Plant based natural fibers and it's composites as ecofriendly materials in acoustics A review

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Abstract:

Sound pollution, or extraneous sound or noise, is rising due to rapidly expanding urbanisation and industrialization. Traditionally, sound-absorbing materials used in industry and research, such as glass fibre, mineral wool, expanded polystyrene, rubber, and plaster, are used to reduce noise pollution. Although glass fibre and mineral wool have extraordinarily high sound absorption coefficients (SAC), they are poisonous and dangerous to both humans and other animals. Conventional fibre consumption is linked to health issues such as mesothelioma, lung cancer, bronchitis, asthma, and skin irritation. This makes sound pollution an imperceptible threat to the environment, as well as to people and other living things on land, in the air, and in water. The agroclimatic of the world is highly varied, with a wide variety of crop varieties that are easily accessible and abundant in nature. These include fruit trees, vegetables, ornamental plants, root tubers, medicinal herbs, aromatic plants, spices, weeds, and plantation crops. The leftovers from agricultural products, such as fruit peels, leaves, tree bark, stalks, fruit brunches, and a host of other components, irritate the environment as solid waste and raise concerns about societal cleanliness. Researchers are addressing the two issues of sound pollution and the disposal of green solid waste by creating biodegradable, environmentally friendly materials that are less hazardous and harmless than conventional materials. Fibre extraction techniques that are frequently employed include mechanical decortications, chemical extraction, water retting, and manual extraction. Retting and decortication are typically the first steps in the fibre extraction process. The above-mentioned methods of extraction are chosen based on the portions of the plant from which the fibre is to be removed. The qualities and properties of individual or composite fibres extracted from a certain plant section are administered by the extraction procedure. This study examines the sound-absorbing coefficient (SAC) of natural fibres that are taken from different plant components, primarily agricultural waste, as well as their composites and uses as environmentally acceptable sound-absorbing materials.

Keywords: agroclimatic, sound pollution, glass fiber, retting, sound absorption coefficient (SAC)

Introduction:

Modern world is at serious risk of Global warming. The pollution of light, sound, water and air are some key factors responsible for it. Sound pollution is an invisible threat to human beings and wildlife on land, air and water. The undesirable or disturbing sound which exceeds 85 decibels causes a sound pollution and professes the health and well-being of humans and other organisms. Rapidly growing urbanization and industrialization increases the sound pollution, which impacts millions of peoples, animals and environment daily. It is causing serious health problems like hearing loss, high blood pressure, heart disease, sleep disturbances and stress in all age groups of humans.[1] The communications in animals, birds and fishes are done using sound. In case of birds and fishes the routine tasks like navigating, finding food, attracting mates, and avoiding predators are done using sound. Due to unnecessary and undesirable sound i.e. sound pollution these routine tasks are becoming more difficult and complicated for them. This has created a question of their survival. In aqua life the oil drills, sonar devices, tests of missiles and seismic tests have made the peaceful marine environment loud and chaotic. Due to this, species like whales and dolphins have altered their behaviour and are endangered. To reduce sound pollution in the living environment as well as wild life is very difficult and complicated but can be minimized by use of conventional fibers like glass fiber, mineral wool, expanded polystyrene, rubber and plaster as sound absorbing materials in the industry and research.[2] Most of the natural fibers are potentially ideal as sound absorption materials to absorb sound wave energy to minimize the effects of sound pollution. Natural fibers have been known as green materials by virtue of biodegradability, excellent sustainability, abundance and renewable energy. Apart from that, the manufacturing of natural fibrous sound absorbers involves a significantly lower carbon footprint compared to conventional synthetic sound absorbers.[4] India is the second largest producer and consumer of fruits and vegetables in the world. It generates million tons of fruit and vegetable waste per year.[5] Fruit Peel (FP) and vegetable waste are produced on a large scale in domestic, food processing and agriculture industries. These large quantities of waste food commodities are causing serious environmental problems as they decompose in landfills and emit harmful greenhouse gases.[6] In acoustic engineering acoustical material plays various of roles like control of room acoustics, industrial noise control, studio acoustics and automotive acoustics. The fibers are used as interior lining for apartments, automotive, aircrafts, ducts, enclosures for noise equipment and insulations for appliances[7].These techniques requires high energy input, chemical and/or enzymatic fiber pre-treatments , so scientists are focusing on development of eco-friendly synthesis of biodegradable natural fiber.[8] Cellulose fibers have attracted attention of researcher due to their low thermal expansion, high aspect ratio, strengthening effect, good mechanical and optical properties. Cellulose fibers are abundant in natural, renewable, biodegradable polymers as the main structural constituent present in a wide variety of living species including plants, animals, and some bacteria. Natural fibres are made of lignin, cellulose, and hemicelluloses.[9]Various agro-industries generate large amounts of cellulosic waste yearly.The chemical treatment of raw material with alkali and bleach , breaks intermolecular and intramolecular hydrogen bonding between the hydroxyl groups of cellulose and hemicellulose and helps to obtain pure cellulose.[10] This helps to increase the hydrophilicity of fibres. This cellulosic fiber is an interesting, actively researched, starting material for production of cellulose nanocrystals for use as reinforcement in different polymer matrixes. Different listed applications of cellulose fibers are as nanocomposites, textiles, paper making, coating additives, security papers, food packaging, gas barriers and sound absorbing materials as important renewable chemical resource to replace conventional fiber materials.[11]

