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The Study of Recycled Low-Density Polyethylene Reinforced Polyurethane Foam for Vehicle Interior Roof Headliner

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Abstract: This study explores the characteristics of Low-Density Polyethylene (LDPE) reinforced Polyurethane foam (PU) for vehicle interior roof headliners, as Polyethylene (PE) has limited suitability in the automotive industry due to its inadequate modulus and temperature resistance. This research seeks to develop environmental friendly composite materials by exploring different composition ratios of LDPE reinforced PU namely 5, 10, 15, and 20 (wt/wt%), utilizing abundant waste resources like LDPE in Malaysia, with a specific focus on their suitability for vehicle interior roof headliners. Polyurethane (PU) foam was formed by mixing of polyol and isocyanates, while recycled low-density polyethylene (LDPE) was incorporated at varying ratios to create LDPE reinforced PU. The mechanical properties of the LDPE reinforced PU were assessed through Tensile tests (ASTM D638) and Impact tests (ASTM D256), and physical properties were examined using Density and Porosity tests (ASTM D792), Thermal analysis simulation, and Optical microscopic (OM) tests (ASTM F410). The sample with a ratio of 10 (wt/wt%) demonstrated the highest density (10 g/cm^3), maximum porosity (0.34%), highest tensile strength (3.68 N/m^2), increment of temperature of 24.9 degree in thermal analysis, and consistent foam structure and cellular form with increasing proportion of plastic waste particles. From the findings, the findings indicate that the sample with a 10 (wt/wt%) ratio displayed the best properties. Moreover, the thermal analysis demonstrated a temperature increase, and the optical microscopic analysis confirmed a consistent foam structure with an increase in the plastic waste particle ratio. These results suggest the promising potential of LDPE reinforced PU foam as a suitable material for automotive applications.

Keywords: Low-Density Polyethylene, Polyurethane, Vehicle Car Headliner.

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1. Introduction

Plastics are lightweight and cheap, making them a very desirable alternative for automotive manufacturers today. As consumers become more concerned about fuel efficiency, every weight reduction may immediately translate into an increase in sales. Furthermore, plastics are corrosion-resistant, long-lasting, malleable, and provide more design flexibility than metals such as PE, PU and many more [1]. Automobile components, as well as interior and exterior furnishings, extensively utilize plastics. Plastics have a wide range of applications in automobiles, spanning from power trains to under-the-hood components and chassis parts, so they must be made of robust, dependable, and typically high corrosion- and heat-resistant polymers. Automotive manufacturers must also comply to a continued of industry regulations, and the materials they choose for production must go through a material quality check to guarantee they are both durable and compliant [2].

Recycled LDPE demonstrates moderate mechanical characteristics that can be influenced by product aging, making it less appealing for particular applications. Thus, to explore alternative uses for recycled LDPE, enhancements in its low mechanical properties can be achieved by incorporating additional materials. In practice, combining recycled LDPE with virgin polymers has proven to be a successful approach for enhancing its mechanical properties, offering an effective means of reutilizing recycled LDPE [3].

1.1 Problem Statement

Malaysia's population is rapidly growing, reaching 32.6 million in 2019. As a result, a massive amount of solid waste has been produced, estimated at 38,200 tonnes per day (1.12 kg/cap/day) in 2018, enough to fill the Twin Towers every seven days. The remaining 82.5% is disposed of in landfills. Landfills, if not managed appropriately, can have a negative impact on the environment, humanity, and the aquatic world. The majority of Malaysia's landfills lack suitable infrastructure [4].

Due to this problem, plastics have been widely utilised in car claddings to enhance fuel economy by making vehicles lighter and minimising corrosion on metal surfaces caused by salt and water. Although plastics have been used both externally and inside for decades, many vehicle manufacturers have recently turned to producing bioplastics and polymers rather of depending on fossil-based plastics in order to reduce their carbon footprint and promote sustainability [4].

2. Materials and Methods

Processing recycled low-density polyethylene (LDPE) plastic waste into LDPE-PU foam with different composition ratios. The LDPE-PU foam samples underwent mechanical and physical testing, including density and porosity (ASTM D792), optical microscopic analysis (ASTM F410), thermal analysis using Ansys production software, and tensile test (ASTM D638) and impact tests (ASTM D256).

