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Investigation of Mechanical and Physical Properties of Eggshell Reinforced with Different Type of Resin

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Abstract: The eggshell that came from the food industries is consider as the non-hazardous waste but can cause environmental pollution. Considering the eggshell waste are rich in calcium carbonate ($CaCO_3$), it is possible to be used as the sustainability insulation product to help the bio economy society and replace the uses of hazardous asbestos insulation. In this review, the tensile strength, sound absorption, and thermal conductivity properties of the eggshell waste composite were discussed. The eggshell powder was characterized under the XRD test. The different types of resins with varied compositions reinforced with the eggshell powder. The result from the XRD pattern of ESP shows the mostly the peak of the pattern was $CaCO_3$. For the tensile test, the tensile strength increasing when the composition increase. The higher composition of the filler content gives the optimum the sound absorption coefficient but in a specific range of the frequency. The thermal conductivity, decreasing when added more percentage of ESP content but certain results show increasing due to different parameter uses. The comparison between asbestos properties, the eggshell composite has potential as the insulation material.

Keywords: Eggshell Waste, Tensile Strength, Sound Absorption, Thermal Conductivity

1. Introduction

Eggshell is the cheapest material and is a regularly used waste product [1]. Because of the cost of disposal, agricultural waste is one of the most emerging problems in the food industry. However, when new uses can be found for these residual materials, it is also an opportunity for the bioeconomy society [2]. Composite materials reinforced with eggshells consist of high strength and modulus fused or bonded to a matrix with different interfaces between them. Eggshell powder, calcium carbonate, and matrix maintain their physical and chemical characteristics in this form; they must create a variety of properties that cannot be accomplished by working alone with either constituent. In general, eggshells with calcium carbonate polymer are the load-carrying members, whereas the surrounding matrix holds them in the desired position, the load transfer medium between them serves as the orientation, and protects them from damage to the environment, for example, to high temperatures and humidity.

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Therefore, although the fibers provide the matrix with reinforcement the latter also performs a number of useful purposes in a polymer composite material reinforced by an eggshell [3].In this study, the eggshell composite was compared with the asbestos. In the past, many of the construction industry used asbestos in buildings for insulation. During activities, asbestos fibres are released into the air. Asbestos fibres can then be inhaled without knowing and trapped in the lungs. If swallowed, they can also be incorporated into the digestive tract [4]. As a result, asbestos can cause lung cancer, lar-ynx and ovarian cancer, mesothelioma (pleural or peritoneal lining tumours), and asbestosis (lung fibrosis) [5]. Table 2.1, 2.2 and 2.3 shows the mechanical and physical properties of the asbestos.

Table 1: Physical properties of selected asbestos fibre [6]

Properties	Chrysolite	Crocidolite	Amosite
Density, (g cm^{-1})	2.4 – 2.6	3.2 – 3.3	3.1 – 3.2
Tensile strength, (MPa)	1,100 – 4,400	1,400 – 4,600	1,500 – 2,600
Hardness, (Mohs)	2.5 – 4.0	4.0	5.5 – 6.0

Table 2: Properties of insulation asbestos and nigerite board [7]

Material	Density (kg/m^3)	Thermal conductivity (W/mK)
Asbestos board	1500 - 1950	0.15 – 2.07
Nigerite board	1350	0.2

Table 3: Comparison of the sound absorption coefficient of fibrous materials [8]

Material	Frequency (Hz)				
	250	500	1000	2000	NRC
Asbestos	0.35	0.50	0.46	0.52	0.46
Bituminous mineral wool felt	0.18	0.50	0.68	0.81	0.54
Wood wool slabs	0.07	0.15	0.56	0.90	0.42

2. Materials and Methods

2.1 Materials

The Material that had been used for this research is eggshell waste collected from stall around Parit Raja, Epoxy resins, and Polyester resins with different compositions as a hardener resin.

