Fabricating and Characterizing Composite Ceramic Foam-Based Porous Material Utilizing a Mixture of Micro Cellulose for Sound Absorber Application

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Abstract. Fabricating porous material can be done using various raw materials, one of them uses plant-based natural fiber to form composite materials. In this research, the natural fibers of sugarcane waste are synthesized into micro cellulose. Subsequently, the micro cellulose is developed as a filler for the composite ceramic foam. The filler is used to adjust pores characteristics. Morphology characterization was carried out by employing SEM to analyze the structure, pores diameter, and pore distance of the composite. It found that the addition of 1 g of micro cellulose in sizes of 212, 425, and 630 μm into the results: pore diameters of 1.29×10^2, 1.53×10^2 and 1.67×10^2 μm and the distance between the pores is 5.4×10^2, 5.15×10^2 and 4.01×10^2 μm. Moreover, such an addition also affects the composite ceramic foam's physical properties such as the difference in water content, height/thickness, and density. The absorption performance in composite ceramic foam was assessed by acoustic impedance tubes following the procedure of ISO 10534-2. The results show that the absorption coefficients of each filler size are 63% at 2 kHz for 1 gr filler with 212 micro cellulose. Meanwhile, 68% and 73% around 1.75 kHz and 2.25 kHz are found for 425 and 630 micro cellulose respectively under the same weight.

Keywords: porous materials · acoustical properties · SEM · sound absorber

1 Introduction

The pore shapes of the porous material are very determined by the raw materials. Based on the shapes of the pores, the porous material is consisting of fibrous, granular, and cellular pores [1, 2]. Fibrous is created from fiber materials such as plants. The fabrication process requires a binder and pressure. Recently, more researchers prefer to use natural fibers because using synthetic fibers such as fiberglass, and glass wool costs

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higher and is environmentally unfriendly [3, 4]. Natural fibers are easily obtainable and readily available, therefore they can be used continuously. Furthermore, natural fibers are biodegradable (easily decomposed) into organics, environmentally friendly, and are able to be used as a composite material [5] The natural fibers that have been used for fibrous material are the kenaf fiber [6] the sugarcane fiber [7] the luffa fiber [8] the sunflower fiber [9] and the rice straw fiber [10]. Porous granular is basically made from grains-based materials such as mineral and synthetic [11]. Synthetic grains have been used many times as sound absorber material [12]. Fabricating synthetic porous material basically needs more time and also a longer process because the fabrication is more complicated and the processing still tends to be petrochemical [13]. Porous cellular is generated by the blowing agent reaction which produces latent gas pressure to push and burst air bubbles to form pores. [14, 15], kaolin, gypsum, and cement are frequently used as binders [16] Porous cellular is more formed on ceramic foam [17, 18]. It can be designed and developed for sound absorber material.

Sound absorber, can be fabricated based on three materials such as organic materials which comes from plants or animals, inorganic materials or synthetic material which comes from industrial products, and metallic material which uses metal mineral mining materials [3, 17]. Based on the results from the prior research, the ceramic foam has been designed into the ceramic foam absorber. In this research, the ceramic foam has been developed into a composite ceramic foam-based absorber. In order to make this composite ceramic foam can be the function as a sound absorber material, it needs to go through a study of absorber physical properties, such as porosity, tortuosity, fiber size, thickness, flow resistivity, density, and compression [19]. Porosity is one of the physical quantities which is very essential to determine the absorption performance in porous materials [20]. The absorber which has too high and too low porosity would not be effective for the absorption performance [15]. The too high or low porosity happens due to uneven or unbalanced pore distributions, pathway shapes, and sizes. The ceramic-based absorber has a higher density compared to the fiber-based absorber. To lower the density of the ceramic absorber, then additional filler is given which comes from the sugarcane waste. The choice of sugarcane waste is because the SCBA (Sugar Cane Bagasse Ash) has been used by prior researchers as a mixture material in ceramic making [21, 22]. The chemical compound contents in the SCBA are SiO_2 (72,3%), Al_2O_3 (5,52%), Fe_2O_3 (10,8%), CaO (1,57%), and TiO_2 (3,68%). Silica is a heat-resistant compound and is often used as a ceramic-making material [23].

