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Utilization of Styrofoam as Soundproofing Material with Auditory Frequency Range

Pemanfaatan *Styrofoam* sebagai Bahan Peredam Bising dengan Rentang Frekuensi Pendengaran

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Abstract

The utilization of bricks made of styrofoam is expectedly able to be a soundproof for noise control and as a preventive action to reduce the steadily increasing prevalence of hearing loss. This study aimed to assess the use of sound absorption material in which styrofoam was utilized to reduce the noise exposure. In this study, fine aggregates (sand and styrofoam) were made with a mixture of cement with a composition of 1:4 and 1:6, also the addition of polystyrene waste with a percentage of 0%, 20%, 40%, 60%, and 80%. Determination of acoustical property of the mixture was done by testing the sound absorption coefficient (α) using Four Microphones Impedance Tube (ISO 140-3). The results showed that the highest value of absorption coefficient was at a frequency of 800 Hz with an additional 80% styrofoam for the composition of 1:4 at 0.4100 dB and at a frequency of 800 Hz with an additional 40% styrofoam for the composition of 1:6 at 0.5870 dB.

Keywords: Noise, sound absorption coefficient, sound transmission loss, styrofoam

Abstrak

Pemanfaatan batako yang terbuat dari *styrofoam* diharapkan dapat menjadi peredam bising guna pengendalian bising dan sebagai langkah pencegahan untuk mengurangi prevalensi penurunan pendengaran yang terus meningkat. Penelitian ini bertujuan mengkaji penggunaan bahan penyerap suara dimana *styrofoam* dimanfaatkan untuk mengurangi paparan kebisingan. Pada penelitian ini, agregat halus (pasir dan styrofoam) dibuat dengan campuran semen dengan komposisi 1:4 dan 1:6, serta penambahan limbah polistirena dengan persentase 0%, 20%, 40%, 60%, dan 80%. Penentuan kemampuan akustik dari campuran dilakukan dengan menguji koefisien penyerap suara menggunakan Empat Mikrofon Tabung Impedansi (ISO 140-3). Hasil menunjukkan nilai tertinggi koefisien penyerap suara berada pada frekuensi 800 Hz dengan penambahan *styrofoam* 80% untuk komposisi 1:4 sebesar 0.4100 dB dan pada frekuensi 800 Hz dengan penambahan *styrofoam* 40% untuk komposisi 1:6 sebesar 0.5870 dB.

Kata kunci: Bising, koefisien penyerap suara, kehilangan transmisi suara, *styrofoam*

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Introduction

An 'unwanted' sound at certain amplitude that could cause discomfort and disturb is called noise.[1] In low- and middle- income countries, 80% of over 275 million people around the world suffer from noise-induced hearing loss (NIHL).[2] Although NIHL is irreversible but Hearing Loss Prevention Program (HLPP) can be implemented to prevent the damage. Employing engineering and administrative control are the innovation of the hearing conservation program for the exposure level that closes to 85 dBA which is benefited to decrease the number of NIHL.[3] A method commonly implemented in many industries is employing personal protective equipment (PPE) program only, such as providing the earmuff and earplug, in which the use of the PPE depends on the workers' behavior and habit. The PPE program only prevents the noise exposure indirectly, however, this program needs to be strictly supervised.[4]

One of the engineering controls that can be considered to reduce the noise exposure is by using a soundproofing material (noise absorbent) which will reduce the level of noise received by the workers. Some previous studies are already conducted to develop any material capable of absorbing the noise by using many kinds of natural fiber wastes, such as cotton, jute fiber, palm fiber , rice husk, rice straw, coconut husk, sawdust, rice husk powder, tea fiber leaf waste, wheat straw, glass-wool and rockwool.[5-14] However, the utilization of these fibers, particularly the glass-wool and rockwool, has health and safety impacts, such as damaging the lungs and eyes.[14] Then the utilization of the fibers has disadvantages since the natural fibers easily absorb the water and are also flammable.[15] In the previous study, styrofoam was added on a brick production and the study found that styrofoam created some air cavities within the transition zone of styrofoam and cement-sand.[16] The more styrofoam being added, the more water will be absorbed by the cavities.[16] This previous study also found that styrofoam is hydrophobic and has smooth surface which makes styrofoam suitable to be mixed with cement and sand as the aggregate. Based on these findings, it is hypothesized that styrofoam might be used as alternative material in brick production and reduce the noise since the air cavity created by the styrofoam in the brick material potentially absorbs the noise. In addition, the previous study presented that by employing styrofoam as a sound-absorbing material with a core thickness of around 30 mm and 40 mm, the absorption coefficient of 0.628 and 0.574 at 500 Hz frequency.[17] In other words, the ability in absorbing the noise was shown by using the styrofoam as the sound-absorbing material.[17]

