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The Characterization of HDPE Plastic Waste Producing Polyurethane Foams (PUFs)

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ABSTRACT

This project research paper comprises an experimental study on the characterization of High Density Poly Ethylene (HDPE) plastic waste producing polyurethane foams (PUFs) for wall partition application. The research is to determine the optimum composition ratio of HDPE plastic waste mixed with polyurethane foams by incorporating various quantities of HDPE plastic waste into the matrix. The samples in this study had been prepared with HDPE plastic waste mixed with polyol and diphenylmethanediisocyanate (MDI) as PUFs component in the process of mixing and curing. The mechanical and physical properties of wall partition sample were studied through the testing of four samples at different ratios of plastic waste to polyurethane foam components, (2:1:1, 3:1:1, 4:1:1, and 5:1:1). Effects of different ratios of HDPE plastic waste to PUFs on tensile strength, bending strength and sound absorption have been investigated. Experimental result exhibited that the tensile strength and bending strength increases with increasing composition ratio, with a maximum value at 0.26MPa and 0.23MPa respectively. The sound absorption coefficient (SAC) of the matrix was measured using an impedance tube. The peak of sample 4:1:1 achieved the greatest value of SAC between 1-1.5 kHz. The samples were also tested under optical microscopy revealing in white and uniform morphology and cellular shape with an increasing composition ratio of plastic waste to PUFs. The experimental result shows that sample 4:1:1 obtained the highest value of density and porosity percentage at 0.0567 g/cm^3 and 1.71% correspondingly. All findings suggested the composition ratio of 4:1:1 is the optimum ratio of HDPE plastic waste to PUFs to be applied for wall partition application.

Key words: Plastic waste, polystyrene, compressive strength, sound absorption, porosity

1. INTRODUCTION

In the past 65 years, plastics production growth has substantially overtaken any other manufactured material [1]. High-density polyethene (HDPE) plastic-type is the third-largest plastic found in municipal solid waste which contributes to the various application about 17.6% in plastic waste classes [2], [3].The researcher has studied various application on the utilization of plastic waste in order to help in reducing plastic waste landfill and also helps in the sustainability of the environment. According to [4], HDPE plastic has a higher strength to density ratio compared to other polyethene due to the long primary and shorter secondary chains.

For a century, the polymer has been the most popular material for the application of sound absorption and reduction of noise [5]. They were also a class of lightweight porous materials with the greatest interest because of their precise properties and potential application in various fields [6]. Polyurethane can be solid or can have an open cellular structure, in which case it is called foam. Polyurethane foams are the most commonly used in industry for their mechanical, electrical, thermal and acoustic properties [7]. Significant to the development of innovation for each technology, polyurethane has evolved into many different functional include wall partition application.

Studies confirm the possibility to reinforce polymer foams with waste materials to enhance their mechanical, thermal and acoustic properties [8]. In this research, HPDE plastic waste mixed with polyurethane foam will use for wall application had utilized including for sound absorption properties which then enhanced to improve mechanical properties of the material and its durability.

2. LITERATURE REVIEW

Generally, plastic is known by their chemical structure that is called polymer's backbone and side-chain which can be grouped into two types of plastic which are thermoplastic and thermosetting polymers [9]. In recent innovation of technology and demand for utilizing more eco-friendly and sustainable construction works allowed an idea of disposing post-consumer plastics waste into wall application [4]. Plastics are man-made materials synthesize from polymers, or long chains of repeating molecules [10]. Plastic is one of the resources that improved its binding properties when softened [9]. Plastic materials are the most common and essential materials in the recent century and modern life [11]that covering a widespread of application in daily life [12]. It is a widely used man-made material in the world through their specific characteristics [11]. Their characteristics include durable and corrosion-resistant, good insulation for cold, heat and sound, saving energy, economical, has a longer life, and most importantly it is light in weight.

In the developing era of plastic industry, many challenges must be faced in order to recovery and recycling of plastic for waste reduction and resource utilization [13]. Waste material from plastics gives out hazardous pollution in our environment and they are very harmful to living-beings if they are not managed in proper disposal. The increase in the amount of waste does affect some environmental harms [14]since polymer require hundreds of years to degrade in normal environmental circumstances [15].

