

Sound Absorption Performance of Sugar Palm Trunk Fibers

*Anditya Endar Prabowo*¹, *Kuncoro Diharjo*^{1,*}, *Ubaidillah*¹, and *Iwan Prasetyo*²

¹Mechanical Engineering Department, Engineering Faculty, Sebelas Maret University, Jl. Ir Sutami No.36 A, Surakarta 57126, Indonesia

²Acoustic Laboratory, Engineering Physics Department, Bandung Institute of Technology, Jl. Ganesha No.10, Bandung 40116, Indonesia

Abstract. The purpose of this research is to investigate the effect of bulk density, thickness, and air gap to sound absorption performance on absorber based sugar palm trunk fibers. The fibers were obtained from solid waste on Small-Medium Enterprises of sago flour processing in Klaten, Central Java, Indonesia. The absorber specimens were formed from the fibers using a simple press molding in an oven at 150 °C. According to ISO 10534-2, the absorber samples were tested using two microphones impedance tube with random noise source to get the curve of the sound absorption coefficient. The result shows that the absorption performance can be improved by increasing bulk density and increasing of sample thickness. Especially at low frequencies, improvement of the sound absorption coefficient can be achieved (NAC > 0.8) by applying the air gap behind the sample. The best performance of absorber based sugar palm trunk fiber can be achieved for (1 000 to 6 000) Hz range frequency.

Key words: Acoustic material, natural fibers, sound absorption coefficient.

1 Introduction

1.1 Sound absorbers from natural materials

Noise pollution causes adverse effects on human health, i.e. bad emotions, sleep disturbances which cause daytime drowsiness, increase the risk of high blood pressure, cardiovascular disease and deafness which may be experienced by people who work in noisy environments [1]. Therefore, to meet human health needs, environmentally friendly acoustic materials are required to solve air pollution problems. In general, the sound absorber is grouped into three types, i.e. porous absorber, membrane absorber, and volume absorber [2]. While porous absorber can be categorized into three types, i.e. cellular, fibrous, and granular [3]. Fibrous is one type of absorber whose widely used. Fibrous type absorber is used in many areas including architecture, automotive industry and audio equipment [4]. The reasons for the use of fiber material are an economic factor and excellent sound absorption performance. Examples of fiber-based absorbers including

*Corresponding author: kuncorodiharjo@ft.uns.ac.id

natural material groups such as cotton (*Gossypium arboreum* L.) [5, 6], sugarcane (*Saccharum officinarum* L.) [7], wood [8], tea-leaf-fiber (*Camellia sinensis* L.) [9], rice straw (*Oryza sativa* L.) [10, 11], kapok (*Ceiba pentandra* L.) [4]; synthetic material group such as glass wool [12], polyacrylonitrile [13] and polyester [14]. Synthetic fibers have negative impacts including production processes which require large amounts of energy, causing high global warming potential [15, 16] and air pollution which irritates on eyes and skin, also cause pulmonary disease [17]. Therefore, research on natural materials is interesting research to seek alternative "green" and sustainable acoustic absorber.

1.2 Previous studies on natural fibers

Lim et al. [18] studied the absorption performance of kenaf fiber (*Hibiscus cannabinus* L.) and they found that the absorption coefficient of the fibers increased along with an increase of bulk density and thickness. For the thickness of 75 mm, the absorption coefficient reached a maximum value of 1.0 at 1 100 Hz. Putra et al. [11] studied the acoustic performance of biomass made from rice straw and absorption coefficient reaches an average value of 0.8 above 2.5 kHz. An increase in the absorption coefficient can be achieved by adding a polyester fabric to the surface. Or et al. [19] proposed noise control absorber made from oil palm (*Elaeis guineensis* Jacq.) empty fruit bunch fibers. The optimum absorption coefficient with values above 0.9 ranging from (1 000 to 1 500) Hz is achieved by 50 mm thick sample with a bulk density of 292.3 kg m⁻³. Xiang et al. [4] investigated sound absorption performance in kapok fibers. This study shows that kapok fibers have acoustic performance similar to glass wool. Moreover, kapok absorber produces a better performance at lower bulk density. Putra et al. [7] studied sugarcane waste fibers and found that sugarcane absorber with a thickness of 0.5 inches has equivalent performance to commercial synthetic fibers with the absorption of 0.65 at (1.2 to 4.5) kHz. Putra et al. [20] proposed noise control absorber made from extracted PALF (pineapple-leaf fibers (*Ananas comosus* (L.) Merr.)). PALF has an average sound absorption coefficient 0.9 at above 2 000 Hz at 20 mm thickness, while the sample with 30 mm thick has an average absorption coefficient of 0.8 at above 1 000 Hz.

