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Soundproofing panel design from eggshell material and tea dregs

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ABSTRACT

Noise reduction in residential and other types of buildings in urban areas is becoming more important. However, the cost of sound-absorbing materials is still prohibitively expensive for some people. The objective of this study is to create alternative sound-dampening materials from composites made from household waste, specifically egg shells and tea waste. The hypothesis of this study is that because eggshell is a porous material and tea waste is a fibrous material, it has the ability to absorb sound. The sound absorption test was performed in accordance with ASTM E-1050-98, a standard for testing impedance and absorption with a digital frequency analysis system. The highest sound absorption coefficient of the egg shell composite was 0.97 at a frequency of 2392 Hz (NC 35), while the highest sound absorption coefficient of the tea waste composite was 0.592 at a frequency of 1960 Hz (NC 30). The results of the analysis show that both types of composites can be used as alternative sound absorbing materials in residential and similar types of buildings.

Introduction

The need to reduce noise and maintain privacy in urban residential and other types of buildings is growing. Despite the fact that hard building materials such as concrete, glass, brick, and other solid and slippery materials have the property of reflecting almost all sound (Astuti et al. 2019). Non-woven materials, fiber glass, mineral wool, felt, glass wool foam, and rock wool are all frequently employed to reduce noise (Muhazeli et al. 2020). However, the price is relatively less affordable for most people (Warman, Isranuri, and Wirjosentono 2016). Various studies on sound absorbing materials have been carried out, including sugarcane bagasse (Ridhola and Elvaswer 2015), dregs tofu (Rizal, Elvaswer, and Fitri 2015), bamboo powder (Fitriani et al. 2014), banana fronds (Permanasari, Larasati, and Widiawati 2014), and areca nut (Warman, Isranuri, and Wirjosentono 2016). Noise dampening panels for household use can also be pursued by utilizing materials found in everyday life, such as organic waste, such as eggshells and dregs or tea residue, which fall under the category of urban solid waste (Murts et al. 2021).

During this time, egg shells were utilized as fertilizer, animal feed, and the remainder was discarded (Tizo et al. 2018). In 2021, Indonesia's chicken egg production will reach 5,155,998 tons, a fourteen thousand tons increase over the previous year (Badan Pusat Statistik 2021). This is due to an increase in egg consumption among Indonesians, particularly since the Covid-19 pandemic, which means that by 2021, it will have reached an average of 2,448 kg per capita per week (Annur 2022). If ten percent of the egg is the eggshell (Yonata, Aminah, and Hersoelistyorini 2017) it can be estimated that in the same year the amount of eggshell waste reached 244.8 kg per capita per week.

So far, egg shells have been identified as materials with good adsorption properties, such as a natural pore structure (Maslahat, Taufik, and Subagja 2017), and contains CaCO3 (Nandiyanto et al. 2022) reach 94-97% (Nurlaela et al. 2014; Villanueva et al. 2023) and protein mucopolysaccharide acids so that they have the opportunity to be developed into adsorbents (Fitriyana and Safitri 2015; Jasinda 2013) . The chemical composition of chicken egg shells consists of 1.71%, 0.36% fat, 0.93% water, 16.21% crude fiber, 71.34% ash (Febrianti and Andrianto 2017). This high chemical content can be used not only as a nutrient mixture to help fertilize plants, but the calcium content in egg shells can also be used to make sound absorbing panels. A mixture of gypsum, cement, silica, and CaCO3 is also used in the banana frond acoustic panel design (Permanasari, Larasati, and Widiawati 2014).
Fibrous materials, in addition to porous materials, are good sound absorbers. Fibrous organic waste is an example of fibrous organic waste (Shchegoleva et al. 2021). Thus far, more tea waste has been disposed of, and only a small amount has been used, despite the fact that there is a large amount of waste produced. Tea waste is high because it is one of the most commonly consumed beverages (Gao and Ogata 2019) as well as the most popular drink besides water around the world, especially black tea (Triwiswara and Indrayani 2020).

Tea waste has been used as an absorbent for synthetic dyes and toxic metals, bioenergy, construction fillers, and polymer composites (Debnath et al. 2022; Guo et al. 2021; Xia et al. 2015). Research on tea dregs as a sound absorber has also been carried out, especially on green tea dregs with cloth coating. The study compared the effectiveness of several thicknesses of tea grounds (Tang et al., 2020). Tea waste can also be used as particle board, but it is less strong than particle board from tea leaf stems (Gao and Ogata, 2020).

Based on the background presented, the formulation of the problems in this study are as follows: (1) It is unknown whether the composition of the eggshell and tea waste composite is known, and (2) It is unknown whether the eggshell and tea waste composite can be used as a sound absorber.