2.1 Material

The critical step in the process is the preparation of raw materials for vehicle interior roof headliner, which involves combining LDPE plastic waste with a PU solution consisting of composite PU samples containing isocyanate and polyol forms. The ratios of polyurethane (PU), hardener, and recycled low-density polyethylene (LDPE) plastic waste used were 1:1:5, 1:1:10, 1:1:15, and 1:1:20. The material used in current study including:

- Polyol.
- Isocyanates.
- Recycled Low-Density Polyethylene.

2.2 Method

The activities and plans were successfully executed according to the methodology, ensuring a smooth process without any notable errors, particularly during the preparation of samples and procedures. The flowchart methodology of the study, depicting the entire research process from start to finish, is illustrated in Figure 2.1.

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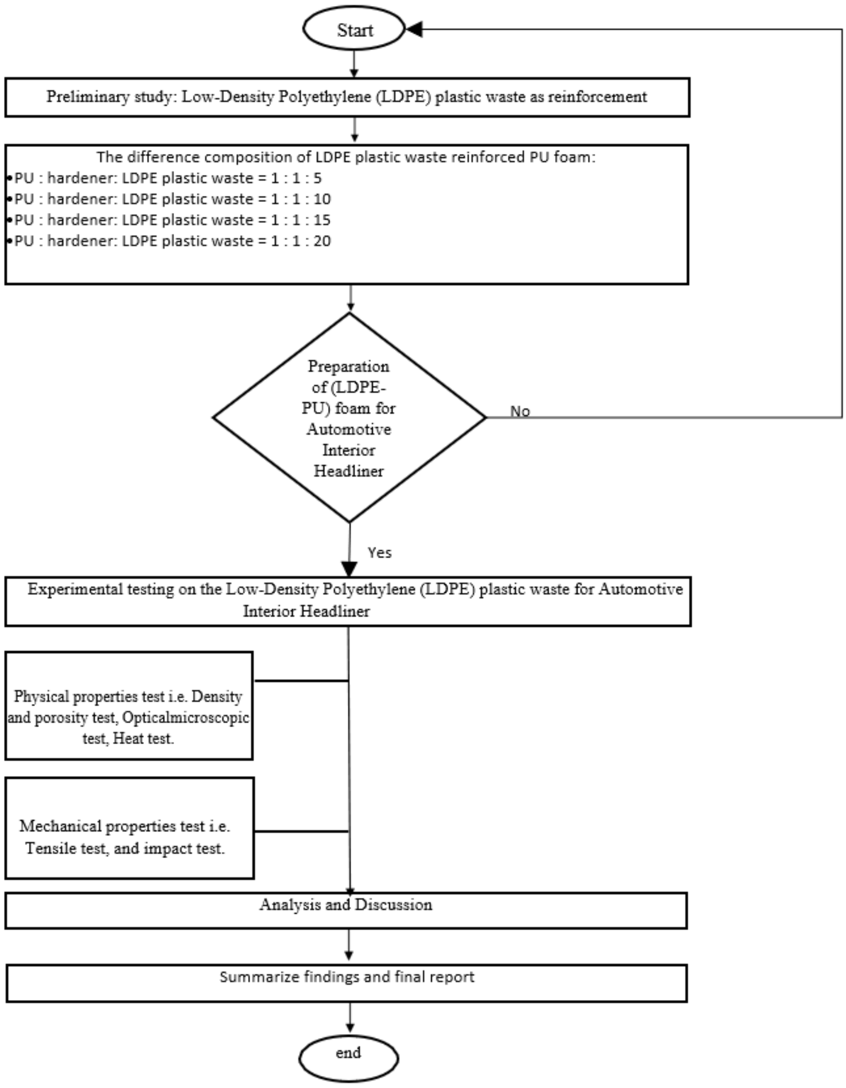

Figure 2.1: Methodology flowchart

3. Results and Discussion

The physical and mechanical properties of LDPE reinforced PU polymer composites for vehicle interior headliners were evaluated through five different tests: density and porosity test, optical microscopic test, heat resistance test, tensile strength test, and impact test. The heat transfer test was carried out using Ansys Fluent software. Various samples with different ratios of recycled LDPE plastic waste reinforced PU (LDPE-PU) foam were prepared for the experiments. The results were analyzed using graphical and tabulated methods and compared to the performance requirements of car roof headliner applications.

