Evaluation and Comparison the Properties of Acoustic Boards Made of Date Palm Fiber

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Applying acoustic panels made of natural fibers, due to their high biodegradable characteristics, light weight, low density, cheap price and non-toxicity, are proper alternatives to acoustic absorbers made of synthetic fibers. Considering their stance and vast applicability in industry, the possibility of producing them of natural palm fibers with sodium silicate adhesive of 10 and 20% in two 16 and 32 mm thicknesses, 350 and 450 kg/m^3 densities, 50 and 100 mm particles length (strands), as variable factors in 16 types of matched panels with 3 repetitions is proposed in this article. The palm-trunk discs constituted the control sample. The effect of variables on sound absorption coefficient was assessed. The effect of variable thickness and adhesive percentage on all frequencies was significant and the effect of density variable on all frequencies except 250 and 2000 Hz was also significant. The effect of particle length was significant except at the 500 Hz frequency. The effects of all variables on porosity were significant. The results of this study suggest that by applying date palm-trunk (an agricultural waste) combined with sodium silicate adhesive, industrial environment-friendly panels can be produced with proper sound absorption coefficient in the field of acoustics. This 32-mm-thick panel was composed of 80% date palm-trunk particles of 50 mm length, 450 kg/m^3 density, and 20% sodium silicate adhesive.

Keywords: Sodium silicate; Sound absorption coefficient; Impedance tube; Date Palm-trunk; Porosity

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INTRODUCTION

Today acoustic boards are widely applied and there are different types of wood panels, such as lignocellulosic and mineral-based panels. They are applied in buildings to insulate and absorb controller sound. The sound absorbers in indoor and outdoor spaces are classified in granular, cellular, and fibrous materials. Sound absorbers made of porous fibers have interconnected cavity networks and change the acoustic energy to thermal energy upon sound wave impacts (Arenas and Crocker 2010; Bansod *et al*. 2016; Rwawiire *et al*. 2017). The most popular sound insulators in the market are made of glass fibers or mineral fibers, which despite their remarkable advantages can harm people’s health and may damage respiratory and vision systems, or cause skin complications upon physical contact. Glass fibers do not cause lung complications such as lung cancer (Jawaid and Khalil 2011; Jayamani and Hamdan 2013). The acoustic panels made of natural fibers, due to their high biodegradability, light weight, low density, non-toxicity, and cheap production cost, have become an appropriate alternative to acoustic absorbers made of synthetic fibers (Asdrubali 2006; Kalia *et al*. 2009; Alsaeed *et al*. 2013; Thakur *et al*. 2014). Many studies have reported on their ability to absorb sound waves due to the spatial abundance of each of these plant resources. Researchers in Berardi and Iannace (2017) revealed that an increase in density of natural fiber samples does increase the sound absorption coefficient in the range of medium and high frequencies. As for the natural fibers of coconut, corn, and sugarcane, researchers in Fouladi *et al*. (2010) found that high-porosity samples made of these fibers increase the sound absorption coefficient rate. According to Al-Rahman *et al*. (2013), a reduction in fibers diameter in micro-porous materials such as palm and coconut fibers increases resistance to airflow and the acoustic absorption coefficient. Regarding the consumption of agricultural wastes in producing sound absorption panels, Zulkifli *et al*. (2008) found that panels made of the agricultural waste and tree bark have the proper properties in sound absorption compared with their commercial counterparts. According to Saadatnia (2005), through increasing thickness, the sound absorption coefficient of panels made of spruce wood increases up to 2000 Hz and decreases at 4000 Hz. Among the variables, both the agricultural waste consumption and density percentage are significant with respect to sound absorption performance. Abdul Latif *et al.* (2016) applied the surface fibers of the oil palm fruit to produce fine particles to make sound-absorbent panels. They introduced the porous structure and low density of fibers as a high sound waves absorption factor and revealed that the polyurethane adhesive percentage has a significant effect on sound absorption at different frequencies. Fastino *et al.* (2012) made boards from corn stalks, with a high sound absorption power. Carvalho *et al.* (2015) produced and compared sound-absorbing boards by consuming bagasse wild pine and eucalyptus fibers and found that the acoustic properties of the boards made of bagasse are higher than the other two. The experimental test results in a study run by Lamyaa *et al*. (2012) indicate that date palm fiber is one of the sound absorbers with proper acoustic properties at both the low and high frequencies and can be consumed as a substitute for commercial synthetic products. In that study, samples with different thicknesses and samples of the same thickness with different densities were tested. Moreover, samples with similar properties and different comparison durations were assessed. This sound-absorbing board is a good potential for an environment-friendly product that is economically feasible when compared with asbestos and synthetic materials based on rock wool. Thicker layer palm fibers considerably increase the sound absorption coefficient at low and high frequencies, especially after being coated by latex, which increases hardness. Due to its special climate, the south of Iran is endowed with favorable conditions for date palms growth. According to the FAO, there exists more than 28 million date palms in this region. This has made Iran one of the 10 largest date cultivating countries in the world (Fathi *et al*. 2017). Researchers in Jayamani *et al*. (2016) reveal that the waste produced per palm tree, per year is 35 kg, and this abundant source of natural plant waste cannot be overlooked by the industry. Consequently, concerning the soft nature of plants’ tissues in absorbing undesirable waves, in this case, the palm tree trunk fiber provides the possibility to assess the production of acoustic panels with mineral glue (sodium silicate) to obtain appropriate sound absorption coefficients.