Therefore, to reduce the possibilities of harmful problem occur from plastic wastes, proper disposal needs to be done. Commonly, several methods such as landfills, incineration, and the reuse and recycling of plastic wastes were used as the disposal of wastes for plastic waste. A huge part of the plastic waste is disposed of in landfills or is incinerated [14]. It is essential for further sustainable solutions that incineration and disposal in landfills are researched and developed. Thus, much research in the area of recycling and reuse of these post-consumed polymers have been conceded out in order to produce raw materials and energy [14].

Management of waste is a difficult process because of the requirement of various evidence from different sources such as influencing elements in waste generation, forecasts of vast quantities and reliable data [15]. The process of Plastic Waste Management (PWM) has been developed in order to manage the waste material of plastic in proper disposal. Plastic Waste Management process contains all the activities and actions required to manage plastic waste from its inception to its final disposal' includes all the activities such as collection, transport, treatment and disposal of plastic waste together with monitoring and regulation. One of the main purposes in waste management is the recycling of waste and thereby making use of properties contained in waste to save primary resources and lessen the environmental impact of all events involved in making primary resources accessible for the production of goods.

Further, the recycling of virgin plastic material can be completed 2 to 3 times only, because, after every recycling, the strong point of the plastic material is reduced due to thermal degradation [15]. Plastic recycling remains steadily low in Europe, compared to other recyclable materials such as paper and metals. In 2016, the recycling rate was just terminated 30%, when approximately 8.4 million tons of plastic waste was recycled [12], [16]. The reuse and recycling of plastic wastes are widely progressed which is the practice of recovering used materials from the waste stream and then incorporating those same materials into the manufacturing processes [17].

3. METHODOLOGY

3.1 Preparation of material

HDPE plastic waste is used to improve the mechanical properties of polyurethane foam. They were collected from used detergent container at KolejKediamanPagoh, UTHM. HDPE has the greatest strength to density ratio than other polyethylene due to longer primary and shorter secondary chains. Figure 1 shows the process flow of HDPE powder preparation. Firstly, the HDPE bottle of plastic waste was cut into smaller size in the range of 5 to 20 mm. Next, the pieces of plastic bottle waste were cleaning in order to eliminate any unwanted element on plastic waste. Then, the pieces of HDPE plastic bottle waste were grinding by using a grind machine to transform the pieces of plastic waste into powder or particle size.

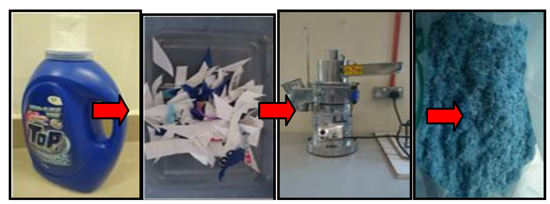

Figure 1: Process Flow of HDPE plastic powder preparation

Figure 2 shows the raw material used for sample preparation. Figure 2 (a) shows grinded HDPE plastic waste in powder. Then the matrix of composition materials used in this experiment is bi-component rigid polyurethane foam. The two main components for the formation of polyurethane foam are Polyol and DiphenylmethaneDiisocyanate (MDI) as shown in Figure 2 (b) and Figure 2 (c) respectively. Both components were obtained from Zheegen Enterprise Sdn. Bhd. The polyol chemical of the foam mixture consists of ingredient such as catalyst, stabilizer, blowing and curing agents. The ratio of mixing for these chemicals is 1:1 by weight. The composite material of polyurethane foams has a cellular structure with closed pores. By utilizing plastic waste into the polyurethane foam matrix, the study aimed to improve the mechanical properties.