This paper discusses the potential of sugar palm (*Arenga pinnata* (Wurmb.) Merr.) trunk (SPT) fiber as a sound absorber based on natural, green and sustainable material. Conventionally, SPT fiber was used as food for worms [21] and mushroom growing media [22]. Until recently, early development of research has been done on palm sugar trunk fiber as raw material in glucose production [22], reinforcement in composite production [23, 24], and a raw material of briquette production [25]. As one of the waste in the flour processing industry with abundant quantity, SPT fiber also causes environmental problem [26]. Considering the potential of the SPT fiber, this paper contributes to the enrichment of acoustic materials and the opportunity to use SPT fiber as a commercial absorber and provide the resolution of solid waste in sago flour processing industries.

2 Materials and experimental setup

2.1 Sample Fabrication

The sugar palm trunk (SPT) fibers were obtained from Small-Medium Enterprises (SMEs) of sago flour processing in Klaten, Central Java, Indonesia. The SPT was processed using shredding machine to produced palm starch traditionally and it left solid waste containing fibers. On the SMEs area, the solid waste accumulates in many places and causes unhealth-smelling pollution. In the other hand, the fiber content in solid waste is quite high, which is

around 50 %. These fibers were separated manually from the other materials. Then, the fibers were dried naturally and finally they were dried in an oven at 80 °C for 30 min to maximize the drying process. The fibers can be classified as hard fibers as shown in Figure 1.

Samples were made according to the standard size of the impedance tube measurement test. Fibers were weighed based on bulk density calculation and desired thickness. Then, the fibers were put into an aluminum mold with a diameter of 30 mm. The forming process of samples was carried out in an oven under the temperature of 150 °C for 10 min. Bulk density was obtained from fibers mass divided by sample volume. Table 1 shows the variation of sample mass, bulk density, and thickness.



Fig. 1. (a) Raw SPT fiber, (b) Example of SPT fiber absorber.

Table 1. The variation of SPT fiber samples.

Mass of sample, m (g)	Bulk density, ρ_{bulk} , kg m ⁻³	Thickness of sample, t (mm)
1.5	70 707	30
2	94 276	30
2.5	117 845	30
3	141 414	30
4	141 414	40
5	141 414	50

2.2 Experimental setup

The measurement of sound absorption coefficient was done according to ISO 10534-2 test standard [26]. The configuration of the sample on the tube as shown in Figure 2. The sample was located at the end of the tube while at the other end mounted two microphones to record the sound. Before the microphones measurement was used, they had to be calibrated first using calibrator CA115 calibrator. The sound was produced by a sound generator. The analyzer was used to process the recorded signal to get the transfer function between two microphones. Then the software BSWA VA-Lab4 basic was used to calculate the sound absorption coefficient.

The measurements were operated in the frequency range of (1 000 to 6 000) Hz. In this research, the frequency of (1 000 to 2 000) Hz was referred to as mid frequency, while the frequency of (2 000 to 6 000) Hz was categorized as high frequency. This experiment varied on bulk density, thickness, and application of air gap behind the sample. All measurements were performed three times in each sample.