Fabricating Porous Composite Foam Ceramic (PCFC) based absorber uses natural fiber as filler. This is introduced to allow the ceramic foam can have particular pore morphology and structures. It has been known that the use of natural fiber filler as a mixture material in porous material can improve absorption performance [24]. This is because the size and fiber compression can affect pore sizes/diameters created on the surface of sound absorber material [25]. While the pore shape, size, and spacing of the ceramic foam absorber affect its absorption performance [26, 27]. The research is to know the characteristics and to develop the fabrication of porous composite ceramic-based acoustic material for sound absorbers. Such an alternative porous material is expected to address twofold problems, one is related to the natural fibrous porous sound absorber, and another one is to deal with a harsh environment in which ceramic is a good composite material.

2 Methods and Experimental

2.1 Synthesis Process of Micro Cellulose

Sugarcane fiber is hydrolyzed using NaOH solution with a concentration of 4 molars then a stirrer with the speed of 450 rpm for 4 h under a temperature of 70–80 °C. The sample is washed/neutralized using distilled water until it reaches pH = 7. The sample is stored in the oven at a temperature of 60 °C for 48 h. The purpose of the hydrolysis process is to separate the hemicellulose from the sugarcane fiber [28]. Drying sample, then the bleaching process by NaOC1 solution with a concentration of 1,25% and a stirrer with the speed of 300 rpm for 45 min under the temperature of 70–80 °C After that, the sample is washed with distilled water and dried in the oven for 48 h at a temperature of 60 °C The purpose of the bleaching process is to separate or remove the lignin layer from the sugarcane fiber [29]. The dried sample then is ground and sieved into sizes of 212, 425, and 630 to create fiber and then is characterized using the FT-IR (Fourier Transform Infrared). Characterization using FT-IR is to measure the molecular vibration and the chemical compound structure in the cellulose fiber. The synthesis process of sugarcane fiber cellulose can be seen in Fig. 1.

2.2 Fabricating Process of Composite Ceramic Foam Micro Cellulose

Materials used for the porous composite ceramic foam consist of (1) Aggregate (sand silica 15%). (2) Filler (the sugarcane micro cellulose) 2%, with the purpose to adjust the pore structures, (3). Foam agent 8% ($Al_2O_3 + CaCO_3$), to create pores, (4) Binder 75%

