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Assessing the Viability of Waste Tyre Rubber Powder as Additives in Rigid Polyurethane Insulation Foam

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Abstract

The increasing global population has led to a rapid rise in garbage production, with predictions indicating a quadruple increase by 2050. The problem statement highlights the complexities of selecting insulation materials, considering factors such as moisture capacity, fire resistance, and environmental impact in the context of climate change. Stone wool, a material with high moisture capacity, may lead to construction and lifetime moisture issues. The aim of the research work is to investigate the potential of waste tyre rubber powder as an additive in insulation panel. In order to achieve the aim, produce insulation foam with different ratio of rigid polyurethane (RPU) and waste tyre rubber powder. Also, to contrast the relative effectiveness of rigid polyurethane and waste tyre rubber powder. Insulation foam specimen which is pure RPU insulation foam and RPU with waste tyre rubber (WTR) powder insulation foam undergoes a compression test, tensile test and thermal conductivity test. Insulation foam with 10 % WTR and RPU has the optimum performance and better proportion ratio as the modified content of insulation foam. The characteristic of 10 % waste tyre rubber (WTR) powder with RPU insulation foam obtain from the testing is 0.19 MPa, 0.23 MPa and 0.0923 W/m˚C respectively which proven an improvement in insulation foam by adding waste tyre rubber (WTR) powder with RPU.

1. Introduction

Along with the population growth, garbage production has been increasing quickly. In comparison to 2016, it is predicted that the world's trash production will roughly quadruple by 2050 and triple by 2100 [1]. Large amounts of waste are dumped in landfills, which is having a negative influence on human health as well as the ecosystem by contaminating the soil, water, and air. According to World-Counts 2020, an improved waste management system might cut world carbon dioxide emissions by up to 15% [2]. Therefore, one of the e-waste is waste tyre rubber powder.

Scrap tyres, one of the most prevalent and significant hazardous solid wastes worldwide, are one of the dangers that go unnoticed. Without proper management, the treatment of used tyres poses a risk to both the environment and public health. For instance, scrap tyre sites are the perfect breeding grounds for insects that spread diseases, and runoff from scrap tyre fires can contaminate surface and groundwater [3]. Tyre disposal is a significant environmental issue since it takes up valuable landfill space and increases the risk of unintentional fires that emit pollution. Tyres are highly flammable, making such fires challenging to control. For instance, one fire in Huntington (United States) lasted for nine months. Waste tyres are a significant contributor to environmental issues since they are not altered by biological deterioration [4].

The importance of proper thermal insulation in buildings is underscored by the need for energy conservation and the increasing demand for enhanced thermal performance in construction. However, challenges arise when using materials with higher moisture capacities, such as stone wool, which can lead to issues like excess moisture during construction or over the building's lifetime. Additionally, the fire resistance of insulation materials is a crucial consideration, as materials without rubber components may pose greater flammability risks compared to those with rubber additives. The impact of climate change further complicates these considerations, with global warming altering climate patterns, making it essential to choose insulation materials that can withstand varying environmental conditions [5]. The aim of the research work is to investigate the potential of waste tyre rubber powder as an additive in insulation panel and contrast the relative effectiveness of rigid polyurethane (RPU) and waste tyre rubber (WTR) powder. SEM test will be conducted to measure the potential of waste tyre rubber powder while three testing will conducted to measure the effectiveness of rigid polyurethane (RPU) and waste tyre rubber (WTR) powder.

2. Methodology

The main proposed of this project is to investigate the potential of waste tyre rubber powder as an additive in insulation panel. Therefore, it must have a good performance with thermal conductivity, compressive strength and tensile strength properties. This project contains of two part which is produce insulation foam with different ratio of rigid polyurethane (RPU) and waste tyre rubber powder and investigate the relative effectiveness of rigid polyurethane and waste tyre rubber powder

Mass mixing at a ratio of 1:1 (OH: NCO) between polyol and isocyanate was used to create rigid polyurethane foam (RPU). Prepared polyol and isocyanate in per each plastic container and different percentage of waste tyre rubber powder which is 2% or 4%, 6% 8% and 10% per each plastic container. Using the mixer to stir the polyol by 2 minutes, then pour the waste tyre rubber powder into it and continue stir it in 1 minutes and 30 second. Lastly, pour the isocyanate into the container that contain polyol and waste tyre rubber powder and stir it in 30 second. It will expand slowly to become a foam.