Figure 2: Raw materials (a) Grinded plastic waste, (b) Polyol, and (c) Diphenylmethanediisocyanate (MDI)

3.2Preparation of samples

Figure 3 (a) shows the sample of composite material polyurethane foams were prepared by mixing the HDPE plastic waste powder with a polyurethane formulation which are isocyanate and forms of polyol. The polyurethane foam sample was prepared by mixing the polyol and isocyanate at a 1:1 ratio at room temperature of 24˚C. Then polyurethane foams were constructed by different ratios of HDPE plastic waste. The ratios of plastic waste in gram (g), polyol in milliliter (ml), and Diphenylmethanediisocyanate MDI in milliliter (ml) were tabulated as shown in Table 1. The ratio of plastic waste to polyurethane foams varied at 2:1:1, 3:1:1, 4:1:1, and 5:1:1. Figure 3 (b) shows the mixture of plastic waste powder and polyol was added with Diphenylmethanediisocyanate MDI in each composition ratios for hardening the matrix samples. The mixture was stirred manually using a glass rod into a mould. The stirring process takes about 2 minutes in order to obtain a homogeneous composition as shown in Figure 3 (c). The samples were then left for one-hour curing process under the atmospheric condition by the moisture in the air as shown in Figure 3(d). Figure 3 (e) shows the complete mixture of plastic waste with polyurethane formed in 5 cm thickness.

Table 1: Different ratios of plastic waste in mixture of polyurethane foams

Sample	Ratio	Plastic waste weight (g)	Polyol volume (ml)	MDI Volume (ml)
1	2:1:1	4	20	20
2	3:1:1	6	20	20
3	4:1:1	8	20	20
4	5:1:1	10	20	20

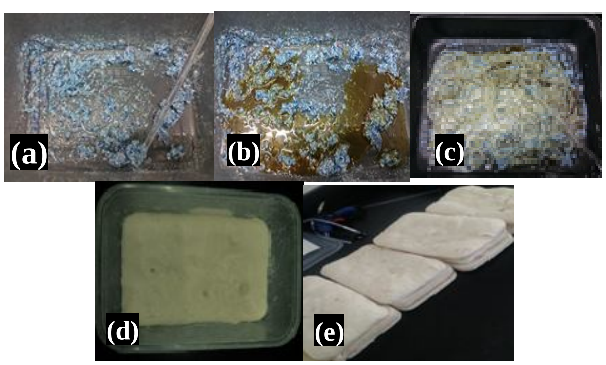

Figure 3: Process of preparing wall partition sample (a) Mix plastic waste powder with Polyol to form a foam, (b) Mixture with added MDI polyurethane for hardening, (c) 1-hour curing, (d) Complete mixture of plastic waste with polyurethane.

Figure 4 shows four samples of polyurethane foam mixed plastic waste with different ratio has labelled.These samples have been cut to sample size for preparing the tensile strength (ASTM D1623), bending (ASTM C293), sound absorption (100mm of the circumference and 30mm of thickness), optical microscopy (50mm x 50mm x 10mm), density and porosity test (ASTM C20-00).

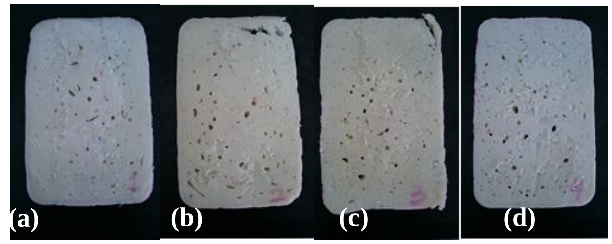

Figure 4: Four samples of polyurethane foam at different ratio; (a) 2:1:1, (b) 3:1:1, (c) 4:1:1, and (d) 5:1:1

4. RESULTS AND DISCUSSIONS

4.1 Tensile strength

Figure 5 shows the graph force versus time for the different ratio of plastic waste in the matrix of polyurethane foam mixture. The graph exhibited that in ratio 5:1:1, the mixture able to withstand the maxi-mum force value of 137.29N, followed by ratio 2:1:1, mixture with the force value of 135.33N, next ratio 4:1:1 with the force value of 113.76N and lastly ratio 3:1:1 can only hold up to the force value of 96.11. However, even though the ratio of 2:1: of the mixture can withstand higher force value than the ratios 3:1:1 and 4:1:1, the duration to withstand the load was only for a short time to compare with the others ratios.

