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Study of Recycled High-Density Polyethylene Reinforce Polyurethane (HDPE-PU) Foam for Automotive Seat Cover Application

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Abstract: One of the key concerns of automotive manufacturers is the NVH issue. Furthermore, corporations are increasingly confronted with the challenge of finding alternative solutions for disposing of significant volumes of packaging. As an outcome, this study proposes a solid-state recycling approach that includes direct recycling of polyethylene as a green engineering shaping technology. The purpose of this research is to find the best HDPE plastic waste reinforced PU foam composition for automotive seat applications. Recycled High-density polyethylene (HDPE) plastic waste can provide new possibilities for a smoother, quieter driving experience while also addressing the issue of materials that contribute to overall vehicle weight. High-density polyethylene (HDPE) plastic waste is prepared for the various ratio of 5, 10, 15, and 20 (wt/wt%). The mechanical properties tests were carried out by Tensile test (ASTM D3574), and Impact test (ASTM D3574). For physical properties test by density test, and porosity test (ASTM C20-00), leaching test (ASTM D6234), and Optical Microscopic (OM) test (ASTM F728-81) was performed. The result showed that the highest strength of tensile strength is 3.68506 N/m^2 while young modulus strength is 62.95083 MPa. Furthermore, the maximum impact test was 1.06 kJ/m^2. The density and porosity test results show the highest average density with 0.286 g/cm^3 and the highest with 0.17% of average porosity. Insulation foams were also investigated under an optical microscope and found to alter in white, homogeneous morphological shape, and cellular form as the percentage of plastic to PUF increased. The optimum composition of recycled High-Density Polyethylene reinforced Polyurethane (HDPE-PU) foam with 10 (wt/wt%) is possible to be applied for automotive seat cover application.

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1. Introduction

Plastics are an ideal material for a wide range of applications, including packaging, medical devices, construction, and transportation because of their quality, strength, and lightweight. However, most plastics produced are single-use plastics, when combined with a

waste culture plastics lead to the accumulation of plastic waste, contamination, and the depletion of valuable resources [1].

Plastic production and usage are increasing these days, resulting in increased plastic waste and environmental issues. Every year, about 8 million tons of plastic waste is dumped into the oceans by coastal nations. Every foot of the world's coastline would appear to be littered with five garbage bags full of garbage. From 2.3 million tons in 1950 to 448 million tons in 2015, plastic production has increased dramatically. By 2050, it is expected to have doubled. The most widely used commodity in the world is High-Density Polyethylene, or High-Density Polyethylene (HDPE). Plastics that are technically advanced, lightweight, and inexpensive are suitable for a wide variety of applications. The issue with plastics is how to handle the end-of-life of goods made of them [2].

Plastics are used to make lightweight and more economical vehicles. Plastics are replacing many metal components in the automotive industry. To achieve the targets of the company`s Green Program, such as waste reduction, it is necessary to increase the plastic recycling rates. Seat cover for the automotive industry which is a protective seat cover is temporary plastic covers placed over the seats of a vehicle to protect them from soiling during the assembly process. A contoured all-plastic seat cover was compared to a plastic seat cover with elastic. The results indicate that use of the contoured seat cover results in cost savings. As a consequence, researchers are increasingly using HDPE plastic waste in their studies to reduce the usage of non-renewable resources and generate an environmentally friendly product. In this research, the study of recycled high-density polyethylene reinforces polyurethane (HDPE-PU) foam for automotive seat cover application [3].

1.1 Research Background

Plastic demand has risen globally over the last 50 years. According to a 2018 report, China's latest policy will result in the replacement of 111 million metric tons of plastic bag waste by 2030. Greenpeace estimates that over 754,000 tonnes of plastic bag garbage were transferred to China's maritime neighbor, Malaysia [4].

The car seat cover is maybe the most recognizable automotive textile without considering the technical requirements. Nevertheless, the seat must be comfortable in terms of psychological, physiological, and thermal aspects. Besides, comfort helps prevent stress and fatigue and therefore contributes to road safety. Thus, textiles have an important contribution in this regard. The safety of the seat covers must be also connected to the flame retardancy of the textile materials. This report deals with a comparative study of technical textiles designed for car seat covers in terms of comfort and safety. The work envisages a comparison traced between various materials, but not a comparison of the analysed properties to a specific, defined value. In this study, the other raw material suitable for automotive seat cover applications is High-Density Polyethylene (HDPE) plastic waste which is great potential for generating commodity strength and good product reinforcing [5].

2. Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Preparation of (HDPE-PU) Foam Sample

The methodology involved few steps in order to produce (HDPE-PU) Foam Sample. First, identify the raw materials involved such as recycled HDPE plastic waste, polyurethane and hardener. Then, prepare the raw materials according to the ratio shown in Table 1.

Table 1 - Ratio of raw materials for producing GW-FC

Samples	Polyurethane (ml)	Hardener (ml)	Recycled HDPE plastic waste (wt/wt%)
A	35	35	5
B	35	35	10
C	35	35	15
D	35	35	20

The polyurethane and hardener measured using a 50 mL syringe containing a chemical solution of at a 1:1 ratio. The sample for ratio 1 mixing on a controlled 35 ml polyurethane mixed solution scale. The hardener mixed completely into the polyurethane blend until it expanded into the recycled HDPE plastic waste and PU (HDPE-PU) foam. Mixing process take about 30 seconds with stirring the mixture to get a proper compound then the foam expanded for 2 minutes. The expanding of the foam with four times the total volume of the mixture. However, last step for fabrication process was curing process that take 24 hours to ensure the foam hardens properly.

2.2 Physical Testing Preparation

2.2.1 Density and porosity test

A density test is a physical procedure that determines a specimen's bulk density based on the density of the liquid and the ambient temperature. The porosity test is a physical test that assesses a sample's apparent porosity as a proportion of the volume of voids over the total volume, ranging from 0% to 100%. The data included the specimen's dry weight in milligrams

(mg), submerged weight in milligrams (mg), and wet weight in milligrams (mg), as well as the water temperature and density in g/cm^2 [6].

(HDPE-PU) foam sample for density and porosity test were prepared in square dimension of 15mm length, 15mm width and 10mm thickness by different composition ratio which is 5, 10, 15, and 20 (wt/wt%) as shown in Figure 1.

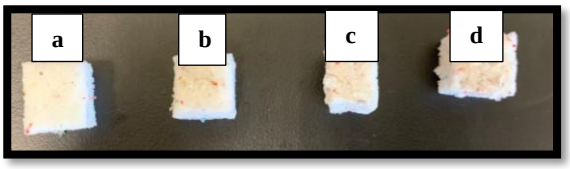

Fig. 1 - Samples for density and porosity test: (a) 5%, (b) 10%, (c) 15%, and (d) 20% of HDPE-PU foam

The method uses a liquid other than water as immersion liquid. So, the sample that are lighter than the liquid and affected by water are generally studied for its specific gravity and density measurement using this test method. The selection of the liquid will be such that the sample should not be dissolved, or otherwise affected by the liquid and the specific gravity of the liquid should be less than the sample. In addition, the immersion liquid should have a low vapour pressure and non-hygroscopic. Lastly, to calculate the apparent porosity, P_a of the specimens, the formula is as shown below in Equation (1).

$$Pa = \frac{\mathrm{Ww-Wd}}{\mathrm{Ww-Ws}} \times 100 \qquad Eq.\ 1$$

Where ww is the weight of wetted sample, wd is the weight of dried sample and ws is the weight of the suspended sample.

2.2.2 Leaching test

Leaching tests are used to determine the constituent concentration or release from a waste material under reference test circumstances or conditions that are more similar to those found at the disposal site. The purpose of leaching test used to assess the potential risk of a waste to release organic and inorganic contaminants into the environment. The standard of leaching testare ASTM D6234 which the method covers a procedure for the shake leaching of mining waste containing at least 80%dry solids (≤20% moisture) in order to generate a solution to be used to determine the inorganic constituents leached under the specified testing conditions that conform to the synthetic precipitation leaching procedure (SPLP) [7].

HDPE-PU foam sample for density and porosity test were prepared in square dimension of 20mm length, 20mm width and 20mm thickness by different ratio of composition which is 5, 10, 15, and 20 (wt/wt%) as shown in Figure 2.