3.1 Density and Porosity Testing

The density test result was shown in Figure 3.1. The density of the sample with the ratio 10 (wt/wt%) is the highest which is 0.55 g/cm^3, while the density of the sample with the ratio 20 (wt/wt%) is the lowest which is 0.457 g/cm^3. The densities of the samples with ratios of 5 (wt/wt%) and 15 (wt/wt%) are 0.487 g/cm^3 and 0.499 g/cm^3, respectively. Hence, LDPE reinforced PU with ratio 10 (wt/wt%) is the best in comparison of density between all four sample tested.

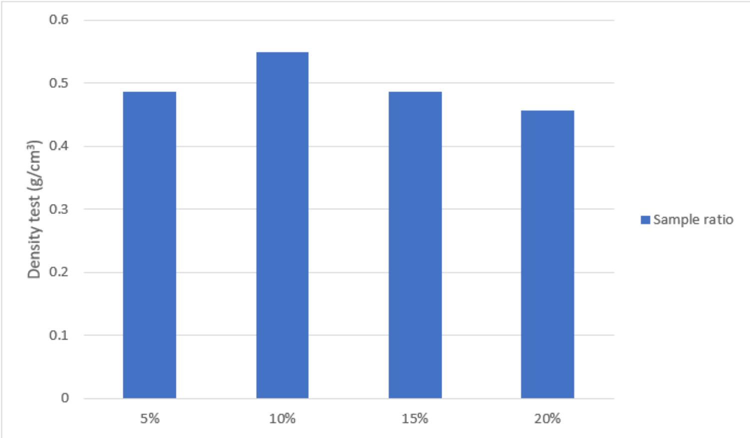

Figure 3.1: Result for density testing.

According to the graph in Figure 3.2, the sample with the ratio 10 (wt/wt%) has the maximum porosity 0.34%, while the sample with the ratio 5 (wt/wt%) has the lowest average porosity with 0.2%. The porosity of a sample with a ratio of 20 (wt/wt%) is 0.12%, while the porosity of a sample with a ratio of 15 (wt/wt%) is 0.22% of the average porosity. According to the observations, the sample with the ratio 10 (wt/wt%) had the highest average porosity, indicating that the sample with the ratio 10 (wt/wt%) was the best ratio of (LDPE-PU) foam as samples.

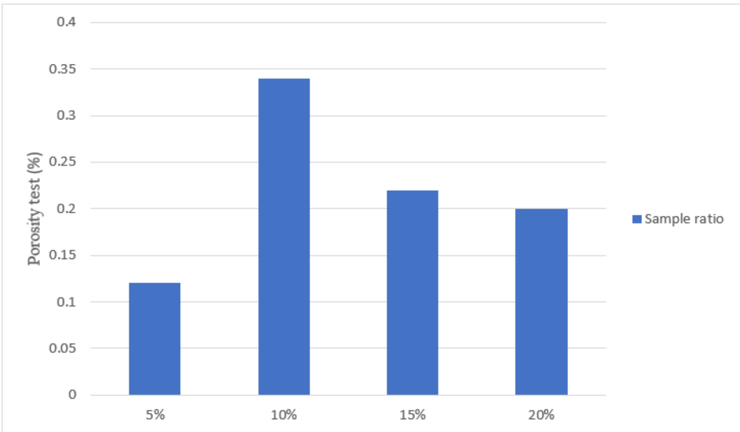

Figure 3.2: Result for porosity testing.

3.2 Optical Microscopic test

Figure 3.3 shows the results of the microscopic analysis performed with an optical microscopic equipment. In this investigation, four LDPE plastic waste reinforced polyurethane foam samples with varied ratios of 5, 10, 15, and 20 (wt/wt%) of the various LDPE plastic waste combinations were used. The structure and cellular form of the foams stay constant as the consistency of the plastic waste particle ratios increases. For microanalysis, optical microscopic (OM) techniques can be utilised, and the instrument can be equipped with both energy-dispersive and wave length dispersive spectrometers.