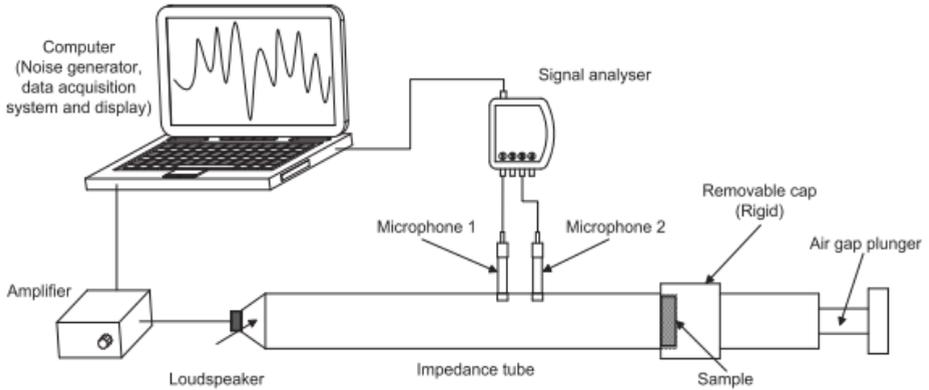


Fig. 2. Measurement setup for the sound absorption test.

3 Results and discussions

3.1 Effect of bulk density

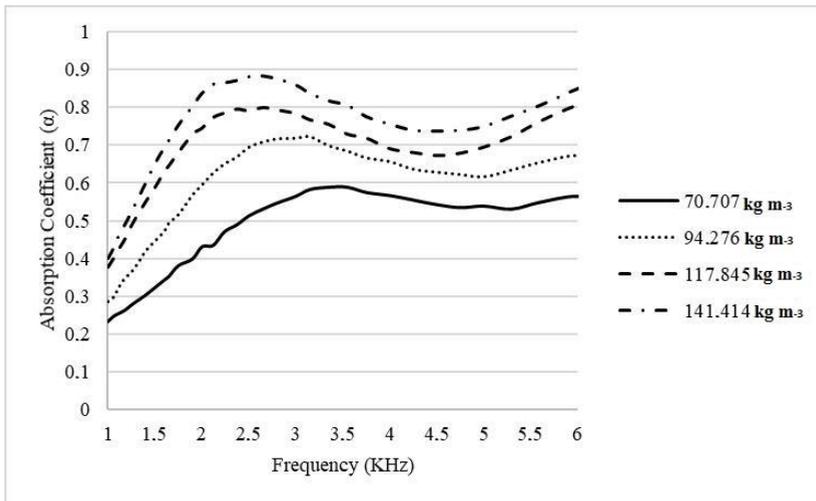


Fig. 3. Sound absorption coefficient of SPT fibers with different bulk density, ρ_{bulk} with constant thicknesses, $t = 30$ mm.

The result of sound absorption coefficient measurement on different bulk density at a fixed 30 mm thickness is shown in Figure 3. At the same thickness, it shows that higher bulk density, higher sound absorption coefficient. The improvement is obvious from mid to high-frequency range. An increase in bulk density causes an increase in flow resistivity and tortuosity [20]. The high flow resistivity enhances the difficulty level of sound waves through fibers, so more energy will be lost due to friction between sound waves and fibers.

While high tortuosity shows the level of complexity of fibers configuration in the sample. It causes more trapped sound waves and more absorbed sound waves.

3.2 Effect of thickness

The result of the sound absorption coefficient measurement varied in thickness is shown in Figure 4. In this result, samples were made with different thicknesses while bulk density was maintained at $141\ 414\ \text{kg m}^{-3}$ (bulk density with the best sound absorption coefficient from previous experiments). For the same bulk density, the measurement result shows that the sound absorption coefficient at lower frequencies increases along with an increase of sample thickness. The samples with 30 mm thick show a good sound absorption coefficient (> 0.8) and it was achieved at frequencies above 2 000 Hz. This is a special characteristic of porous absorber which has good sound absorption at high frequencies. The increasing sample thickness causes an improvement in sound absorption coefficient below 1 250 Hz.