In the field of condensed matter physics, the scanning electron microscope (SEM) is a vital research and development instrument. It is the most popular tool for studying the morphology and surface topography of bulk materials at the nanoscale. Approximately 200 times greater than the spatial resolution of traditional optical microscopes, it can consistently obtain an image resolution of 1-2 nm on a range of various materials.

The rigid polyurethane and waste tyre rubber powder to produce insulation foam qualities or performances will receive further attention in this study. While five composite specimens (modified insulation foam made of rigid PU additive mix with waste tyre rubber powder) with different weight ratios were tested with compression test and tensile stress test, a rigid polyurethane and waste tyre rubber powder insulation foam specimen was having compression test, tensile test and thermal conductivity test.

2.1 Material

Waste tyre rubber powder (WTR) was utilized as the additive's raw material in this investigation and its purchased from Kilang Rubber Seng Huat Resources Sdn Bhd. Rigid polyurethane (RPU) has been used to be the insulation foam for adding additives to prove that WTR can act as additive in insulation foam. In order to make sure WTR can act as an additive, it will conduct a Scanning Electron Microscope (SEM) to observe the internal structure of WTR. Both materials are illustrated in Figure 1.

(a)

Figure. 1 *WTR powder used in testings*

2.2 Specimen preparation

Mass mixing at a ratio of 1:1 (OH: NCO) between polyol and isocyanate was used to create Rigid Polyurethane Foam (RPU). Prepared polyol and isocyanate in per each plastic container and different percentage of waste tyre rubber powder which is 2 % or 4 %, 6 % 8 % and 10 % per each plastic container. Using the mixer to stir the polyol by 2 minutes, then pour the waste tyre rubber powder into it and continue stir it in 1 minutes and 30 seconds. Lastly, pour the isocyanate into the container that contain polyol and waste tyre rubber powder and stir it in 30 seconds. It will expand slowly to become a foam.

2.3 Mould preparation

One rectangular and one-cylinder shaped moulds will be prepared to create the foam. Rectangular shaped moulds with 300 mm of width and length have been done fabricated in Furniture Engineering Technology Workshop, UTHM. The thickness inside the mould is 80 mm. Sample mould are illustrated in Figure 2.

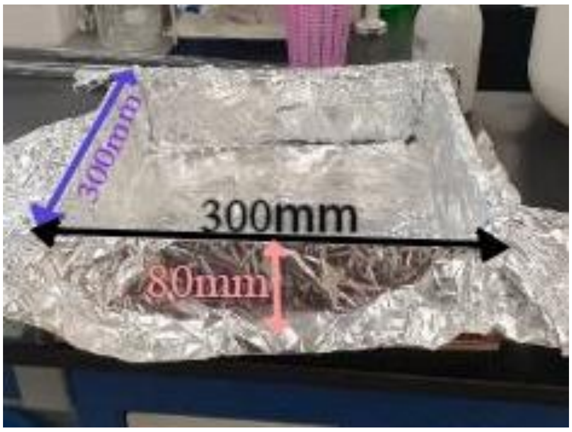


Figure 2: *Sample mould*

2.4 Testing

Three testing have been done conducted is compressive strength test, tensile test and thermal conductivity test. Each testing consists of a different procedure and apparatus.

