DEVELOPMENT OF A COMPOSITE GASKET USING EGG SHELL GLASS POWDER AND EPOXY RESIN

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Abstract
In this present work, the egg shell was reinforced with glass fiber in the presence of epoxy resin and hardener to produce composite gasket using the hand lay-up method. The experiment was conducted on tensile strength, impact strength, flexural strength, density, hardness, water absorption and compared with standard gasket. The best results from the density test (1.68 g/cm^3) and water absorption test (0.35%) are within the range of the conventional gaskets (1.65 g/cm^3 and 0.38 %). The best results from hardness test (25.47 VHN), impact test (5.14 J) and flexural strength (21.53 MPa) are significantly low compared to conventional gasket (having impact strength of 10.67 J, hardness strength of 40.29 VHN, and flexural strength of 2742.74 MPa). Base on the result obtained show that the composite material could be used as a replacement for some conventional gasket in simple machinery such as taps, injector nozzles etc. but not to be used in car gasket as they do not possess the required tensile and flexural strength.

Keywords
Egg shell, composite gasket, strength, conventional gaskets, simple machinery

1. INTRODUCTION

Composites exist in nature such as wood, with long cellulose fibers held together by a substance called lignin. Composite materials are formed by combining two or more materials that have quite different properties, and they do not dissolve or blend into each other [1-3]. A typical composite material is generally composed of reinforcement (fibers, particles, etc.) embedded in a matrix (polymers, metals, ceramics, etc.) [4-8].The composite, resulting from the combination of fibers and matrix, possesses higher specific stiffness and specific strength, and is lighter than conventional engineering materials [9-13].

A gasket is a mechanical seal that fills the space between two mating surfaces [14-16]. Gaskets can be made from several flat materials, such as embossed steel, other metals, high temperature fiber materials, graphite, ceramic composite, cork, rubber, interface materials, and composites that use a combination of the above [17]. These include gasket production using: maize husk fibers waste tire crumb and coconut coir, rubber and maize , eggshell and polymer-based [18-21].

Chicken egg shell (E.S) is a biomaterial consisting of calcium carbonate with a weight fraction(of ~95%) and other materials like (SiO_2, AL_2O_3, P, S, Cl) with a weight ratio (~5%) [22-24]. The generalized egg shell structure, which varies widely among species, is a protein lined with mineral crystals, usually of a calcium compound such as calcium carbonate. These characteristics qualify egg shell (ES) as a good candidate for bulk quantity, inexpensive, lightweight and low load-bearing composite applications, such as the automotive industry, trucks, homes, offices, and factories. Eggshell has been used as a reinforcement agent in polymer composites [25-29]. This present study developed a composite gasket utilizing waste egg shells with epoxy resin.

2. MATERIALS AND METHOD

2.1. Materials

The base material for this research work is eggshell which mostly used as feed for birds and as waste in Nigeria for landfill, alongside other non-biodegradable wastes. Glass fibre is a commonly used synthetic fibre made from silicates, soda, clay, limestone, boric acid and various metallic oxides [30], this was used as reinforcement. Epoxy resin is a representative thermosetting polymer that has been widely used because of its excellent thermal and chemical stability and good mechanical properties [31-32] used as binder.

2.2. Preparation of the Composite

The egg shell was collected from restaurants, bakeries and hatcheries around the Federal University of Agriculture, Abeokuta. The eggshells were rinsed in water to remove dirt and then soaked in a solution of dilute hydrochloric acid (HCl) to separate the calcium-rich eggshells from the membranes lying inside the eggshells [33]. The separated eggshells were sundried and milled using hammer mill. The milled eggshell was passed through three different sieves of mesh sizes 75, 50 and 25 µm. Broken glasses obtained from Oshodi, Lagos were also milled using ball milling machine into particles of size 150 microns. Both egg shell and glass fiber were combined in the same proportion by weight and added to reduced epoxy and hardener. The mixing ratio of the epoxy resin and hardener is 2:1 [34].

2.3. Design of Experiment

Below is the optimal design obtained from Minitab.