The objectives of this research are to (1) find the optimal composition for the manufacture of eggshell and tea dregs composite, (2) determine the potential of eggshell and tea dregs as a sound absorber, and (3) create a sound-absorbing design from the eggshell and tea dregs composite.

Because eggshells are porous materials and tea dregs are fibrous materials, the hypothesis of this study is that they can be used as alternative sound absorbing materials. This is based on the discovery that composites with small and dense particle sizes, like tea dregs, and high porosity, like eggshells, also have high absorption coefficient values (Mutia et al. 2019). So far, there has been no research related to sound absorbing material from egg shells and tea waste so it is hoped that through this research an alternative sound absorber that is affordable and environmentally friendly can be developed.

Method

This study is divided into three stages: pre-testing, testing, and application of test results. Experiments in the Pre-Testing Phase include the creation of composites from egg shells and composites from tea waste. Egg shells and tea waste are two common materials used as reinforcement in composite mixtures (Kulviwat et al. 2023; Sowińska-Baranowska and Maciejewska 2023) thereby increasing the tensile, flexural, impact and hardness strengths of the composite (Sivakumar et al. 2022).

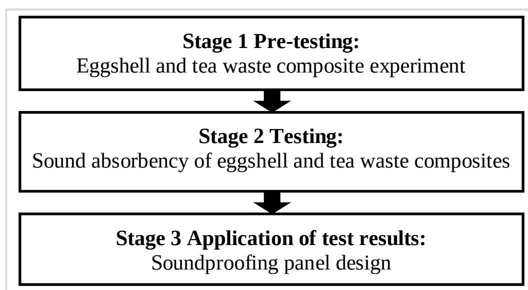

Figure 1. Research scheme

The Acoustics Laboratory, Physics Study Program, Sebelas Maret State University, conducted the sound absorption testing stage. This test is based on the ASTM E-1050-98 standard for testing the impedance and absorption of a sound absorbing material with a tube, two microphones, and a digital frequency analysis system (figure 2). Using this reference, researchers tested the sound absorption of water hyacinth and coconut coir materials (Setyowati et al. 2018), corn husk fiber (Berliandika et al.

2019), and shell-reinforced composites (Setyowati et al. 2019). The purpose of this test is to compare the sound absorption of the two types of materials with the fixed variables, namely the ratio of material composition (2:1) and thickness (12 mm). According to a study conducted by (Puspitarini, S. F. M. A., and Yulianto 2014) The thickness of the material sample does affect the value of the sound absorption coefficient because samples that are not too thick tend to have a lot of pores (porous) so that sound is easily absorbed by the sample.

Figure 2. Instrumen and samples for sound absorption test with reference to ASTM E-1050-98

Each composite material sample was divided into three specimens. According to the standard tool used to determine the average value of the three specimens (figure 2), the egg shell specimen (CT 1-3) and the tea dregs specimen (AT 1-3) are circular in shape with a diameter of 30 mm. The value of the sound absorption coefficient will be determined by this sound absorption test. The sound absorption coefficient (α) is a ratio or physical quantity that indicates a material's ability to absorb sound energy when it is exposed to it (Fitriani et al. 2014). The higher the absorption coefficient, the better the absorption ability because it shows that most of the sound is absorbed and only a little is reflected back (Amares et al. 2017). An absorption coefficient value of 0 (zero) indicates that no sound is absorbed, while an absorption coefficient value of 1 (one) indicates that sound is completely absorbed (Hayat, Syakbaniah, and Darvina 2013).

After determining the sound absorption coefficient, the results are analyzed to determine the noise criterion (NC). This NC category will determine the type of room that is appropriate for the use of materials derived from composite egg shells and tea waste. The NC value is calculated by converting the frequency value (Hz) to the noise rating value (dB). Conversion can be done using online applications such as https://www.rapidtables.com/ or https://www.justfreetools.com/.

Result and discussion

During the pre-testing stage, an experimental method was used to create a composite from egg shell material and tea waste, particularly black tea, in order to obtain the best sample composition as a sound absorption test specimen (tables 1 and 2). This composite is made with a PVAc (Poly Vinyl Acetate) type adhesive under the trademark Bio Phaeton, which is said to be more environmentally friendly. The mass of the material between the eggshell and tea grounds cannot be the same to produce the same thickness, which is about 12 mm, because eggshells are heavier than tea grounds. However, through experimental results it is known that there are similarities in the two types of composites, namely the composition between the material and the best adhesive is 2:1 (tables 1 and 2).

Table 1. Experimental results of eggshell composites

Sp	Composition Material: Adhesive	Result	Figure
1	6:1 (300 gr:50 gr)	It dries very quickly, the adhesive doesn't stick together, the surface isn't smooth.	
2	3:1 (300 gr:100 gr)	Quick dry, less sticky adhesive substance, less smooth surface.	
3	2:1 (300 gr:150 gr)	Dries quickly, adheres well, smooth surface, no cracks, clearly visible eggshell grains.	
4	3:2 (300 gr:200 gr)	It takes a long time to dry, it sticks well, there are no cracks,	

Sp	Composition Material: Adhesive	Result	Figure
5	1:1 (300 gr:300 gr)	the eggshell grains are less visible. It takes a very long time to dry, the eggshell grains are not visible because they are covered with adhesive.	