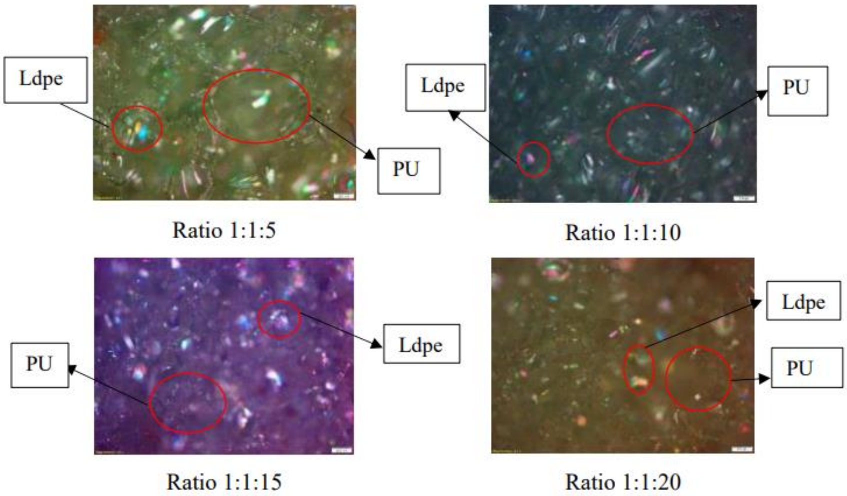

Figure 3.3: Result of optical microscopic test

3.1.3 Thermal Analysis

Based on Figure 3.4 shows the result of (LDPE -PU) foam with comparison to other material which is foam-backed, and foam-PU. From the result, foam backed reach 27.5° C from room temperature and both PU foam and LDPE reinforced PU foam with ratio of 10 (wt/wt%) increase to 24.9° C from room temperature. According to the result, foam-backed temperature was increasing 3.5° C from room temperature while PU foam and LDPE reinforced PU foam increase 0.9° C from room temperature.

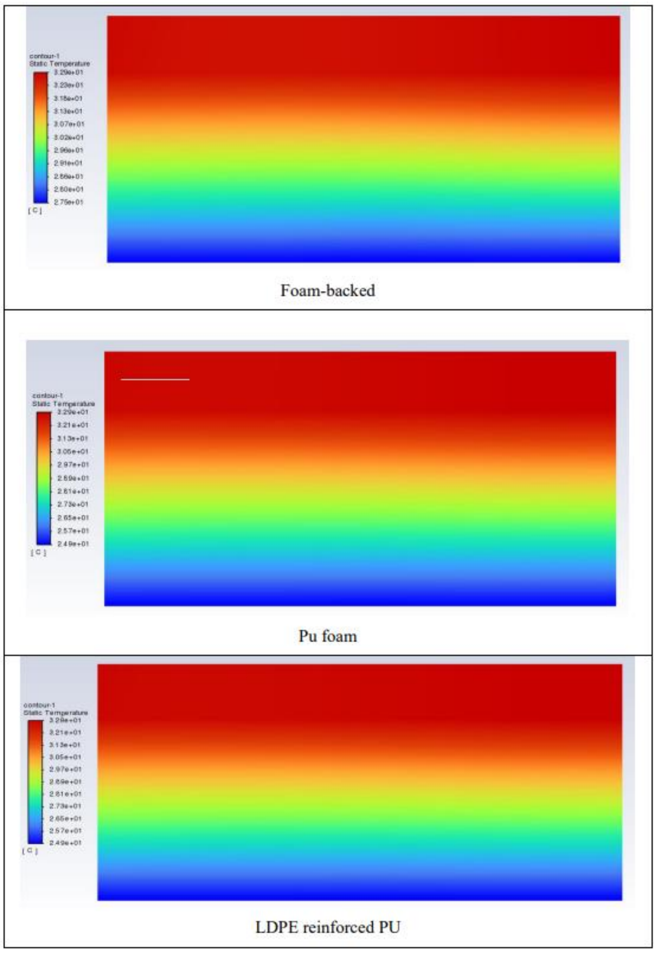

Figure 3.4: Result for Thermal analysis

Figure 3.5 illustrates the temperature increase when applying external heat of 35°C to LDPE-Pu foam-baked and PU materials. Both LDPE-PU and PU demonstrate a temperature increment of 0.9°C. This similarity indicates that LDPE-PU possesses comparable properties to PU, making it an effective heat insulator. In contrast, the conventional foam-baked materials used in roof headliners in the market do not offer the same level of heat insulation**.**

