrene foam waste using solvents, such as gasoline, acetone, and toluene, to dissolve polystyrene

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foam at room temperature. The adhesiveness was tested using envelope paper. The results show that the adhesive properties are superior in the mixture of toluene and gasoline compared to the other solvents [13]. However, toluene is less eco-friendly than acetone. The glueing process using adhesives from polystyrene foam waste offers several advantages, including strong adhesion properties and a broad range of applications across various industries [14].

The development of adhesives from polystyrene foam waste presents an innovative solution to reduce the amount of polystyrene foam waste while providing useful products for industries. Not only does this approach help overcome waste management issues, but it also lessens dependence on new raw materials derived from natural resources. However, further research is necessary to develop optimal technologies and processes for effectively converting polystyrene foam waste into eco-friendly adhesives.

A thorough literature review on the utilization of waste polystyrene reveals that several studies have focused on developing adhesive/glue materials from waste polystyrene. However, there is a lack of detailed analysis regarding the mechanical properties of adhesives synthesized using gasoline and acetone as solvents in the glueing medium. Additionally, no comparisons have been made between the properties of polystyrene-based adhesives and those of commercial adhesives commonly used in Indonesia. Therefore, this research aims to develop low-cost and eco-friendly adhesives as an alternative to more expensive options, while also providing data on the mechanical properties of various joining materials, such as paper, cardboard, and wood.

2. EXPERIMENTAL SECTION

2.1. Materials

The preparation of adhesive materials from polystyrene foam waste collected from leftover electronic packaging. The other materials used included 80 gsm paper, cardboard, wood strips and Polyvinyl Acetate (Fox Glue), pertalite gasoline from Pertamina, and 99.75% acetone (Mallinckrodt).

2.2. Instrumentation

The equipment employed in this experiment included glassware, an analytical balance (Mettler Toledo), magnetic stirrer (Heidolph), and a Universal Testing Machine (UTM).

2.3. Preparation of Adhesive from Polystyrene Foam Derivative

This study used the solubility method to prepare the adhesive material. Initially, polystyrene foam waste was collected from the landfill, then washed with water to remove dust and dried in the sun. The dried polystyrene foam was cut into small pieces using a knife. The small pieces were gradually added to a beaker glass containing a mixture of gasoline and acetone solvents in various compositions (**Table 1**). The mixture was stirred using a magnetic stirrer at room temperature until the solution reached saturation.

The solution was then put into aluminium foil and folded for further testing. The variations in the composition of gasoline and acetone solvents were given different codes.

Table 1. Composition of gasoline and acetone solvents

Code	Composition	
	Gasoline (gr)	Acetone (g)
A	5.0	0.0
B	4.5	0.5
C	4.0	1.0
D	3.5	1.5
E	3.0	2.0
F	2.5	2.5

2.4. Analysis of Mechanical Properties of the Adhesive Material

Strength tests were carried out using a Universal Testing Machine (UTM) instrument to evaluate adhesive strength. Various materials, such as paper, cardboard, and wood were tested for their adhesiveness. To prepare the specimen for the mechanical properties test, the selected substrate materials were cut into rectangles measuring 10 mm x 70 mm. Two pieces of material were then glued together using an adhesive sample with dimensions of 10 mm x 20 mm at the ends. The specimens were left for 24 h under a load of 3.5 kg to optimize the glueing process. Then the tensile test was carried out by pulling both ends of the specimen at 10 mm/min speed until the glue connection on the specimen. A total of 3 specimen samples were used for each test, and the average results were calculated.

3. RESULT AND DISCUSSION

3.1. Solubility in Various Compositions of Gasoline and Acetone Solvents

The solubility of polystyrene foam in gasoline and acetone was carried out by dissolving the foam in various compositions of these solvents. This approach aims to determine the quantity of waste dissolved in the solvent, providing information for more efficient solvent composition. The following formula was used to calculate the % solubility (**Eq. 1**).

$$\text{Solubility (wt.\%)} = [\text{Polystyrene foam mass} / (\text{Polystyrene foam mass} + \text{Solvent mass})] * 100 \quad (1)$$

The results of the solubility calculation for polystyrene foam are presented in **Table 2**. Notably, code F, used a gasoline and acetone composition of

50:50, achieved the highest solubility results among the different solvent compositions tested.