Classification of natural fibers:

Natural fibers are a type of hair-like material which are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. These fibers are easily available, biodegradable and renewable in nature. In general, natural fibers are classified based on the origin, and further categorised based on part of the plant from which they are extracted. The following table illustrates the classification of natural fibers.

1. Seed
2. Leaf
3. Stalk
4. Fruit
5. Skin

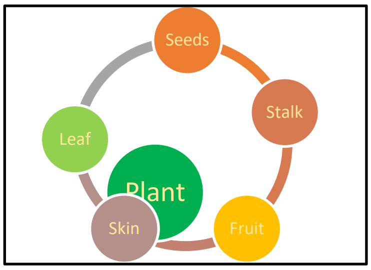

Fig.1 **C**lassification of natural fibers

Fiber extraction methods:

Selection of appropriate method of extraction plays very important in controlling size and area of natural fiber. Natural fibers can be synthesised by using chemical or physical (mechanical) methods. Mechanical process includes high pressure homogenization, ultrasonication, and ball milling methods. Chemical process commonly uses acid hydrolysis and alkali hydrolysis.[12] Most common synthesis method used is water retting.

1.Hand scraping
2.Water retting
3.Ball milling
4.Steam explosion
5.Chemical
6.Mechano-chemical

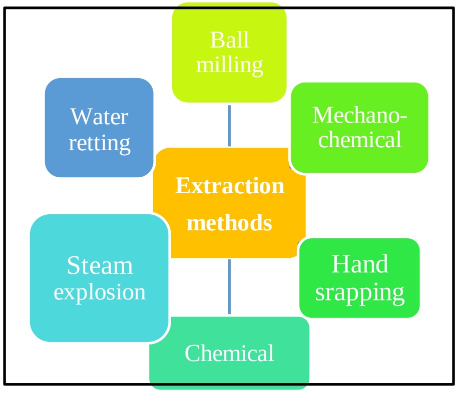

Fig.2 Fiber extraction methods

Factors affecting the acoustical properties of materials:

Commercial acoustical panels are made from synthetic fibers such as glass fiber which are hazardous to our health as well as to the environment, and quite high priced so, researchers are paying more attention to natural fibers as alternative materials with a combination of high acoustic and thermal properties. The size, diameter, tortuosity, thickness, porosity and density of fiber affects the acoustical properties of material.[13]

1.Porosity – The number, size and type of pores present in the material plays important role in sound absorption mechanism in porous material. More the number of pores on the surface of the material more the sound gets dampened by friction. The porosity of a porous material is defined as the ratio of the volume of the voids in the material to its total volume. [14]

2.Diameter- As thin fibers can move more easily than thick fibers on sound waves, it has shown that fiber diameter decreases, the sound absorption coefficient of the material increases. Also, the fine fiber content increases sound absorption coefficient due to an increase in airflow resistance by means of friction of viscosity through the vibration of the air. [15]

3.Tortuosity - A measure of the elongation of the passage way through the pores, compared to the thickness of the sample is called tortuosity. Tortuosity describes the influence of the internal structure of a material on its acoustical properties [16].The high frequency behaviour of sound absorbing porous materials is also determined by the value of tortuosity.