2.2 Sample preparation

The eggshells waste (ESW) was washed several times in clean water to remove impurity, membranes, and dirt manually such in figure 1. The clean of the eggshell waste (ESW) has been dried under the sun at three hours. Then, the eggshell waste (ESW) crushed into a piece for the sieving process to obtain an average particle size of 100µm powder. The eggshell powder (ESP) then examined the characteristic of eggshell by using the X-ray Diffraction test (XRD).

(a) (b)

Figure 1: (a) Washing process (b) Dried process

2.3 Previous researcher parameter

Due to the pandemic of COVID 19, the studies continued by reviewing the previous research for the mechanical and physical tests. Tables 4, 5 and 6 show the parameter of tensile sound absorption and thermal conductivity test. The different researcher uses the different material, hardener and composition of the eggshell composite.

Table 4: List of parameters from the previous researcher for the tensile test.

Reinforced material	Hardener matrix	Composition	Standard	Dimension (mm)	References
1) Eggshell powder 2) Glass fiber	Polyester resin	CI= 50:50:0 CII= 45:50:5 CIII= 40:50:10	ASTM D 3039	250 x 25 x 3	[9]
Eggshell powder (ESP)	Epoxy resin	Ep+4%ESP Ep+8%ESP Ep+12%ESP Ep+16%ESP	ASTM D-638	150 x 3 x 5	[10]
1) Snail shell 2) Eggshell	Epoxy resin	Ep+5wt%S Ep+10wt%S Ep+15wt%S Ep+20wt%S	ASTM D3039	-	[11]
Eggshell powder (ESP)	Poly (lactic acid) (PLA)	PLA+1wt% ESP PLA+2wt% ESP PLA+3wt% ESP PLA+4wt% ESP PLA+5wt% ESP	ASTM D790-10	100 x 10 x 0.05	[12]
Eggshell powder (ESP)	Polypropylene Carbonate (PPC)	PPC+1wt% ESP PPC+2wt% ESP PPC+3wt% ESP PPC+4wt% ESP	ASTM D790-10	100 x 10 x 0.05	[13]

Table 5: List of parameters from the previous researcher for sound absorption test.

Reinforced material	Hardener matrix	Frequency range	Standard	Dimension (mm)	Author
Eggshell waste (ESW)	Carboxymethyl Cellulose Polyethylene Glycol	1600 Hz to 5000 Hz	Impedance tube ASTM E1050-98	28	[14]
CaCO3 fillers	Polyurethane	63–1600 Hz 1000–6300 Hz	Impedance tube	10 x 20	[15]
Banana fiber	Epoxy resin	500 Hz – 6000Hz	Transfer function ASTM E1050-12	25 x 5	[16]
Betelnut fiber	Polyester resin	400Hz - 6000 Hz	Transfer function ASTM E1050-10	25 x 6	[17]
Luffa fiber	Epoxy resin	500 – 6300Hz	Transfer function ASTM E 1050-12 [38]	10	[18]

Table 6: List of parameters from the previous researcher for a thermal conductivity test.

Reinforced material	Hardener Matrix	Composition	Method	Dimension (mm)	Author
Eggshell powder (ESP)	Epoxy resin (Nitofill, EPLV)	Ep+1%ESP Ep+2%ESP Ep+3%ESP Ep+4%ESP	Lee's Disk	50 x 3	[19]
Chicken eggshell (CES)	Polyurethane resin TiO2 paste Xylene	PU+0%CES PU+1%CES PU+5%CES PU+10%CES	KD2 Pro Thermal Properties Analyzer	1.3 x 60	[20]
Eggshell waste	Polyester resin	PR+10%ESW PR+20%ESW PR+30%ESW PR+40%ESW PR+50%ESW	Lee's Disk	40 x 6	[21]
Eggshell	polyvinyl alcohol	PVA+5wt% ES PVA+10wt% ES PVA+15wt% ES PVA+50wt% ES	Steady State	-	[22]
Eggshell powder (ESP)	Epoxy resin	Ep+1wt% ESP Ep +2wt% ESP Ep +3wt% ESP Ep +4wt% ESP	Searle's	-	[23]