The utilization of styrofoam can be increased by conducting a further study to produce "light brick". The ability of brick as a soundproof is expected to be used for noise control, also as the preventive action of hearing loss. Hence, the aim of this study was to obtain the appropriate material capable of reducing the noise exposure by finding the best composition of the mixture in which the styrofoam was added.

Method

This study used experimental method and primary data. Data analysis was by implementing ASTM E-1050-98 procedure to measure the sound absorption coefficient.[18] Variable measured in this study was the ability of styrofoam in a mixture to reduce noise exposure based on different composition of styrofoam in the mixture. Sound-absorbing material was developed from cement, fine aggregate, and water and the ratio of cement to fine aggregate were 1:4, 1:6, and 1:8 as a composite. The treated styrofoam wastes added to the composite were 0%, 20%, 40%, 60% and 80% of the total volume of the composite (cement and fine aggregates). The styrofoam waste has been cleaned before being added to the composite to ensure that it was free of dirt and grease which could affect the composite's quality. In addition, the styrofoam waste was also sieved to ensure that the composite met the requirements for fine aggregate referring to SNI-03-6821-2002.[1] There are three specimens on each mixture, and as a result, the total sample in this study was 45 samples. The specimens' diameter was 10 cm. The detailed composition of each specimen is shown in the Table 1.

The sound absorption coefficient test was conducted in Acoustical Laboratory of Physics, Department Faculty of Mathematics & Natural Sciences Universitas Sebelas Maret Surakarta by using ASTM E-1050-98 procedure. The absorption coefficient (α) test was conducted at 250 Hz, 400 Hz, 500 Hz, 800 Hz, 1000 Hz, 1250 Hz, and 1600 Hz. The frequencies were obtained from the test results using Impedance Tube Method.

After the styrofoam was cleaned and ready, the mix-

Table 1. The Composition of Cement and Fine Aggregate with Various Additional Percentage of Styrofoam Waste

Sample code	Cement Fine Aggregate Ratio		Additional % of Styrofoam Waste From the Total Volume of Cement and Fine Aggregate
	Cement	Fine Aggregate	
4-0	1	4	0
4-2	1	4	20
4-4	1	4	40
4-6	1	4	60
4-8	1	4	80
6-0	1	6	0
6-2	1	6	20
6-4	1	6	40
6-6	1	6	60
6-8	1	6	80
8-0	1	8	0
8-2	1	8	20
8-4	1	8	40
8-6	1	8	60
8-8	1	8	80

ing process began and included the cement, sand, and styrofoam itself. The three mixture compositions were cement : fine aggregate with ratio 1:4, 1:6, and 1:8 with a percentage of 0%, 20%, 40%, 60% and 80% styrofoam (value FAS = 0.645). This specimen fabrication refers to the requirement of acoustic testing at low frequency up to 1600 Hz. Then the absorption coefficient (α) was determined. Absorption coefficient (α) is the ratio of absorbed sound energy by the material towards total sound energy that hit the material itself. It has a range of 0 to 1. Material with α= 0 shows that material has the capability/potential to absorb 0 or reflection, and material with α= 1 shows that the material itself has the capability/potential of proper absorption, i.e. 100%.[19]

Since there were three replications on each mixture, the absorption coefficient (α) value was obtained by calculating the mean of each mixture's absorption coefficient. Then the equal variances across group of samples was determined by using Lavene test. This test is used to verify the assumption that the samples have equal variances. The ethical clearance of this study was obtained from the Ethics Committee of Faculty of Public Health, Universitas Indonesia (No.33/H2.F10/PPM.00.02/2014).