Table 1: Mixture composition

Sample Number	Egg Shell (wt%)	Glass fiber (wt%)	Epoxy (wt%)
A	--	--	100
B	2.5	2.5	95
C	5	5	90
D	7.5	7.5	85
E	10	10	80
F	12.5	12.5	75

The epoxy resin consists of the binder and hardener in the ratio 2:1.

2.4. Method of Production

Hand laying method was adopted in this work. It involved manually laying of the fibre reinforced material in the mould and applying resin in layers to build thickness with the removal of trapped air by hand or roller pressure. The composite was then allowed to cure under room temperature and atmospheric pressure for just above 24 hours and was then removed from the mold.

2.5. Characterization of the Mechanical Properties of the Samples Produced

The density and water absorption rate, were determined using standard method. The static tensile test was carried out using the UTM, opposite ends of the samples were held by the gauge of the UTM and pulled apart. The samples elongated in the direction parallel to the applied load. Flexural test was conducted using three-point and four-point bend testing ISO 178, ASTM D 790, and ASTM D 6272. Impact test was done on the composite samples according to ASTM D 7136M-05, ASTM D 3763, and ISO 6603. Hardness test was measured both at ambient temperature and at an elevated temperature, the materials were placed into the furnace and maintained at an elevated temperature of 200°C for 30 minutes. After removing the samples from the furnace the same procedure was used for the hardness measurement. Hardness values were shown on the screen corresponding to Vickers hardness number.

Plate (a) Dry egg shell (b) Milled egg shell (c) Milled glass (d) Scale, epoxy resin, hardener& mixed samples

3. RESULTS AND DISCUSSION

3.1 Density Test

The results of the density test performed on the manufactured samples are shown in Figure 1. The results of the Density Test were 0.88, 1.51, 0.96, 1.23, 1.5, 1.68, and 1.65g/cm^3, for Samples A, B, C, D, E, F, and CR respectively. It could be observed that density increased with the addition of reinforced materials (both eggshell and glass powder), with the exception of Sample B that did not follow the trend. It could also be seen that Samples F and CR have about the same densities.

The results agreed with Samotu *et al.*, [35], who stated that the addition of a filler matrix to a natural fiber increases its density. The density of sample F (12.5 eggshell and 12.5% glass fibre) conforms with the density of the commercially known gasket of popular commercial brand, which lies between 1.60 g/cm^3 to 1.65 g/cm^3.

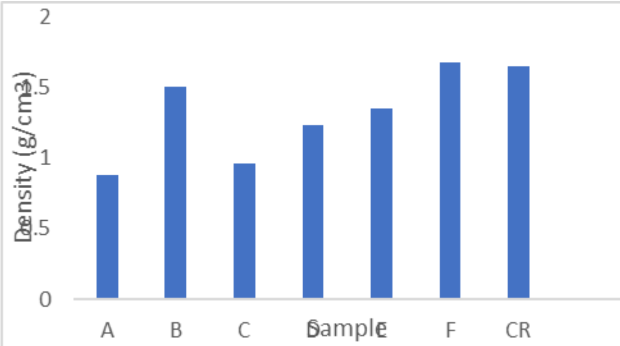

Figure 1: Showing the variation of density with samples

3.2. Water Absorption

This test was carried out to determine how the gasket would perform when exposed to water or the maximum percentage of water absorbed by the gasket samples. Figure 2 represents the percentage of water absorption in terms of the percentage increase in weight for gasket samples produced from egg shell and glass fiber. Results for the Water Absorption Test were 7.84%, 0.35%, 4.87%, 2.44%, 1.05% and 0.53% for Samples A, B, C, D, E and F respectively. It could be observed from Figure 2 that water absorption decreased with increase in reinforced materials except in Sample B that did not follow the trend. The interfacial bonding between the glass fibers and the natural fibers increases the porosity level [35-36]. The commercially available gasket of Nissan shows very low water absorption due to their material (stainless steel), and their application in sealing the top cylinder with the engine block.

