Sound Absorption Coefficient and Water Content Responses in Acoustic Analysis Based on Renewable Polyurethane Foam Composites

Hanani Abdul Wahab, Anika Zafiah M. Rus, M. F. L. Abdullah, Nur Munirah Abdullah

Abstract: ***In physiological health, negative effects are felt when unwanted noise is present. Given the negative effects of the unwanted noise, it become important to examine how environmentally-friendly and efficient sound absorbing materials could be developed. Some of the materials associated with acoustic absorption properties entail polymer foams. Particularly, the foams aid in controlling noise. The central purpose of this study was to examine renewable polymer (PU) foam composites' aspects of moisture content and acoustical properties. Four major parameters that were evaluated included the thickness of the sample, the type of filler, the ratio of the fillers, and the nature of the monomer. A design of experiment (DoE) technique was employed. To prepare the PUs foams, 28 mm and 100 mm were selected as diameters for the cylindrical shapes on focus. Plotting the main effects was achieved through ANOVA, upon which variations in the role and performance of the selected input factors were discerned. From the findings, it was established that when bio-epoxy (B) was used in conjunction with renewable PU foams, the moisture content was greater than the case involving petroleum based PU foam synthesis. Hence, renewable PU foam composite is seen to be realized at 0.9, especially if the filler ratios and size are increased; with the experimental conditions set at 3 kHz. Overall, the study established that the renewable Pus' state of sound absorption exhibits good agreement with the case of synthetic PU foam.***

Index Terms**:** ***Acoustic; ANOVA; DoE; PU foams; Renewable***

I. INTRODUCTION

Currently, one of the notable environmental pollutants is noise. With its associated negative effects on the health of the public, noise refers to an undesirable sound. The long-term effect entails impaired human lifestyle. Previous studies have focused on some of the methods through which acoustic systems could be improved, especially among sound absorbing materials that aid in improving the quality of human life [1-5]. The extent to which the sound absorbing materials could absorb the sound form a major determinant of their categorization into various groups. In particular, the materials are expected to reflect minimal sound waves while ensuring that most of the waves (sound waves) are absorbed as desired [6].

Hence PU foams (flexible polyurethane) exhibiting high porosity have gained increasing use towards controlling noise. They have gained use in industrial scenarios because of their promising features or properties such as acoustic absorption properties, excellent viscoelasticity, being light in weight, and effective sound absorption [7, 8]. However, most of polyurethane (PU) foams are based of raw materials from petroleum. Nonetheless, recent environmental issue invokes studies on bio-based monomers such as palm oil and waste vegetable oil [9 -11]. Currently, issues of sustainability when using polymer foams arises thus movements towards the production of bio-based plastics and composites became an important aspect. Thus, advancement towards bio-foam is further focused for better sustainability options. Thus, advancement towards bio-foam is further focused for better sustainability options. Additionally, natural fiber use in relation to PU foam fabrication is increasing. The trend is associated with the modern technical developments that have led to the realization of more environmentally friendly and economical fiber processing techniques, as well as the biodegradable nature of the natural fibers [12-14].

The DoE experimental approach refers to a technique of solving problems systematically, especially in the engineering field. His method incorporates techniques and principles during the phase of data collection [15]. In one of the previous studies by P. Muray et al., [16], it was documented that the DoE optimization technique is advantageous because it gives insight into a cause and effect correlation between or among variables, eventually supporting the processes of input management and optimization before reaching the production stage [17, 18]. As such, this study applies the DoE's factorial technique to gain insight into the operation of various parameters. Particularly, the approach is applied to the Pus foams to establish the correlation between factors that affect PU foam composite responses.

II. METHODOLOGY

As indicated in Figure 1, a one-shot technique was employed towards polymer preparation. To prepare the composite and the polymer foam, both the cross linker and the polyols were mixed. The ratio at which

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they were mixed stood at 1:2. The steps involved is started with the step (i), the polyol were pour in the plastic container, (ii) added fiber filler: flakes (L) or powder (P) with (0%, 5%, 10%, 15% or 20%) of matrix weights ratios. Then, (iii) the isocyanate was poured in the mixture and vigorous stirred (iv) for 30 seconds and (v) left at room temperature to expand and cure for 24 hours. Upon curing, the samples were cut using knife and cylindrical shape for acoustical test purpose [18].