4.Thickness – Several studies in porous materials significantly showed a direct relationship between low frequency sound absorption and thickness of the material. The thumb rule states that effective sound absorption of a porous absorber is achieved when the material thickness is about one tenth of the wavelength of the incident sound [17]. At low frequencies there was increase of sound absorption as the material gets thicker, at higher frequencies thickness has trivial effect on sound absorption. [18].

5.Density – Density is one of the important factors that governs the sound absorption behaviour of the material. When the apparent density of the material is large, the number of fibers per unit area increases. The cost of an acoustical material is also directly related to its density. There is increase of sound absorption value in the middle and higher frequency as the density of the sample increased. Less dense material with more open structures sound of low frequencies (500Hz) and denser the structure absorption of the frequencies above 2000 Hz. [19]

1. Porosity
2. Diameter
3. Tortuosity
4. Thickness
5. Density

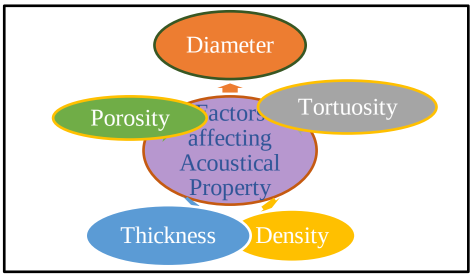

Fig. 3 Factors affecting the acoustical properties of materials

Characterization techniques:

The extracted fibers were characterised by XRD, SEM, TEM, FTIR, TGA to analyse different parameters to decide its use as effective sound absorbing material.

1. (FT-IR) spectroscopy - Structural analysis by Fourier transforms infrared
2. (TGA) Thermogravimetric analysis -Thermal analysis
3. SEM - Morphological Studies by the images
4. X-Ray Diffraction Studies -The phase behaviour
5. Mechanical properties - Tensile strength, Young's modulus, elongation at break, and energy at break
6. (EDX) Energy dispersive X-ray spectroscopy - To identify elements (Carbon, Oxygen, and Nitrogen, etc.) present in natural fiber

Individual fibers:

1.Kenaf fiber:

Francesco D'Alessandro et.al. studied the samples made up of kenaf fiber extracted by mechano -chemical method, from stems two types of fibres, a coarser one in the "bast", and a finer one in the "core" were produced. Bast fibres (about 35 %) are suitable for paper, textiles and rope; core (about 65 %) is usually used as a biomass or it can be reduced to particles and bonded into panels similar to particle board. This exhibited an averaged absorption coefficient equal to 0.85 in the 500-5000 Hz range and equal to 0.65 in the 100 – 5000 Hz range. By comparing the result with traditional fibrous absorber, they found the performance these kenaf samples slightly poor, suggesting eco-friendly alternative to the traditional mineral wool blankets for thermo-acoustic applications with low impact on the human health.[20]

Ebrahim Taban et.al. also studied performance of panels made up of Kenaf fibers for building applications. The kenaf fiber extraction method used was mechanical method. For the optimised panels, the statistical analysis's findings recommended a thickness of 33 mm and a bulk density of 150 kg/m3. The results showed that the mean of SAC increased from 0.68 to 0.72 after covering the optimized panels with spacer fabrics.[21] E. Taban et.al. discussed the mathematical and experimental examination of the sound absorption behaviour of sustainable kenaf fiber at low-frequency range using the Delany–Bazley model (D–B model) as well as Nelder–Mead method. As the thickness of the sample becomes lower and lower, the result of the absorption performance of the kenaf fiber at low frequency was suggestively decreased. The kenaf fibers have shown a comparable sound absorption performance with several natural fibers. [22]

2.Durian fiber:

Christian Elmarc O et. al. made an efficient, cost effective and environmentally friendly sound damping fiber board from ground durian peel (DuriBoard) as sound damping materials.The durian peel fibers were extracted by mechanical method(grinding in coeffe grinder).Two experimental samples of pore diameter of 147 µm against 43.7 µm were prepared and identified the difference of sound reduction in high and low frequencies. The Duri Board found more effective against the egg carton under low frequency with 0.98 NRC and can be served as an alternative to commercial egg carton.[23] Azma Putra et.al. extracted the fiber from dried durian husk the agricultural wastes, by milling it using ultra centrifugal mill and then drying process. The results bring out that the durian husk fibers have absorption coefficient of more than 0.5 above 1 kHz a for 20 mm thick sample of and with minimum density of 160 kg/m [24]

