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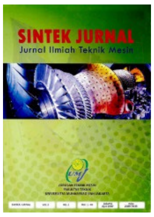

FABRICATION AND SIMULATION STUDIES ON SOUND ABSORPTION COEFFICIENT OF NATURAL MICROFIBERS REINFORCED SILICONE RUBBER

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ABSTRACT

Silicone rubber (SR) is known as stable and able to get through an extreme environment. Moreover, the combination of SR and natural fiber as the composite for the sound absorption application is still limited. For this reason, this study was aimed to fabricate the natural fiber-reinforced porous SR for the sound absorption material. Then, the composites were simulated using multilinear regression method to predict the sound absorption coefficient and its factor influence. The composite fabrication was started with the alkalization of oil palm fiber treatment. Furthermore, the porous SR were prepared using NaCl filler to form the pores. Then, the specimen containing NaCl was soaked in warm water and all specimens were dried at 110 °C to remove the remaining water. The addition of fibers enhances the density value to the highest value of 1.061 g/cm^3 with 6 wt% microfibers. The higher the microfiber addition led to the higher α value in low frequency, it occurred at SR/6 wt% microfibers with the α value of 0.356. Additionally, the most suitable equation with the smallest error is Equation 6 which has the RMSE and values of 0.05234 and 0.6138, respectively.

Keywords: silicone rubber; oil palm fiber; sound absorption; multilinear regression.

1. INTRODUCTION

A composite with the combination of natural fiber and polymeric matrix, called natural fiber-based composite has attracted the attention of many researchers in recent years. This is due to the natural fiber has a lower impact on the environment, is low-cost, lightweight, and renewable [1]–[3]. Moreover, the natural fiber-based composite using natural fibers provided some comparable results to the synthetic composite for the mechanical properties [2], [4]. The natural fiber-based composite provides a wide range application, especially sound absorption materials. The sound absorption material plays role as sound insulator that absorbs noise from the environment which produce a harmful effect on human health [5].

Noise have become more complex and a serious concern, a sound absorption material is continuously advanced to reduce noise from the environment. The sound absorption mechanism occurs when the sound hits the material, then the sound energy is converted into heat energy in the material. The suitable materials for the sound absorption are made from fiber, rubber, or other materials containing cavity or pores [6], [7]. These materials cause the air vibrating and converting the wave, then resulting the reduced and dissipated sound [6].

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Recently, several studies about the composite material made of natural fiber for the sound absorption application have been done. The Kenaf fiber reinforced urea-formaldehyde and polypropylene composite has been studied by Jayamani and Hamdan, 2013. They found that the highest sound absorption coefficient reached the value of 0.072 at 2,200 Hz for the Kenaf fiber reinforced urea-formaldehyde with 80% weight percentage and 0.6 mm fiber length [8]. Other natural fibers reinforced polymeric matrix composite which has been investigated, such as coir, broom, banana, wood, *Arenga pinnata*, and palm fibers [9]–[14]. Zulkifli et al., 2009 specifically studied the acoustical properties of pure coir and oil palm fiber without any addition of polymeric matrix. They both gave a good sound absorption coefficient at higher frequency with the value of 0.50 and 0.64, respectively [15].

The composite made of natural fiber and polymeric matrix for sound absorption material has been widely developed. The commonly used polymeric matrix for sound absorption material is polyurethane foams and silicone rubber [4], [6], [7], [12]. Silicone rubber (SR) is known as stable and non-reactive polymer which can get through an extreme environment at –60 to 300 °C [6]. The suitable form of SR for the sound absorption material is the porous type. This porous SR enhance the sound absorption compared to the solid type, as inspected by the previous researches [4], [6], [16]. Yet combination of porous SR and natural fiber as the composite for the sound absorption application is still limited. Hence, this study was focused on the fabrication of natural fiber reinforced porous SR for the sound absorption material. The natural fiber used in this study was oil palm fiber. The reason for choosing this natural fiber was due to the large number of waste from the production of palm-based cooking oil and other derivative products [17]. Additionally, palm fiber is a promising natural fiber for sound absorption material in a higher range of frequency [15], [18]. The palm fibers used were treated using alkaline followed by bleaching method before combining with the polymeric matrix to enhance the adhesion interface between fibers and matrix, the treatment made the fiber diameter smaller until microscale [19], [20]. Besides the fabrication of palm fiber reinforced SR, the composites were thoroughly investigated by modeling to predict the sound absorption coefficient and its factor influence. The modeling was carried out to overcome some drawbacks of the sound absorption coefficient testing, such as high prices and time-consuming testing.