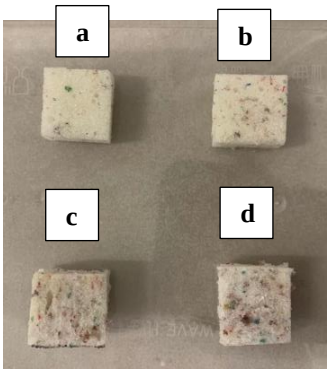

Fig. 2 - Samples for leaching test: (a) 5%, (b) 10%, (c) 15%, and (d) 20% of HDPE-PU foam

The method used with using hydrochloric acid (HCl) and nitric acid (HNO3) as the materials to test the level of erosion on the (HDPE-PU) foam samples. The test observed the reaction on the samples with several steps by using dropping technique was with three drop of solution on each samples. After 24 hours, the observation on the samples compared before and after reaction.

2.2.2 Optical microscopic test

The optical microscopic, often known as the light microscope, enlarges images using a light/lens combination. Optical microscopes are used to examine small objects such as cells. Because this microscope does not have the maximum magnification, there are just a few features visible when observing a cell. The lenses are usually housed in a cylindrical tube. The shortest lens has the lowest magnification power, and the longest lens has the highest magnification power. 4x, 10x, and 40x magnifying lenses are routinely used. The UTHM Pagoh Material Science Laboratory houses the optical microscope that was used. The magnification photo of the polyurethane mixed plastic foam sample was obtained using the experimental machine [8]. The microscope was analysed image structure measurements of sample, as indicated in Figure 3.

Fig. 3 - Optical Microscopic

The lens is 10 mm away from the stage, and the target is set to 20x. The computer screen microstructure of the sample is evaluated using the software. Zoom in on the image with the range button in the x50, x100, x200, and x300 ranges. In several spots, the photo obtained the best view of the surfaces. The porous surfaces and mechanical boundaries of the sample can be interpreted and examined using the image.

2.3 Mechanical Testing Preparation

2.3.1 Tensile test

The performance and quality of manufacturing materials are critical to the market's success. Tensile testing determines whether a material is durable and efficient when subjected to a stretching force. These tests are carried out under regulated temperature and pressure settings to determine the material's maximal strength or load capacity. Tensile and stress testing are two of the most common mechanical tests performed on the material. Scientists conduct them by stimulating the material and evaluating the material's response to its forces. The material is lengthened as a result of the tightness. The material's intensity and elongation are measured by the researchers. Insufficiency or severe deformation occurs when a material can no longer withstand the force placed on it. The ASTM D1623 rigid foam tensile testing tensile foam test used in this study [9].

All samples were rectangularly formed for the tensile test, measuring 120 mm long, 25 mm wide, and 5 mm thick. A tensile specimen's cross-section is usually one uniform sample. It has a scale and two shoulders or grip portions. The shoulders are big to make them easier to grab, but the cross-section of the indicator section is smaller to allow for deformation and failure in that region. Figure 4 shows the sample of tensile test.

The sample measured, as well as the cross-sectional area. The samples inserted in the designated sample grip assembly. The universal tester is the first standby to activate. After connecting to the tensile strength testing machine, the software was launched. The system installed with the tensile portion. The sample carefully clamped and secured to prevent sliding during testing. The clamping mechanism used to secure the sample. Grips that are suitable for standardised inspection. Tensile test started with the indicated rate. Until the sample separates, keep track of the ultimate tensile resistance and other parameters. Figure 5 shows the schematic diagram of tensile test [10].

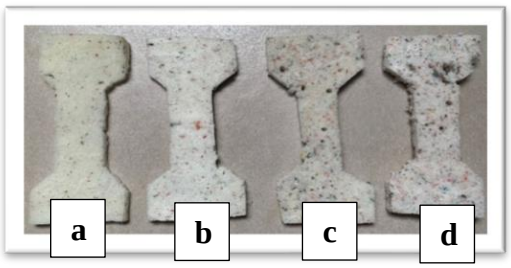

Fig. 4 - Sample of tensile test: (a) 5%, (b) 10%,(c) 15%, and (d) 20% of HDPE-PU foam