Table 2. Experimental results of tea dregs composite

Sp	Composition Adhesive	Results	Figure
1	2:1 (100 gr:50 gr)	Very fast drying, dense, no cracks on the surface, tea leaves are clearly visible.	
2	4:3 (100 gr:75 gr)	Dries quickly, hard, the surface is less dense or hard, the tea leaves are clearly visible.	
3	1:1 (100 gr:100 gr)	It takes a long time to dry, the result is soft, the tea leaves are clear and dark.	
4	4:5 (100 gr:125 gr)	It takes a long time to dry, the result is mushy, the tea leaves are clear and darker.	
5	2:3 (100 gr:150 gr)	It takes a very long time to dry, the result is very mushy, the tea leaves are clear and darker.	

The sound absorption test results on the eggshell composite (table 3) show that the three eggshell specimens (CT 1-3) absorb sound most effectively between 2000 and 3000 Hz. Figure 3 demonstrates that the absorption abilities of the three specimens show the same typical results. The CT-2 specimen has the highest coefficient value of 0.970 at a frequency of 2256 Hz. The CT-3 specimen has a coefficient of 0.7 at a frequency of 2392 Hz, while the CT-1 specimen has a coefficient of 0.5 at a frequency of 2320 Hz.

Table 3. Sound absorption test result on eggshell composite samples

F (Hz)	Sample 1	Sample 2	Sample 3
448	0.010	0.015	0.007
504	0.119	0.123	0.112
1000	0.212	0.195	0.169
2000	0.431	0.829	0.537
2256	0.497	**0.970**	0.672
2320	**0.500**	0.955	0.690
2392	0.498	0.919	**0.700**
3000	0.340	0.479	0.523
4000	0.213	0.350	0.286
5000	0.223	0.355	0.282
6000	0.165	0.265	0.243

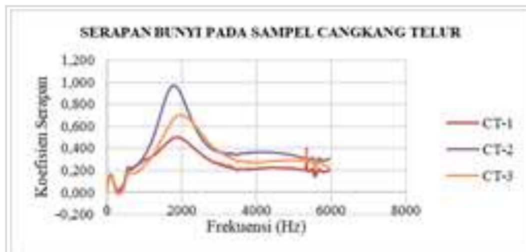

Figure 3. Graph of sound absorption in eggshell composite specimens

The three samples of tea dregs all showed the same typical results in the sound absorption test, as shown in figure 4. The tea waste composite absorbed the most in the frequency range 1400-1960 Hz and was relatively evenly distributed up to 400 Hz. The AT-1 sample had the highest coefficient value, which was 0.592 at a frequency of 1960 Hz, while the AT-2 sample had a coefficient value of 0.531 at a frequency of 1400 Hz and the AT-3 sample had a coefficient value of 0.589 at a frequency of 1960 Hz.

Table 4. Sound absorption test result on tea dregs composite samples

F (Hz)	Sample 1	Sample 2	Sample 3
456	0.069	0.085	0.064
504	0.162	0.182	0.153
1000	0.121	0.207	0.111
1400	0.482	**0.531**	0.481
1960	**0.592**	0.420	**0.589**
2136	0.582	0.385	0.582
2504	0.518	0.316	0.519
3000	0.471	0.287	0.464

F (Hz)	Sample 1	Sample 2	Sample 3
4000	0.519	0.360	0.507
5000	0.522	0.397	0.524
6000	0.422	0.318	0.490

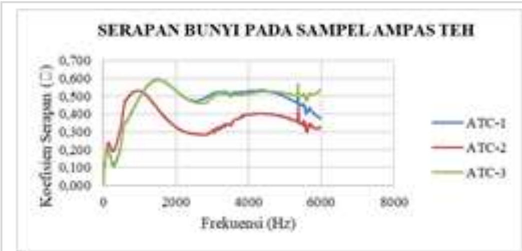

Figure 4. Graph of sound absorption in tea dregs composite specimens

A material is categorized as a sound absorbing material if it is capable of absorbing and transmitting as many sound waves as possible and reflecting them as little as possible (Muhazeli et al. 2020). Thickness, density, and porosity are all factors that influence a material's ability to absorb sound waves (Amares et al. 2017). This also accounts for the difference in the sound absorption coefficient values between the three samples of each material (tables 3 and 4). Although the six specimens were made from the same material, there were differences, particularly in density, which could have resulted from the uneven pressing process across the entire surface, which had an effect on the porosity of the test samples.