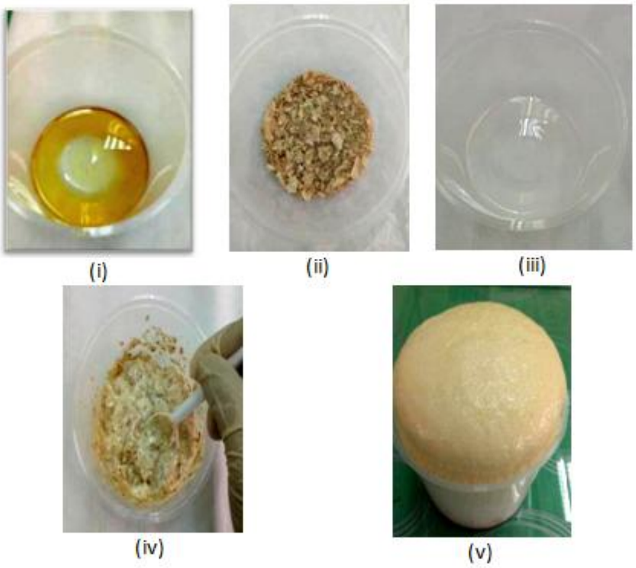

Fig. 1: Schematic diagram of PUs foam composite fabrication

To ensure that the fabricated PU foams' operatory conditions were optimized, the DoE's factorial technique of design was implemented [18]. The target input factors included X4, X, X2 and X1 (see Table 1). With level numbers set at 3, 2, 5 and 2, the experiment's designed matrix was applied to a full factorial design (see Figure 2).

From the various alternative blowing agents that would be used in the place of those deemed environmentally hazardous, water becomes a promising alternative. This outcome is informed by its significant impact on the performance of the PU foams. Also, the environmental friendliness and cost-effectiveness of water account for its growing use. It is further notable that the carbon dioxide emanating from the water is not toxic and, instead, yields improvements in material properties such as thermal conductivity and density. To produce natural polyols, water is mixed with monomers. In the presence of hydroxyl groups (OH), it is expected that the solution reacts with the isocyanate [19].

Table I: Input Factors

Factors	Name	Level
X1	Monomer type	E-epoxy, B-bioepoxy
X2	Filler ratio (%)	0,5,10,15,20
X3	Filler type	L-flakes, P-powder
X4	Sample Thickness (mm)	10, 20, 30

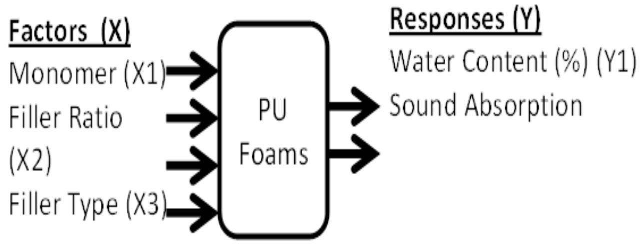

Fig. 2: PUs foams factors and responses

Loss on drying (LOD) method is a widely used test method to determine the moisture content of a sample [20]. Moisture test was conducted using Moisture Analyzer - Adam Equipment - PMB 53 as in Fig. 3 and then were analyzed the effects of water contents on the acoustical properties of the PU foams. The moisture/water content of the samples was examined using, loss on drying (LOD) moisture meter method as shown in (1). The sample is weighed, dried, and weighed again. The difference in the two weights is then compared with either the initial mass or dry mass and the moisture content calculated.

$$\%moisture = 100 * \frac{(initial\_mass - dry\_mass)}{(initial\_mass)} \quad (1)$$

Fig. 3: Moisture Analyzer - Adam Equipment - PMB 53

To determine the coefficient of sound absorption, different types of the Tube Impedance Kit were used (see Figure 4). Also, a two-microphone impedance tube was used to calculate the coefficient of sound absorption [21]. For the PU foam and its sound absorption state, the absorption level frequencies, which were also used to calculate determine the behavior of the composite, were set between 0 and 6000 Hz. For the selected cylindrical samples, 100mm was set as the diameter. Additional experimental conditions saw a low frequency range set between 100 and 2000 Hz. In relation to the high frequency range, which was set between 200 and 6000 Hz, the diameter of the target samples was 28 mm. imperative to note is that in all the investigations, the thickness of the selected samples stood at 30 mm, 20 mm, and 10mm.