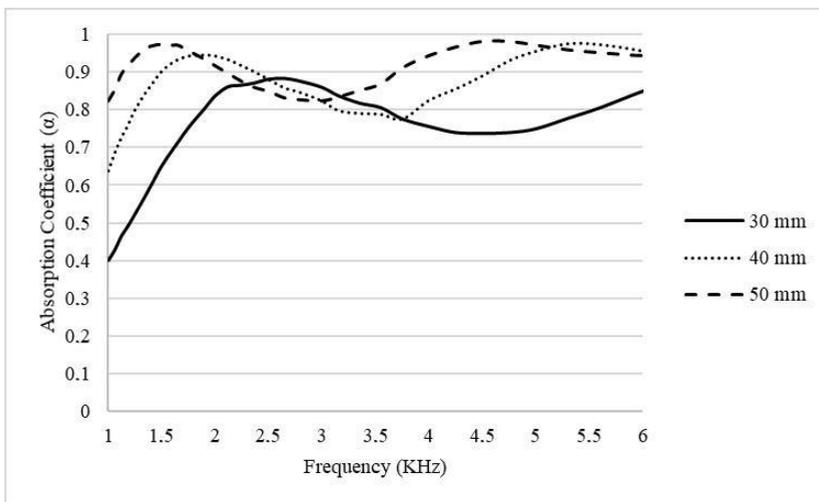


Fig. 4. Sound absorption coefficient of SPT fibers with different thicknesses, t with constant bulk density, $\rho_{\text{bulk}} = 141\ 414\ \text{kg m}^{-3}$.

3.3 Effect of air gap

This research also investigated the effect of adding an air gap applied behind the sample. The configuration of the sample in the impedance tube is illustrated in Figure 5. The sound absorption coefficient was measured using four different air gap configurations, i.e., $d = 0$ mm, 10 mm, 20 mm, and 30 mm. The application of an air gap is intended to shift the peak toward a lower frequency. However, the sound absorption coefficient above the peak frequency has decreased slightly due to the formation of peaks and dips caused by standing waves in the air gap behind the sample [18, 27]. The decline phenomenon can be seen in Figure 6.

In order to obtain good sound absorption coefficients at lower frequencies, the application of air gap is more efficient than using full-thickness absorbers. Application of the air gap can reduce the use of fiber so that the production costs can be reduced. As shown in Figure 7. sample with a thickness of 30 mm added with 10 mm air gap thickness indicates a sound absorption capability similar to a full thickness sample of 40 mm in the (1 000 to 2 500) Hz frequency range.

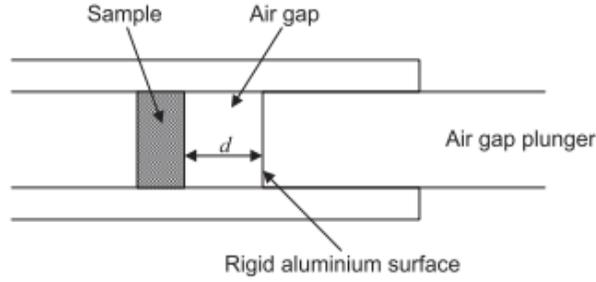


Fig. 5. Setup for air gap behind the sample.