Acoustic materials are classified into three groups: (1) sound absorbing materials, (2) sound barrier materials, and (3) sound absorbing materials (damping materials) (Hayat, Syakbaniah, and Darvina 2013). The three egg shell composite samples and the three tea waste composite samples in tables 3 and 4 both had sound absorption coefficients greater than 0.5. Materials with absorption coefficients greater than 0.3 are effective sound absorbers (Hayat, Syakbaniah, and Darvina 2013). Other research also confirms that materials with an absorption coefficient > 0.5 are sound absorbers, absorption coefficients < 0.2 are sound reflectors (Kaharuddin and Kusumawanto 2011). As a result, the eggshell and tea waste composite is not only a material that can absorb sound (absorbing material), but it can also be used as a damping material. The composite material of egg shells and tea dregs in this study is classified as a passive sound absorber because it has a lower ability to reduce sound in the frequency range of 20-200 Hz (Muhazeli et al. 2020). This type of silencer minimizes sound reflection by passively absorbing sound and does not require an external energy supply, so it is widely applied to buildings or transportation equipment.

It is additionally evident from the sound absorption test results that a 2:1 ratio composition of the material and the adhesive is an appropriate composition. It affects the ability of composite materials to absorb sound because incoming sound waves are absorbed by the material, in addition to saving adhesives, speeding up the drying process, and visually displaying egg shells or tea powder more clearly.

Sound absorbing materials are generally resistive, fibrous, porous or active resonators (Yudhanto, Wisnujati, and Yahya 2015). It is difficult for sound waves to penetrate high density materials such as tea dregs because the porosity is small, the speed of sound particles is small, and the impedance is large, resulting in more sound being reflected than absorbed (Hayat, Syakbaniah, and Darvina 2013; Samsudin, Ismail, and Kadir 2016). On the other hand, materials with high porosity, such as eggshells, are better at absorbing sound, because more sound waves are absorbed than reflected (Rizal, Elvaswer, and Fitri 2015; Yudhanto, Wisnujati, and Yahya 2015). Therefore, the eggshell composite showed better results in absorbing sound than the tea waste composite.

The noise criterion (NC) value is calculated using the frequency value obtained from the sound absorption test. In the United States, the term Noise Criterion (NC) is commonly used, whereas in Europe, the International Organization for Standardization (ISO) term Noise Rating (NR) is used. The noise frequency content (dB) is used to calculate the NC and NR noise criteria or ratings.

Table 5. Noise rating criteria

Criteria	Octave Band Numbers							
	63	125	250	500	1000	2000	4000	8000
NC 20	51	41	33	26	22	19	17	16
NC 25	54	45	38	31	27	24	22	21
NC 30	57	48	41	35	31	29	28	27
NC 35	60	53	46	40	36	34	33	32
NC 40	64	57	51	45	41	39	38	37
NC 45	67	60	54	49	46	44	43	42
NC 50	71	64	59	54	51	49	48	47
NC 55	74	67	62	58	56	54	53	52
NC 60	77	71	67	63	61	59	58	57
NC 65	80	75	71	68	66	64	63	62
NC 70	83	79	75	72	71	70	69	68

Source: Beranek in Cirrus Research (2013)

The type of room or area that is suitable for the application of sound absorbing materials can be determined once the noise criterion (NC) value is known. Table 6 demonstrates area type recommendations based on noise criteria.

Table 6. Recommended area types based on noise criteria

Type of Room - Space Type	Recommended NC Level NC Curve	Type of Room - Space Type	Recommended NC Level NC Curve
Residences		**Hospitals and Clinics**	
Apartment Houses	25-35	- Private rooms	25-30
Assembly Halls	25-30	- Operating rooms	25-30
Churches	30-35	- Wards	30-35
Courtrooms	30-40	- Laboratories	35-40
Factories	40-65	- Corridors	30-35
Private Homes, rural and suburban	20-30	- Public areas	35-40
Private Homes, urban	25-30	**Schools**	
Hotels/Motels		- Lecture and classrooms	25-30
- Individual rooms or suites	25-35	- Open-plan classrooms	35-40
- Meeting or banquet rooms	25-35	Movie motion picture theatres	30-35
- Service and Support Areas	40-45	Libraries	35-40
- Halls, corridors, lobbies	35-40	Legitimate theatres	20-25
Offices		Private Residences	25-35
- Conference rooms	25-30	Restaurants	40-45
- Private	30-35	TV Broadcast studios	15-25
- Open-plan areas	35-40	Recording Studios	15-20
- Business machines/computers	40-45	Concert and recital halls	15-20
		Sport Coliseums	45-55
		Sound broadcasting	15-20

Source: Beranek in Cirrus Research (2013)

According to the data in table 7, the noise level that the eggshell composite material can muffle is between 33.5 dB and 33.8 dB. This noise level value indicates that the eggshell composite can effectively dampen sound in the NC 30-35 range (table 6). Areas that do not exceed NC 35 are suitable for the use of eggshell composite materials. Eggshell composite materials can be used as sound absorbers, particularly in apartments, meeting halls, places of worship, private homes, hotel/inn rooms or meeting rooms, private rooms or meeting rooms in offices, classrooms, or school movie theaters.