EXPERIMENTAL

Materials

The date palm-trunk was obtained from Maran Ghaleh village of Jiroft, Iran. The sodium silicate adhesive Na_2SiO_3 with a density of 2.4 g/cm^3 was purchased from

SadroKavir Petro Kavir Company, Yazd, Iran, from which a solution of SiO_2 and Na_2O (silica to soda) of about 3.4 ratio in water as an alkaline (pH = 7 to 14) solution was made. The Bergamo hydraulic press (Bergamo, Italy) was applied to produce the boards, and the Shot Blast machine (SB120; Sina Sannat Company, Tehran, Iran) was applied to separate the strands. The sound absorption coefficient was measured according to ISO 10534-2 (1998) with a static wave generating device, impendence tube model Sw477 + Sw422 of BSWA Co. (Beijing, China), in the central laboratory of the Amirkabir University of Technology in Tehran, Iran (Fig. 1). To measure the required fiber density in the porosity test the pico-metric method was applied. The variable factors in providing the acoustic panel samples were board thickness of 16 and 32 mm, densities of 350 and 450 kg/m^3, particle lengths of 50 and 100 mm, and the volume of adhesive at 10 and 20%. Calculation of the three replications of 48 samples was obtained according to the content shown in Table 1.

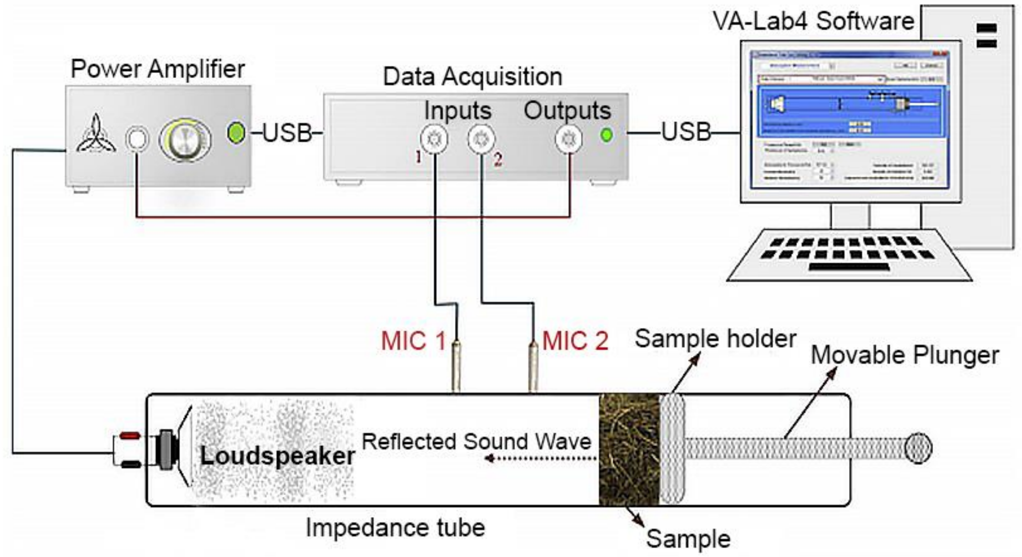

Fig. 1. Schematic of IT structural components

Table 1. The Composition of the Component of the Samples

Sample ID	Thickness (mm)	Density (kg/m^3)	Particle Length (mm)	Adhesive (%)
1	16	350	50	10
2	16	350	50	20
3	16	450	50	10
4	16	450	50	20
5	16	350	100	10
6	16	350	100	20
7	16	450	100	10
8	16	450	100	20
9	32	350	50	10
10	32	350	50	20
11	32	450	50	10
12	32	450	50	20
13	32	350	100	10
14	32	350	100	20
15	32	450	100	10
16	32	450	100	20