2. METHODS

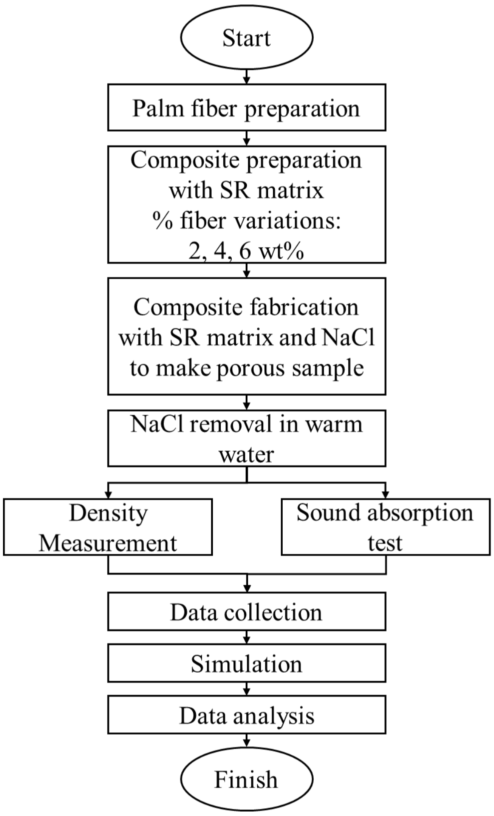


Figure 1. Research flow chart

Figure 1 shows the brief process of this research which will be further explained in the following section.

3.1 Composite Fabrication

The palm fiber is obtained from the empty fruit bunch as the waste from the palm oil industry in Sumatra, Indonesia. The empty fruit bunches of palms were prepared and washed, then dried until no water contain. The preparation began with collecting and crushing the empty fruit bunches using a mechanical crusher, continued by sieving to homogenize the size up to 280 microns. The fibers were alkalized using 2 % of natrium hydroxide (NaOH) [21], followed by bleaching using a solution mix of NaOH and hydrogen peroxide (H_2O_2). Furthermore, the treated fibers were washed until neutral and ready to be used with the polymeric matrix. The obtained fiber had a diameter size range of 51 – 60 µm.

The polymeric matrix used was silicone rubber RTV 585 pre-polymer and *Bluesil* catalyst. In order to form a porous SR, NaCl was used as the pore-forming agent or sacrificial filler. Since silicone rubber has a high viscosity, the pre-polymer was dissolved into hexane to reduce its viscosity [22], then it could be mixed with the NaCl and the palm fiber with the variation of 2, 4, and 6 wt%. After the fiber, the pre-polymer, hexane, and NaCl were homogeneously mixed, the 2 % catalyst was added. Hexane removal was carried out by heating at 30 °C for 1 hour and leaving it curing [23]. Furthermore, the NaCl removal to obtain the porous SR was to soak the resulting specimen in warm water until it floated, then dry the specimen at 110 °C to eliminate the remaining water.

After all samples were ready, the density measurement was done using ASTM D792 standard. Then, the sound absorption coefficient testing was carried out based on ASTM E1050 standard by impedance tube method with the frequency range of 125 – 4000 Hz. The specimens were prepared in 100 mm of diameter and height of 10 mm as seen in Figure 2. Additionally, the density measurement was conducted using the calculation of specimen in air and water according to ASTM D792 standard.