Table 7. Noise level of eggshell composite specimens

Spesimen	Frequency (Hz)	Noise level (dB)
CT-1	2320	33,7
CT-2	2256	33,5
CT-3	2392	33,8

In the tea dregs composite sample, the noise level that was effectively absorbed was in the range of 31.5 – 32.9 dB (table 8) so that the tea dregs composite was included in the NC 30 category (table 5). Therefore, the area suitable for the application of tea waste composite material is one that does not exceed NC 30. According to the data in table 6, the suggested rooms for NC 30 include residential areas such as private homes, meeting halls, office meeting rooms, or classrooms. at school.

Table 8. Noise level of tea dregs composite specimens

Spesimen	Frequency (Hz)	Noise level (dB)
AT-1	1960	32,9
AT-2	1400	31,5
AT-3	1960	32,9

Based on the findings of this study, two sound dampening panel designs are recommended. First, eggshell composite soundproofing panels that can be installed in private homes or apartments, particularly in study or work spaces (figure 5).

Figure 5. Soundproofing design recommendation from egg shells

The second design is a sound dampening panel made from tea waste composite material. These panels can be installed in office meeting rooms, hotel meeting rooms, or meeting rooms in cafes and restaurants (figure 6).

Figure 6. Soundproofing design recommendation from tea grounds

Thus far, egg shells and tea waste have been investigated for their potential as building materials. Egg shells used as a cement substitute are said to reduce costs and carbon emissions by 10-15% (Murts et al. 2021). The addition of tea waste as a pore forming agent in the manufacture of ceramic bricks produces hybrid bricks with better thermal insulation, lighter weight and lower compressive strength (Ibrahim et al. 2023). Thus, this research offers other uses of egg shells and tea waste as sound absorbing materials in a building.

Every household can practice using eggshell waste and tea waste as sound-absorbing materials in their respective dwellings. When viewed from an eco-design perspective that optimizes the use of material resources with minimal impact on the environment, employing materials that are easily obtained from the nearby environment is very profitable (Kim et al. 2020). This is because egg shells and tea waste are materials that are easily decomposed (compostable), sources can be renewed (renewable), and come from waste materials (waste material).

Eggshell and tea waste materials are also included in the category of regenerative materials because they have the potential to reduce waste piles if utilized as acoustic material products in certain elements of a building (Kaharuddin and Kusumawanto 2011). Thus, eggshell waste and tea waste have the potential to be used as eco-materials, namely the category of materials that cause a minimum impact on the environment but offer maximum performance to meet design requirements.

Conclusion

Based on the results of the research that has been done, the following conclusions are obtained. (1) The material composition ratio of the eggshell and the PVAc adhesive that can be used as a sound absorber is 2:1, resulting in a product that dries quickly, adheres well, has a smooth surface, no cracks, and the eggshell grains are clearly visible. Similarly, the composition ratio of the tea dregs and the PVAc adhesive is 2:1, resulting in a product that dries quickly, is solid, has no cracks on the surface, and the tea leaves are clearly visible; (2) The factors that influence the egg shell composite to absorb sound better than tea waste are density and porosity; (3) Egg shells and tea dregs have potential as alternative sound absorbing materials because the sound absorption coefficient is more than 0.5. The highest sound absorption coefficient of the egg shell composite was 0.97 at a frequency of 2392 Hz (NC 35), while the highest sound absorption coefficient of the tea waste composite was 0.592 at a frequency of 1960 Hz (NC 30); (4) Based on the noise criterion (NC), soundproofing panels from eggshell composites can be applied in apartments, assembly halls, places of worship, private homes, rooms or meeting rooms in hotels/inns, private rooms or meeting rooms in offices, classrooms or a movie theater at school. However, sound absorbing panels from tea waste composites are more suitable for residential applications such as private homes, assembly halls, meeting rooms in offices, or classrooms in schools.

Suggestions for future research based on the findings of this study include comparing the ability of eggshell and tea waste materials to dampen sound between laboratory tests and calculations in real rooms. Another suggestion that can be pursued is the investigation of other organic and inorganic household waste materials that have the potential to be used as an alternative to other sound absorbing materials, such as fruit peels, cardboard, or beverage packaging bottles.

References

Amares, S., E. Sujatmika, T. W. Hong, R. Durairaj, and H. S.H.B. Hamid. 2017. 'A Review: Characteristics of Noise Absorption Material'. *Journal of Physics: Conference Series* 908 (1). https://doi.org/10.1088/1742-6596/908/1/012005.