3. Results and Discussion

3.1 X-Ray Diffraction (XRD) analysis

Figure 2 has shown the pattern of the X-Ray Diffraction (XRD) of the eggshell waste powder sample. From this sample show that all the diffraction peak represent a characteristic of calcite or known as calcium carbonate (CaCO3) and the highest peak intensity at 29.4˚ (2θ). The red triangle shape marked on the peak of the pattern represents the calcite element located at the peak of the pattern. It is confirmed that the calcite (CaCO3) is a major content of eggshell waste.

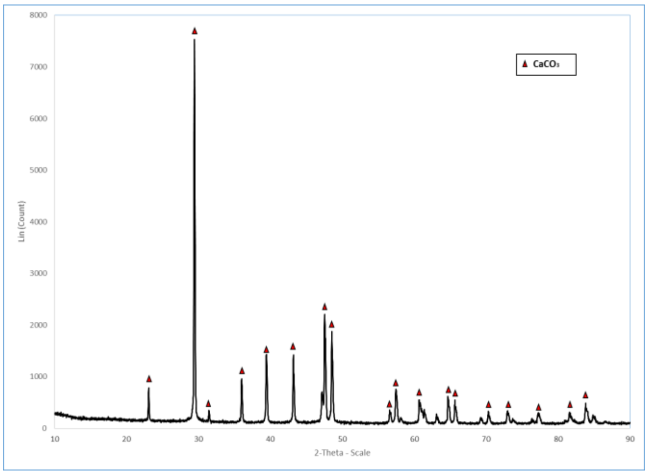

Figure 2: ESP characteristic pattern

3.2 Tensile Test

3.2.1 Ultimate tensile strength (UTS)

The ultimate tensile strength (UTS) of eggshell waste reinforced with resin focused on different researchers as follows. Hiremath et al [9], describes that eggshell powder reinforced polyester resin as a hardener, tensile strength for the filled composite is higher compared to unfilled composite. The composite as a filler material with 10wt% eggshell powder can withstand greater tensile stress with reading 150MPa than those with 0wt% and 5wt% eggshell powder as a filler material with a reading below than 150 MPa.

Mohammed & Haitham [10], reported epoxy resin reinforced with the eggshell powder. The tensile strength of the specimen from pure epoxy with 30MPa decreases by 38% with the addition of 4wt% filler content with 18.5MPa then starts to rise by as the filler composition increases by 8wt%, 12wt%, 16wt% with reading 24.4MPa, 34MPa and 47MPa.

Gbadeyan et al.,[11], reported achatina fulica snail and eggshells reinforced composite materials. The eggshell tensile strength increased from 46.19 MPa at neat to 48.45 MPa and 51.55 MPa to 62.7 MPa. Then it is dropped with 53.45MPa at 20 wt%. Then the snailshell show that gains tensile strength from 46.19 MPa to 59.22 MPa to 69.05 MPa and starts dropped at 15 wt% with 61 MPa tensile strength. The data shows that both shell particles give an improvement of tensile strength when the weight percentage increased. The snailshell reinforced composite observed has higher tensile strength compared with the eggshell reinforced composite for 5%, 10%, and 20% cases.

Ashok et al.,[12]**,** reveal poly(lactic acid)/eggshell powder composite films the tensile strength increased when the filler content up to 4wt% then dropped afterward. The tensile strength was increased with 16.8MPa at 0wt% to 17.7MPa, 21.1MPa, 25.5MPa, 30.6MPa at 4wt% filler content after that dropped at 5wt% with 22.5MPa. From the trend of the graph, the tensile strength increased of composite films over the matrix was 82.1% respectively.