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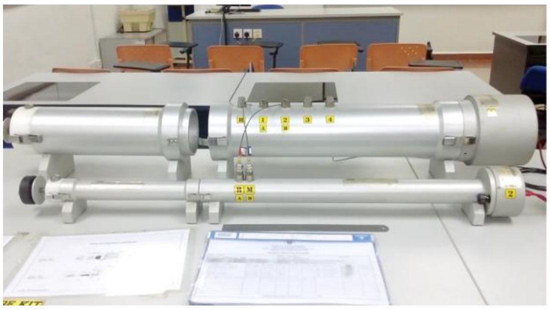

Fig. 4: Tube Impedance Kit types SSC 9020 B/K & SSC 9020 B/TL (ASTM E1050)

III. RESULT AND DISCUSSIONS

A. Main effects and interaction plot for moisture content

Fig. 5 shows the effects of input factors monomer type (X1), filler ratio (X2) and filler type (X3) in polymer foam production were analyzed to investigate the water content (%) (Y1) in the PUs foam. The fabricated PUs foam and its composites based on waste vegetable oil bio-epoxy (B) gives higher moisture content (%) as compare to petroleum based synthetic epoxy (E). The factor, X2 of filler ratio shows inconsistent effect to the moisture content. This also revealed that the smaller size of fiber filler (powder); P has little effect on the moisture content (% (Y1)).

The matrix interaction plots for moisture content (%) in Fig. 6 shows the mean response for all full interaction between 3 input factors monomer type (X1), filler ratio (X2) and filler type (X3). With 3 input factors, there are 6 possible ways to create an interaction plot. The interaction effect indicates that the relationship between filler ratio and moisture content depends on the type of monomer, B or E. It appears that, there are interactions between monomer (X1) and filler ratio (X2); since a change to one factor cause the effect of another factor to change. PU foams fabricated with bio-epoxy (B) with lower filler ratio have higher moisture content (%) while synthetic epoxy (E) based Pus foam with higher filler ratio (X2) have higher moisture content (%). However, monomer (X1) and filler type (X3) interaction plots are in parallel lines shows that there is no interaction between monomer (X1) and filler type (X3).

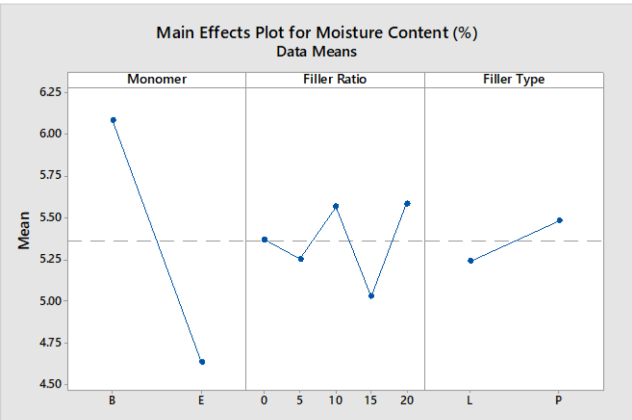

Fig. 5: Main effects plot for moisture content, (Y1)(%)