Production Procedure

The palm-trunk initial moisture content of approximately 40% was obtained through the weight method. The trunk was proportioned with a belt saw in timbers that were put in piles, for approximately 6 months for air drying to the moisture content of approximately 12%. The dried timbers were cut into discs of 20 cm diameter and 5 cm thickness and then fed into the shot Blast machine and mechanically converted into finer matter (Fig. 2). This fine matter first passed through sieve #8 and was retained on sieve #5. In the oven, the moisture content of the particles was reduced 3 to 4%, and the diameter of the strand was measured as between 0.8 to 1 mm. To produce these boards, first, according to Table 1, the palm-trunk particles were mixed with sodium silicate adhesive in a precise 3.4 ratio by spraying. The cake moisture was 10%. The cake was formed in the molds and initially pressed manually and covered with load aluminum foil to prevent sticking to the press plate surface. The subject cake was put under a 50 kg/cm^2 load, at 110 °C for 15 min in the press machine. The obtained samples were placed in the climate room for 2 weeks, and then the final moisture of the panels was measured through the weighting method (Fig. 3).

Fig. 2. Strands of palm-trunk

Fig. 3. The product sample

Fig. 4. The control sample

A sample of a non-processed date palm-trunk disc was applied as the control sample (Fig. 4). The tests of the sound absorption coefficient were run in the impedance tube based on the transfer function method ISO 10534-2 (1998) and the sound absorption coefficient was assessed at 250, 500, 1000, 2000, and 4000 Hz frequencies. Porosity (Ø), is a fraction of the matter mass. The porosity rate in porous materials was within the 0 to 1 range composed of air cavities, obtained through Eq. 1. The fiber density, ρ fiber, was calculated through the pycnometric method, which yielded the 1474 kg/m^3. The apparent density, ρ bulk, was extracted from produced board densities according to Eq. 1:

$$Ø = 1 - \frac{\rho\ bulk}{\rho\ fiber} \tag{1}$$

To assess the data obtained in this study, the statistical method of analysis of variance at 1 and 5% was analyzed through SPSS software (IBM Corp., Version 26, Armonk, NY, USA), and results are displayed in Table 2.

RESULTS AND DISCUSSION

The effect of research variables on sound absorption coefficient was assessed and is observed in Table 2. The thickness variable effect and adhesive percentage on all frequencies and the density variable on all frequencies except 250 and 2000 Hz were significant. The effect of the particle length variable was significant at all frequencies except 500 Hz. The thickness, density, strand length, and adhesive percentage at 1% porosity were significant. The interaction among different variables on sound absorption coefficient and porosity are given in Table 2.

Effect of Thickness on the Sound Absorption Coefficient

For the thickness variable effect on sound absorption coefficient, the results indicate that the highest effect was at the middle of 1000 and 2000 Hz frequencies, while the same at 4000 Hz frequency was reverse and as thickness increased, the absorption coefficient peak shifted towards lower frequencies. According to Hemond (1983), this drop was due to both the anatomical structure of the sound-absorbing material and the reflection of the sound waves attributed to the effect of different wavelengths and wave energies.

Table 2. Variance of Independent and Interactive Effects of Different Variables on Sound Absorption Coefficient and Porosity

Dependent Variable	Frequency (Hz)					Porosity
	250	500	1000	2000	4000	
Thickness	**.000	**.000	**.000	**.000	**.000	**.000
Density	^{ns}.175	**.000	**.000	^{ns}.820	**.000	**.000
Particle Length	**.000	^{ns}.824	**.003	**.002	**.000	**.000
Adhesive	**.000	**.000	**.000	**.000	**.000	**.000
Thickness*Density	^{ns}.412	**.000	**.000	**.000	**.000	**.000
Thickness*Particle Length	^{ns}.061	**.000	**.000	**.000	**.000	**.000
Thickness*Adhesive	**.000	**.000	**.000	**.000	**.000	**.002
Density*Particle Length	**.000	**.000	**.000	**.000	**.000	**.000
Density*Adhesive	**.000	**.000	**.001	**.000	**.000	**.000
Particle Length*Adhesive	*.018	**.000	**.000	**.000	^{ns}.167	**.000
Thickness*Density*Particle Length	^{ns}.783	**.000	**.000	**.000	**.000	**.000
Thickness*Density*Adhesive	^{ns}.783	**.000	^{ns}1.000	**.000	**.000	**.000
Thickness*Particle Length*Adhesive	^{ns}.412	**.000	**.000	^{ns}.260	**.008	**.000
Density*Particle Length*Adhesive	**.000	**.000	^{ns}1.000	**.000	**.000	**.000
Thickness*Density*Particle Length*Adhesive	^{ns}.175	**.000	*.012	**.000	**.000	**.000