Table 2. Solubility of polystyrene foam in various solvent compositions

Code	Solubility (wt.%)
A	46.24
B	37.50
C	34.21
D	32.43
E	32.43
F	47.92

3.2. Infrared Spectroscopy Characterization

Functional groups were identified through infrared spectroscopy characterisation to ensure the successful synthesis of the polystyrene adhesive material. The characteristic vibrations of functional groups were examined when subjected to infrared radiation.

The analysis showed that no new transmission bands appeared or disappeared after polystyrene was converted into the adhesive sample. This result implies that the chemical composition of the polystyrene remained unchanged even after being dissolved in gasoline and acetone. The transmission band (**Fig. 1**) at 3044 cm^{-1} corresponded to the aromatic C-H stretching vibration, while the band at 2902 cm^{-1} was associated with the vibration of the CH_2 group [15]. In addition, the transmission bands at 1607, 1490, and 1443 cm^{-1}, were attributed to the aromatic C=C stretching vibrations of the benzene ring, as expected in the polystyrene structure [16]. Intense vibrational modes at lower wavenumbers at 757, and 697 cm^{-1}, showed the out-of-plane bending vibrations of C-H typical for polystyrene [17].

3.3. Tensile Test of Adhesive Material Made from Paper and Cardboard

The strength of materials used as adhesive materials, such as paper and cardboard, was tested using UTM (**Fig. 2**). The force-displacement curves for paper and cardboard materials are presented in **Fig. 3**. The average force required to tear paper and cardboard was 69.9 and 272.7 N, respectively.

3.4. Tensile Test of Various Solvent Variations on Paper Material

The cut paper was glued using adhesive samples with various solvent variations, labeled A, B, C, D, E, and F. Each glue test was applied to one end of a paper piece measuring 10 mm x 20 mm, after which another paper was attached to form a bond (**Fig. 4**).

The test results indicate that failure occurs away from the adhesive joint because the strength of the paper is smaller than that of the adhesive. Consequently, these results do not provide information about the strength of the glue sample because the paper breaks outside the glued area. The measurement results are presented in **Fig. 5**.

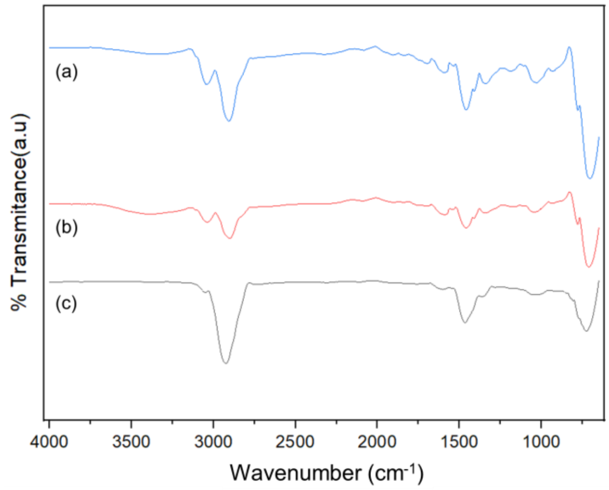

Fig. 1. Infrared spectra of (a) adhesive sample; (b) polystyrene waste; (c) gasoline.