Results

Two parameters were taken to examine the acoustic capability or potential of styrofoam waste material, i.e., the sound absorption coefficient (α) and sound transmission loss (TL). The measurement of absorption coefficient (α) was performed at 125, 250, 500, 1000, 2000, and 4000 Hz frequencies. This test was carried out using an Impedance Tube.

Based on the table above, in composition of 1:4 between cement and fine aggregate, the maximum absorption coefficient (α) value was shown in sample code 4-8. In the other words, the maximum capability to absorb the noise was at which the styrofoam was added by 80% to the fine aggregate among the 1:4 composition. The maximum ability to absorb the noise was in the frequency at 800 Hz and the absorption coefficient (α) value was 0.4100 (Table 2).

On the other hand, in 1:6 compositions between cement and fine aggregate, the maximum value was presented in sample code 6-4. It means that the maximum ability to absorb the noise was at which 40% styrofoam was added to the fine aggregate. The maximum ability to absorb the noise among the 1:6 composition was in the frequency at 800 Hz and the absorption coefficient (α) value

Table 2. Absorption Ability of Styrofoam Waste Material on Mixed Composition of 1:4 and 1:6 Based on Variation of Styrofoam Addition

Sample Code	Sound Absorption Coefficient α						
	250Hz	400Hz	500Hz	800Hz	1kHz	1.25kHz	1.6kHz
4-0	0.0466	0.0288	0.3640	0.0838	0.0516	0.0644	0.0777
4-2	0.0140	0.0770	0.1540	0.2740	0.0825	0.0661	0.0992
4-4	0.0280	0.0865	0.1610	0.2580	0.0944	0.0953	0.1630
4-6	0.0179	0.0903	0.1650	0.2680	0.1070	0.1730	0.1170
4-8	0.0217	0.0781	0.1250	0.4100*	0.2050	0.1625	0.136
6-0	0.0355	0.1550	0.3130	0.2490	0.1040	0.1050	0.1950
6-2	0.0580	0.2170	0.3260	0.2760	0.1710	0.1080	0.1640
6-4	0.0392	0.1130	0.1650	0.5870*	0.2230	0.1700	0.1940
6-6	0.0792	0.2720	0.4630	0.2590	0.1580	0.2050	0.2760
6-8	0.0689	0.2200	0.2740	0.2550	0.1850	0.1600	0.2030
8-0	0.0799	0.2729	0.4139	0.1421	0.1013	0.1325	0.2272
8-2	0.0587	0.2188	0.4558	0.3539	0.1399	0.1231	0.1766
8-4	0.0858	0.3502	0.5138	0.1991	0.1286	0.1625	0.2643
8-6	0.091	0.288	0.5169*	0.318	0.1795	0.1553	0.2398
8-8	0.1292	0.2681	0.3524	0.217	0.1497	0.1677	0.2324

Notes:
*The maximum absorption coefficient (α) value

Table 3. Lavene Test Results

Source	Type III Sum of Squares	Df	Mean Square	F	p Value	Partial Eta Squared
Corrected Model	2.730a	14	0.195	3.814	0.001	0.640
Intercept	119.643	1	119.643	2340.746	0.000	0.987
Prosen_Sty	0.462	4	0.115	2.258	0.086	0.231
Composition	1.469	2	0.734	14.367	0.000	0.489
Prosen_Sty*Komposisi	0.799	8	0.100	1.955	0.088	0.343
Error	1.533	30	0.051			
Total	123.906	45				
Corrected Total	4.263	44				

was 0.5870.

Furthermore, in 1:8 composition between cement and fine aggregate, the maximum value was presented in sample code 8-6. It means that the maximum ability to absorb the noise was at which 60% styrofoam was added to the fine aggregate. The maximum ability to absorb the noise among the 1:8 composition was in the frequency at 500 Hz and the absorption coefficient (α) value was 0.5169.

The test results (Table 3) indicated that the compositions of styrofoam (1:4, 1:6, or 1:8) were significantly correlated with the ability of styrofoam to absorb the noise (p value < 0.05). In other words, the Lavene test showed that the greater the composition of Styrofoam in the fine aggregate, the better it is to absorb the noise.

