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Optimization of Experimental Conditions for Fabrication of Polyurethane Foam Filled With Wood Fibers as Sound Absorptive Materials

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Abstract
This is to highlight that the present study is to substitute petroleum based polymer and thus, reducing the dependency on the consumption of petroleum based oil products. Therefore, the main objective of this study is to optimize the design and performance of polyurethane (PU) foams filled wood fibers using design of experiment method (DoE). This study focused on fabrication of polyurethane (PU) foams and its composites based on renewable bioepoxy (B) and petroleum based synthetic epoxy (E), crosslinker and wood fibers. The PUs foams were prepared in a cylindrical shape with 100 mm and 28 mm diameter in respect to low and high frequency absorption level as well as the sound absorption coefficient (α) according to ASTM E1050. The experimental data from impedance tube test results were discussed on α values. The effect of different size of wood filler loading in PUs foam and its composites were analyzed and discussed in detail such as main pore size, interconnected pore, struts thickness and α. Meanwhile, UV accelerated weathering test, was conducted according to ASTM D 4587, to investigate the acoustical properties of polymer foam composite upon ultra-violet (UV) irradiation time exposure. Results concluded that the longer time UV irradiation exposure produced bigger main pore and interconnected pore size and appear to reduce the value of α.

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1. Introduction

The sound absorption coefficient (α) of a material is a dimensionless number valued between zero and one, over a range of frequencies, that represents a percentage of sound energy absorbed based on a unit area exposed to the sound. In other words, it is known as the ratio of absorbed energy to incident energy, considering the amount of sound absorbed by the material. [1]. In other words, alpha (α) is described as a measure of the acoustic energy absorbed by the material at incidence and is generally expressed as a decimal energy varying between 0 and 1.

Sound absorbing materials are classified on the ability of the material to absorb as much as sound waves and to reflect as minimal as it could and at the same time to transmit more waves [2]. Porous materials are excellent for sound absorption and good heat insulator. Its open pores permit confined airflow via the material thus absorbing sound and additionally preventing efficient heat exchange.

Rus and Shafizah [3] investigated the porous materials with uniform and non-uniform pore structure give different results at different frequency level. Flexible high-porosity PUs foams have been commonly used as noise control materials in many industrial applications due to light weight, efficient sound absorption, excellent viscoelasticity and acoustic absorption properties [4,5].

Natural fiber is essentially completely biodegradable and recent technological advances have made natural fiber processing more economical and environmentally friendly [6-8]. Many researchers studied and examined the suitability, durability and capabilities of natural fibers embedded in polymeric matrices [9]. Researchers focused on the effect of fiber surface changes as well as on manufacturing processes to enhance fiber or polymer performance. Alternatively, some researchers investigated and compared between different natural fiber composites and their stability in various applications [10]. The effective sound absorption of any natural fiber polymer composite material can therefore be achieved by having a more tortuous pathway, a higher surface area, a higher resistance to flow and a low porosity within it at the optimum range.

The effect of exposure to UV radiation is reliable for improving the acoustic properties of sound absorbing material. Based on the study conducted by Rus et al., [11-23], it gave higher acoustic properties of PUs foam from renewable resources after UV exposure. This is due to UV exposure to decreased morphological cell structure.

2. Experimental Materials and Methodology

2.1. Design of Experiment

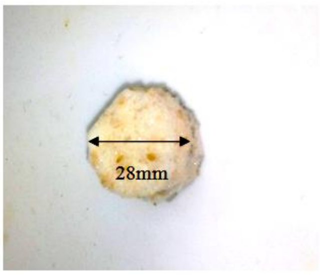
The factorial design of experiment (DoE) method is used to determine the name of the samples and the interrelation between the different inputs factors (X) [12-14] which contributes to the effect of responses (Y) is as shown in Table 1.

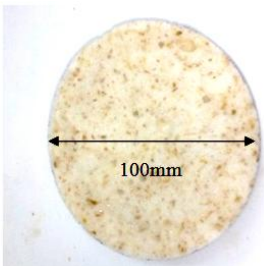
Table 1. Input Factors (X) and Responses (Y)

Input factors (X)	Responses (Y)
Monomer type, X1	Main Pore Size (μm), Y1
Filler ratio (%), X2	Interconnected Pore Size (μm), Y2
Filler type, X3	Strut Thickness (μm), Y3
UV time exposure (hours), X4	Sound Absorption Coefficient (α), Y4

2.2. Sound Absorption Coefficient Test

The sound absorption test is conducted and calculated according to ASTM E1050 standard to assess the ability of certain materials to absorb noise. PUs foam was prepared in a cylindrical shape with a diameter of 100 mm and 28 mm for low and high frequency respectively, as shown in Figure 1.