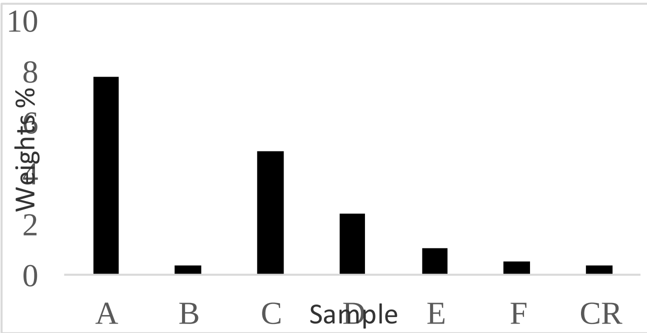

Figure 2: Showing the graphical representation of the water absorption test carried out on the samples

3.3. Flexural Testing

The results of Flexure Test carried out were 4.07, 10.12, 3.44, 2.88, 64.02 and 32.50 MPa for A, B, C, D, E and F respectively. Sample E with 10% glass fibre gave the highest flexure stress. Flexure stress generally decreased with increase in glass fibre except for Samples B, E and F that did not follow a particular pattern. It can therefore be inferred that hybridization increases the flexure stress of the composite. The random planar arrangement of the fibers is likely to lead to rigidity and better absorption of compressive forces, increasing overall bending strength [36]. The results of Sreekala *et al.*, [37]; Arthanarieswaran *et al.*, [38], they reported that there is a rise in flexural stress with increased glass fiber content in composites, agree with this statement.

The results of Flexure Strain at Maximum Stress are shown in Table 2. According to the Flexure Strain at Maximum Flexure Stress, generally decreased with increase in glass fibre from Samples A to D, except with Sample B. The Flexure Strain later increased at Sample E and decreased again at Sample F. All the Samples demonstrated higher Flexure Strain at Maximum Flexure Stress compared with the Control Sample. Whereas the Control Sample (popular commercial brand) had a higher value of Maximum Flexure Stress than all the Samples, its Flexure Strain at Maximum Flexure Stress was the lowest. This was due to their material (stainless steel) which is known to have high Flexure Stress. In this case, the composite gasket is seen to be lacking and will not be a good substitute where large Flexure Stress is concerned.

Table 2: Flexural test result.

Sample	Maximum Flexure Stress (MPa)	Flexure Strain at Maximum Flexure Stress (%)	Flexure strain at Break (Standard) (mm/mm)
A	16.6252	2.20267	0.02568
B	30.09051	3.22002	0.03385
C	19.06683	1.82464	0.02116
D	25.12739	1.19003	0.01591
E	64.01973	4.64801	0.04648
F	17.87678	1.64735	0.01931
CR	2742.74725	0.61633	0.00793

3.4 Hardness Test

Figure 3, shows comparison between the hardness properties of each gasket produced. The results of Hardness Test carried out were 21.67, 25.47, 24.23, 21.93, 22.37 and 23.73 VHN needed for A, B, C, D, E and F at ambient temperature (25^0C) respectively. At elevated temperature (150°C), the hardness values of Samples A, B, C, D, E and F were 23.42, 28.91, 23.64, 22.17, 21.85 and 26.62 respectively. Sample B with2.5% eggshell and 2.5% glass fibre gave the highest hardness value. Hardness property generally decreased with increase in glass fibre except for Samples E and F that did not follow a particular pattern under the two conditions. The variation in the hardness number of the composite material also agrees with observations made by Mishra [39] and Agunsoye *et al*., [40], they stated that the composite's Vickers hardness test gave values of 15.884 VHN, 16.098 VHN, and 16.88 VHN for 10, 15, and 20 wt. % reinforcement, respectively, and this is because the amount of Nano-particle addition reaction has increased, which dominates the cross-linking process and results in the development of a stronger material with improved hardness. It is essential to know the hardness of the materials because the gasket must have higher resistance to deformation to prevent leakage after being compressed by the pipe.