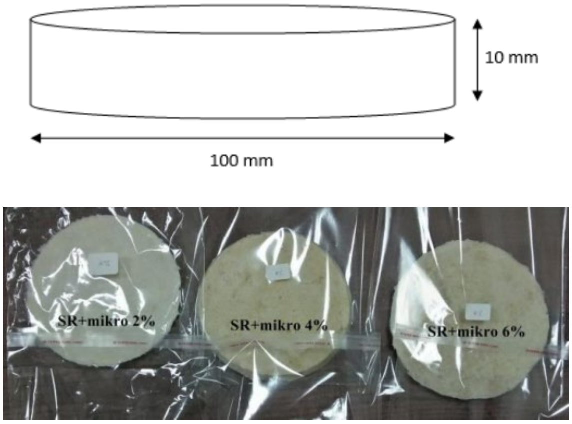


Figure 2. Sound absorption test specimen

3.2 Simulation Technique

Multilinear regression is a technique to model or to predict dependent variable from two or more independent variables [24] which formulated as follows:

$$f(x) = y = a_0 b + a_1 x_1 + a_2 x_2 + \cdots + a_n x_n + \varepsilon \quad (1)$$

where y is dependent variable; a_0 and $a_1, a_2, \ldots, a_n$ are regression coefficient of bias b and features $x_1, x_2, \ldots, x_n$, respectively. n denotes the number of features while ε refers to regression error. In this study, density d and frequency fr were used to model the sound absorption coefficient ab. Let $K(d)$ and $L(fr)$ in respective order represent the feature function of d and fr; and the featuring technique is by means of its original and squared values. This means that $K(d)$ is equal to either d or d^2 and $L(fr)$ is equal to either fr or fr^2 (see Eq. (2)).

$$K(d) = \begin{cases} d \\ d^2 \end{cases} \text{ and } L(fr) = \begin{cases} fr \\ fr^2 \end{cases} \quad (2)$$

With that, there will be four potential feature combinations to predict the absorption coefficient ab, see Figure 3. Let $M(K, L)$ is a function to estimate the absorption coefficient ab with the input of feature K and L. The regression is as follow:

$$M(K, L) = a_0 b + a_1 K + a_2 L + \varepsilon \quad (3)$$

where K and L can be either d or d^2 and fr or fr^2, respectively as explained previously. In order to find a_0, a_1, and a_2, a least square system is employed to find the minimum estimation error, that is:

$$a_0, a_1, a_2 = arg \min_{a_0, a_1, a_2} (M - \varepsilon)^2 \quad (4)$$

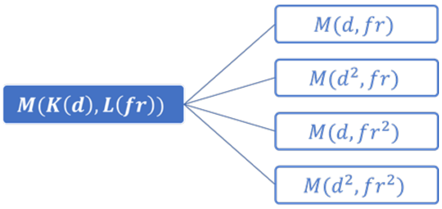


Figure 3. Potential feature combination

3. RESULTS AND DISCUSSION

3.1 Density Measurement

The density measurement of oil palm microfiber reinforced porous silicone rubber with 2, 4, and 6 % of weight percentage was displayed in Table 1. The addition of filler was found to enhance the density of the composite with increasing the filler amount (see Figure 4), as stated by previous study [25]. The highest density was achieved by 6 wt% microfiber addition with the value of 1.061 g/cm^3. Otherwise, the lowest density was obtained by neat SR of 0.952 g/cm^3. The density enhancement for every weight percentage is less significant due to the addition of the filler is too narrow.

Table 1. The effect of the weight percentage to the composite density

Specimen	Density (g/cm^3)
Neat SR	0.952
SR/2% microfiber	1.002
SR/4% microfiber	1.016
SR/6% microfiber	1.061

The neat silicone rubber exhibited a lower density than the oil palm microfiber reinforced composite silicone rubber due to the filler addition deforming the formed pores of the porous SR. The filler addition led to the shrinkage of the pores, so the density increased. This was in line with the research result of Shan et al., 2012 [26].