Feng et al.,[13], reported polypropylene carbonate bio-Filler (eggshell powder) composite films the tensile strength increased when the filler content up to 4wt% then dropped afterward. The tensile strength was increased with 12.8MPa at 0wt% to 13.1MPa, 14.2MPa, 17.6MPa, 23.2MPa at 4wt% filler content after that dropped at 5wt% with 13.8MPa. From the trend of the graph, the tensile strength increased of composite films over the matrix was 81% respectively.

3.2.1 Elongation break

The elongation break of eggshell waste reinforced with resin focused on different researchers as follows. Hiremath et al.,[9], states that eggshell powder reinforced polyester resin as a hardener. The composite as a filler material with 10wt% eggshell powder can experience more deflection with displacement between 10mm and 15mm than those with 0 wt% and 5 wt% eggshell powder as a filler material with displacement between 5mm and 10mm. The ultimate filler composite load is taken by 10wt%, and the deflection is greater. Adding filler content may have limited crack and delamination propagation.

Mohammed & Haitham [10], reveal that the elongation percentage at break values for the epoxy resin reinforced with eggshell powder, decreasing from pure epoxy by 14.8% to 12.3% and 5.4% elongation break with added 4wt% and 8wt% eggshell powder. Then start increasing again with 7% elongation at 12wt% eggshell powder and then decreasing again with 4.9% elongation at 16wt%.

Ashok et al.,[12], observed the percentage of elongation at break of poly(lactic acid)/eggshell powder composite films decreasing from 4.02% at 0wt% to 3.52%, 2.13%, 1.73%,1.43%, 2.86% then start to increase at 5wt% of filler content with 2.86%. It can state that the increasing filler loading will decrease the percentage elongation at break. The increasing filler loading can affect stiffness and reduce the ductility of composite films.

Feng et al [13], describe the percentage of elongation at break of polypropylene carbonate bio-Filler (eggshell powder) composite films decreasing from 8.21% at 0wt% to 7.05%, 6.19%, 5.86%, 5.25%, 5.25% then start to increase at 5wt% of filler content with 7.85%. It is showing that the percentage elongation at break decreasing with increasing the filler loading thus can affect the stiffness and reducing ductility of the composite films.

3.2.1 Young Modulus

Gbadeyan et al.,[11], describes the tensile modulus of the neat matrix, and the reinforced composites not only increased in tensile strength but also their stiffness. The stiffness of the reinforcement of snailshell increased by around 15% and 20%. The eggshell particle stiffness increase was not proportional to the amount of reinforcement but increase at 15 wt%, while the hybrid composite increased by 5% stiffness at 10 wt% and dropped afterward.

Ashok et al.,[12], reported Young's modulus of poly(lactic acid)/eggshell powder composite films increased with filler content with 1.964GPa at 4wt% then dropped sharply at 5wt% with 1.389GPa of young's modulus. The trend from the graph shown in the figure shows the same as the tensile strength graph trend. The increase in modulus of composite film over the matrix was 70.4% respectively.

Feng et al.,[13], reveals Young's modulus of polypropylene carbonate bio-Filler (eggshell powder) composite films increased with filler content with 1.378GPa at 4wt% then dropped sharply at 5wt% with 0.983GPa of young's modulus. The trend from the graph shown the same as the tensile strength graph trend. The increase in modulus of composite film over the matrix was 67% respectively. Table 7 depicts the summaries comparison for tensile test from previous researcher results.

Table 7: Comparison of previous researcher tensile test data

Composite	Selected composition	Tensile strength (MPa)	Elongation	Yield strength (GPa)	Author
ESP+Pr	CIII= 40:50:10	150	10 – 15mm	-	[9]
ESP+Ep	Ep+16%ESP	47	4.9%	-	[10]
ES+Ep	Ep+15%ES	62.7	-	8 - 9	[11]
ESP+PLA	PLA+4%ESP	30.6	1.43%	1.964	[12]
ESP+PPC	PPC+4%ESP	23.2	5.25%	1.378	[13]