Annur, Cindy Mutia. 2022. 'Konsumsi Telur Ayam Di Indonesia Meningkat Sejak Pandemi'. KataData Media Network. 2022.

Astuti, Adindra Maharsi K, Danny Hidayat, Vincent Fanuel Gedalya, and Patricia P Noviandri. 2019. 'Pelepah Pisang Sebagai Alternatif Material Dalam Mengurangi Suara'. In *SMART (Seminar on Architecture Research & Technology)*, 4:31–40. https://doi.org/10.21460/smart.v4i1.

Badan Pusat Statistik. 2021. 'Produksi Telur Ayam Petelur Menurut Provinsi (Ton), 2019-2021'.

Berliandika, Suryaning;, Iwan ; Yahya, and Ubaidillah. 2019. 'Acoustic Performance of Corn Husk Fiber (Zea Mays L) Waste Composite as Sound Absorber with Latex Adhesive'. In *AIP Conference Proceedings*. https://doi.org/https://doi.org/10.1063/1.5095335.

Debnath, Banhisikha, Dibyajyoti Haldar, and Mihir Kumar Purkait. 2022. 'Environmental Remediation by Tea Waste and Its Derivative Products: A Review on Present Status and Technological Advancements'. *Chemosphere* 300 (August): 134480. https://doi.org/10.1016/j.chemosphere.2022.134480.

Febrianti, Arisya, and Dimas Andrianto. 2017. 'Pemanfaatan Cangkang Telur Ayam Sebagai Penambah Nutrisi Kalsium Pada Tanaman Bayam (Amaranthus Tricolor L.) Dengan Budidaya Hidroponik'. Institut Pertanian Bogor.

Fitriani, Mustika Cahya, Restu Kristiani, Eki Muqowi, Melati Wijayanti, Harjana, and Iwan Yahya. 2014. 'Analisa Kinerja Akustik Komposit Limbah Serbuk Bambu Dengan Bahan Perekat Tepung Sagu'. In *Bamboo Bienalle*. https://doi.org/10.13140/2.1.3629.1844.

Fitriyana, Fitriyana, and Eka Safitri. 2015. 'Pemanfaatan Cangkang Telur Ayam Sebagai Adsorben Untuk Meningkatkan Kualitas Minyak Jelantah'. *Konversi* 4 (1): 12. https://doi.org/10.20527/k.v4i1.260.

Gao, Pin, and Yoshito Ogata. 2019. 'Biodegradability of PLA and Tea Waste Composites Based on "CHAMU" and the "Tea Waste Recycling System"'. In *IOP Conference Series: Materials Science and Engineering*. Vol. 563. https://doi.org/10.1088/1757-899X/563/2/022034.

———. 2020. 'CHAMU: An Effective Approach for Improving the Recycling of Tea Waste'. In *IOP Conference Series: Materials Science and Engineering*. Vol. 711. https://doi.org/10.1088/1757-899X/711/1/012024.

Guo, Shasha, Mukesh Kumar Awasthi, Yuefei Wang, and Ping Xu. 2021. 'Current Understanding in Conversion and Application of Tea Waste Biomass: A Review'. *Bioresource Technology* 338 (October): 125530. https://doi.org/10.1016/j.biortech.2021.125530.

Hayat, Wahyudil, Syakbaniah, and Yenni Darvina. 2013. 'Pengaruh Kerapatan Terhadap Koefisien Absorbsi Bunyi Papan Partikel Serat Daun Nenas'. *Pillar of Physics* 1 (April): 44–51. https://doi.org/http://dx.doi.org/10.24036/501171074.

Ibrahim, Jamal Eldin F.M., Mohammed Tihtih, Ethem İlhan Şahin, Mohamed A. Basyooni, and István Kocserha. 2023. 'Sustainable Zeolitic Tuff Incorporating Tea Waste Fired Ceramic Bricks: Development and Investigation'. *Case Studies in Construction Materials* 19 (December): e02238. https://doi.org/10.1016/j.cscm.2023.e02238.

Jasinda. 2013. 'Pembuatan Dan Karakterisasi Adsorben Cangkang Telur Bebek Yang Diaktivasi Secara Termal'. Universitas Suamtera Utara.

Kaharuddin, and Arif Kusumawanto. 2011. 'Rekayasa Material Akustik Ruang Dalam Desain Bangunan'. *Forum Teknik* 34 (1): 9.

Kim, Harrison, François Cluzel, Yann Leroy, Bernard Yannou, and Gwenola Yannou Le Bris. 2020. 'Research Perspectives in Ecodesign'. *Design Science* 6. https://doi.org/10.1017/dsj.2020.5.