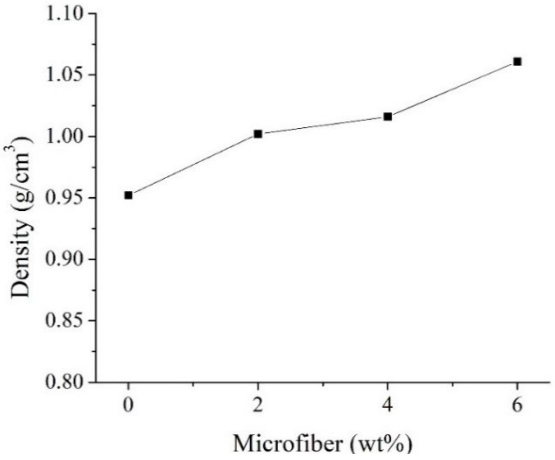


Figure 4. The effect of the weight percentage to the composite density

3.2 Sound Absorption Test

The sound absorption test was performed with the frequency range of 125 – 4000 Hz for each specimen. The result showed the sound absorption coefficient was improved in low frequency range (less than 1000 Hz) for each SR composite as displayed in Table 2. The improvement was due to the oil palm microfiber addition as mentioned in the previous study [27]. All specimens exhibited an increase in the sound absorption coefficient along with the frequency enhancement as displayed in Figure 5.

Table 2. The sound absorption test results in different frequencies

Frequency (Hz)	Weight Percentage (wt%)			
	0	2	4	6
125	0.152	0.192	0.175	0.233
250	0.266	0.281	0.268	0.269
500	0.344	0.347	0.252	0.356
1000	0.372	0.371	0.352	0.355
2000	0.403	0.414	0.395	0.413
4000	0.431	0.426	0.425	0.421

The highest coefficient at low frequency was achieved by SR/6 wt% microfiber composite with the value of 0.233 and the lowest coefficient was 0.152 for neat SR at 125 Hz. However, there is a declining coefficient value at high frequency (more than 1000 Hz) in the microfiber addition compared to the neat SR. The higher the weight percentage addition of the microfiber to the composite led to a decrease in the coefficient value. The neat SR has a 0.431 coefficient value and SR/6 % microfiber composite has the coefficient value of 0.421 at the same frequency (4000 Hz). The possible reason for this is due to the density increment with the higher microfiber addition. The density increment led to a denser composite due to the broken pores formed by the fiber addition into the matrix. So, the sound was not able to penetrate well since the pores became smaller and resulted in the reflected sound [28].

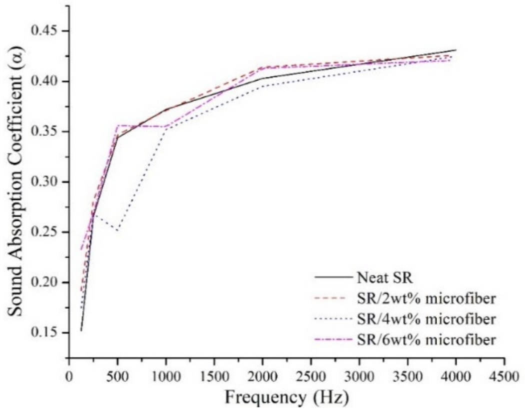


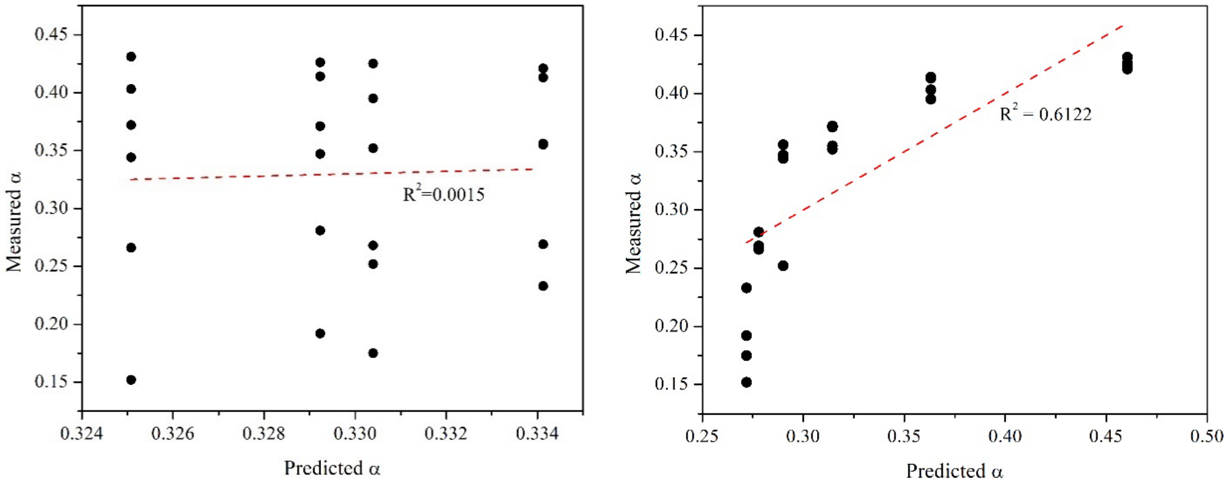
Figure 5. Sound absorption coefficient result with the increase in the frequency