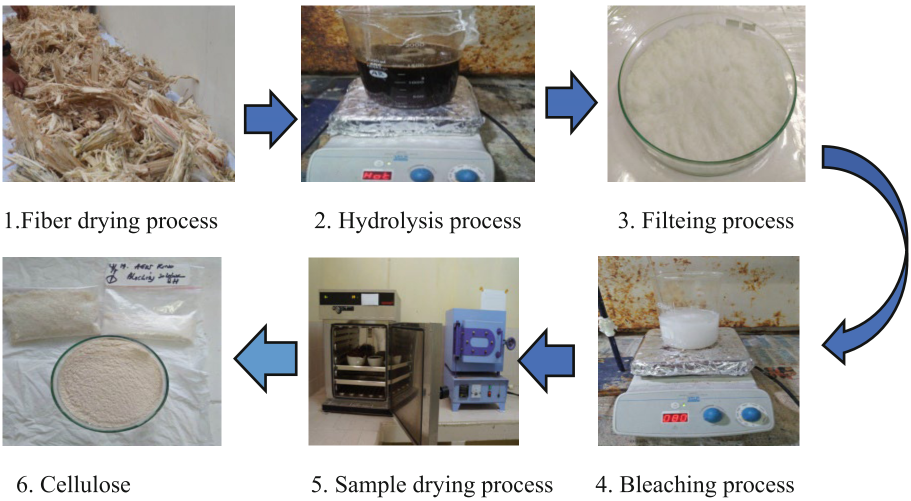


Fig. 1. The synthesis process of sugar cane micro cellulose

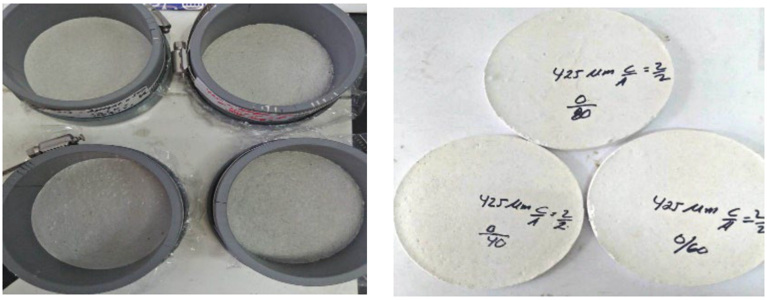


Fig. 2. The form of porous ceramic fabrication

gypsum powder ($CaSO_4.2H_2O$), and Portland Composite Cement (PCC). The purpose of additional PCC into gypsum powder is to lower the viscosity so that during the synthesis process, the ceramic paste will not dry or thicken quickly. (5) Solvent (40 ml of water). Fabricating process: mix all materials in the tube and stir until it becomes a homogeneous dough. Pour the solvent and stir until it becomes a ceramic paste, then pour the paste into a mold that has been smeared with lubricant. The purpose of a lubricant is to simplify the production process. Dry the sample by convection process for 21 days at room temperature so the water content decrease. Later, continue the drying process by forced convection and put the sample into an oven under the temperature of 60–70 °C for 72 h so the water content in the porous composite ceramic foam decrease. The form of the porous composite foam ceramic can be seen in Fig. 2.

2.3 Absorption Coefficient of Composite Ceramic Foam Micro Cellulose

The absorption coefficient of the composite ceramics foam is obtained by testing 20 mm thick samples with diameters 30 and 100 mm using the acoustic impedance tube following the standard of ISO 10534-2 as shown in Fig. 3. From this measurement absorption coefficients of 250 Hz up to 6 kHz are obtained and discussed in Sect. 3.

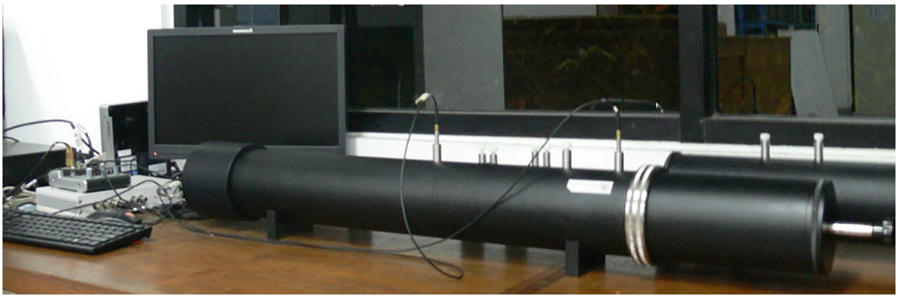


Fig. 3. Schematic measurement for obtaining the sound absorption coefficients

Table 1. Changes in water content and physical properties of the porous materials

Type of filler	Filler size micro	Initial weight (g)	Weight change/weeks (g)			Total weight change (g)	Decrease of moisture (%)	Thickness (mm)	Density (g/cm^3)
			I	II	III				
Cellulose fiber	212	210	194	185	169	41	19.5	23.0	0.254
	425	210	197	189	175	35	16.7	24.0	0.232
	630	210	200	193	182	28	13.3	26.0	0.223

3 Result and Discussion

3.1 Physical Properties of Composite Ceramic Foam Micro Cellulose

The physical properties of ceramic foam occur due to the influence of the addition and the size of the micro cellulose into the paste. The addition of micro cellulose is affecting the physical properties such as moisture, thickness, and density of the composite ceramic foam. The addition of 1 g of rough micro cellulose (630 μm) causes a low moisture drop because a rough/bigger filler absorbs more water and causes an increase in humidity of the composite ceramic foam. On the other hand, the addition of finer cellulose fiber (212 μm) which has a high density so it is more binding and makes the composite ceramic foam becomes It's of composite ceramic foam micro cellulose can be seen in Table 1.

3.2 Characterization and Morphology of Composite Ceramic Micro Cellulose

Measuring the pore morphology and structures of the Porous Composite Ceramic Foam (PCCF) was done through characterization using the SEM (Scanning Electron Microscope) by Hitachi SU 3500. The addition of sugarcane fiber micro cellulose (filler) in ceramic paste is able to affect the pore paths and shapes created in the composite ceramic foam. The filler addition in various sizes and compositions has also been produced in various pore paths and shapes. The shapes of pores and morphology of the PCCF utilizing micro cellulose fiber can be seen in Figs. 4–6.