** Significant at the 0.01 level * Significant at the 0.05 level ^{ns} non-significant

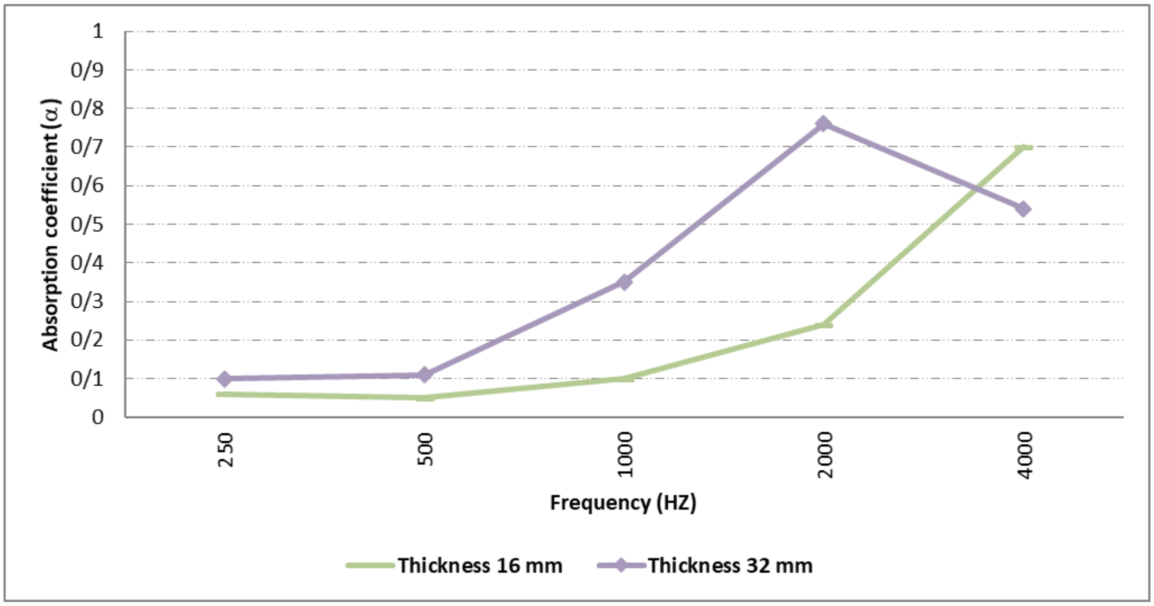

Fig. 5. Effect of board thickness on the sound absorption coefficient

As observed in Fig. 5, the sound absorption properties of boards made of date palm-trunk fibers increased considerably with an increase in frequency, in a sense that at low frequencies, low absorption coefficients, and high frequencies, high absorption coefficients were obtained. The material thickness, especially at lower frequencies, contributed to diminishing the sound energy and 450 kg/m^3 density. At 1000 and 2000 Hz frequencies, the absorbent sound absorption coefficient was 32 mm higher than that of the 16 mm coefficient (0.35, 0.76, and 0.1, 0.24) respectively; thus, at lower frequencies, the effectiveness and efficiency of absorbent materials in diminishing sound is directly related to material thickness. Researchers in Taban *et al*. (2019) and Xie *et al*. (2004) found that by increasing thickness and porosity, the absorption coefficient of the material increases. This may be due to the longer depletion process caused by thermal conductivity and viscosity between air and adsorbents in the composite being formed, which would increase the sound absorption by increasing the thickness of the composite (Mamtaz *et al*. 2016). The results of the tests run on rice straw, textile waste, glass wool, shredded rubber, felt, and polyester materials indicate that an increase in the thickness of the absorbent material would increase sound absorption especially at lower frequencies (Nick *et al*. 2002; Asdrubali *et al*. 2008; Tiuc *et al*. 2015). As observed, increased thickness of the sound-absorbing materials, whether fibrous or porous, had a similar effect on the sound absorption rate.

Effect of Density on the sound Absorption Coefficient

In this context, according to Fig. 6, the most effective absorption was observed at 500 and 1000 Hz frequencies. At 4000 Hz the situation was reversed; that is, by increasing density, the sound absorption coefficient decreased at this frequency. The relation between the pores and the material density volumes, (*i.e.*, the percentage of adsorbents in a determined volume concerning the sound absorption coefficient) was the causation of this phenomenon. The density of the subject boards revealed a dual feature against sound absorption at different frequencies. At 500 and 1000 Hz frequencies, the absorption performance was higher in boards with higher densities due to the low energy at these frequencies. Consequently, a higher volume of material per unit of the board resulted in a higher volume of absorbed energy, while in the boards with lower density, low energy waves at these frequencies passed through, which meant they were absorbed less by the matter. These findings correspond to that of Yang *et al.* (2003) and Saadatnia (2005).