Discussion

According to the results, which is in line with the results of previous studies, styrofoam material can be used as noise absorbent as proven by the findings showing that the mixed compositions of styrofoam with 1: 4, 1: 6, and 1: 8 had the potential to reduce noise. Another study declared that mixed composition of cement with fine aggregates (rice husk and sand) with 10% and 100% noise absorbent get the result of 0.42 – 0.05.[17] The absorption coefficient value of composition mixture of 10% cement, 80% sand, and 10% rice husk was 0.42, in which this value was the highest one.[20] A prior study also showed that the natural fibres, such as the rice straw and kenaf fiber, were able to wave the noise effectively. These fibers' mass and diameters had a big effect on sound absorption coefficient.[21]

The previous study on noise absorbents using coconut coir showed the average value of absorption coefficients with a composition of 20% coconut coir, 20% recycled rubber, and 25% polyurethane was 0.50.[22] While another study showed that the highest absorption coefficient in the utilization of coconut coir was 0.83 on 3784 Hz frequency with a 10 mm thickness of coconut coir.[23] Based on these studies, it could be concluded that sound-absorbing materials could be made by utilizing fibers. There are some advantages in using natural fibers instead of styrofoam since the natural fibers are recyclable, biodegradable, also less in health hazards.[24] However, the natural fibers commonly only have higher sound absorption coefficients at higher frequency range.[25] In addition, all natural fibers usually absorb the moisture, especially during the condition with high humidity.[26] In general, the natural fibers are already hydrophilic in nature and tend to absorb the water even from the air.[27]

The results of this study presented that the composition of fine aggregate and styrofoam gained the highest absorption coefficient of 0.5870 on 800 Hz frequency in 1:6 composition. Styrofoam is one of the porous absorbing materials that contain cavities, channels or intersections, so that the sound or noise is able to enter through.[28] Besides, styrofoam also has a high elastic modulus.[29] The results of this study are in accordance with the prior studies, such as study by Sinarep, *et al,*[30] finding that styrofoam with the thickness of 30 mm and 40 mm could reduce the noise and the absorption coefficient value were 0.512 and 0.719. The absorption coefficient measurement showed that the development of noise absorbent can be conducted by utilizing styrofoam. The ratio of sound absorbed by the material per total sound energy which stroke the material itself is the definition of absorption coefficient. In addition, absorption coefficient calculates how much sound is absorbed by the material and the transmission of sound through it.[31]

Sound absorption ability of a material is divided into six classes, if value of $\alpha < 0.1$, the material was not included as sound-absorbing material.[8,32] According to the results of this study, on the material without an additional styrofoam and with additional 20%, 40%, and 80% styrofoam at 1:4 composition presented that the ability of this composition in absorbing the noise could be categorized into classification D (α between 0.30 - 0.55). On the other hand, the addition of 60% styrofoam was categorized into classification C (α between 0.60 - 0.75). Moreover, on the material without additional styrofoam and with additional 20%, 60%, and 80% Styrofoam at 1:6 composition could be classified into classification D (α between 0.30 - 0.55), while the additional 40% styrofoam at 1:6 composition was categorized into classification C (α between 0.60 - 0.75). Then in 1:8 composition, either in the additional 20%, 60%, or 80% styrofoam, most of the absorption coefficient results were categorized into classification D.

Based on the findings of this study and other prior studies, the results commonly presented that fiber could be used as a noise absorbent. Therefore, fibers can be developed as simple materials for implementing the engineering control and reducing the level of noise exposure. According to a study, exposure to noise modifies the function of human body systems and organs and can be a significant factor to stress and a high blood pressure.[33] The other study also mentioned that noise can cause stress, annoyance, and sleep disturbance.[34] Hence, the development of noise absorbent also affects the improvement of public health quality. Conducting the interventions and educating the workers by the industries, insurance companies and the suppliers, providing the workers compensation are suggested to also adopt engineering control to reduce the noise exposure.[20] A further study is recommended to determine the ability of styrofoam as a noise barrier. A study also suggested that vegetation can be useful to perceived the noise barrier performance.[35]

Conclusion

In this study, the results indicate that noise absorbent material can be developed by utilizing styrofoam. The potential use of styrofoam as 'light brick' to reduce the noise is also suggested by the findings. Since styrofoam is cheaper and lighter than other synthetic materials, its utilization as noise absorbent performs a good potential.

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