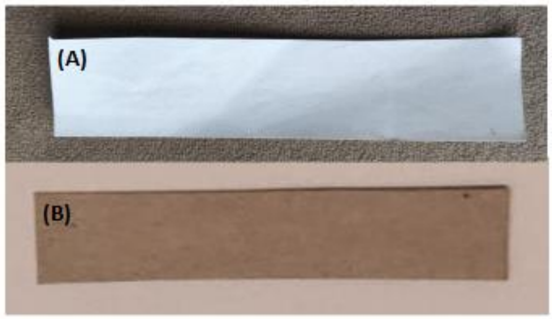

Fig. 2. Specimen for strength analysis of paper (A) and cardboard (B) materials

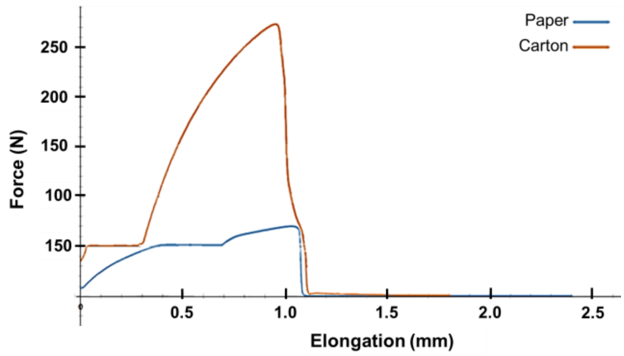

Fig. 3. Force displacement curve on paper-based material

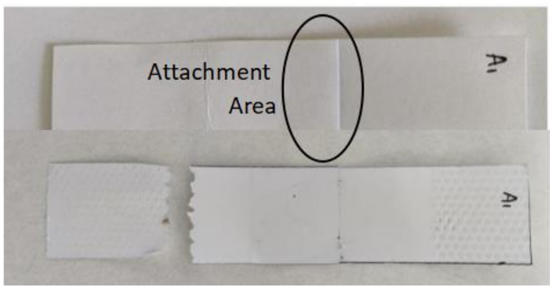

Fig. 4. Paper before (top) and after (bottom) tensile test.

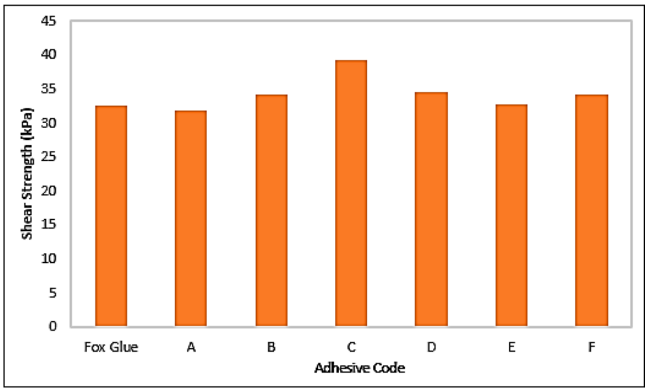

Fig. 5. Shear strength graph of various adhesives with paper material.

3.5. Determination of the Adhesive Strength of Various Solvent Variations on Cardboard Material

Similar to the use of paper materials, various adhesive material samples with solvent variations with codes A, B, C, D, E, and F were also tested on cardboard material. Each glue test was applied to one end of the paper, covering an area of 10 mm x 20 mm. Then, another piece of cardboard was attached to the end to join the two cardboards (**Fig. 6**).

Fig. 6. Cardboard before (top) and after (bottom) tensile test.

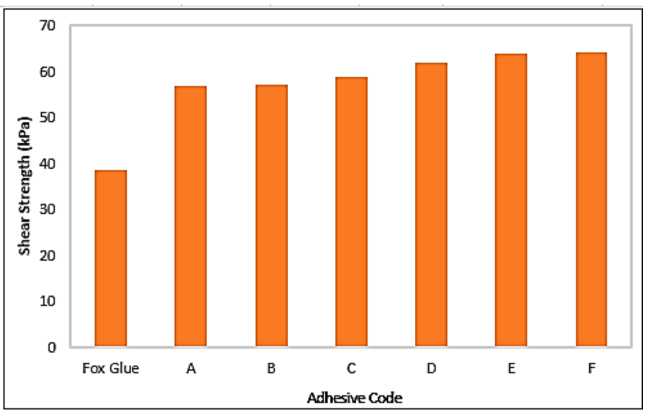

Fig. 7. Shear strength graph of various adhesives with cardboard material.

The test results are shown in **Fig. 7**. The highest value of adhesive shear strength on cardboard was obtained for the adhesive sample code F, which was 64.1 kPa. This value significantly exceeds that of the commercial glue samples, which obtained shear strength values of 38,6 kPa. This indicates that the greater the quantity of dissolved polystyrene, the better the adhesive strength. As shown in **Table 2**, sample code F had the highest solubility (wt.%). Uttaravalli *et al.* have conducted similar research using m-Xylene solvent, resulting in a higher shear strength value of 580 kPa [6].

The measurement results demonstrate that the adhesive samples are effective for joining materials, as indicated by their superior strength value compared to conventional commercial adhesives.

3.6. Determination of the Adhesive Strength of Various Solvent Variations on Wood Material Tensile

After obtaining satisfactory results for adhesive samples on paper and cardboard material, the study continued to evaluate the adhesive strength on wood material. Each glue test was applied to one end of the wooden piece with an area of 10 mm x 20 mm. Then, another piece of wood was attached to the end to join the two pieces (**Fig. 8**).