Table 1: Laboratory Testing

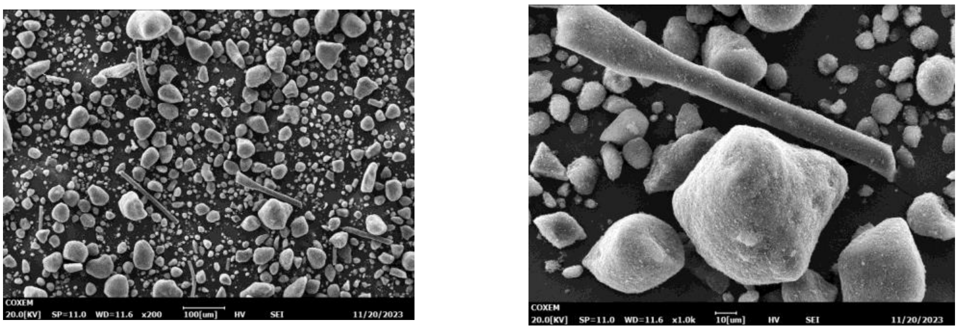
Laboratory Tests	Standards
Compressive Strength Test	ASTM D1621
Tensile Strength Test	ASTM D1623
Thermal Conductivity Test	ASTM C518

3. Finding and discussion

All the data was recorded and analysed to evaluate whether the waste tyre rubber powder is suitable to use in rigid polyurethane as insulation foam. The analysis is important to get final result and to look whether this studies already achieve the objective.

3.1 Scanning Electron Microscopy (SEM)

The low-magnification and high-magnification inset images clearly show the pore channel in waste tyre rubber (WTR) powder. From the image, it has sizes like circular and rectangular in the waste tyre rubber (WTR) powder.



(a) **(b)**

Figure 3: *Low-magnification SEM images of (A) and high-magnification SEM images of (B)*

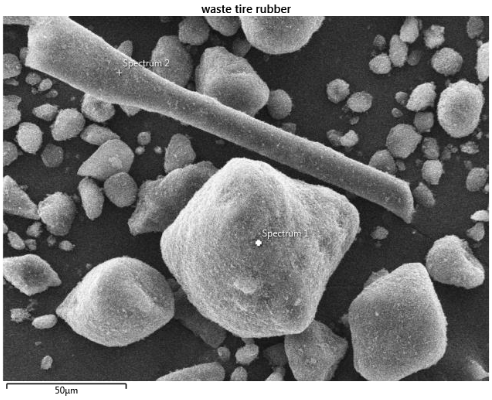


Figure 4: *Spectrum 1 that check with SEM-EDX*

Table 2: *Element of spectrum 1*

Element	Weight (%)
Carbon (C)	78.19
Zinc (Zn)	5.24
Silicon (Si)	3.68
Sulphur (S)	2.71
Oxygen (O)	9.25
Copper (Cu)	0.94
Total	100.00

From table 1, spectrum 1 has six types of elements, which are carbon (C), zinc (Zn), silicon (Si), sulphur (S), oxygen (O), and copper (Cu), which have different percentages of weight, which are 78.19%, 5.24%, 3.68%, 2.71%, 9.25%, and 0.94%, respectively. The colour of the insulation foam produced by waste tyre rubber (WTR) powder with RPU was black because carbon (C) from waste tyre rubber (WTR) powder was added to it. Silicon (S) and zinc (Zn) helped transform rubber into a solid article during vulcanization or tyre curing. The curing system shortens the vulcanization time [6]. From the SEM test, waste tyre rubber (WTR) powder had the potential as an addictive in insulation panel.

3.2 Compression Test Result

Compression test was conducted on various percentage of waste tyre rubber powder in rigid polyurethane as insulation foam and pure rigid polyurethane insulation foam. Five types of percentage of waste tyre rubber powder in rigid polyurethane as insulation foam had been chosen to use, there are 2 % (0.4 g), 4 % (0.8 g), 6 % (1.2 g), 8 % (1.6 g) and 10 % (2.0 g). The result had been tabulated in graph.

Pure RPU insulation foam has a higher compressive strength than the different percentages of WTR powder with RPU insulation foam, which are 2 % (0.29 MPa), 4 % (0.21 MPa), 6 % (0.22 MPa), 8 % (0.20 MPa), and 10 % (0.19 MPa). The result shows that after insulation foam of RPU mix with 2 % WTR powder, there was more elongation than other insulation foam, which is 71.62 mm, either pure RPU insulation foam or 4 %, 6 %, 8 %, and

10 % WTR powder with RPU insulation foam. However, if more waste tyre rubber powder, which is 4 %, 6 %, 8 %, and 10 %, is added, the elongation rate will increase, but it has reached the limit.