3.3 Sound absorption test

Mohamad et al.,[14], describe the sound coefficient of polymeric sponge replication method with eggshell waste is observed that 70% of eggshell waste composition has a higher sound absorption coefficient with 0.92 at 5000 Hz frequency compared with 50% and 60% eggshell waste composition. While 60% of eggshell waste composition shows the lowest sound absorption coefficient at 5000 Hz frequency and shows the lowest coefficient around 1000 Hz frequency with a value 0.51 coefficient. The result can conclude that the thicker material has a higher sound absorption coefficient at a higher frequency. Choe et al., [15], reveal the polyurethane composite foams including $CaCO_3$ fillers for enhanced sound absorption observed the sound coefficient increase with increasing filler content. The filler content at 6 %wt $CaCO_3$ filler content shows the highest sound absorption coefficient with 0.9 – 1.0 coefficient compared with 0 wt%, 2 wt% 4 wt%, 8 wt%, and 10 wt% due to lowest open porosity.

Jayamani et al.,[16], reported the sound absorption coefficient of banana fibers reinforced epoxy composite's higher sound absorption at high frequency. It is observed that if the fiber content increase will increase the sound absorption coefficient of a composite. At composition 20 wt% shows the higher sound absorption coefficient while the lowest sound absorption coefficient observed at 5 wt% banana fiber composite. Jayamani et al.,[17], describe the betelnut fiber polyester composites as the sound absorption coefficient obtained from range 300 to 6000Hz frequency. The lowest sound absorption shows that it was composite with 5 wt% of betelnut fibers. The value of the coefficient varies between 0.03 to 0.20 with increasing frequency. The composite 20 wt% of betelnut fibers shows the higher sound absorption coefficient reaches a peak with reading 0.27 coefficient.

Koruk & Genc [18], describe the sound absorption coefficient of luffa fiber-reinforced epoxy that luffa fiber composite has a high sound absorption coefficient. The luffa composite sample with thickness 10mm observed that increasing the frequency will increase the sound absorption coefficient. The highest sound absorption coefficient located at 5000 and 6300 Hz frequency. The average of the sound absorption coefficient of luffa composite and fiber epoxy ratio for range 500 – 6300Hz is around 0.03 coefficient. Table 8 shows summaries of previous researcher result for sound absorption coefficient.

Table 8: Comparison of previous researcher sound absorption coefficient data

Composite	Selected composition	Sound coefficient, α	Author
ESP+CMC+PEG	70%	0.92	[14]
$CaCO_3$+PU	6wt%	0.9 – 1.0	[15]
Banana fiber+Ep	20wt%	0.8 – 1.0	[16]
Betelnut+polyester	20wt%	0.25 – 0.3	[17]
Luffa fiber+Ep	Fiber epoxy ratio of 4	0.7 – 0.8	[18]

3.4 Thermal conductivity test

Hamdi & Habubi [19], describe the thermal conductivity of chicken eggshell composite the neat epoxy thermal conductivity was 0.23 W/mK respectively. Then the thermal starts to decrease with the increased percentage of the filler content. The range of the thermal conductivity shows in figure starting from 0.195 to 0.23 W/mK. At these ranges can conclude the epoxy eggshell composite to heat transfer is very low. The filler content at Ep/4%ES shows the lowest thermal conductivity value which is the best ratio in slowing down the heat current in the epoxy matrix.

Ang et al.,[20], reported the thermal conductivity of polyurethane coating containing chicken eggshell at 0wt% with 0.09 W/mK increased drastically with 0.131W/mK at 1wt% eggshell proportion. Afterward, it is slightly increased from 0.131W/mK to 0.132W/mK and 0.134W/mK respectively. From this result, it is proved that the chicken eggshell does not contribute to thermal insulation properties. The increased thermal conductivity as the proportion of chicken eggshell filler increases could be due to the formation of preferential paths through coating composite where heat conduction has taken place.