3.3 Simulation

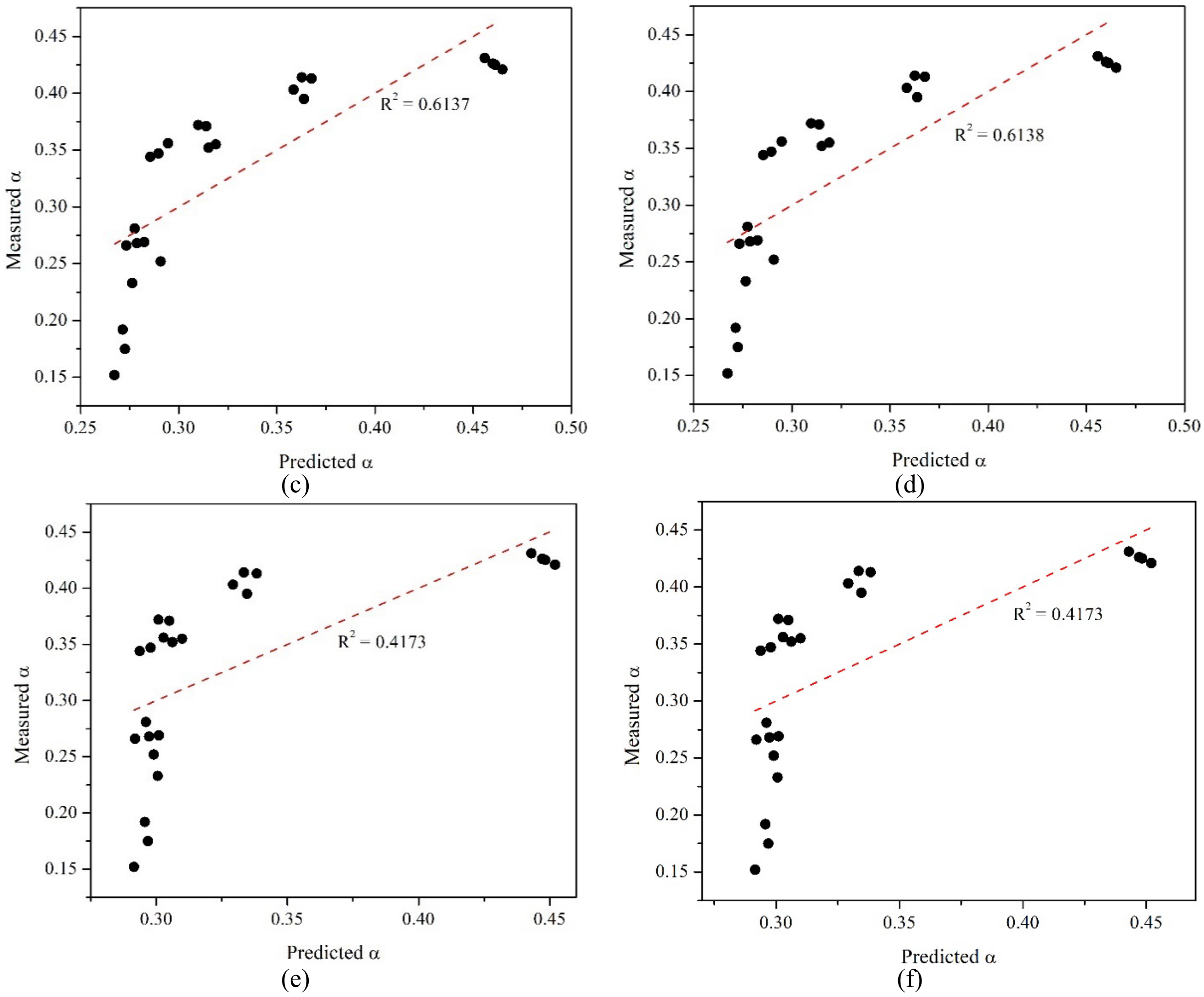
The sound absorption coefficient (α) value was predicted using multilinear regression. Thus, six types of equations were applied and observed to find the most suitable equation to estimate the α value with small error. The smallest value of *Root Mean Square Error* (RMSE) and the highest value of determination coefficient (R^2) lead to the most suitable equation to use. Equation 1 has RMSE and R^2 values of 0.08416 and 0.0015, respectively. The RMSE and R^2 values of Equation 2 are 0.05245 and 0.6122, respectively. Furthermore, Equation 3 has an RMSE value of 0.05235 and R^2 value of 0.6137. Equation 4 has RMSE and R^2 values of 0.05234 and 0.6138, respectively. Equation 5 has an RMSE value of 0.06429 and R^2 value of 0.4173, additionally, Equation 6 has the same value. This is due to the d (density) providing a less significant effect. All the RMSE, R^2, and regression coefficients are shown in Table 3. The smallest RMSE and the highest R^2 value are possessed by Equation 4. This is indicated that Equation 4 is the most suitable equation to predict the α value with small error. Moreover, the predicted α values of each equation were plotted corresponding to the measured α values as displayed in Figure 6.