However, the compressive strength of waste tyre rubber (WTR) powder with rigid polyurethane (RPU) insulation foam also corresponds with the standard compressive strength of insulation foam, which is 0.172 MPa parallel to the rise and 0.084 MPa perpendicular to the rise [7]. However, the result clearly shows that all of the compressive strength of insulation foam, no matter whether it was pure rigid polyurethane (RPU) foam or the five different percentages of foam mixed with waste tyre rubber (WTR) powder and rigid polyurethane (RPU), was higher than the standard compressive strength.

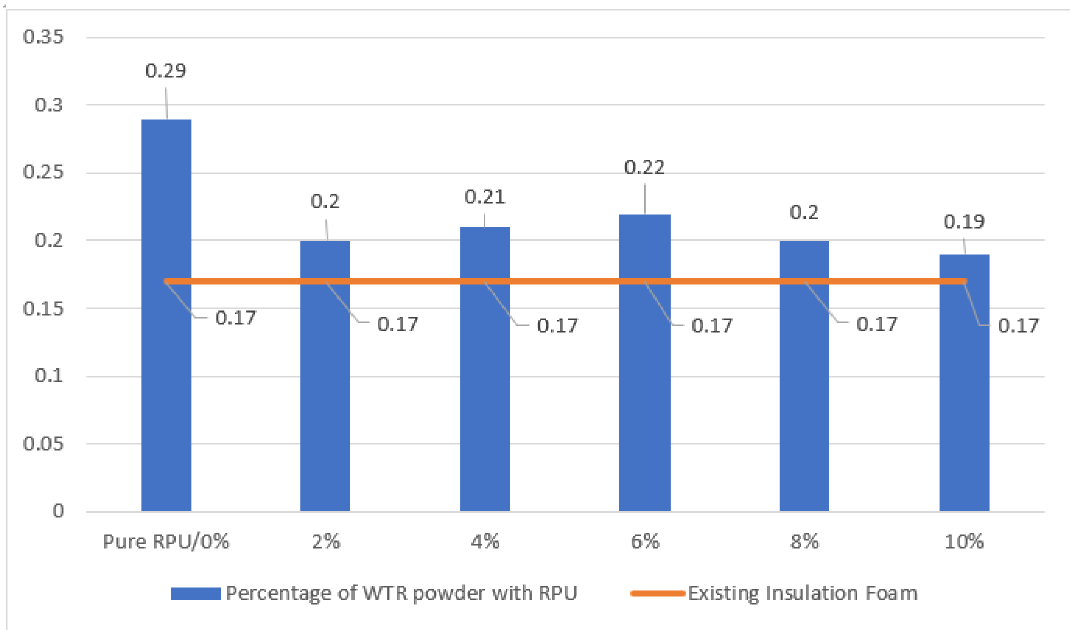


Figure 5: *Graph of compressive strength for each insulation foam compare with existing insulation foam*

3.3 Tensile Test Result

Tensile stress test was conducted on various percentage of waste tyre rubber (WTR) powder in rigid polyurethane (RPU) as insulation foam and pure rigid polyurethane (RPU) insulation foam. Five types of percentage of waste tyre rubber (WTR) powder in rigid polyurethane (RPU) as insulation foam had been chosen to use, there are 2 % (0.4 g), 4 % (0.8 g), 6 % (1.2 g), 8 % (1.6 g) and 10 % (2.0 g). The result had been tabulated in graph.