Abdullah [21], observed the thermal conductivity of eggshell composite decreasing when the volume fraction of eggshell increased. The graph shows that the volume fraction at 10% with value 1.4W/m.c start dropped with increasing the volume fraction to around 0.6W/m.c at 60% volume fraction. It can be concluded that the thermal conductivity decreases as the volume fraction increases due to an increase in the volume of natural fiber in the composite sample that has less thermal conductivity than polyester resin.

Hussien [22], reveal the thermal conductivity of polyvinyl alcohol (PVA) – eggshell composite increasing when then eggshell content increases up to 40% afterward dropped at 50% drastically. From the graph shown in figure observed that the thermal conductivity increasing slowly up to 30% eggshell content at the first stage then reaches a peak at 40% eggshell content at the second stage. Afterward, it starts the reverse effect of thermal conductivity.

Abdel malik et al.,[23], reported the eggshell powder/epoxy polymer thermal conductivity increased when the percentage composition of eggshell powder increases. The thermal conductivity start increasing from neat epoxy with value around 0.23W/mK increased with added percentage composition 1%, 2%, 3%, 4% and 5% with the highest value obtain around 0.26 W/mK at 5% composition. This possibility hooks up to the higher thermal conductivity of CaO which has the highest composition in eggshell. Table 9 shows the comparison for thermal conductivity result from previous researcher.

Table 9: Comparison of previous researcher thermal conductivity data

Composite	Selected composition	Thermal conductivity, W/mK	Author
CES+Ep	4%	0.195	[19]
CES+Ep	1wt%	0.131	[20]
ES+Polyester	60%	0.6 -0.62	[21]
ESP+PVA	50%	0.03 - 0.05	[22]
ESP+Ep	1%	0.23 – 0.24	[23]

4. Conclusion

In conclusion, the result from the XRD pattern of eggshell waste powder shows the mostly the peak of the pattern was calcium carbonate or known as calcite (CaCO3). For the tensile test, mostly the graph shows the same trend which is the ultimate tensile strength, and Young's modulus increases with an increase in the composition of eggshell powder then dropped at the highest content of the eggshell powder but for the elongation at break percentage was in the opposite trend. The sound absorption coefficient the higher composition of the filler content gives the optimum the sound absorption coefficient but in a specific range of the frequency. The thermal conductivity of the sample observed was decreasing when added more percentage of eggshell powder content and certain was increasing. The comparison of eggshell composite properties with the asbestos properties in the literature review study found that the mechanical properties are better to compare with eggshell composite but in term of physical properties seems the eggshell composite can challenge the asbestos. For the future study, added more physical tests such as water absorption, flammability, and chemical test for the studied sample to determine the robustness of the sample.

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References

[1] A. A. and V. C. Sekhar, "Investigation on the mechanical properties of egg shell powder reinforced polymeric composites," *Int. J. Eng. Res. Technol.*, vol. 3, no. 12, pp. 288–291, 2014.

[2] A. Laca, A. Laca, and M. Díaz, "Eggshell waste as catalyst: A review," *J. Environ. Manage.*, vol. 197, pp. 351–359, 2017.

[3] J. Senthil and M. R. P, "Preparation and Characterization of Reinforced Egg Shell Polymer Composites," *Int. J. Mech. Eng. Robot.*, vol. 3, no. 3, pp. 7–17, 2015.

[4] OSHA, "OSHA Fact Sheet - Asbestos," 2014.

[5] M. Neira, "Chrysotile asbestos," p. 44, 2014.

[6] R. Kusiorowski, T. Zaremba, J. Piotrowski, and J. Adamek, "Thermal decomposition of different types of asbestos," *J. Therm. Anal. Calorim.*, vol. 109, no. 2, pp. 693–704, 2012.

[7] J. K. Odusote and K. S. Dosunmu, "Development of chicken feather reinforced insulation paperboard from waste carton and Portland cement," *J. Eng. Res.*, vol. 16, no. 1, pp. 44–52, 2019.