(a) (b)

Figure 1: PUs foam (a) diameter of 28 mm, (b) diameter of 100 mm

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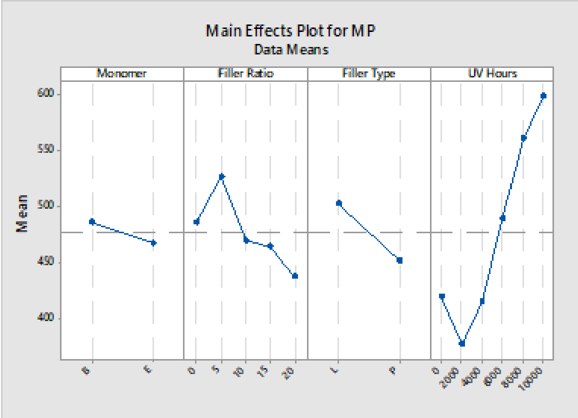
3. Result and Discussion

3.1. Morphological structure test

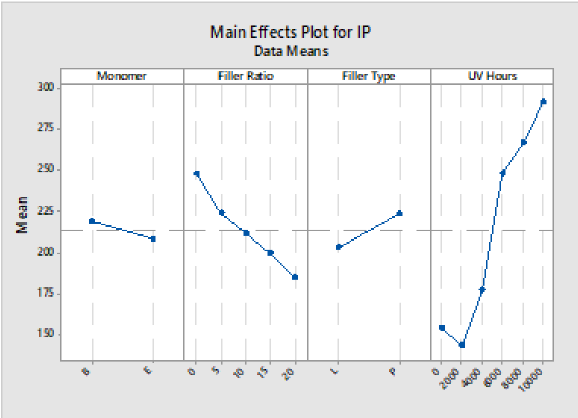
The effects of input factors (X) in polymer foam production were examined to evaluate the responses (Y) for PUs foam and its composite. Figure 2(a), (b) and (c) shows the main effect plot response obtained from Scanning Electron Microscope (SEM) experimental result. Referring to Figure 2(a), the increase in filler ratio, X2 shows decreases the main pore size (µm), Y1 of the PU foam. PUs foam with powder, P filler have smaller Y1 as compare to PUs foam with flakes, L filler. Figure 2(b) reveals that the higher filler ratio, X2 decreases the interconnected pore size, Y2. This has also showed that the smaller size of filler, X3 increases the interconnected pore size, Y2 [12-14].

In Figure 2(c), the response of strut thickness, Y3 discovered that the synthetic epoxy, E has smaller strut thickness, Y3 than bioepoxy, B. It was also discovered that the increase of filler ratio, X2 beyond 15% appears to decrease in strut thickness, Y3.The PUs foam with flakes, L filler shows the higher strut thickness, Y3 as compare to PUs foam with filler type, powder (P).

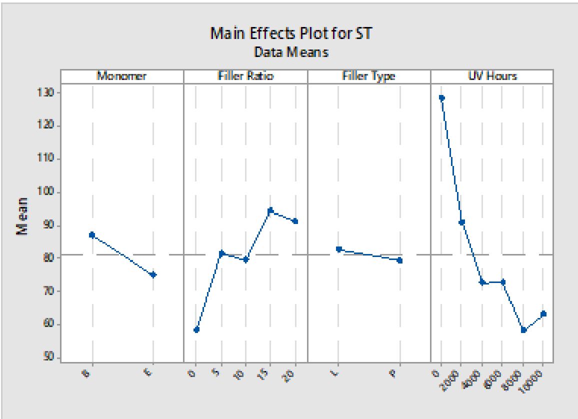
Referring to the response for UV time exposure, X4; it discovered that the longer hours PUs foam exposed to the UV irradiation appears to increase in mean size of Y1 and Y2. However, the longer PU foams exposed to UV irradiation exposure the smaller strut thickness, Y3 was revealed.