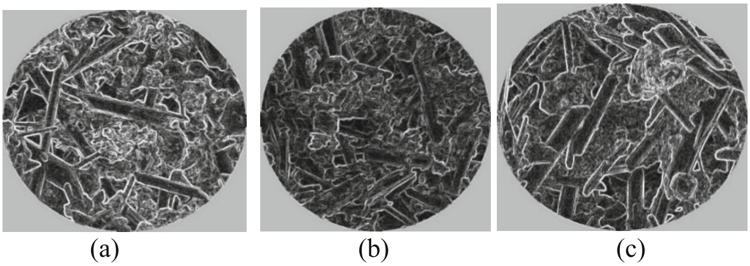


Fig. 4. The shape and path of the pores on the ceramic foam composite using micro cellulose 212 μm (a) the addition of 0.5 g, (b) 0.75 g, (c) 1.0 g.

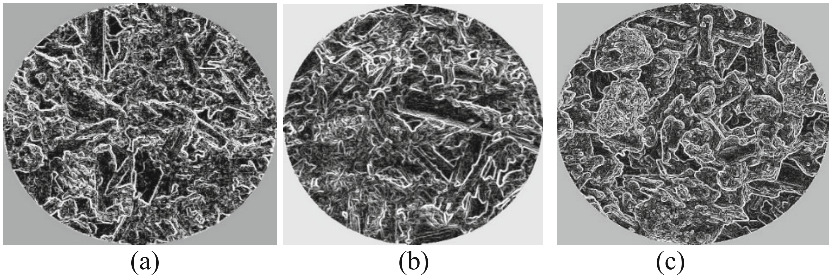


Fig. 5. The shape and path of the pores on the ceramic foam composite using micro cellulose 425 μm (a) the addition of 0.5 g, (b) 0.75 g, (c) 1.0 g.

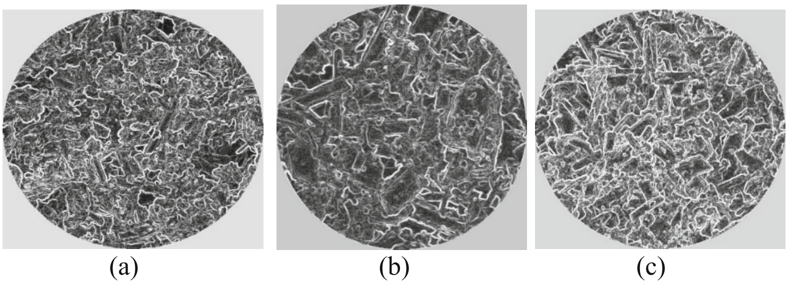
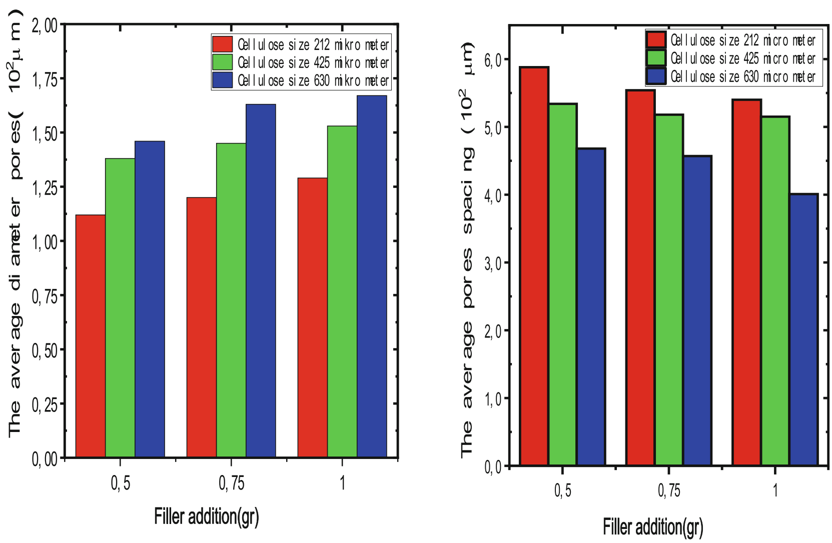


Fig. 6. The shape and path of the pores on the ceramic foam composite using micro cellulose 630 μm (a) the addition of 0.5 g, (b) 0.75 g, (c) 1.0 g.