According to Table 4.3, 10 % WTR powder with RPU insulation foam has a higher tensile stress which is 0.22 MPa than other different percentages of WTR powder with RPU insulation foam, which are 2 % (0.20 MPa), 4 % (0.11 MPa), 6 % (0.18 MPa), 8 % (0.16 MPa) and pure RPU insulation foam is 0.15 MPa. The result shows that after insulation foam of RPU mix with 10 % WTR powder, there was more elongation than other insulation foam, which is 9.421 mm, either pure RPU insulation foam or 2 %, 4 %, 6 %, and 8 %WTR powder with RPU insulation foam. The gauge length and break span of pure RPU foam is 3.23 mm when the force at peak is 19.94 N while the 2 % WTR powder with RPU foam have 5.54 mm when the force at peak is 27.92 N. Besides that, 4 % WTR powder with RPU foam have 2.86 mm gauge length and break span with 9.97 N force at peak, 6 % and 8 % WTR powder with RPU foam have same force at peak which is 17.95 N but gauge length and break span respectively is 3.40 mm and 2.93 mm and 10 % WTR powder with RPU foam have 2.64 mm gauge length and break span with 23.93 N force at peak.

Results have proven improvement in tensile stress by adding the waste tyre rubber (WTR) powder to rigid polyurethane (RPU) to produce insulation foam. However, the tensile stress of waste tyre rubber (WTR) powder with rigid polyurethane (RPU) insulation foam also corresponds with the standard tensile stress of insulation foam, which is 0.210 MPa parallel to the rise and 0.150 MPa perpendicular to the rise [7]. However, the result clearly shows that all of the tensile stress of insulation foam, no matter whether it was pure rigid polyurethane (RPU) foam or the five different percentages of foam mixed with waste tyre rubber (WTR) powder and rigid polyurethane (RPU), was higher than the existing insulation foam which is 0.15 MPa.

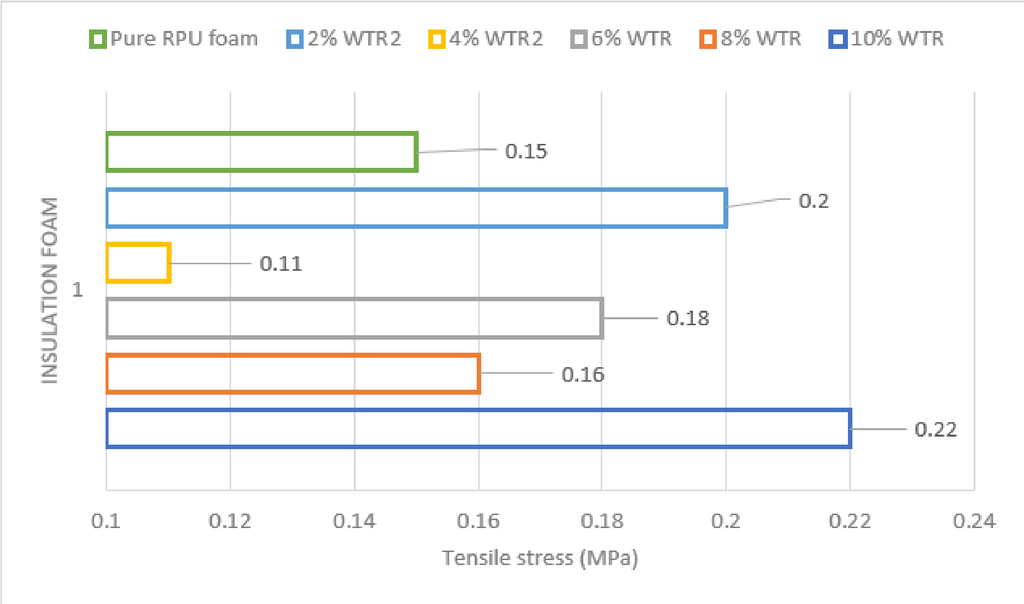


Figure 6: *Graph of tensile stress for each insulation foam*

3.4 Thermal Conductivity Test Result

Thermal conductivity test was conducted on various percentage of waste tyre rubber (WTR) powder in rigid polyurethane (RPU) as insulation foam and pure rigid polyurethane (RPU) insulation foam. Five types of percentage of waste tyre rubber (WTR) powder in rigid polyurethane (RPU) as insulation foam had been chosen to use, there are 2 % (0.4 g), 4 % (0.8 g), 6 % (1.2 g), 8 % (1.6 g) and 10 % (2.0 g). The result had been tabulated in graph.