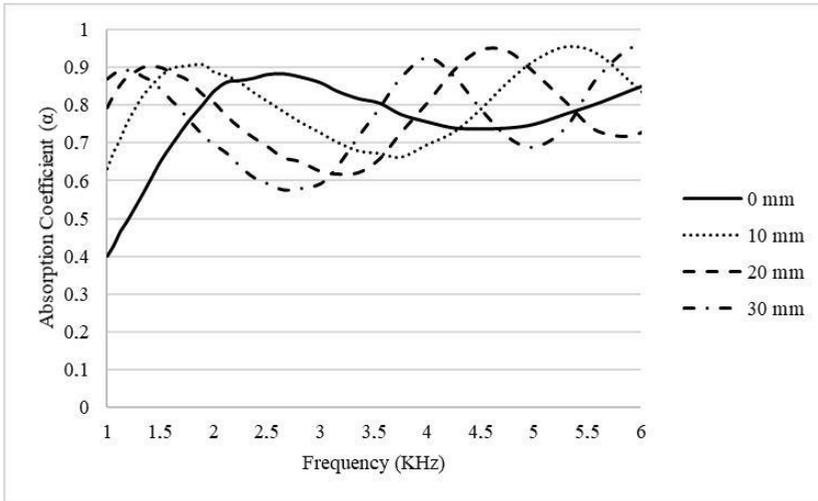


Fig. 6. The sound absorption coefficient of SPT fibers with a different air gap, d with constant thickness, $t = 30$ mm and bulk density, $\rho_{\text{bulk}} = 141\,414$ kg m^{-3} .

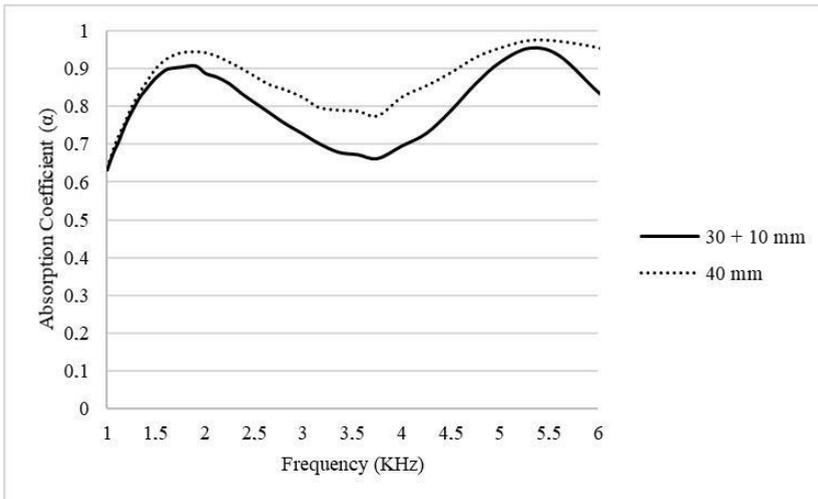


Fig. 7. Comparison of sound absorption coefficient between sample with a thickness of $t = 40$ mm without air gap and $t = 30$ mm with air gap thickness of $d = 10$ mm at the same SPT fiber bulk density of $141\,414$ kg m^{-3} .

4 Conclusion

Sound absorption performance has been investigated in this experiment. From the experiment, samples with bulk density $141\ 414\ \text{kg m}^{-3}$ have the optimum sound absorption coefficient on 30 mm thick sample with a value above 0.7 at a frequency above 1 600 Hz. This research also showed that samples with 50 mm thickness had the optimum sound absorption performance compared to samples with lower thickness with values above 0.8 at a frequency of 1 000 Hz and above. Furthermore, the sound absorption coefficient reaches 0.9 at (1 200 to 2 000) Hz range of frequency. Good sound absorbing performance at lower frequencies can also be achieved by applying the gap behind the sample. The use of air gap allows fiber usage reduction compared to full thickness samples in the same total space.

The author would thank the Ministry of Research, Technology and Higher Education, The Republic of Indonesia, especially the Directorate General of Research and Development Strengthening for support of research and publication financial by a scheme of Post Graduate Research Grant (*Hibah Tim Pascasarjana*) 2018 (0045/E3/LL/2018, 16 Januari 2018, No.4497, Kuncoro Diharjo, Universitas 11 Maret, skema PTP).