Based on the above, the size and weight composition of sugarcane fiber micro cellulose can affect the size, distance/space, and shapes of pore paths. The use of sugarcane fiber micro cellulose in 212 μm size can produce semi-opened pores and short paths. As the composition adds to 0.75 and 1 g, the non-kinematic (closed) pores increase. Therefore, the addition of weight composition can increase the production of non-kinematic pores in the composite ceramic foam. The addition of sugarcane fiber micro cellulose in 425 μm size can also produce semi-opened pores, and filler in 630 μm size was added, the pore diameter was getting bigger and paths were also deeper and creating the dead-end pore paths. When filler was added for 0.75 and 1 g, the kinematic pore and structure production became more increasing, and made the pore formed on the composite ceramic foam surface also became denser/closer in space. The denser/closer the pore structure formed, the more paths formed and structured in the composite ceramic foam, then the higher the absorption performance would be. Pores with deeper paths give higher absorption properties because the deeper the pore paths, the bigger the attenuation energy will be. On the contrary, the small size pores with short paths will be more reflective and can decrease the absorption performance. The addition of filler into the ceramic foam is affecting the diameter and pores spacing, as shown in Fig. 7a–b.

Figure 7a–b shows that cellulose filler addition can affect the pore size/diameter. Given filler/sugarcane fiber micro cellulose in 212 μm size with 0.5 g composition into the ceramic paste, the pore size is 1.12×10^2 μm. When the filler composition increased at 0.75 g and 1 g, the forming pore sizes become bigger at 1.20×10^2 μm and 1.29×10^2 μm. The increase in pore diameter is caused by the filler/sugarcane fiber micro cellulose which affects the paste viscosity thus the air bubble production in the ceramic paste is improved and makes the pores bigger in size. The addition of sugarcane fiber micro cellulose in 630 μm size, for 0.5 g into the paste produces pore with 1.46×10^2 μm in diameter. As the filler composition increased for 0.75 g and 1 g, the produced pores are in 1.63×10^2 μm and 1.67×10^2 μm. The increasing pore size in ceramic foam is caused by the filler addition which is a solid material, therefore it affects the pore diameter/size in the composite ceramic foam. Using the mixture of a rough sugarcane fiber micro cellulose produces higher moisture or humidity due to the fiber which can keep more water content as shown in Table 1. The addition of a fine (212 μm) sugarcane fiber micro cellulose has produced small size pores with tenuous space. Small-size filler



(a) (b)

Fig. 7. (a) The filler addition with pore diameter, (b) The filler addition with pores spacing

produces small-size pores. The addition of a rough sugarcane fiber micro cellulose has produced bigger size pores with closer/denser space and a fine sugarcane fiber micro cellulose increases the paste viscosity.

3.3 Acoustic Performance of Composite Ceramic Foam

The addition of filler in various sizes and weight compositions produces also various pore sizes and shapes and results in various acoustical performances of the composite ceramic foam. The absorption coefficient performance of each filler can be seen in Figs. 8, 9 and 10.

The addition of fine (212 µm) sugarcane fiber micro cellulose for 0,5 g shows that the maximum absorption performance of the composite ceramic foam can reach up to 50%, and when the addition of this micro cellulose increased to 0.75 g, the acoustical performance is also increasing for 5% more and makes the maximum level for the

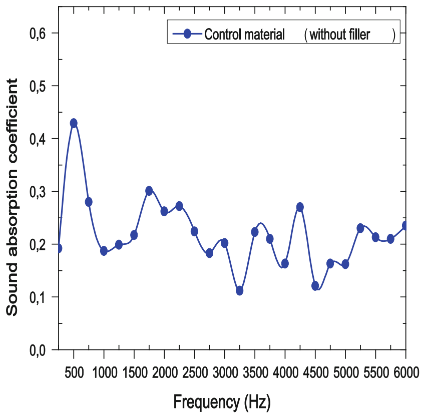


Fig. 8. Composite ceramic absorber performance without micro cellulose (filler)