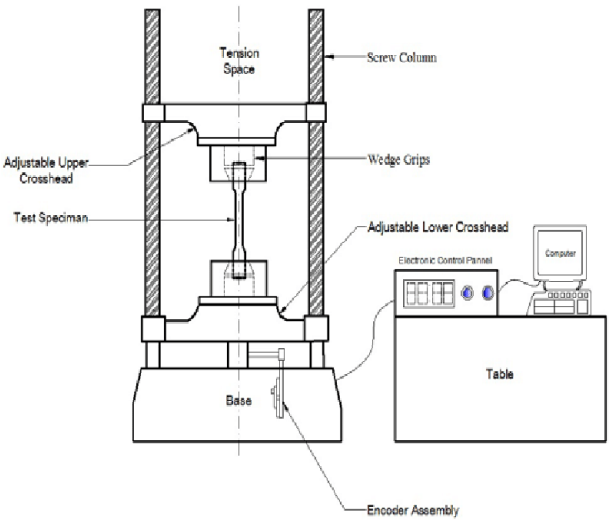

Fig. 5 - Schematic diagram of tensile test

2.3.2 Impact Test

Impact tests were performed to determine the hardness of a material. A material's strength is a factor in its ability to absorb energy during plastic deformation. Brittle materials have low strength despite the limited amount of plastic deformation they can undergo. The impact value of a substance can also changes with temperature. At lower temperatures, a substance's impact energy is generally high. Because it allows for a greater number of material imperfections that can act as stress risers and impact energy, the size of the specimen affects the impact test's value. The standard of impact test are ASTM D256 which is izod impact testing [11].

Four samples of (HDPE-PU) foam were made in various quantities, including 5, 10, 15, and 20 (wt/wt %). A rectangular shape was employed with a length of 60 mm, a width of 15 mm, a breadth of 3 mm, and a depth of 3 mm for the central notch. Figure 6 indicates the sample for impact test.

Figure 7 shows the schematic diagram of impact test. After all the samples had been prepared, the ASTM D256 step were selected the appropriate pendulum strength and secure the sample in the vice. Then switch on the display. The computer tested before to the start of the experiment. A total of twelve pendulum swings used in the calibrating process. Then the samples secured so

that the knot's vertically cantilevered surface faces the direction of impact. Then, pressing the start button, snap the pendulum back into position. After ensuring that the pendulum arm swing plane cleaned and the pendulum released, allowing the sample to break. The data were recorded, as well as the graph output. For subsequent samples, the test were repeated [12]

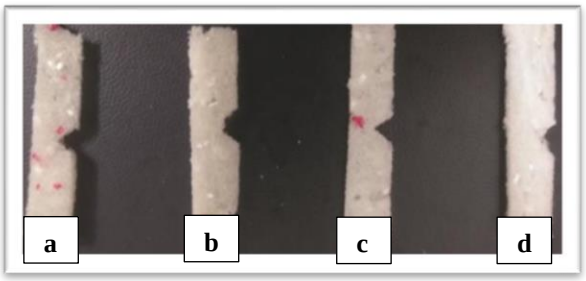

Fig. 6 - Sample of impact test specimen: (a) 5%, (b) 10%, (c) 15%, and (d) 20% of HDPE-PU foam

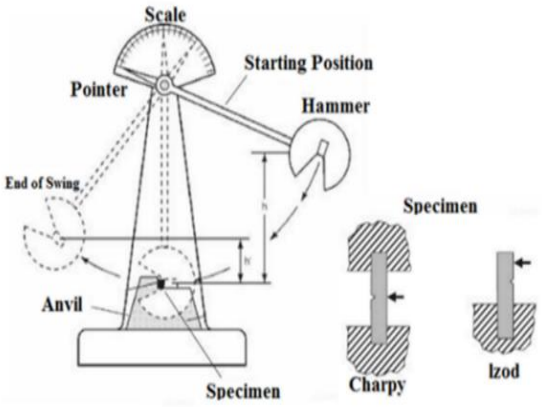

Fig. 7 - Schematic diagram of impact test [13]

3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, the chronological timeline, different case groupings, different experimental configurations, or any logical order as deemed appropriate.