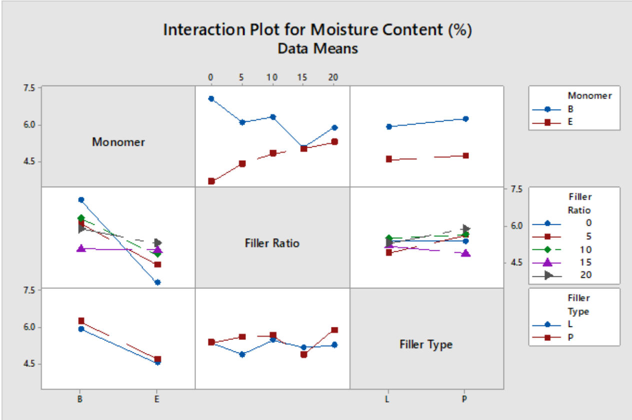

Fig. 6: Interaction plot matrix for moisture content, (Y1)(%)

B. Main Effects and Interaction Plots for Sound Absorption Coefficient, α

To determine the coefficient of sound absorption, factors that were consider, which formed the independent variables, included the thickness of the sample (X4), the type of the filler (X3), the ratio of the filler (X2), and the type of the monomer (X1). Figure 7 show the absorption level as set at a low frequency. Particularly, the range of this frequency was set between 500 Hz and 1000 Hz. The figure gives insight into the state of the monomer type X1. Regarding the ratio of the filler, the results suggest that thee parameter poses an inconsistent impact on the coefficient of absorption; with the latter results obtained after setting the frequency at 1000 Hz.

Relative to the type of the filler and its impact on the coefficient of sound absorption, it is evident that a nearly equal value is obtained when a comparative analysis of the powder filler and PU foam containing flakes is conducted. However, an increase in the thickness of the sample is observed to reduce the coefficient of material sound absorption. At a frequency set in the range between 1500 Hz and 2000 Hz, additional results suggest that the E monomer exhibits a lower value compared to a case in which the B monomer is used. However, an increase in the ratio of the filler causes an increase in the coefficient of sound absorption, suggesting that the two variables exhibit a positive or direct relationship.

It was notable further that an increase in the size of the filler would increase the coefficient of material sound absorption. For the PU foam, however, an increase in the thickness of the sample did not have a significant effect in the coefficient of material sound absorption. At 1500 Hz, it is notable that there is elastic collision; hence less incident energy is lost. The eventuality is that the coefficient of sound absorption decreases.

When the frequency level was set at medium to high, which stood between 2500 Hz and 4000 Hz (see Figure 8), findings regarding the X1 type of monomer indicated that there is a maximum increase in the coefficient of material sound absorption with an increase in the ratio of the filler. Also, the impact posed by the power filler was observed to be lower than that which was felt when the PU foams with flakes were used as the fillers. Additional investigations focused on material behavior and relationships between and among variables when a high level of frequency was used as part of the experimental conditions, under these conditions, which ranged from 4500 Hz to 6000 Hz (see Figure 9), the B monomer exhibited a lower coefficient of sound absorption compared to the E monomer. Also, an increase in the ratio of the filler was observed to cause an increase in the coefficient of sound absorption; hence a direct relationship. Similarly, the powder filler exhibited lower values of the coefficient of sound absorption than the PU foams containing the L filler. Given maximum sample thickness in these experimental conditions (that involved high frequency levels), the value of the coefficient of sound absorption increase in X4. At 6000 Hz, there was a gradual decrease in the value of the coefficient of sound absorption.

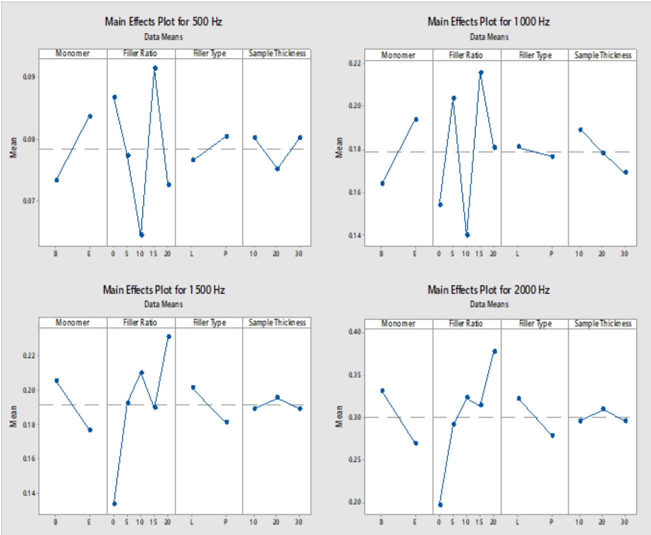

Fig. 7: Main effects plot for sound absorption coefficient response, (Y2) at low frequency (500-2000Hz)