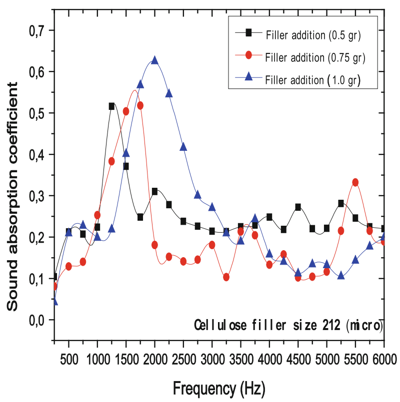


Fig. 9. Composite ceramic absorber performance using micro cellulose in 212 µm

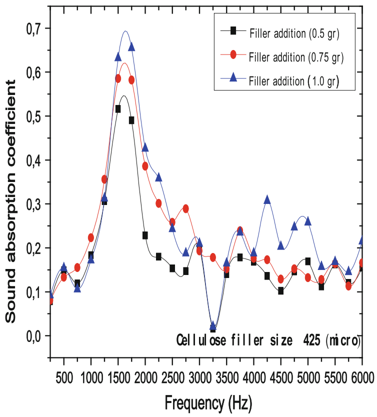


Fig. 10. Composite ceramic absorber performance using micro cellulose in 425 μm

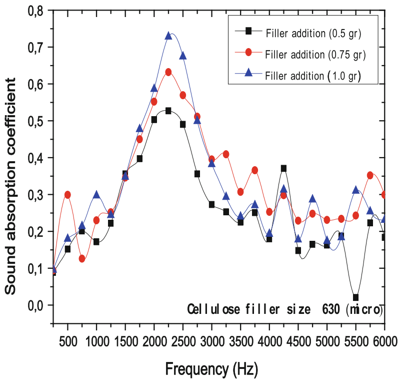


Fig. 11. Composite ceramic absorber performance using micro cellulose in 630 μm.

composite ceramic foam up to 55%. And then, when the addition is increased to 1 g, the absorption performance is also increased up to 8% more and makes the maximum level for the absorption reach up to 63% (Fig. 9). The addition of filler in 425 μm size for 0.5, 0.75, and 1 g into the paste shows an increase in absorption. The addition of 0.5 gr filler produces absorption of up to 52%. And when the 0.75 g filler is added, the absorption increases to 6% more. And the 1 g addition makes the absorption reach up to 8% more and makes the acoustical performance in the composite ceramic foam reaches up to 64%. And then when the filler in 630 μm size for 1 g was added into the paste, the composite ceramic foam shows the acoustical performance up to 75%. The more filler composition increases, the denser/closer the pores formed in the composite ceramic foam. When the sound waves propagate into the denser with longer path kinematic pores, the phenomenon of energy changing will be most likely to occur. The use of filler in 630 μm size is able to increase the opened pores with longer paths and denser/closer space. The composite ceramic foam with opened pores and long winding paths can reduce wave reflection and transmission but can also increase the absorption performance. The too-small size pore structure is not effective to absorb the propagated acoustical wave particles. The too-small in-size pores have a big resistance value which will lead to an increase in the reflective value. But the too-large pores are also less effective in detaining the sound wave-particle flows because the propagated particles inside the pores don't have frictions to change energy, therefore, they are not effective in their absorption performance inside the porous material.

4 Conclusion

To create good acoustic performance on ceramic foam composites, design the pores as closely as possible to form kinematic pores by adding filler. The open pores (kinematic pores) with a dense and long path can reduce reflective and transmission events and increases the absorption process. The addition of fillers can affect the pore structure and make the pores more dense. This research shows that the design of the absorber made of ceramic composite with a mixture of cellulose filler with a size of 630 microns and the addition of a mass of 1 g shows a better absorption coefficient than the filler with a size of 212 microns and absorption performance up to 75%.

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References

1. Cao, L., Fu, Q., Si, Y., Ding, B., Yu, J.: Porous materials for sound absorption, Compos. Commun., 10, April Ed., pp. 25–35 (2018).
2. Salissou, Y., Panneton, R.: Pressure/mass method to measure open porosity of porous solids Pressure/mass method to measure open porosity of porous solids, Journal Appl. Phys., 124913 (2007).
3. Cuiyun, D., Guang, C., Xinbang, X., Peisheng, L.: Sound absorption characteristics of a high-temperature sintering porous ceramic material, Appl. Acoust., 73(9), pp. 865–871 (2012).
4. Glé, P., Gourdon, E., Arnaud, L.: Acoustical properties of materials made of vegetable particles with several scales of porosity, 72, pp. 249–259 (2011).
5. Weidong, Y., Yan, L. I.: Sound absorption performance of natural fibers and their, *S*CTS, 55(8), pp. 2278–2283 (2012).
6. Lim, Z. Y., Putra, A., Nor, M. J. M., Yaakob, M. Y.: Sound absorption performance of natural kenaf fibers, Appl. Acoust., 130, September Ed. 2017, pp. 107–114, (2018).
7. Othmani, C., Taktak, M., Zain, A., Hantati, T., Dauchez, N., Elnady, T.: Acoustic characterization of a porous absorber based on recycled sugarcane wastes, Appl. Acoust., 120, pp. 90–97 (2017).
8. Koruk, H., Genc, G.: Investigation of the acoustic properties of bio luffa fiber and composite materials, Mater. Lett., 157, pp. 166–168 (2015).
9. Mati-baouche, N., De Baynast, H., Michaud, P., Dupont, T., Leclaire, P.: Sound absorption properties of a sunflower composite made from crushed stem particles and from chitosan bio-binder, Appl. Acoust., 111, pp. 179–187 (2016).