3.1 Density and Porosity Test

Figure 8 showed the graph analysis result of density test. Sample B had the highest density with 0.286 g/cm3 while sample D had the lowest density with 0.207 g/cm3. For sample A with 0.243 g/cm3 and sample C with 0.224 g/cm3 of density analysis. From these observation, sample B is the best ratio of (HDPE-PU) foam in the density analysis.

According to Formisano, A., & Durante, M 2017 studied the potential of wood fibers as reinforcement in cellular biopolymers shown there was an increase in density, for all fiber treatments, from 5 to 10 wt% fiber content. For examples, the addition of wood flour into a PLA matrix significantly affected the expansion ratio and a raise in the wood-flour content noticeably increased the density of the foamed samples. The materials with 20 wt% which cannot be considered as foams had, however, lower densities than the reinforced foams with 10 wt% wood fibers[14].

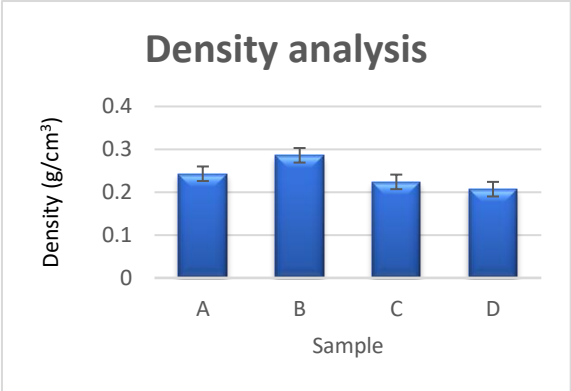

Fig. 8 - Result of density analysis

Based on the graph that showed in the Figure 9, sample B with 0.17% was the highest of average porosity while sample D was the lowest average porosity with 0.1%. Sample A with 0.13% and sample C with 0.12% of average porosity. From the observation, sample B had the highest average porosity that showed sample B was the best ratio of (HDPE-PU) foam as samples.

According to Alamri & Low (2010), this large increase in apparent porosity is owing to the presence of fiber-reinforced, which resulted in the production of fiber-matrix interfacial regions and, as a result, voids in the sample [15]. According to Alomayri & Low (2013), increasing porosity with increasing fiber content caused fibers to clump together during mixing, resulting in entrapped water-filled spaces that later transformed into voids. However, the materials with 20% wood fibers, which cannot be termed foams, exhibited lower porosities than the reinforced foams with 10% wood fibers [16].

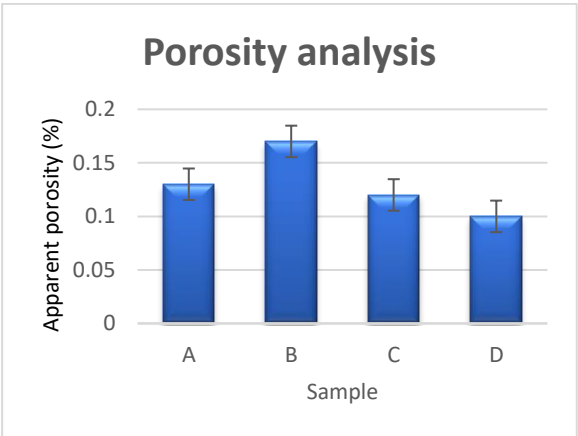

Fig. 9 - Result of porosity analysis

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3.2 Leaching analysis

Based on the result shown in Figure 10 there are two types of acid used in the experiment which is hydrochloric acid and nitric acid. This experiment was carried out by dripping three drops of acid on each samples. The experiment of hydrochloric acid showed nothing changes after 15 minutes on the samples. The reaction of hydrochloric acid on the sample does not give any change or erosion. While for the experiment of nitric acid showed the effect of yellow spots on the sample after 15 minutes.