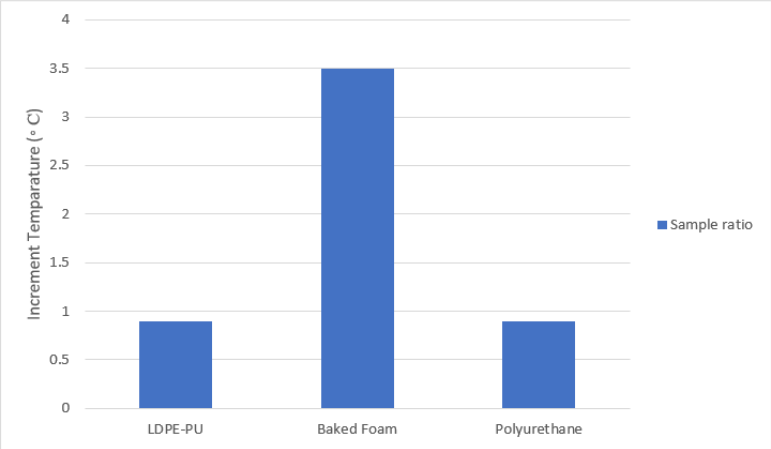

Figure 3.5: Different in temperature changes

3.1.4 Tensile Test

According to the data presented in Figure 3.6, sample with ratio 10 (wt/wt%) exhibited the highest tensile strength at 3.68 N/m^2, while sample with ratio 20 (wt/wt%) displayed the lowest at 1.98 N/m^2. Sample with ratio 5 (wt/wt%) had a tensile strength of 3.46 N/m^2, and sample 15 (wt/wt%) recorded 2.05 N/m^2. It was observed that sample with ratio 10 (wt/wt%) of (LDPE-PU) foam, had the most favorable performance among the samples.

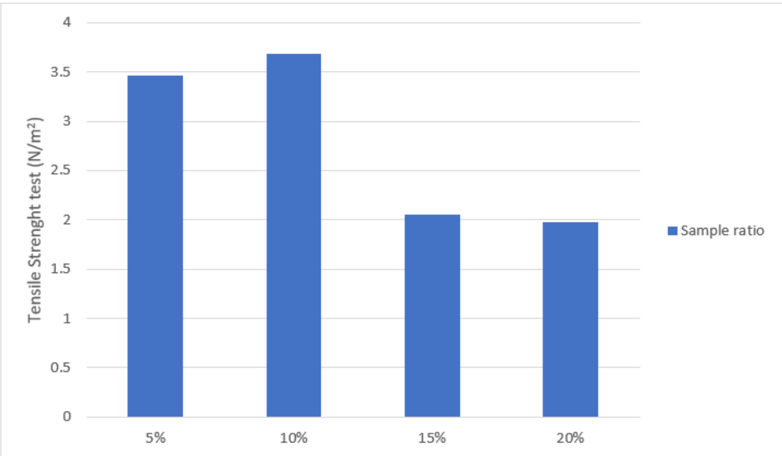

Figure 3.6: Result for tensile strength

Young's modulus, also known as the modulus of elasticity, measures a material's ability to withstand changes in length under tension or compression. It is determined by dividing the longitudinal stress by the strain. According to the graph presented in Figure 3.7, sample with ratio 10 (wt/wt%) exhibited the highest Young's modulus pressure at 62.95 MPa, while sample with ratio 20 (wt/wt%) displayed the lowest at 30.19 MPa. Sample with ratio 5 (wt/wt%) recorded a Young's modulus pressure of 61.23 MPa, and sample with ratio 15 (wt/wt%) showed 35.75 MPa. The graph indicated that sample with ratio 10 (wt/wt%) had the most favorable ratio among the samples and was characterized as very strong. This means that it could withstand significant stress without stretching much and would break abruptly.