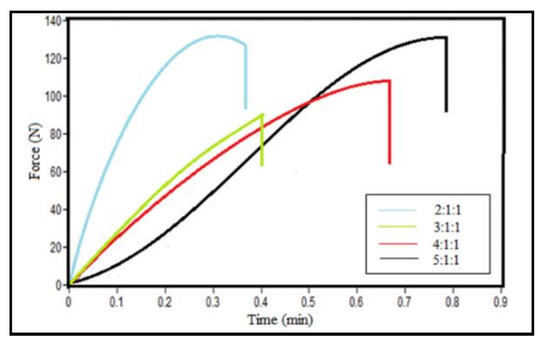

Figure 5: Force versus time at different ratio of plastic waste

Figure 6 shown the tensile strength result of the samples. It is shown that at ratio 5:1:1 withstand the highest tensile strength value of 0.26MPa, followed by ratio 4:1:1 with the tensile strength value of 0.22MPa, then ratio 2:1:1 with the tensile strength value of 0.15MPa, and lastly, ratio 3:1:1 which can hold up to the tensile strength value of 0.11MPa.

Plastic waste particle in the matrix were an excellent at reinforcing the strength of the polyurethane forms [18]. The mechanical behaviour of polyurethane described that the modification of polyurethane foams with plastic waste improved tensile strength thus, by incorporating HDPE plastic waste, they provided more cross-linking reaction between the hydroxyl (OH) groups of the polyol with MDI to give higher cross-linked density, hence improved the mechanical properties of the polyurethane [19].

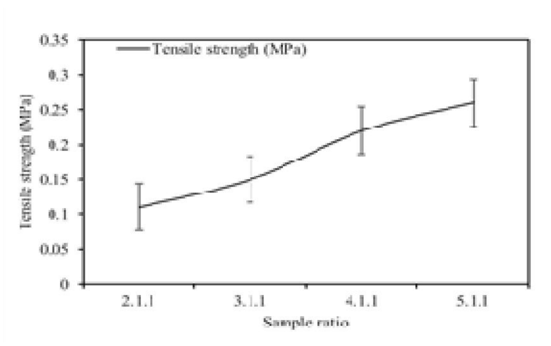

Figure 6: Tensile strength at different ratio of plastic waste

4.2Bending strength

Figure 7 shows the bending strength of the samples increases as ratio of the matrix increases. The bending strength of sample of ratio 5:1:1 has withstand the maximum value of bending strength of 0.23 MPa, hence the lowest bending strength is 0.05 MPa which is on the matrix ratio 2:1:1. The value of bending strength on the sample increases as the ratio of plastic waste particles in the mixture increases. It can be said that, the mechanical strength of the sample increases as the amount of plastic waste increases in the mixture of polyurethane foam.

According the results, the bending loads are carried by face sheet and transported through core when the polyurethane foams in a matrix structure [19]. Thus, the bonding quality between skin-core and the strength of core are critical structures to convey the load. Furthermore, the effect of PUF density on bending strength, reveals that as the density of the PUFs increased the bend-ing strength also improved [20]. Therefore, it shows that the lower amount plastic waste in polyurethane foams undergo severe bending before the fracture however, the higher amount of plastic waste in polyurethane foams suffered with cell shear and cell wall crushing before the complete rupture.