Table 3. Value of a_0, a_1, a_2, RMSE, and R^2.

Equation	a_0	a_1	a_2	RMSE	R^2
Equation 1: $a_0 + a_1 d$	0.08303	0.24604	0.00000	0.08416	0.0015
Equation 2: $a_0 + a_1 fr$	$4.87 \cdot 10^{-5}$	0.26581	0.00000	0.05245	0.6122
Equation 3: $a_0 + a_1 d + a_2 fr$	0.08303	$4.87 \cdot 10^{-5}$	0.18214	0.05235	0.6137
Equation 4: $a_0 + a_1 d^2 + a_2 fr$	0.04240	$4.87 \cdot 10^{-5}$	0.22268	0.05234	0.6138
Equation 5: $a_0 + a_1 d + a_2 fr^2$	0.083023	$9.47 \cdot 10^{-9}$	0.21237	0.06429	0.4173
Equation 6: $a_0 + a_1 d^2 + a_2 fr^2$	0.08303	$9.47 \cdot 10^{-9}$	0.21237	0.06429	0.4173



(a) (b)



(c) (d)

(e) (f)

Figure 6. Prediction of sound absorption coefficient (α) using (a) Equation 1: $a_0 + a_1 d$; (b) Equation 2: $a_0 + a_1 fr$; (c) Equation 3: $a_0 + a_1 d + a_2 fr$; (d) Equation 4: $a_0 + a_1 d^2 + a_2 fr$; (e) Equation 5: $a_0 + a_1 d + a_2 fr^2$; and (f) Equation 6: $a_0 + a_1 d^2 + a_2 fr^2$.

4. CONCLUSION

The fabrication and simulation of silicone rubber composites were successfully carried out. The density of each silicone rubber composite was measured and proven that the addition of fibers enhances the density value to the highest value of 1.061 g/cm^3 with 6 wt% microfibers. The sound absorption test resulted a high α value in the low-frequency range for the silicone rubber composites. The higher the microfiber addition led to the higher α value in low frequency, it occurred at SR/6 wt% microfibers with the α value of 0.356. Moreover, in higher frequency, the α value of SR composites diminished and was lower than the neat SR. This was due to the microfiber addition breaking the pores formed in the matrix. The simulation was applied using six equations, the most suitable equation with the smallest error is Equation 6: $a_0 + a_1 d^2 + a_2 fr^2$ which has the RMSE and R^2 values of 0.05234 and 0.6138, respectively.

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