[8] P. Sun and Z. Guo, "Preparation of steel slag porous sound-absorbing material using coal powder as pore former," *J. Environ. Sci. (China)*, vol. 36, pp. 67–75, 2015.

[9] P. Hiremath, M. Shettar, and M. C. Gowrishankar, "Investigation on mechanical and physical properties of GFRP-Egg shell powder hybrid composites," *Indian J. Sci. Technol.*, vol. 9, no. 32, 2016.

[10] R. A. Mohammed and R. Haitham, "Experimental Investigation Investi Gation of Some Properties of Epoxy Reinforced By," no. February, 2019.

[11] O. J. Gbadeyan, S. Adali, G. Bright, B. Sithole, and A. Omojoola, "Studies on the mechanical and absorption properties of achatina fulica snail and eggshells reinforced composite materials," *Compos. Struct.*, vol. 239, no. August 2019, 2020.

[12] B. Ashok *et al.*, "Tensile and Thermal Properties of Poly(lactic acid)/Eggshell Powder Composite Films," *Int. J. Polym. Anal. Charact.*, vol. 19, no. 3, pp. 245–255, 2014.

[13] Y. Feng *et al.*, "Preparation and Characterization of Polypropylene Carbonate Bio-Filler (Eggshell Powder) Composite Films," *Int. J. Polym. Anal. Charact.*, vol. 19, no. 7, pp. 637–647.

[14] Z. Mohamad, K. Roslan, N. S. Zainal, F. M. Noor, A. E. Ismail, and S. Hayyan, "The characterization of eggshell waste by using polymeric foam replication method," *Test Eng. Manag.*, vol. 81, no. 11–12, pp. 1071–1079, 2019.

[15] H. Choe, J. H. Lee, and J. H. Kim, "Polyurethane composite foams including CaCO3 fillers for enhanced sound absorption and compression properties," *Compos. Sci. Technol.*, vol. 194, no. April, p. 108153, 2020.

[16] E. Jayamani, S. Hamdan, P. Ezhumalai, and M. K. Bakri, "Investigation on dielectric and sound absorption properties of banana fibers reinforced epoxy composites," *J. Teknol.*, vol. 78, no. 6–10, pp. 97–103, 2016.

[17] E. Jayamani, S. Hamdan, M. R. Rahman, and M. K. Bin Bakri, "Investigation of fiber surface treatment on mechanical, acoustical and thermal properties of betelnut fiber polyester composites," *Procedia Eng.*, vol. 97, pp. 545–554, 2014.

[18] H. Koruk and G. Genc, *Acoustic and mechanical properties of luffa fiber-reinforced biocomposites*. Elsevier Ltd, 2019.

[19] W. J. Hamdi and N. F. Habubi, "Preparation of epoxy chicken eggshell composite as thermal insulation," *J. Aust. Ceram. Soc.*, vol. 54, no. 2, pp. 231–235, 2018.

[20] B. C. Ang, N. Ahmad, Z. C. Ong, S. C. Cheok, and H. F. Chan, "Study of the mechanical and the thermal insulation properties of polyurethane coating containing chicken eggshell and rice husk ash as fillers," *Pigment Resin Technol.*, vol. 45, no. 5, pp. 313–319, 2016.

[21] D. F. A. Abdullah, "Theoretical and Experimental Investigation of Natural Composite Materials As Thermal," vol. 4, no. 2, pp. 26–36, 2011.

[22] H. M. Hussien, "Studying the Ultrasonic Properties , DC Conductivity and Coefficient of Thermal Conductivity of PVA-Egg Shells Composites," vol. 18, no. Peters 1998, pp. 28–36, 2013.

[23] A. A. Abdelmalik, M. O. Ogbodo, and G. E. Momoh, "Investigating the mechanical and insulation performance of waste eggshell powder/epoxy polymer for power insulation application," *SN Appl. Sci.*, vol. 1, no. 10, pp. 1–12, 2019.