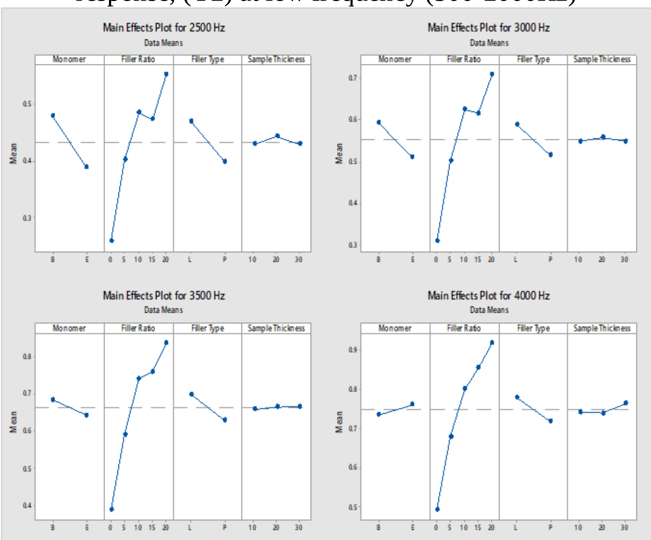

Fig. 8: Main effects plot for sound absorption coefficient response, (Y2) at medium high frequency (2500-4000Hz)

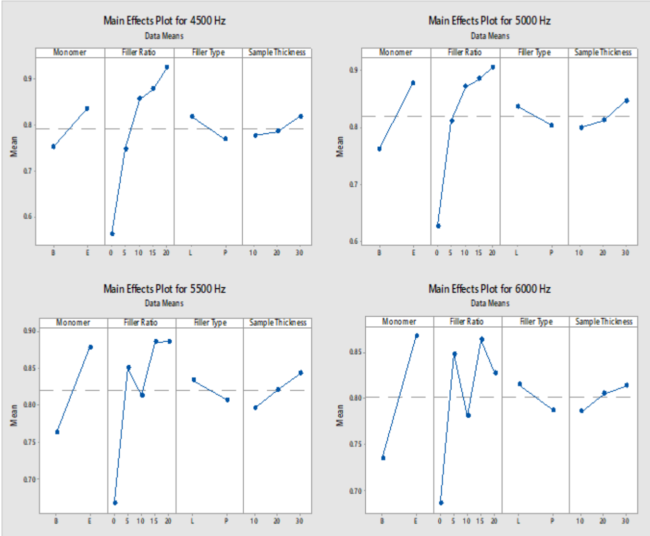

Fig.9: Main effects plot for sound absorption coefficient response, (Y2) at high frequency (4500-6000Hz)

The matrix interaction plots for the low (1000Hz) and high (5500Hz) frequency level of sound absorption coefficient, α is shows in Fig. 10 and Fig 11. At low frequency (1000Hz), Fig. 9 shows the effect of filler type (X3) on the α response depend on the level of filler ratio (X2) (at 20%) and the effect of filler ratio (X2) depends on the level of filler type (X3). This type of behavior occurs when a significant interaction exists between 2 variables. The plot shows that there is a significant difference in the α response between monomer type (X1) B and E. There appear to be significant main effects associated with monomer type (X1), filler ratio (X2) and sample thickness (X4). There is also a significant interaction between the two variables indicated by the diverging line segment between sample thickness = 20 to 30mm and filler ratio = 15 to 20 %. However, there is no significant interaction between sample thickness (X4) andfiller type (X3) and between filler type (X3) and monomer (X1).