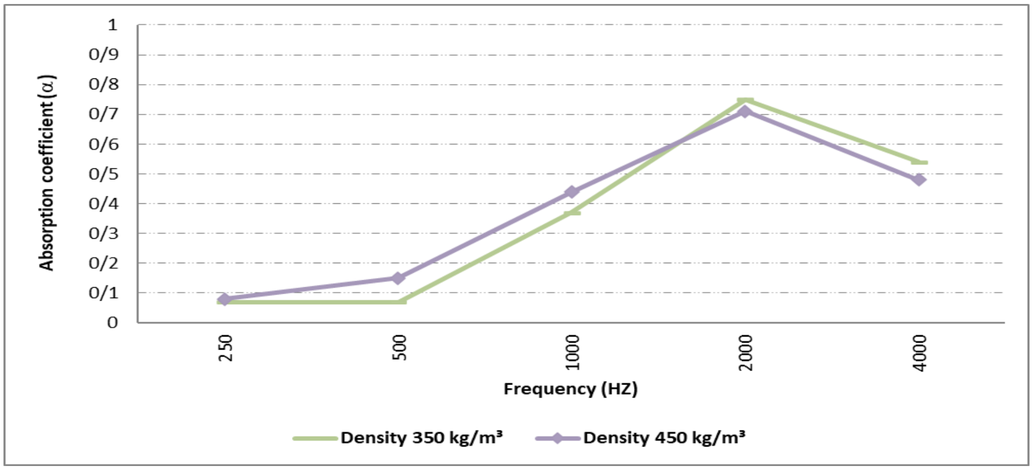

Fig. 6. Effect of density on the sound absorption coefficient

The Particle Length Effect on the Sound Absorption Coefficient

As observed in Fig. 7, the highest effect was at 2000 and at 4000 Hz the same effect was inverse, where at increased particle length, the sound absorption coefficient decreased. The results of the tests completed on the particle length indicate that boards produced with longer particles increased the sound absorption coefficient at the intermediate frequencies because the frequency of the natural vibrations of the fibers was inversely proportional to their length, and the longer the fiber length, the lower the natural frequency of the vibrations. This can dampen the energy of the co-frequency sound waves colliding therein and yield a better absorption at lower frequencies by preventing waves from entering the panel at higher frequencies.