10. Buratti, C., Belloni, E., Lascaro, E., Merli, F., Ricciardi, P.: Rice husk panels for building applications : Thermal, acoustic and environmental characterization and comparison with other innovative recycled waste materials, Constr. Build. Mater., 171, pp. 338–349 (2018).
11. Shuai, L., Weiguo, X., Yuxiao, C., Xiang, Y.: An experimental study on the acoustic absorption of sand panels, Appl. Acoust., 116, pp. 238–248 (2017).
12. Bujoreanu, C., Nedeff, F., Benchea, M., Agop, M.: Experimental and theoretical considerations on sound absorption performance of waste materials including the effect of backing plates, Appl. Acoust., 119, pp. 88–93 (2017).
13. Berardi, U., Iannace, G.: Acoustic characterization of natural fibers for sound absorption, Build. Environ., 94, July Ed., pp. 840–852 (2015).
14. Tang, X., Yan, X.: Acoustic Energy Absorption Properties of Fibrous Materials : A Review, July Ed., (2017).
15. Chen, J. H., Liu, P. S., Sun, J. X.: Sound absorption performance of a lightweight ceramic foam, Ceram. Int. (2020).
16. Kim, H., Hong, J., Pyo, S.: Acoustic characteristics of sound absorbable high-performance concrete, Appl. Acoust., 138, October Ed. 2017, pp. 171–178 (2018).
17. Du, Z., *et al.*: The sound absorption properties of highly porous silicon nitride ceramic foams, J. Alloys Compd., xxxx, p. 153067 (2019).
18. Arenas, J. P.: Recent Trends in Porous Sound-Absorbing Materials, first edit (2010).
19. Seddeq, H. S.: Factors Influencing Acoustic Performance of Sound Absorptive Materials, Aust. J. Basic Appl. Sci., 3(4), pp. 4610–4617 (2009).
20. Leclaire, P., Dupont, T.: Acoustics of porous materials with partially opened porosity, 134(6) (2013).
21. Souza, A. E., Teixeira, S. R., Santos, G. T. A., Costa, F. B., Longo, E.: Reuse of sugarcane bagasse ash (SCBA) to produce ceramic materials, J. Environ. Manage., 92(10), pp. 2774–2780 (2011).
22. Schettino, M. A. S., Holanda, J. N. F.: Processing of porcelain stoneware tile using sugarcane bagasse ash waste, Process. Appl. Ceram., 9(1), pp. 17–22 (2015).
23. De Soares, M. M. N. S., Garcia, D. C. S., Figueiredo, R. B., Teresa, M., Aguilar, P., Cetlin, P. R.: Comparing the pozzolanic behavior of sugar cane bagasse ash to amorphous and crystalline SiO_2, Cem. Concr. Compos., 71, pp. 20–25 (2016).
24. Bulent Ekici, A. K., Bulent Ekici, H. K.: Improving Sound Absorption Property of Polyurethane Foams by Adding Tea-Leaf Fibers, Arch. Acoust., 37(4), pp. 515–520 (2012).
25. Koizumi, T., Tsujiuchi, N., Adachi, A.: The development of sound absorbing materials using natural bamboo fibers, 2002.
26. Han, F., Seiffert, G., Zhao, Y., Gibbs, B.: Acoustic absorption behavior of an open-celled aluminum foam, 36, pp. 294–302 (2003).
27. Dupont, T., Leclaire, P., Cedex, N., Panneton, R.: Acoustic methods for measuring the porosities of porous materials incorporating dead-end pores, 133(4) (2013).
28. Pereira, P. H. F., Jacobus, C., Cioffi, M. O. H., Mulinari, R., Da Luz, M.: Sugarcane bagasse pulping and bleaching: thermal and chemical characterization, 6(2005), pp. 2471–2482 (2011).
29. Daniella Mulinari, G. J., Rocha, Lúcia, M., Da, C. P.: Surface modification of sugarcane bagasse cellulose and its effect on mechanical and water absorption properties of sugarcane bagasse cellulose/ hdpe composites, 5, pp. 661–671 (2010).