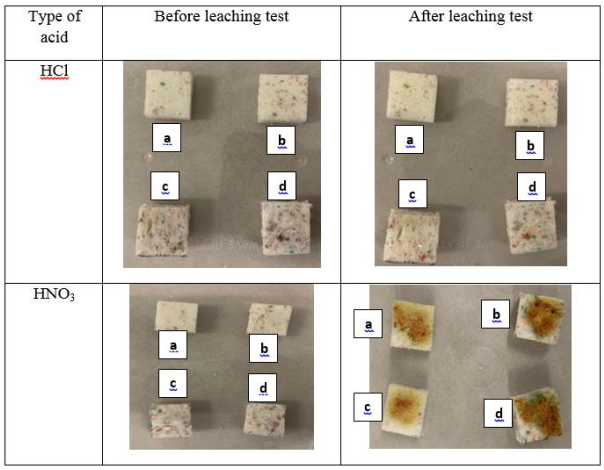

Fig. 10 - Result of leaching analysis

3.3 Optical microscopic analysis

The result of the microscopic analysis conducted using an optical microscopic machine is shown in Figure 11. In this study, there are four of HDPE plastic waste reinforced polyurethane foam samples were used with different ratio which is 5, 10, 15, and 20 (wt/wt%) of the various HDPE plastic waste combination. With the rising consistency of the plastic waste particle ratios, the structure and cellular shape of the foams remain the same. Optical microscopic (OM) can be used for microanalysis, and it is possible to attach both energy-dispersive and wavelength-dispersive spectrometers to the instrument, but the quality of the analyses will not be as high as for a dedicated electron microprobe because in the context of an OM it is not possible to reproduce the same analytical geometry as for a microprobe. The worst result for OM analysis is 20% recycled HDPE which had more fiber pull out from the matrix and left a wide deep hole, it might due to poor adhesion for matrix-reinforcement bonding due to lesser amount epoxy to form bonding with more PEFB fibers [17].

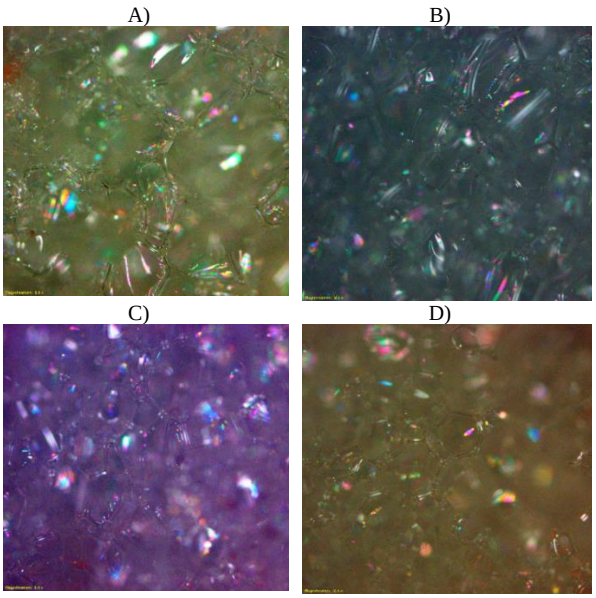

Fig. 11 - Result of Optical microscopic (OM). (a) Ratio of 5 (wt/wt%), (b) Ratio of 10 (wt/wt%), (c) Ratio of 15 (wt/wt%) and (d) Ratio of 20 (wt/wt%)

3.4 Tensile analysis

Based on the graph that showed in the Figure 12, sample B was the highest tensile strength with 3.68506 N/m2 while sample D was the lowest with 1.98079 N/m2 of tensile strength. Sample A with 3.46978 N/m2 and sample C with 2.05904 N/m2 of tensile strength. From the observation showed that sample B was the best ratio among other sample with ratio 10 (wt/wt%) of (HDPE-PU) foam. From the graph shown that if the recycled plastic waste mixture increase, the tensile strength will be decrease because the ratio of plastic waste mixture affected the tensile strength.

According to Bei Dai, Guangming Zhou, Jin Sun (2015) shown Experimental study on the mechanical properties of looped fabric reinforced foam core sandwich composite state the reason of tensile testing is that the flatwise tensile strength is mainly determined by the tensile strength of the foam core as the damage mode is the foam core damage. The tensile strength of the foam material increases with the increase of its density, and thus the tensile strength of samples also increases accordingly [18].