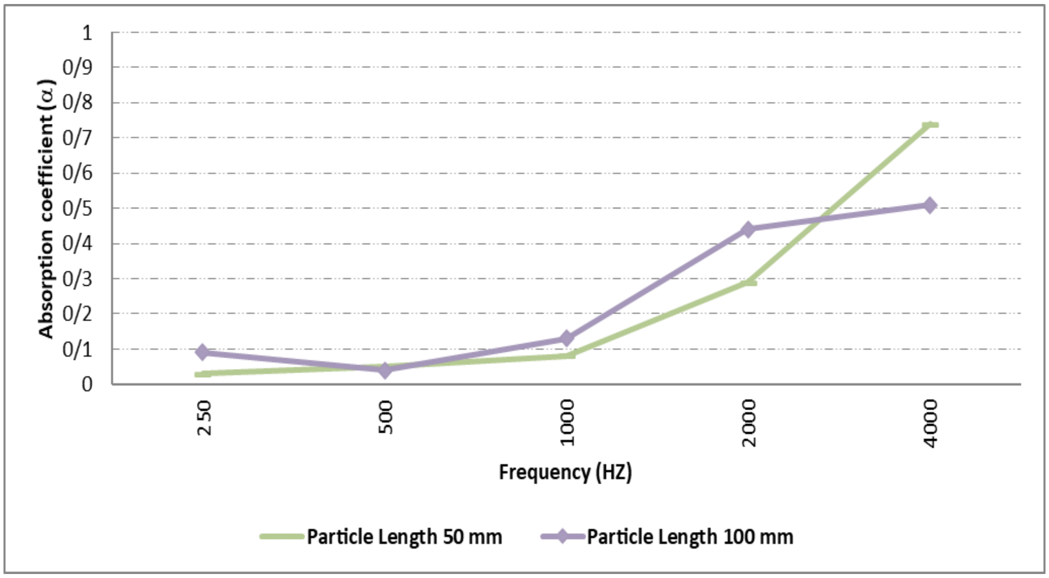

Fig. 7. The particle length effect on the sound absorption coefficient

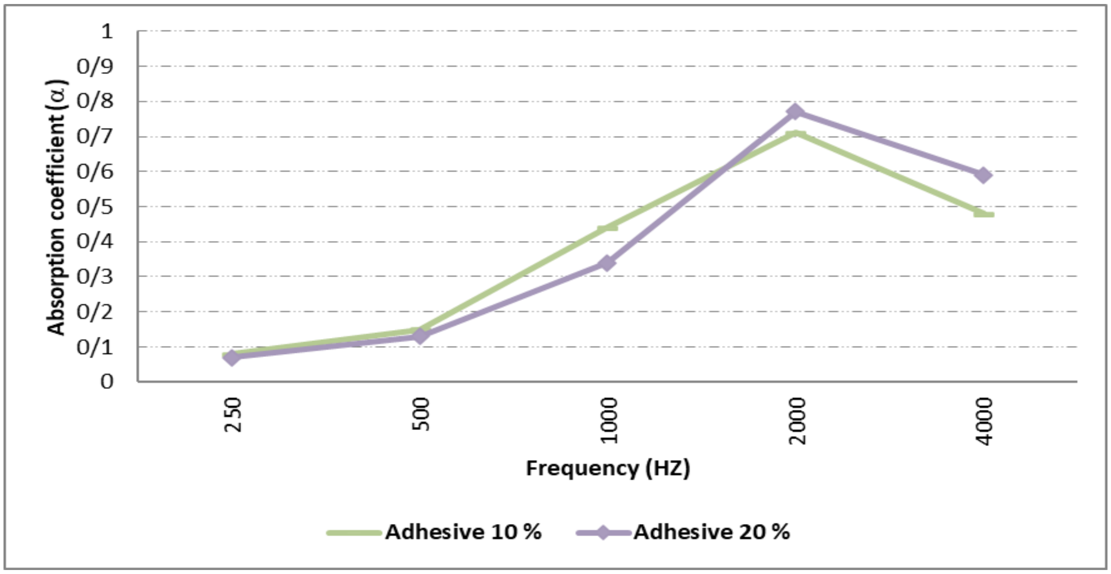

Fig. 8. The adhesive percentage effect on the sound absorption coefficient

The Adhesive Percentage Effect on the Sound Absorption Coefficient

As observed in Fig. 8, at middle frequencies of 500 and 1000 Hz, by increasing the adhesive percentage, the sound absorption coefficient decreased, and at 2000 Hz, by increasing the adhesive percentage, the absorption coefficient increased. The results obtained on the adhesive percentage indicate that an increase in the adhesive percentage at 2000 Hz led to a decrease in the sound absorption coefficient. Through increasing the percentage of adhesive, the surface acoustic impedance of the panel increased, thus, causing an increase in the impedance mismatch and reduced sound waves penetration into the panel that in turn reduced the absorption coefficient.

Porosity

In relation to the effect of variables on porosity, the results reveal that thickness, density, particle length, and adhesive percentage were significant at 1% porosity. As observed in Fig. 9, the highest porosity was that of sample #9 with a 0.77 porosity and 350 kg/m^3 density, while, the lowest was of sample #8 with 0.68 porosity and 450 kg/m^3 density.

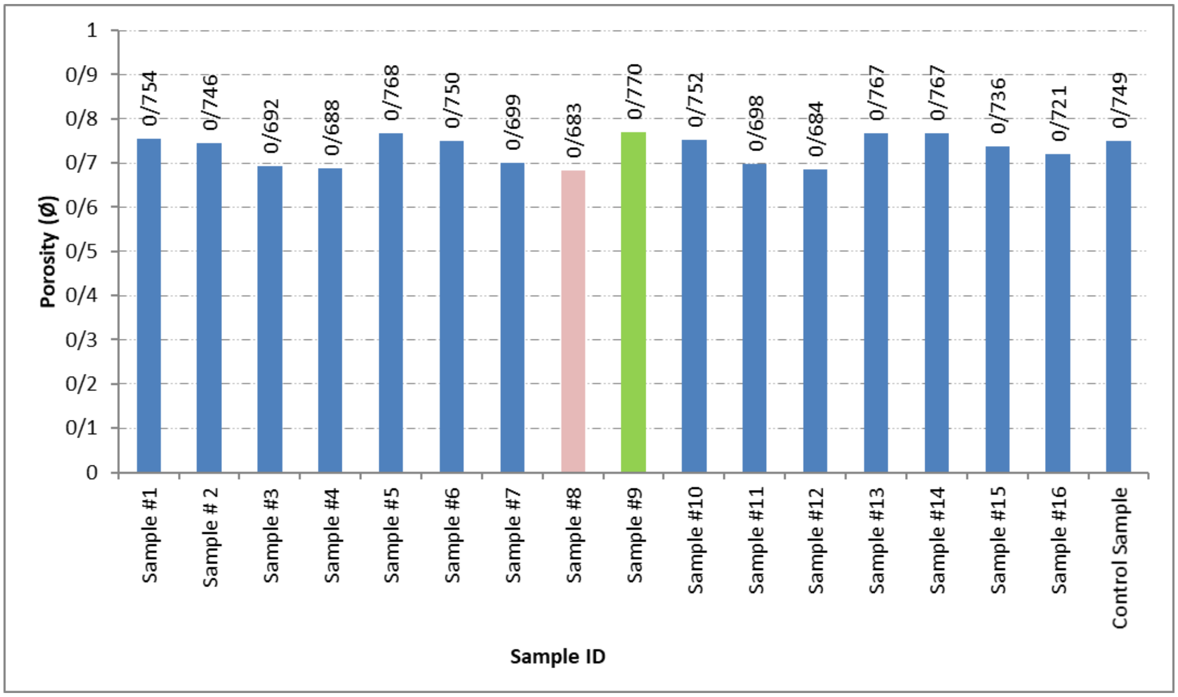

Fig. 9. Comparison of sample porosity with the control sample

According to Figs. 10 through 13, the porosity increased with an increase in particle thickness and length, and it decreased with an increase in density and adhesive percentage. As observed in Fig. 13, higher porosity (due to an increase in thickness) improves the sound absorption coefficient of materials.