References

1. M. Basner, W. Babisch, A. Davis, M. Brink, C. Clack, S. Janssen, S. Stansfeld, *The Lancet*, **383**,9925:1325–1332(2014).
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3988259/>
2. T.D. Rossing. *Springer handbook of acoustics. 2nd ed.* Heidelberg, New York: Springer (2014). <https://www.springer.com/gp/book/9781493907540>
3. J.P. Arenas, M.J. Crocker, *Sound & Vibration*, **44**,7:12–17(2010).
<http://www.sandv.com/downloads/1007croc.pdf>
4. H.F. Xiang, D. Wang, H.C. Liua, N. Zhao, J. Xu, *Chinese J. Polym. Sci.*, **31**,3:521–529(2013). <https://link.springer.com/article/10.1007/s10118-013-1241-8>
5. D.V. Parikh, Y. Chen, L. Sun, *Text. Res. J.*, **76**,11:813–820(2006).
<https://pubag.nal.usda.gov/pubag/downloadPDF.xhtml?id=14594&content=PDF>
6. N. Jiang, J.Y. Chen, D.V. Parikh, *Bioresour. Technol.*, **100**,24:6533–6536(2009).
<https://pubag.nal.usda.gov/download/37975/PDF>
7. A. Putra, Y. Abdullah, H. Efendy, W.M. Farid, M.R. Ayob, M.S. Py, *Procedia Eng.*, **53**:632–638(2013).
<https://www.sciencedirect.com/science/article/pii/S1877705813002002>
8. A. Ashori, *Bioresour. Technol.*, **99**,11:4661–4667(2008).
https://www.researchgate.net/profile/Alireza_Ashori/publication/5780696_Wood-plastic_composites_as_promising_green-composites_for_automotive_industries_Review_Paper/links/5a324aca458515afb690c293/Wood-plastic-composites-as-promising-green-composites-for-automotive-industries-Review-Paper.pdf
9. S. Ersoy, H. Küçük, *Appl. Acoust.*, **70**,1:215–220(2009).
<https://www.sciencedirect.com/science/article/abs/pii/S0003682X0700196X>
10. H. Yang, D. Kim, Y. Lee, H. Kim, J. Jeon, C. Kang, *Bioresour. Technol.*, **95**,1:61–65(2004). <https://www.sciencedirect.com/science/article/pii/S0960852404000446>
11. A. Putra, Y. Abdullah, H. Efendy, W.M.F.W. Mohamad, N.L. Salleh, *Adv. Acoust. Vib.*, **2013**:1–7(2013). <http://downloads.hindawi.com/journals/aa/2013/605932.pdf>