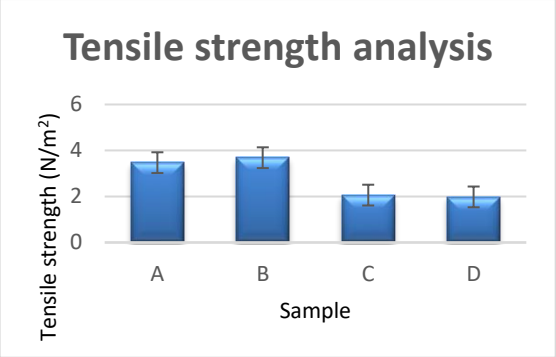

Fig. 12 - Result of tensile analysis

When a material is exposed to lengthwise tension or compression, Young's modulus is a measurement of its ability to withstand length changes. The longitudinal stress divided by the strain represents Young's modulus, also known as the modulus of elasticity. Based on the graph shown in the Figure 13 the highest young modulus pressure was sample B with 62.95083 MPa while sample D was the lowest with 30.1953 MPa of young modulus pressure. For the sample A with 61.2334 Mpa and sample C with 35.7589 MPa of young modulus pressure. That shown sample B had the best ratio from the other samples and very strong because it can withstand a lot of stress with do not stretch very much and will break suddenly [19].

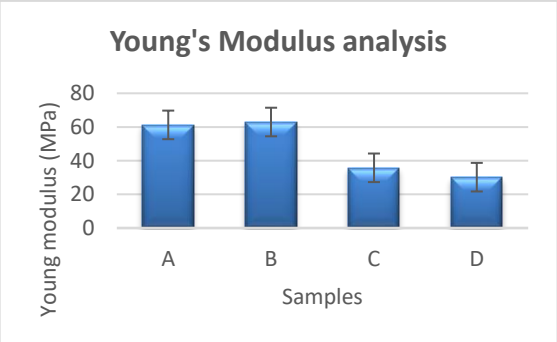

Fig. 13 - Result of young modulus analysis

3.5 Impact analysis

The distinct ratio (HDPE-PU) foam was shown in Figure 14. Sample B had the maximum impact strength with 1.06 kJ/m2 while sample D had the minimum impact strength with 1.0 kJ/m2. Sample A with 1.04 kJ/m2 and sample C with 1.02 kJ/m2 of impact strength. With the analysis shown that sample B was the strongest with ratio 10 (wt/wt%) of ratio (HDPE-PU) foam to withstand the maximum impact strength value of 1.06 kJ/m2.

The effect parameters of peak load absorbed energy/impact energy ratio, and contact period climbed with impact energy but decreased with impactor size. The impact energy and contact length decrease as the thickness of the face layer increases, whereas the peak load increases. Furthermore, the planar damage diameter and indentation depth increase with impact energy while decreasing with face sheet thickness. Furthermore, based on the falling weight impact results, the energy dissipation capabilities of composite structures without foam core were higher than the other. This attribute has a considerable impact on the foam content and thickness, as well as the structure arrangement [19].

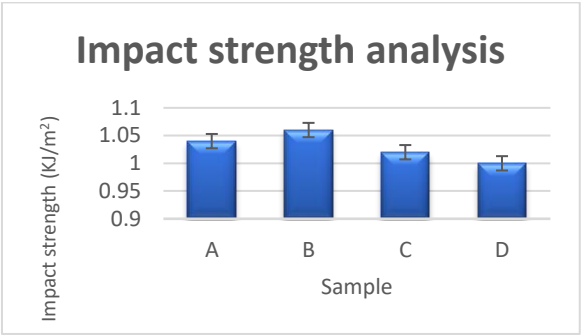

Fig. 14 - Result of Impact analysis

4. Conclusion

In conclusion, the objectives of this study were achieved. The optimum composition of recycled High-Density Polyethylene reinforced Polyurethane (HDPE-PU) foam with 10 (wt/wt%) which is sample B possible to be applied for automotive seat cover application. There were because sample had the highest density with 0.286 g/cm3 while average porosity with 0.17%. Furthermore, with the ratio 10 (wt/wt%) of sample B had the highest tensile strength with 62.95083 MPa that showed can withstand a lot of stress with do not stretch very much and will break suddenly. Moreover, sample B with the ration 10(wt/wt%) had the strongest bonding of the structure from analysing of Optical microscopic (OM). The physical and mechanical tests based on different ratio of recycled HDPE plastic waste for automotive seat cover application had been conducted and evaluated. The result and analysis clearly showed the best ratio to be produce automotive seat cover application.

Acknowledgement

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