Kulviwat, Natasha, Fredrick Nwude Eze, and Chitchamai Ovatlarnporn. 2023. 'The Impact of Alginate Composites Enriched with Spent

Black Tea, Green Tea, Jasmine Tea, and Oolong Tea Wastes on the Shelf-Life Extension of Fruits and Vegetables'. *Applied Food Research* 3 (1): 100290. https://doi.org/10.1016/j.afres.2023.100290.

Maslahat, Mamay, Agus Taufik, and Prima Wahyu Subagja. 2017. 'Pemanfaatan Limbah Cangkang Telur Sebagai Biosorben Untuk Adosrpsi Logam Pb Dan Cd'. *Jurnal Sains Natural* 5 (1): 92. https://doi.org/10.31938/jsn.v5i1.104.

Muhazeli, Noor Sahirah, Nur Azmah Nordin, Ubaid Ubaidillah, Saiful Amri Mazlan, Siti Aishah Abdul Aziz, Nurhazimah Nazmi, and Iwan Yahya. 2020. 'Magnetic and Tunable Sound Absorption Properties of an In-Situ Prepared Magnetorheological Foam'. *Materials* 13 (24): 5637. https://doi.org/10.3390/ma13245637.

Murts, Gebrehiwet Tadese, Chhotu Ram, and Kibrom Alebel Gebru. 2021. 'Fabrication and Characterization of Cement Based Floor Tiles Using Eggshell and Plastic Wastes as a Low Cost Construction Materials'. *Case Studies in Construction Materials* 15 (December): e00747. https://doi.org/10.1016/j.cscm.2021.e00747.

Mutia, Putri, Ngatijo Ngatijo, and Helga Dwi Fahyuan. 2019. 'Pengaruh Jenis Serat Alam Terhadap Koefisien Absorpsi Bunyi Sebagai Peredam Kebisingan'. *Jurnal Ilmu Fisika Dan Pembelajarannya (JIFP)* 3 (1): 18–23. https://doi.org/10.19109/jifp.v3i1.3175.

Nandiyanto, Asep Bayu Dani, Risti Ragadhita, Meli Fiandini, Dwi Fitria Al Husaeni, Dwi Novia Al Husaeni, and Farid Fadhillah. 2022. 'Domestic Waste (Eggshells and Banana Peels Particles) as Sustainable and Renewable Resources for Improving Resin-Based Brakepad Performance: Bibliometric Literature Review, Techno-Economic Analysis, Dual-Sized Reinforcing Experiments, to Comparison with C'. *Communications in Science and Technology* 7 (1): 50–61. https://doi.org/10.21924/cst.7.1.2022.757.

Nurlaela, A, S U Dewi, K Dahlan, and D S Soejoko. 2014. 'Pemanfaatan Limbah Cangkang Telur Ayam Dan Bebek Sebagai Sumber Kalsium Untuk Sintesis Mineral Tulang'. *Jurnal Pendidikan Fisika Indonesia (Indonesian Journal of Physics Education)* 10 (1): 81–85. https://doi.org/10.15294/jpfi.v10i1.3054.

Permanasari, Maharani Dian, Dwinita Larasati, and Dian Widiawati. 2014. 'Banana Bark as A Part of Acoustic Design Unit by Hybrid Technology Application'. *ITB Journal of Visual Art and Design* 6 (2): 143–50. https://doi.org/10.5614/itbj.vad.2014.6.2.5.

Puspitarini, Yani, Fandi Musthofa A S, and Agus Yulianto. 2014. 'Koefisien Serap Bunyi Ampas Tebu Sebagai Bahan Peredam Suara'. *Jurnal Fisika* 4 (2): 96–100.

Ridhola, Fajri, and Elvaswer. 2015. 'Pengukuran Koefisien Absorbsi Material Akustik Dari Serat Alam Ampas Tebu Sebagai Pengendali Kebisingan'. *Jurnal Ilmu Fisika* 7 (1): 1–6. https://doi.org/https://doi.org/10.25077/jif.7.1.1-6.2015.

Rizal, Arlindo, Elvaswer, and Yulia Fitri. 2015. 'Karakteristik Absorbsi Dan Impedansi Material Akustik Serat Alam Ampas Tahu (Glycine Max) Menggunakan Metode Tabung'. *Jurnal Ilmu Fisika* 7 (1): 14–18. https://doi.org/https://doi.org/10.25077/jif.7.1.14-18.2015.

Samsudin, Emedya Murniwaty, Lokman Hakim Ismail, and Aeslina Abdul Kadir. 2016. 'A Review on Physical Factors Influencing Absorption Performance of Fibrous Sound Absorption Material from Natural Fibers'. *ARPN Journal of Engineering and Applied Sciences* 11 (6): 3703–11.