12. V. Tarnow, J. Acoust. Soc. Am., **105**,1:234–240(1999).
<http://orbit.dtu.dk/files/5393908/Tarnow.pdf>
13. H.F. Xiang, S.X. Tan, X.L. Yu, Y.H. Long, X.L. Zhang, N. Zhao, et al., Chinese J. Polym. Sci., **29**,6:650–657(2011). <https://link.springer.com/article/10.1007/s10118-011-1079-x>
14. K. Kosuge, A. Takayasu, T. Hori, J. Mater. Sci., **40**,20:5399–5405(2005).
<https://link.springer.com/article/10.1007/s10853-005-4338-9>
15. F. Asdrubali, *Survey on the acoustical properties of new sustainable materials for noise control*, Paper presented in Euronoise (Tempere, Finland, 2006).
<http://www.ciriaf.it/ft/File/Pubblicazioni/pdf/1279.pdf>
16. F. Asdrubali, S. Schiavoni, K.V. Horoshenkov, Build. Acoust., **19**,4:283–311(2012).
<https://journals.sagepub.com/doi/abs/10.1260/1351-010X.19.4.283>
17. World Health Organization (WHO), *Air quality guidelines for Europe, 2nd ed.* Copenhagen: World Health Organization Regional Office for Europe (2000).
https://wedocs.unep.org/bitstream/handle/20.500.11822/8681/Air_quality_guidelines.pdf?sequence=3
18. Z.Y. Lim, A. Putra, M.J.M. Nor, M. Y. Yaakob, Appl. Acoust., **130**:107–114(2018).
<https://www.sciencedirect.com/science/article/abs/pii/S0003682X17305583>
19. K.H. Or, A. Putra, M.Z. Selamat, Appl. Acoust., **119**:9–16(2017).
<https://www.sciencedirect.com/science/article/abs/pii/S0003682X16305412>
20. A. Putra, K.H. Or, M.Z. Selamat, M.J.M. Nor, M.H. Hassan, I. Prasetyo, Appl. Acoust., **136**:9–15(2018).
<https://www.sciencedirect.com/science/article/pii/S0003682X17310708>
21. N.T. Rahmawati, J. Prodi Biol., **6**,8:447–454(2017). [in Bahasa Indonesia]
<http://journal.student.uny.ac.id/ojs/index.php/biologi/article/download/7882/7508>
22. D.A. Herawati, L. Wijayanti, *Produksi Glukosa dari Limbah Padat Industri Pati Aren Menggunakan Trichoderma sp.*, [Glucose production from solid waste Aren starch industrial using *Trichoderma sp.*], paper presented in Seminar Nasional Teknologi Kimia, Industri dan Informasi, (Makassar, Indonesia, 2015). [in Bahasa Indonesia]
<http://docplayer.info/39546086-Produksi-glukosa-dari-limbah-padat-industri-pati-aren-menggunakan-trichoderma-sp.html>
23. M.B.N. Rahman, B. Riyanta, K. Diharjo, J. Ilm. Semesta Tek., **14**,1:26–32(2011). [in Bahasa Indonesia]
<http://journal.umy.ac.id/index.php/st/article/download/567/713>
24. Wijoyo, A. Nurhidayat, *Kajian Ketangguhan Impak Komposit Sandwich Serat Aren-Polyester dengan Core Gedebog Pohon Pisang*, [Toughness study of composite impact of Aren-polyester fiber sandwich with banana tree Gedebog Core], Simposium Nasional RAPI XII, (Surakarta, Indonesia, 2013), Proceedings Simposium Nasional ke-12 RAPI 2013 12:111–116. [in Bahasa Indonesia]
https://publikasiilmiah.ums.ac.id/bitstream/handle/11617/4035/M18_TM30_2_Wijoyo_UNSA.pdf?sequence=1&isAllowed=y
25. E. Pamungkas, M.R.A. Cahyono, Y. Prisusatyo, Y.I. Yuraida, Y.T. Karunawardani, *'Briquette La Bendo', Pemanfaatan Limbah Ampas Onggok Menjadi Bisnis Briket sebagai Pemberdayaan Masyarakat Dusun Bendo Desa Daleman Kecamatan Tulung Kabupaten Klaten*, ['Briquette La Bendo', Utilization of Onggok dregs waste into a briquette business as community empowerment in Dusun Bendo, Daleman Village, Tulung District, Klaten Regency] (Makassar, Indonesia, 2013), e-Proceeding PIMNAS 2013. [in Bahasa Indonesia]
<https://media.neliti.com/media/publications/170101-ID-briquette-la-bendo-pemanfaatan-limbah-am.pdf>

26. M. Firdayati, M. Handajani, *Jurnal Infrastruktur dan Lingkungan Binaan*, **1**,2:22–29(2015). [in Bahasa Indonesia]
https://www.researchgate.net/profile/Marisa_Handajani/publication/266584054_Jurnal_Studi_Karakteristik_Dasar_Limbah_Industri_Tepung_Aren_1/links/54c90c7b0cf25087c4ec4128.pdf
27. L.Z. Ying, A. Putra, M.J.M. Nor, N. Muhammad, *Sound Absorption of Multilayer Natural Coir and Kenaf fibers*, paper presented in The 23rd International Congress of Sound and Vibration, (Athens, Greece, 2016).
<https://ukm.pure.elsevier.com/en/publications/sound-absorption-of-multilayer-natural-coir-and-kenaf-fibers>