The test results are shown in **Fig. 9**. The adhesive sample code F achieved the highest adhesive shear strength on cardboard, which was 407.6. kPa. In comparison, previous research using methyl ethyl ketone as a solvent reported a shear strength of 4407 kPa [6], higher than that of sample code F. However, it shows that the F code produces a higher shear strength value than the commercial glue used in this research, which obtained a shear strength of 134 kPa. Similar to the results on paper material, the F code sample also yielded the best results because more polystyrene dissolved will provide better adhesion.

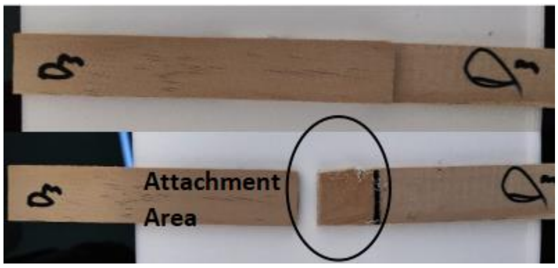

Fig. 8. Wood before (top) and after (bottom) tensile test

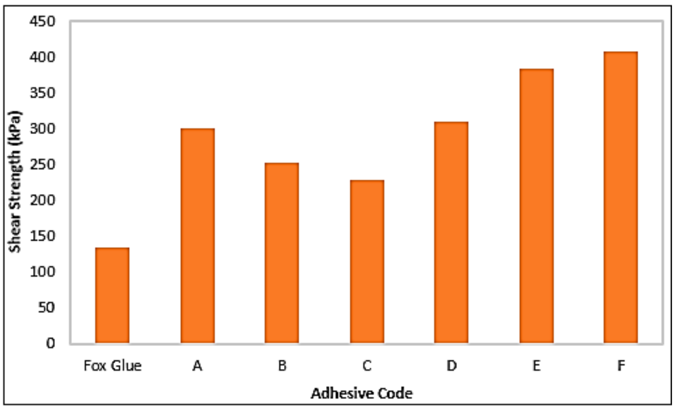

Fig. 9. Shear strength graph of various adhesives with wood material.

The average value of the mechanical properties of the adhesive is shown in **Table 3**. The self-developed adhesive showed superior adhesion performance compared to the commercial glue. As indicated in **Table 3**, the shear strength value of the A-F code adhesive was higher than commercial glue (fox glue). Among the adhesives with various solvent compositions, the highest shear strength value was obtained for the F sample code of 157 kPa.

Table 3. Mechanical properties of various adhesive samples

Sample	**Shear force** (N)	Shear Strength (kPa)	Strain (elongation) (%)	Youngs Modulus (N/mm²)
Fox Glue	116	58	0.96	1956.84
A	239	119	0.96	2778.23
B	207	103	0.79	2970.18
C	193	96	0.89	2925.52
D	249	124	0.92	2653.83
E	300	150	0.93	2935.86
F	315	157	0.95	3121.76

The results indicate that the shear strength of the adhesive sample depends on the interaction of polystyrene foam and the material used for testing the adhesiveness. The more dissolved polystyrene foam, the more adhesive material will be produced, resulting in higher shear strength. This study shows that adhesive F exhibits better adhesion capabilities than commercial adhesives, making it a viable substitute for commercial adhesives.

CONCLUSION

This study developed a cost-effective adhesive material from polystyrene foam waste, transforming this waste into a value-added product. The adhesive material was prepared by dissolving polystyrene foam waste in a mixture of gasoline and acetone solvents with various compositions. The solubility of the adhesive depended on the physicochemical interactions between the polystyrene foam and the selected solvent compositions. The optimal ratio of gasoline and acetone solvents, specifically 50:50 in the F code sample, yielded the highest solubility for the polystyrene foam. Variations in adhesive materials, such as paper, cardboard, and wood, were used to investigate the suitability of the self-developed adhesive for joining these materials. The results indicated that the F code sample provided the highest adhesive strength compared to the other samples, demonstrating its potential as a substitute for commercial adhesives.

SUPPORTING INFORMATION

There is no supporting information for this paper. The data that support the findings of this research are available upon request from the corresponding author (A.N. Roziafanto).

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CONFLICT OF INTEREST

The authors have no conflict of interest in this publication.

AUTHOR CONTRIBUTIONS

ADM, AAW, MFK, PA, SM, and YRP conducted the experiments. ANR wrote and revised the manuscript. All authors agreed to the final version of this manuscript.

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