3.Hemp fiber:

Andrea Santoni et.al. studied the enhancement effect of manufacturing process of hemp fibrous materials. The hemp fibers were extracted by using mechano-chemical method and studied the effects each chemical treatments on material's physical characteristics and sound absorption coefficient. The study revealed that an alkaline treatment (02 NaOH) performed on the material does not significantly affect either its acoustic performance or its physical properties. The acoustic performance of the material found enhanced, by increasing air flow resistivity and reducing the effective radius of the fibres [25]

4.Date palm empty fruit (DPEFB) fibres:

Date palm empty fruit (DPEFB) is mainly considered as agricultural waste. In this study Ebrahim Taban et. al. deals with the acoustic performance of DPEFB fibres extracted from empty fruit by mechano-chemical method. Scanning Electron Microscope (SEM) revealed the values of outer diameter of the DPEFB fibres in the range of 200–720 µm , thickness of the cell wall less than 5 µm. and the average diameter, the average density of the fibres together with the binder mixture 465 µm and 930 kg/m3 respectively. The sound absorbing samples of two different densities of 100 kg/m^3 and 200 kg/m^3 and with thicknesses of 10–40 mm was processed and fabricated from (DPEFB) fibres. The samples with the thickness of 20 mm and 30 mm for density 100 kg/m^3 revealed that the absorption coefficient is 0.6–0.8 above 1.5 kHz, for the thickness of 40 mm, the values even reached the value of 0.9. For the density of 200 kg/$m^3$the values can reach 0.7–0.8 above 1 kHz.[26]

5.Date Palm Fibre (DPF) and Coconut Coir Fibre (CCF):

Lamyaa Abd AL Rahman et.al. examined the pure micro porous materials from two types of fibers, Date Palm Fibre (DPF) and Coconut Coir Fibre (CCF). The results showed that date palm fibre and coconut coir fibre have good acoustic properties at low and high frequencies. [27]

6.Arenga pinnata fiber:

Lindawati Ismail et.al. investigated the potential of using Arenga pinnata fiber as raw material for sound absorbing material. The sound absorption coefficients of Arenga pinnata were within the range of 0.75 – 0.90 for the frequency range 2000 Hz to 5000 Hz. The maximum sound absorption coefficient was obtained from the thickness of 40 mm.[28]

7.Coir fiber :

Ida Norfaslia Nasidi et.al. studied morphology of coir fiber (CF) treated with NaOH and revealed that the extracted fiber was be free of impurities including lignin and hemicellulose layer from the fibre surfaces. FTIR spectra supported this finding by changing the peak. Again, the fibre diameter was reduced as with increased concentrations of alkali. The results conclusively indicated that treated CF at the concentrations of 7% and 8% NaOH gained the highest SAC values across the low and high-frequency ranges, with coefficient average of 0.9 and above. Thus, the alkali treatment reduces the diameter of fiber and increases SAC.[29]

8.Pineapple leaf fiber (PALF):

The pineapple leaf (PALF) as an alternative natural acoustic material was studied by Azma Putra et. al. The samples with different densities and thicknesses were made from raw pineapple leaf fibres and their effects on the sound absorption characteristic was observed. By adjusting the fibre densities and/or adding an air gap, pineapple leaf fibres can obtain an average sound absorption coefficient of 0.9 over 1 kHz.The results shown that the sound absorption performance of pineapple leaf fibres was similar to that of the commercial synthetic rock wool fibres.[30]

In comparison to synthetic fibres, natural fibres along with natural fiber composites are attracting industries because of their low density, low cost and enhanced specific mechanical properties they possess. Natural fiber composites are finding the new robust option in almost all the applications.

Composites fibers :

Following are some examples of composite fibers and with SAC values.