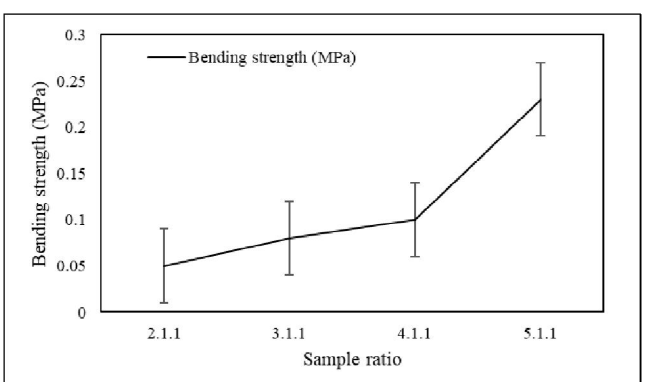

Figure 7: Bending strength at different ratio of plastic waste

4.3Sound absorption coefficient

Figure 8 shows the result of sound absorption on the samples modified with different ratio of plastic waste in the polyurethane foam that had been tested by the impedance tube machine. The graph reported that more amount of filler of plastic waste particle in the polyurethane foams, the higher the sound absorption coefficient by the polyurethane foam can be enhanced. The peak of sample ratio 4:1:1 achieved the highest value of sound absorption coefficient between 1-1.2 kHz frequency. However, sample ratio 5:1:1 at 1.3 kHz frequency until higher frequency ranges sound absorption has progress higher than other samples. Sample ratio 3:1:1 at peak between 1-1.5 kHz frequency has lower sound absorption coefficient than sample ratio 4:1:1. Lastly, sample ratio 2:1:1 at the lowest sound absorption coefficient than other samples.

Density of PU foam was increased by the incorporation of plastic waste particles, the level of sound damping can be enriched more [21]. From the sound absorption coefficient result the value of the SAC increases when the of plastic waste ratio increase [8]. The increases particle of plastic waste in the ratio that influence the increases of SAC.

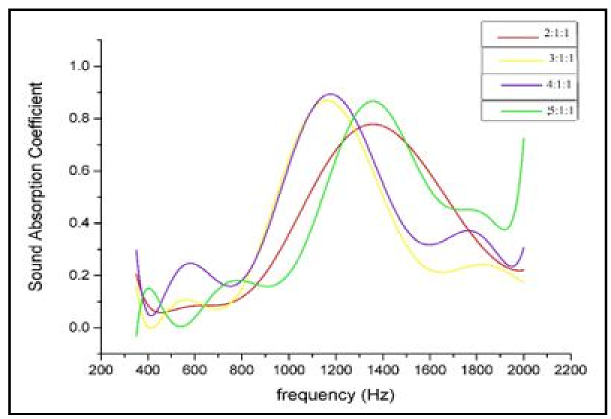

Figure 8: Sound absorption at different ratio of plastic waste

4.4Microstructure analysis

The appearance and microstructure of polyurethane foam mixed plastic waste particles are shown in Figure 9. All the sample foam was visible in white and uniform, without any visible difference due to the additional of plastic particles. The morphology and cellular shape of the foams with the increasing of plastic waste particle ratios content remain the same as one another. From the visual, it can be seen that the cells are mostly in closed cells and are in spherical shapes. It may seem that some of the cell image are brighter than the others because of the folded cell edge.

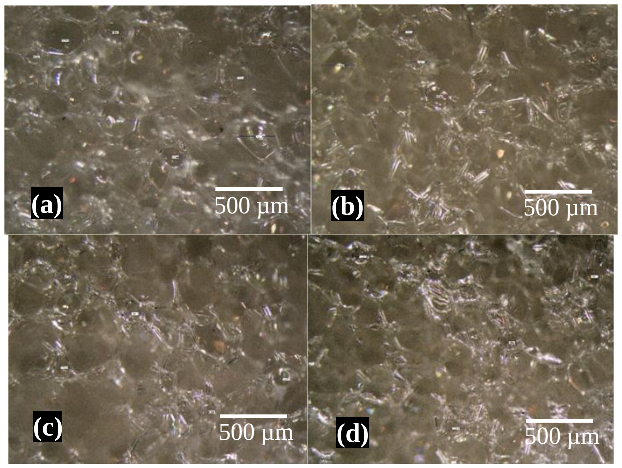

Figure 9: Microstructure image of polyurethane foam at different ratio of plastic waste particles (a) 2:1:1, (b) 3:1:1, (c) 4:1:1, and (d) 5:1:1

4.5Density and porosity test

Figure 10 showed the density result of the samples at different ratios of plastic waste particles in polyurethane foam. The result showed the density of the sample increases as the ratio of the plastic waste particle increases in the matrix. The lowest density indicated to the sample of ratio of 2:1:1 with 0.0423 g/cm^3. Followed by the second lowest is the sample of ratio 3:1:1 with density of 0.0467 g/cm^3. Sample with ratio of 4:1:1 has the highest density value with 0.0567 g/cm^3 and subsequently by sample of ratio 5:1:1 with density value of 0.0560 g/cm^3. From the result, it be observed that the amount of plastic waste particle in the polyurethane foam influence the density value of the matrix.