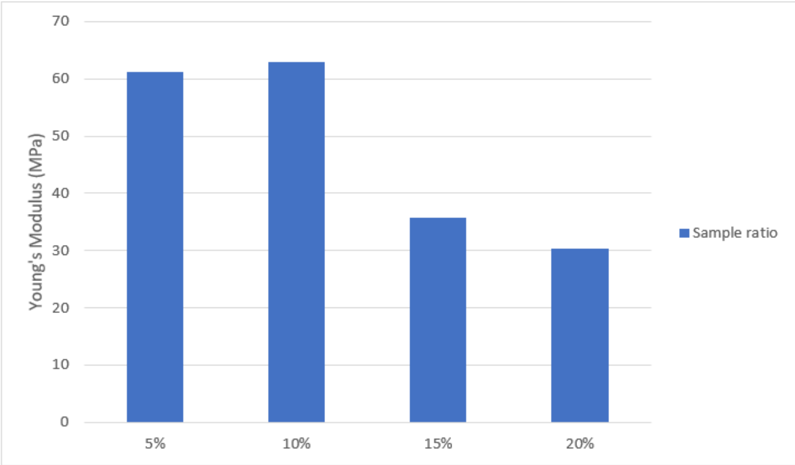

Figure 3.7: Result for Young's Modulus

3.1.5 Impact test

Figure 3.8 presented the different ratios of (LDPE-PU) foam. Among the samples, sample with ratio 10 (wt/wt%) exhibited the highest impact strength at 1.035 kJ/m^2, while sample with ratio 20 (wt/wt%) displayed the lowest impact strength at 1.000 kJ/m^2. Sample with ratio 5 (wt/wt%) recorded an impact strength of 1.023 kJ/m^2, and sample with ratio 15 (wt/wt%) showed 1.012 kJ/m^2. Through analysis, it was determined that sample with ratio 10 (wt/wt%) of (LDPE-PU) foam, demonstrated the highest strength and could withstand a maximum impact strength of 1.035 kJ/m^2.

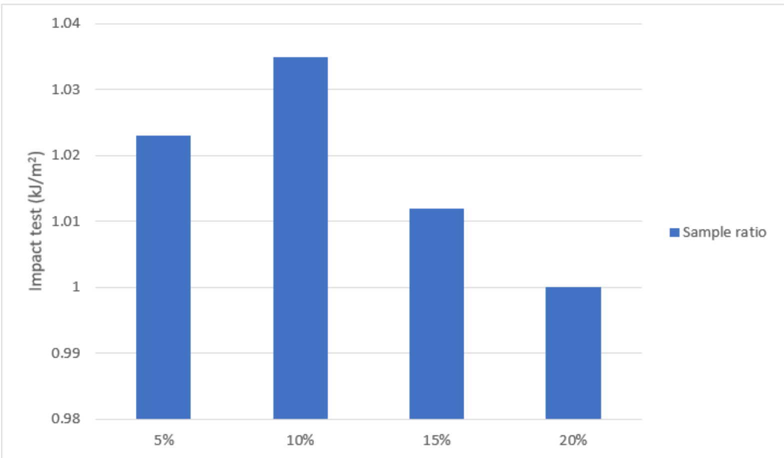

Figure 3.8: Result for impact test

3.2 Discussion

The analysis clearly indicates that a sample with a ratio of 10 (wt/wt%) of (LDPE-PU) foam exhibited the optimal performance. Sample with a ratio of 10 (wt/wt%) demonstrated the highest density at 0.55 g/cm3 and a low average porosity of 0.34%. It displayed a strong structure capable of withstanding a maximum impact strength of 1.035 kJ/m2 . Furthermore, sample with the ratio of 10 (wt/wt%), exhibited the highest tensile strength at 3.68 N/m2 , indicating its ability to endure significant stress without substantial elongation before sudden failure. Also the sample with ratio 10 (wt/wt%) has the same thermal insulation as PU with increment of 0.9°C which prove that Adding LDPE on PU can be a great insulation. However, the mechanical and physical properties declined for samples with ratios of 15 and 20 (wt/wt%), possibly due to defects in the curing phase or the unsuitability of the ratios for the mixture. The inclusion of different plastic waste into the polyurethane foam has a direct influence on the mechanical characteristics of the samples within the given region.

4. Conclusion

The optimal composition of recycled Low-Density Polyethylene reinforced Polyurethane (LDPE-PU) foam, specifically at a ratio of 10 (wt/wt%), potentially can be applied for automotive roof headliner application. Comprehensive physical and mechanical tests were conducted and evaluated using varying ratios of recycled LDPE plastic waste specifically for automotive roof headliner application. The results and analysis unequivocally demonstrated that the recommended ratio is the most effective for producing automotive roof headliner application as adding shredded LDPE plastic in PU foam not only reduce the cost of raw material usage for fabricating interior roof headliner, also maintain the properties mechanically and physically to without sacrificing much attribute to make it relevant in automotive industrial use.

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