1.Finger millet straw fiber (F), darbha fiber (D), and ripe bulrush fibers (R) individual and composite:

K. M. Rakesh et al. studied sound absorption properties of three plant-based natural fibers, finger millet straw fiber (F), darbha fiber (D), and ripe bulrush fibers (R) individual and composite. Finger millet , Darbh and ripe bulrush fibers were extracted by chemical , hand separation and combined retting process respectively. The study showed significant increase in SAC values of individual and composites fibers F, D, R and with an increase in sample thickness, fiber the stack-up arrangement, and addition of an air gap. Out of these three Darbha fibers (D) exhibited superior sound absorption of 0.86 NRC as an individual and composite of darbha fibers and ripe bulrush fibers irrespective of stacking up arrangement and combination type in the critical frequency range of 500 Hz–2000 Hz.The results suggestively indicate use of darbha fiber as sound absorption material either individually or in hybrid combinations effectively.[30]

2. Sugarcane bagasse/bamboo charcoal composite fiber:

Five different waste sugarcane bagasse/bamboo charcoal composite materials (BBC-A, BBC-B, BBC-C, BBC-D, and BBC-E) were produced by Santhanam Sakthivel et.al. and tested for physical and sound absorption properties. Because of their higher material density, the natural green composite mats (BBC-B and BBC-D) exhibited the superior physical and acoustic absorption. The composite materials were absorbing more than 70% of the incident noise (50–4000Hz). Under high humidity conditions no substantial changes in the inducing parameters and acoustic properties of the natural fiber composite materials observed. In green building initiatives these alternative materials will prove to be cost-effective.[31]

3.Composite of wood and polyester fiber:

A sound-absorbing composite material of wood fiber and polyester fiber was produced Limin Peng et. al. using composite technology based on wood and polyester foam. As the levels of airflow resistance reduced, the material's sound absorption coefficient rose.When the airflow resistivity continued to reduce and exceeded the optimum value, the sound absorption coefficient of the materials showed a trend of decrease.[32]

4.Sisal fibre–reinforced polypropylene composites:

The randomly oriented sisal fibre–reinforced polypropylene composites are fabricated using extrusion–injection moulding technique and investigated the effect of fibre weight fraction (0%–30% in step of 10%) on vibrational damping and acoustic characteristics. The studied sisal/PP composite has a great potential to work as acoustic proof member in automotive and aerospace applications. [33]

5.Ramie, flax and jute fibers and their composites:

Sound absorption coefficients of ramie, flax and jute fibers and their composites were measured by the two-microphone transfer function technique in the impedance Tube. The sound absorption properties of natural fiber of ramie, jute and flax and their reinforced composites were overall better than those of the glass and carbon fibers and their reinforced composites. Jute fiber reinforced composite has the best sound absorption property and the sound absorption coefficient can be as high as nearly 0.9 at 10000 Hz so especially at high frequency these composites found very beneficial for the aeronautical applications. [34]

Conclusion:

This paper reviewed different natural sound absorbing fibers extracted from agricultural waste. The raw material fibers of kenaf, durian hemp, date palm empty fruit, date palm, coconut coir and arenga pinnata fiber and the composite fibers of date palm empty fruit fiber and arenga pinnata were reviewed. The Mechano-chemical extraction method is used widely in most of the fiber extraction process. The alkali pre-treatment helped to remove dust, reduce the diameter of fiber and produce pure cellulose fiber with increased strength. The characterization technics like XRD, SEM , TEM, FTIR,TGA used to analyse different parameters of the extracted fibers .The comparison of SAC between natural fiber sound absorbers and natural fiber composite with commercially available glass fiber shown that natural fibers and their composites are superior to the glass fiber. Depending on SAC values the natural fibers have wide variety of applications like residential, industrial, automotive, aerospace, aeronautical and thermo-acoustic. The natural fibres along with composites are becoming more promising because of their low density, low cost, specific mechanical properties and biodegradable nature.

References:

1. Marquis-Favre, C.; Premat, C.; Aubrée, D.; Vallet, M. Noise and Its Effects—A Review on Qualitative Aspects of Sound. Part I: Notions and Acoustic Ratings. Acta Acust. United Acust. 2005, 91, 613–625.
2. McLaughlin, E.C., “The Strength of bagasse fiber reinforced composites”. J. Material Science 15 (April 1980) pp.886-890.
3. European Council Directive 67/548/EEC of 27 June 1967. On the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances. Off. J. Eur. Commun. 1967, 196, 1–98
4. Arenas, J.P.; Crocker, M.J. Recent trends in porous sound-absorbing materials. Sound Vib. 2010, 44, 12–18.
5. Sharma P, Kaur H, Sharma M, Sahore V. A review on applicability of naturally available adsorbents for the removal of hazardous dyes from aqueous waste. Environ Monit Assess 2011; 183: 151–195.
6. Patel S. Potential of fruit and vegetable wastes as novel biosorbents summarizing the recent studies. Rev Environ Sci Biotechnology 2012; 11: 365–380
7. Beranek, L. Leo, 1992. “Noise and Vibration Control Engineering, Principles and Applications” Chapter 8: Sound-Absorbing Materials and Sound Absorbers, Wiley, New York.
8. Favre, C. Premat, C. Aubrée, D. Vallet, M. Noise and Its Effects A Review on Qualitative Aspects of Sound. Part I: Notions and Acoustic Ratings. Acta Acust. United Acust. 2005, 91, 613–625.
9. Dos Santos, R.M.,Neto, W.P.F., Silvério, H.A., Martins, D.F., Dantas, N.O and Pasquini,D. (2013). Cellulose nanocrystals from pineapple leaf, a new approach for the reuse of this agro-waste. Journal of Industrial Crop s and Products. 50, 707–714.
10. MohammadK. Hossain , MohammadR. Karim , Mahm udurR. Chowdhury , MuhammadA. Imam , Mahesh H osur , Shaik Jeelan Ramsis Farag “Comparative mechanical and thermal study of chemically treated and untreated single sugarcane fiber bundle”
11. Abraham, E, Deepa B. Pothan, L, A.Jacob, M.Thomas S. Cvelbar, U and Anandjiwala, R.(2011). Extraction of nanocellulose fibrils from lignocellulosic fibres:A novel approach.Journal of Carbohydrate Polymer 86, 1468– 1475.
12. Müeller, D. H., Krobjilowski, A., Journal of Industrial Textiles, Vol. 33, No. 2, 111-130 (2003).Patchiya Phanthong, Prasert Reubroycharoen, Xiaogang Hao, Guangwen Xu, Abuliti Abudula, Guoqing Guan” Nanocellulose: Extraction and application”

13. Allard, J.F., C. Depollier and P. Guignouard, 1989. “Free Field Surface Impedance Measurements of Sound-Absorbing Materials with Surface Coatings” Applied Acoustics, 26(3): 199-207.

14.Tao Yang , Lizhu Hu , Xiaoman Xiong , Michal Petru, Muhammad Tayyab Noman Rajesh Mishra and Jiˇrí Militký “Sound Absorption Properties of Natural Fibers: A Review” Sustainability 2020, 12, 8477; doi:10.3390/su12208477.

15.Sun, F., P. Banks-Lee and H. Peng, 1993. “Sound Absorption In An Anisotropic Periodically Layered Fluid-Saturated Porous Medium”, Applied Acoustics, 39: 65-76.

16.Youn Eung Lee and Chang Whan Joo, 2003. “Sound Absorption Properties of Recycled Polyester Fibrous Assembly Absorbers”, AUTEX Research Journal, 3(2): 2003.

17.Con Wassilieff, 1996. “Sound Absorption of Wood Based Materials” Applied Acoustics, 48(4):

18.Michael Coates and Marek Kierzkowski, 2002.“Acoustic Textiles – Lighter, Thinner And More Absorbent”, Technical Textiles-International.

19.Ibrahim M.A. and R.W. Melik, 1978. “Physical Parameters Affecting Acoustic Absorption Characteristics of Fibrous Materials”, Proceedings of the mathematical and physical society of Egypt, 46.

20.D’Alessandro, F. and Pispola G. 2005. Sound absorption properties of sustainable fibrous materials in an enhanced reverberation room. Paper presented in the 2005 Congress and Exposition on Noise Control Engineering. Rio de Janeiro, Brazil. 07-10 August.

21.E.Taban , Valipour , D. D. Abdi ,S. Amininasab "Mathematical and experimental investigation of sound absorption behaviour of sustainable kenaf fiber at low frequency"

22.Ebrahim Taban, Parham Soltani, UmbertoBerardi, Azma Putra, Seyyed Mohammad Mousavi, Mohammad Faridan , Seyed Ehsan Samaei , Ali Khavanin "Measurement, modeling, and optimization of sound absorption performance of Kenaf fibers for building applications" Building and Environment 180 (2020) 107087.