The increased cell density polyurethane foams resulted in matrix weight loss for the foamed samples [22]. Meanwhile, the added plastic waste caused incremental weight gain for the foams because the mass density of plastic waste was higher than PUFs. Therefore, the mass density of the plastic waste mixed with polyurethane at ratio 4:1:1 foam showed a higher mass density than that of lower in composition ratios.

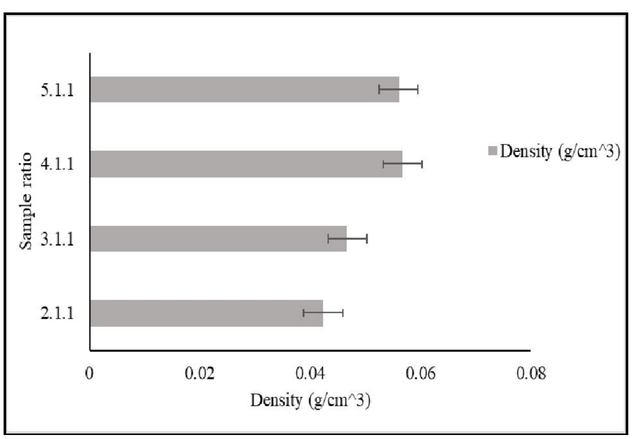

Figure 10: Density at different ratio of plastic waste particle

Figure 11 shows the porosity percentage result of the samples at different ratio of plastic waste particle in polyurethane foam. The result has indicated that the highest porosity percentage is the sample of ratio 4:1:1 with 1.71% followed by the sample of ratio 2:1:1 with porosity percentage of 1.21%, then sample of ratio 3:1:1 has the porosity percentage of 1.17%, and lastly, the lowest porosity percentage is the sample ratio of 5:1:1. at 0.88%. Wang et al.[22]studied the porosity curve for nano-composite foams stated that the fillers were contribute for generating smaller and denser cell in the nano-composite foams.

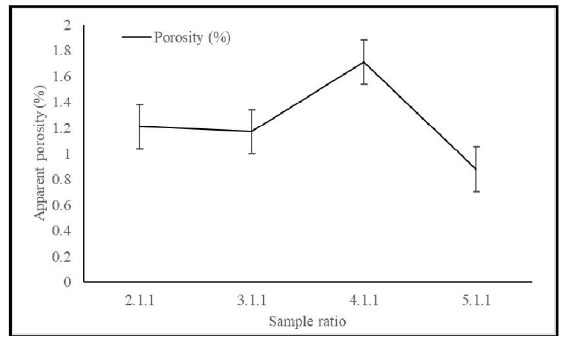

Figure 11: Apparent porosity at different ratio of plastic waste particle

5. CONCLUSION

In conclusion, the objectives of this study are achieved. Experimental result exhibited that the tensile strength and bending strength increases with increasing composition ratio at 0.26MPa and 0.23MPa respectively. The sound absorption coefficient (SAC) of the matrix was measured using an impedance tube. The peak of sample 4:1:1 achieved the greatest value of SAC between 1-1.5 kHz. PUFs were also tested under optical microscopy revealing in white and uniform morphology and cellular shape with an increasing composition ratio of plastic waste to PUFs. The experimental result shows that sample 4:1:1 obtained the highest value of density and porosity percentage at 0.0567 g/cm3 and 1.71% correspondingly. Based on the mechanical and physical test on the wall partition samples, it can be concluding that the optimum ratios of plastic waste mixed polyurethane foam are in the ratio of 4:1:1. The ratios show that the mechanical and physical properties of the sample increase as the ratios of plastic waste particles increases. Hence, the sample of plastic waste mixed polyurethane foam is applied to the wall partition application. From this study, environmental problems can be reduced and the sustainability of natural resources can be maintained.

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