Seddeq, Hoda S. 2009. 'Factors Influencing Acoustic Performance of Sound Absorptive Materials'. *Australian Journal of Basic and Applied Sciences* 3 (4): 4610–17.

Setyowati, Erni, Gagoek Hardiman, Purwanto, and Mochamad Arief Budihardjo. 2019. 'On the Role of Acoustical Improvement and Surface Morphology of Seashell Composite Panel for Interior Applications in Buildings'. *Buildings* 9 (3). https://doi.org/10.3390/buildings9030071.

Setyowati, Erni, Iwan Yahya, Edi Supriyo, Intan C. Romadhona, and Aris Minardi. 2018. 'On the Sound Absorption Improvement of Water Hyacinth and Coconut Husk Based Fiber Reinforced Polymer Panel'. In *MATEC Web of Conferences*. Vol. 159. https://doi.org/10.1051/matecconf/201815901004.

Shchegoleva, I. D., E. N. Molchanova, O. V. Maslova, and O. S. Sokolova. 2021. 'Justification for the Use of Waste from Tea

Production'. In *IOP Conference Series: Earth and Environmental Science*. Vol. 640. https://doi.org/10.1088/1755-1315/640/2/022014.

Sivakumar, Aburpa Avanachari, Sankarasabapathi Sankarapandian, Siva Avudaiappan, and Erick I.Saavedra Flores. 2022. 'Mechanical Behaviour and Impact of Various Fibres Embedded with Eggshell Powder Epoxy Resin Biocomposite'. *Materials* 15 (24). https://doi.org/10.3390/ma15249044.

Sowińska-Baranowska, Anna, and Magdalena Maciejewska. 2023. 'Potential Utilization of Ground Eggshells as a Biofiller for Natural Rubber Biocomposites'. *Materials* 16 (8). https://doi.org/10.3390/ma16082988.

Tang, Xiaoning, Xueting Liu, and Xiong Yan. 2020. 'Investigation on the Sound Absorption Properties of Waste Green Tea Residues Covered by Woven Fabric'. *Journal of Natural Fibers* 19 (4): 1323–32. https://doi.org/https://doi.org/10.1080/15440478.2020.1764455.

Tizo, Maribel S., Lou Andre V. Blanco, Andrian Cris Q. Cagas, Buenos Rangel B. Dela Cruz, Jimrey C. Encoy, Jemalyn V. Gunting, Renato O. Arazo, and Val Irvin F. Mabayo. 2018. 'Efficiency of Calcium Carbonate from Eggshells as an Adsorbent for Cadmium Removal in Aqueous Solution'. *Sustainable Environment Research* 28 (6): 326–32. https://doi.org/10.1016/j.serj.2018.09.002.

Triwiswara, M., and L. Indrayani. 2020. 'Utilization of Black Tea Waste as Natural Batik Dyes on Cotton and Silk'. *IOP Conference Series: Earth and Environmental Science* 456 (1). https://doi.org/10.1088/1755-1315/456/1/012051.

Villanueva, Valeria, Fabrizzio Valdés, Rommy Zúñiga, María Villamizar-Sarmiento, E. Soto-Bustamante, Patricio Romero-Hasler, Ana Riveros, et al. 2023. 'Development of Biodegradable and Vermicompostable Films Based on Alginate and Waste Eggshells'. *Food Hydrocolloids* 142. https://doi.org/142. 10.1016/j.foodhyd.2023.108813.

Warman, Ikhwansyah Isranuri, and Basuki Wirjosentono. 2016. 'Kajian Karakteristik Absorpsi Suara Material Peredam Suara Dari Serat Batang Pinang Raja Dengan Menggunakan Poliuretan Dan Gipsum Sebagai Matrik'. *Jurnal Teknik Dan Teknologi* 11 (22): 32–39.

Xia, Guangmei, K. Obbi Reddy, C. Uma Maheswari, J Jayaramudu, Jinming Zhang, Jun Zhang, and A. Varada Rajulu. 2015. 'Preparation and Properties of Biodegradable Spent Tea Leaf Powder/Poly(Propylene Carbonate) Composite Films'. *International Journal of Polymer Analysis and Characterization* 20 (4): 377–87. https://doi.org/10.1080/1023666X.2015.1019257.

Yonata, Diode, Siti Aminah, and Wikanastri Hersoelistyorini. 2017. 'Kadar Kalsium Dan Karakteristik Fisik Tepung Cangkang Telur Unggas Dengan Perendaman Berbagai Pelarut'. *Jurnal Pangan Dan Gizi* 7 (2): 82–93.

Yudhanto, Ferriawan;, Andika Wisnujati, and Yahya Iwan. 2015. 'Characterization of Performance Acoustic Sandwich Composite With a Core of Polyurethane Foam-Agave Sisalana Fiber Reinforced Polyester for Noise Absorption'. *Jurnal Teknologi* 8 (2): 112–18.