For the effects of coconut, corn, and sugarcane natural fibers, researchers in Fouladi *et al.* (2013) found that an increase in porosity increases the sound absorption coefficient rate.

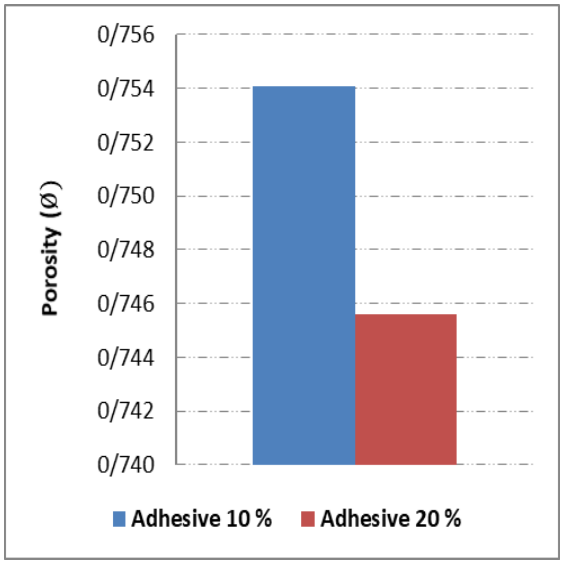

Fig. 10. The adhesive percentage effect on porosity

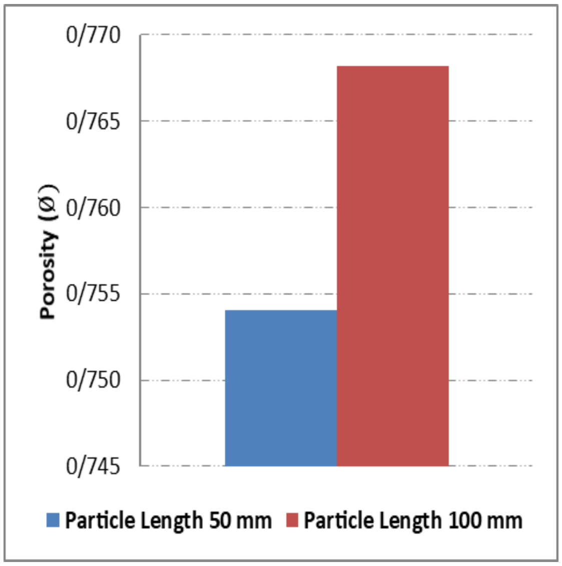

Fig. 11. The particle length effect on porosity

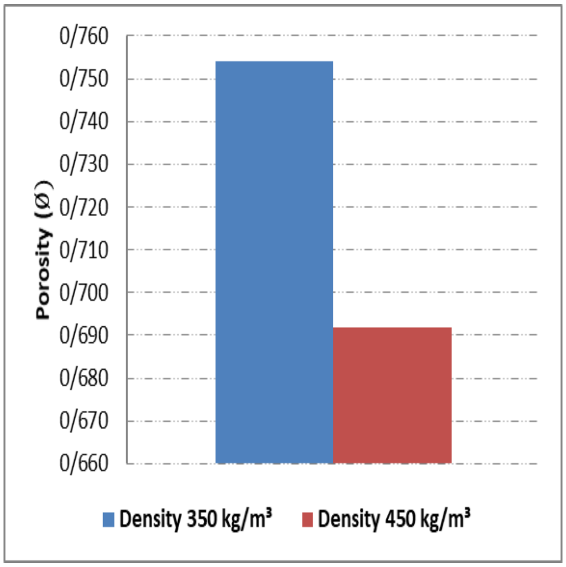

Fig. 12. The density effect on porosity

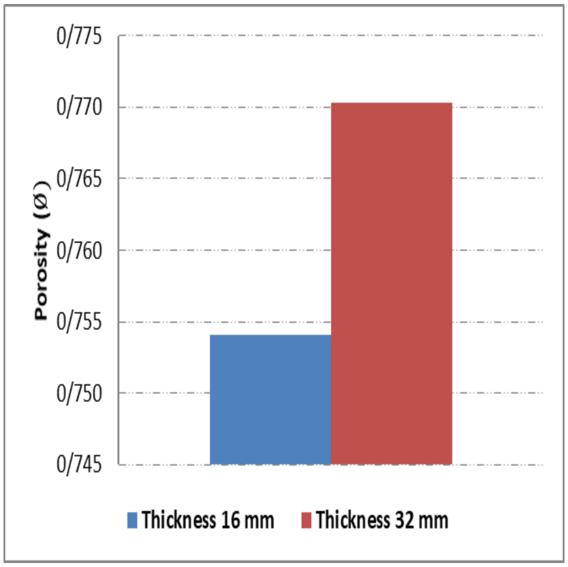

Fig. 13. The thickness effect on porosity

Sample Comparison

The noise reduction coefficient (NRC) of the boards produced in this study were compared with that of the control sample, as shown in Fig. 14. As shown, sample #12 with 450 kg/m^3 density and particle length 50 mm with adhesive 20%, with 0.38 NRC at height noise reduction coefficient outperformed the control sample with 0.24 NRC.

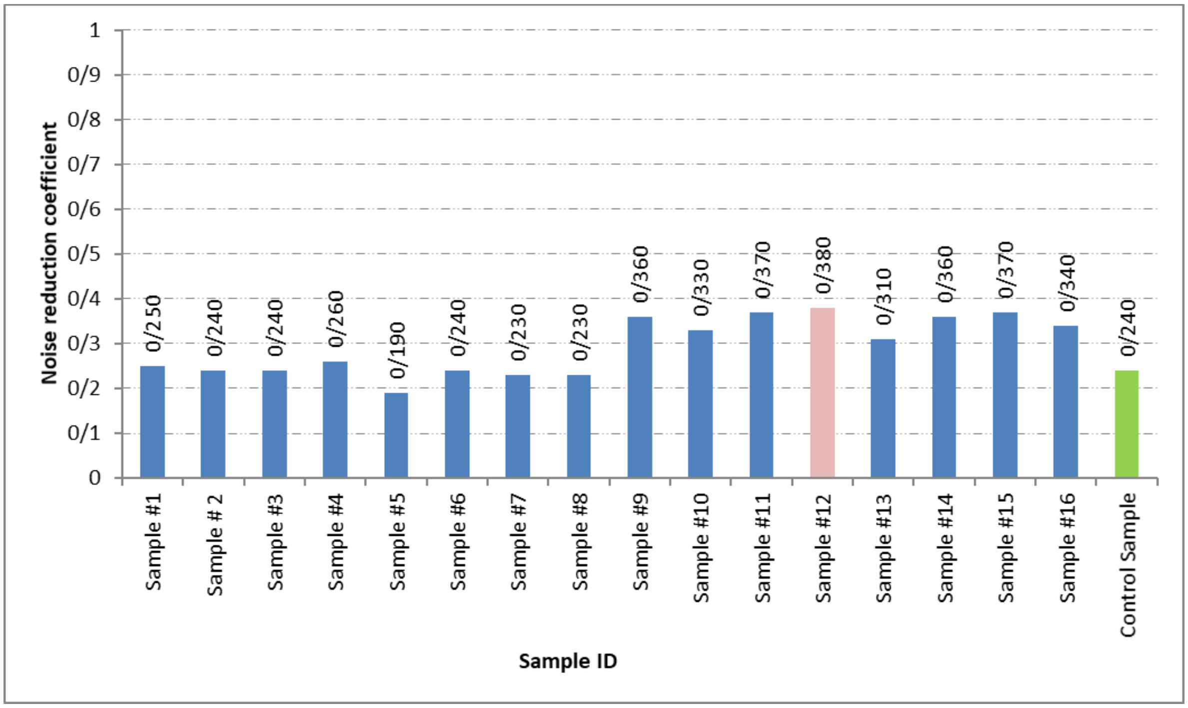

Fig. 14. Comparison of NRC of samples with the control sample

CONCLUSIONS

1. According to the procedure of making the subject panels in this experiment, an increase in the adhesive percentage leads to an increase in acoustic impedance of the panel surface, and this mismatch in impedance causes a decrease in wave penetration into the panel.
2. According to the findings, an increase in sample thickness, which is directly related to the fibrous porous absorbent, shifts the absorption coefficient towards low frequencies of about 2000 Hz.
3. According to the findings, consuming agricultural waste (date palm trunk) and mineral glue (sodium silicate) in producing samples of 32 mm thickness, 450 kg/m3 density, 50 mm particle length (strands) and 20% adhesive, would allow the production of acoustic panels with 0.38 NRC, in comparison with that of the control sample at 0.24 NRC. Moreover, this generation of acoustic panels do not pollute the environment and would lead to an increase in noise reduction coefficient by about 60%.

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