(a)



(b)



(c)

Figure 2: Main effects plot for responses (a) Main Pore Size, Y1 (MP) (b) Interconnected Pore Size, Y2 (IP) (c) Strut Thickness, Y3 (ST)

3.2. Sound Absorption Coefficient Characteristics

With an increase in porosity and/or a decrease in the diameter of the pore, the sound absorption coefficient (α) values increases [12-15]. The interconnected pore (IP) of the polymer porous materials was therefore another significant parameter for controlling the acoustic performance.

Effects of different size fiber filler with different percentages loading in polymer foam production and UV exposure time were analyzed to evaluate the response of sound absorption coefficient, Y4 (α). Figure 3 shows the synthetic epoxy, E offers a lower α than the bioepoxy, B. The filler ratio, Y2 factor indicated that the higher filler ratio (with maximum 20%) gives higher Y4 response. The PU foams filled with flakes, L have higher α value as compare to powder, P filler. While the increasing time of UV exposure, X4 shows reduces of Y4 response of PUs foam.

Figure 4 displays the matrix interaction plots for the sound absorption coefficient, α. This shows that the sound absorption coefficient (α) response of PUs foam with factor filler type, X3 depends on the level of the filler ratio (at 20%) and the filler ratio, X2 depends on the filler type, X3 factor. The plot reveals that there is a significant difference between bioepoxy, B and synthetic epoxy, E response in the frequency level factors. The main effects associated with the monomer type, X1 and the filler ratio, X2 are significant. Nevertheless, there is no significant interaction between UV exposure time, X4 or monomer type, X1 and between the filler type, X3 and the monomer type, X1.

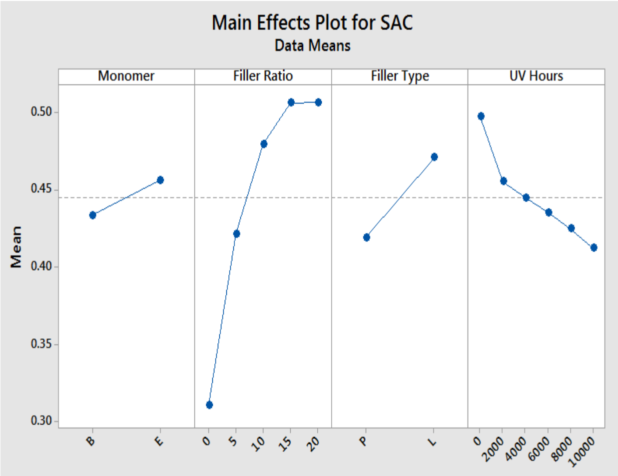


Figure 3: Main effects plot for α

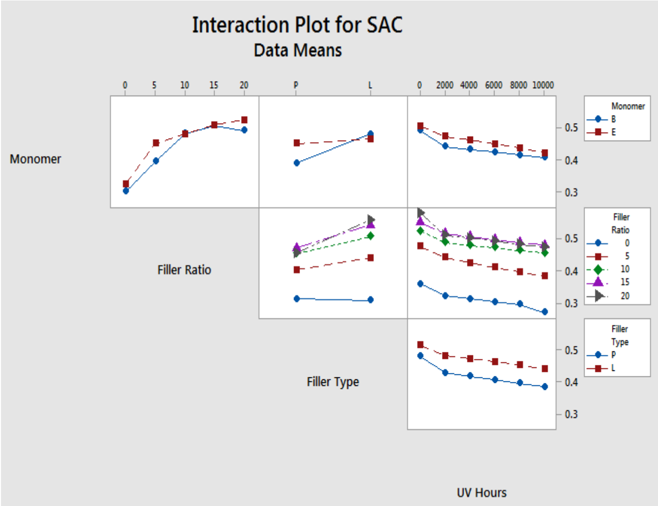


Figure 4: Interaction plot matrix for α

4. Conclusion

Four key variables, such as monomer, filler ratio, filler size and UV exposure time, were used to test the acoustic properties of polyurethane foams filled with wood fibers. Correlation between the factors; Xs reported an important finding that was inferred as the longer UV exposure time produces larger main pore sizes and interconnected pore sizes; which affect the quality of the sound absorption coefficient (α).

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