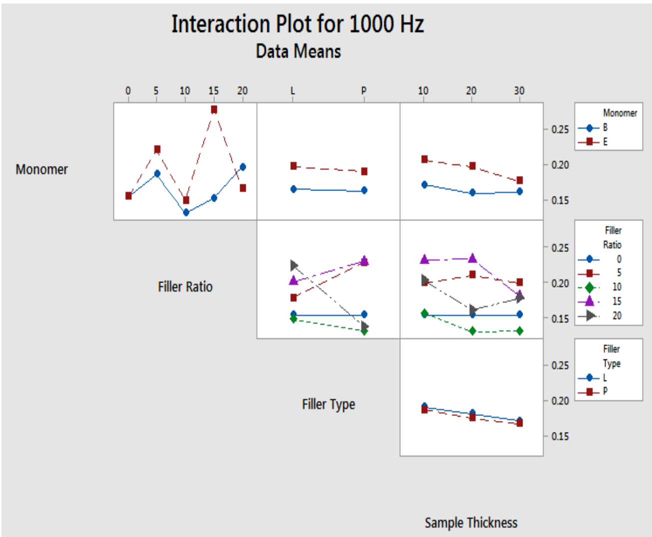

Fig. 10: Interaction plot matrix for sound absorption coefficient response, (Y2) at low frequency (1000Hz)

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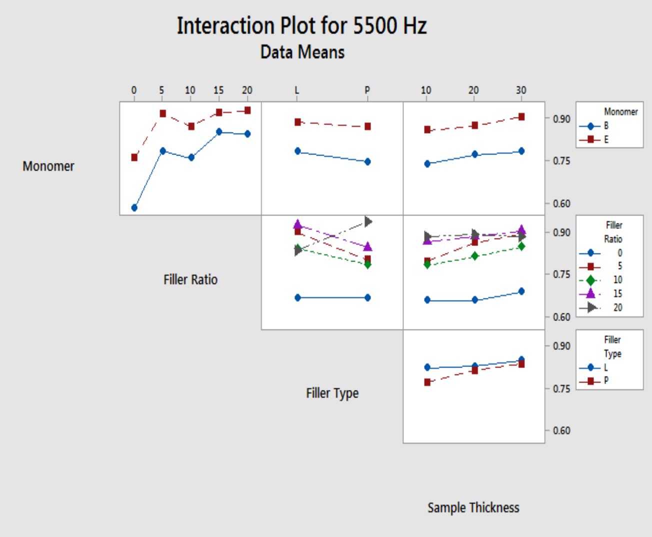

Fig. 11: Interaction plot matrix for sound absorption coefficient response, (Y2) at high frequency (5500Hz)

At higher level frequency (5500 Hz), Fig. 10 shows that there is a significant difference in the αresponse (Y2) between B and E monomer (X1) and that the highest (20%) filler ratio(X2) does appear to deliver a the highest α value. There is no main significant interaction between simple thickness (X4) and monomer (X1) and between filler type (X3) and monomer (X1). There appear to be significant main effects associated between the filler type (X3) and sample thickness (X4)indicated by the diverging line segment between sample thickness = 20 to 30mm.

IV. CONCLUSION

PUs foams fabricated with waste vegetable based bio-epoxy (B) represents an alternative renewable resource. The fabricated PUs foam based on waste vegetable oil bio-epoxy (B) gives higher moisture content (%) as compare to petroleum based synthetic epoxy (E). Regarding the coefficient of the sound absorption response, higher filler ratios and larger filler sizes are seen to increase the coefficient value of the maximum sound absorption. The latter results are seen to hold when the frequency level is low. Under high frequency level, the maximum coefficient value of the sound absorption is achieved when the experimental conditions are characterized by increased sample thickness, the presence of the highest filler ratio, and the presence of larger-sized filler. In conclusion, the study indicated that PU is a promising material for sound absorption; especially due to its high porosity and low density. In future, there is a need for scholarly investigations to determine the role of water content in shaping the PU pore structure's state of morphology, upon which the material's nature of acoustic performance could be predicted.

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