According to the data collected as shown in Tables 4.4, 10 % WTR powder with RPU foam has the lowest thermal conductivity, which is 0.0923 W/m°C. The highest thermal conductivity is 0.1101 W/m°C, which is the pure RPU foam. Besides that, the thermal conductivity that is second lowest is 8 % WTR powder with RPU foam, which is 0.0933 W/m°C. 2 % WTR powder with RPU foam has 0.0999 W/m°C thermal conductivity and 4 % WTR powder with RPU foam has the second highest thermal conductivity, which is 0.1051 W/m°C . Also, 6 % WTR powder with RPU foam has a 0.0938 W/m°C thermal conductivity.

Thermal conductivity for insulation foam corresponds to 0.030 W/m°C [8]. However, 10 % WTR powder with RPU foam has a thermal conductivity which is 0.0923 W/m°C , but it still improves by adding the WTR powder. A good insulation foam will have a high thermal resistance so that the foam can effectively resist the transfer of heat, providing better insulation for the desired application, which is building. When an insulation foam has high thermal resistance, it implies that the foam has low thermal conductivity, which is 10 % WTR powder with RPU foam [9].

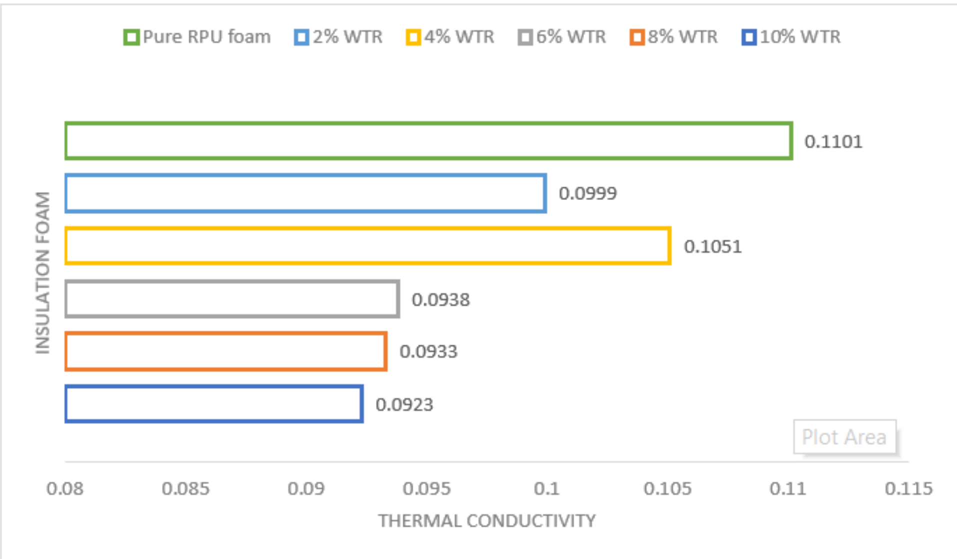


Figure 7: *Graph of thermal conductivity for each insulation foam*

4. Conclusion

In this research, pure RPU insulation foam has been proven to be improved by adding WTR powder with RPU into insulation foam. Compared to the pure RPU insulation foam, WTR powder with RPU insulation foam has more advantages on its performance which is thermal conductivity. In conclusion, this research is considered as a successful and objectives have been entirely achieved. For instance, research showed that the proposed to modified WTR powder with RPU insulation foam could be subjected for further studies and improvements since there are infinite variables needed to be determined.

The limitations of research that derived from the challenges that occurred while carrying out this study are as follows which is the lack of apparatus such as a mould of thermal conductivity test for insulation foam that could be produced. Number of recommendations are suggested in order to improve overall performances of insulation foam (waste tyre rubber powder mix with rigid polyurethane) for future study which is select more testing to study out the characteristics of waste tyre rubber powder with rigid polyurethane insulation foam. In conclusion, this research is considered as a successful and objectives have been entirely achieved. For instance, research showed that the proposed to modified WTR powder with RPU insulation foam could be subjected for further studies and improvements since there are infinite variables needed to be determined.

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