22.Christian Elmarc O. Bautista, Jigo L. Byoyo, Cyril R. Cafe, Joshua L. Necosia, Ian Van P.Razo "Duriboard: Synthesis And Acoustic Properties Of Durian (Duriozibethinus) Peel-Based Sound Damping Fiberboard" International Journal of Advances in Science Engineering and Technology, ISSN(p): 2321 –8991, ISSN(e): 2321 –9009 Vol-7, Iss-2, Spl. Issue-2 Jun.-2019, http://iraj.in

23. Azma Putra , Muhammad Nur Othman , Thaynan Oliveira , M'hamed Souli , Dg Hafizah Kassim , Irianto and Safarudin Herawan "Waste Durian Husk Fibers as Natural Sound Absorber: Performance and AcousticCharacterization"Buildings2022,12,1112. https://doi.org/10.3390/buildings12081112.

24. Andrea Santoni, Paolo Bonfiglio, Patrizio Fausti, Cristina Marescotti Valentina Mazzanti Francesco Mollica, Francesco Pompoli "Improving the sound absorption performance of sustainable thermal insulation materials: Natural hemp fibres" .

25. Ebrahim Tabana, Ali Khavanina, , Abdolreza Ohadib , Azma Putra Ahmad Jonidi Jafarid Mohammad Faridane, Ardalan Soleimaniana "Study on the acoustic characteristics of natural date palm fibres: Experimental and theoretical approaches", Building and Environment 161 (2019)106274.

26. Lamyaa Abd ALRahman, Raja Ishak Raja and Roslan Abdul Rahman "Experimental Study on natural Fibers for Green Acoustic Absorption Materials"

27. Lindawati Ismail, Mohd. Imran Ghazali, Shahruddin Mahzan, Ahmad Mujahid Ahmad Zaidi "Sound Absorption of Arenga Pinnata Natural Fiber"

28. Ida Norfaslia Nasidi, Lokman Hakim Ismail and Emedya Murniwaty Samsudin "Effect of Sodium Hydroxide (NaOH) Treatment on Coconut Coir Fibre and its Effectiveness on Enhancing Sound Absorption Properties". ISSN: 0128-7680 e-ISSN: 2231-8526DOIhttps://doi.org/10.47836/pjst.29.1.37

29. Azma PUTRA, Khai Hee OR, Mohd Zulkefli SELAMAT , Mohd Jailani Mohd NOR , Muhamad Haziq HASSAN, Iwan PRASETIYO"Sound absorption of extracted pineapple leaf fibres"https://doi.org/10.1016/j.apacoust.2018.01.029

30. K. M. Rakesh,1 Ramachandracharya Srinidhi, S.Gokulkumar , K. S. Nithin,3 S. Madhavarao, S. Sathish, Alagar Karthick , M. Muhibbullah , and Sameh M. Osman "Experimental Study on the Sound Absorption Properties of Finger Millet Straw, Darbha, and Ripe Bulrush Fibers" Hindawi Advances in Materials Science and Engineering Volume 2021, Article ID 7382044, 12 pages https://doi.org/10.1155/2021/7382044.

31. Santhanam Sakthivel, Selvaraj Senthil Kumar, Eshetu Solomon, Gedamnesh Getahun,Yohaness Admassu, Meseret Bogale ,Mekdes Gedilu, Alemu Aduna, and Fasika Abedom "Sound absorbing and insulating properties of natural fiber hybrid composites using sugarcane bagasse and bamboo charcoal"

32. Limin Peng, Boqi Song, Junfeng Wang, and Dong Wang "Mechanic and Acoustic Properties of the Sound-Absorbing Material Made from Natural Fiber and Polyester"

33. Vignesh Sekar , Mohammad Hosseini Fouladi , Satesh Narayana Namasivayam , and Sivakumar Sivanesan "Additive Manufacturing:A Novel Method for Developing an Acoustic Panel Made of Natural Fiber-Reinforced Composites with Enhanced Mechanical and Acoustical Propertie

34. YANG WeiDong & LI Yan "Sound absorption performance of natural fibers and their composites" Sci China Tech Sci, 2012, 55: 2278–2283, doi:10.1007/s11431-012-4943-1

35. Koizumi, T., N. Tsujiuchi and A Adachi, 2002 "The Development of Sound Materials Using Natural Bamboo Fibers, High Performance" WIT Pres