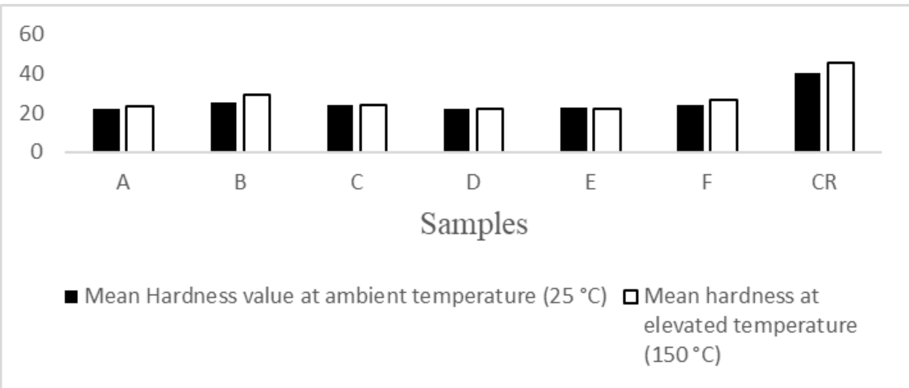

Figure 3: Graph of variation of hardness with samples both at ambient and elevated temperatures.

3.5 Impact Test

The impact fracture energy of the developed gasket composites. 4.26, 3.65, 4.31, 3.36, 5.14, and 4.08 J for Samples A, B, C, D, E and F respectively. The low values of the impact strength show that the composite gasket can only be used in applications that withstand a low level of impact energy, such as those encountered in low-pressure systems or simple machinery.

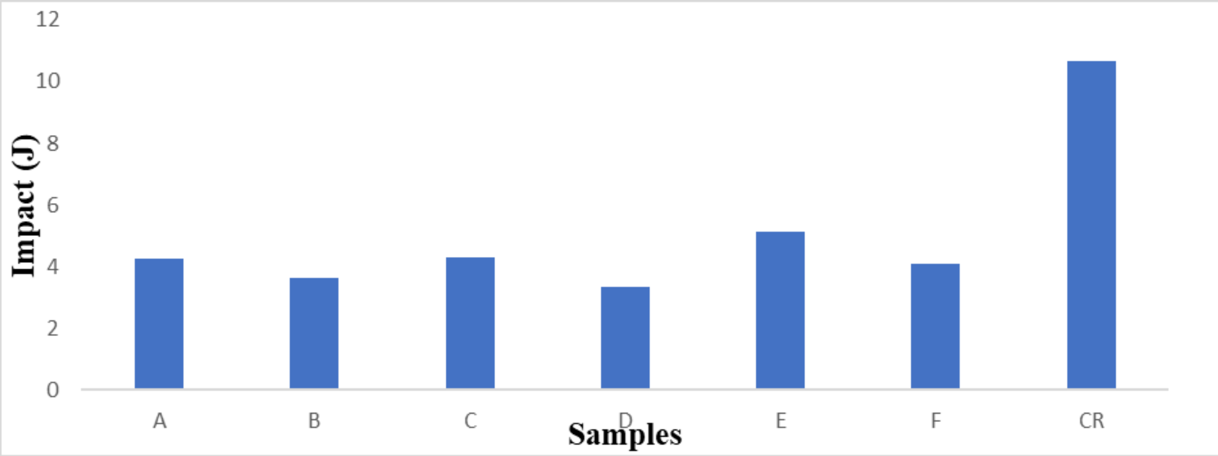

Figure 4: Graph of variation of impact energy with samples.

3.6 Tensile Strength

Table 3, shows the tensile strengths for Samples. The results were 10.05, 11.25, 8.91, 10.023, 12.347 and 9.023 MPa for Samples A, B, C, D, E and F respectively. The sample composition of 7.5 eggshell powder and 7.5% glass fibre had the highest tensile strength of 12.347 MPa. It could also be observed that the tensile strength increased with increase in the glass fibre composition. The tensile strength obtained were generally lower compared with the Control (456.418 MPa).

Introducing reinforcements lowered the tensile stress obtained for Sample B from 11.23 MPa to 9.023 MPa in Sample F. Also, introducing reinforcement lowered the elongation percentage at the break of the composite material from 22.562 % to 7.074 %. This result agreed with that obtained by Kelly *et al*., [41]; Samotu *et al*. [35], they reported a decrease in tensile strength of their composites from 87.29 % to 37.50 % which is a 49.79 % reduction and also Chary and Ahmed, [41]; Agunsoye *et al*., [40] also stated that experiment conducted showed that tensile properties of the composites were found to decrease with the increase in the filler particle size and filler volume fraction. The control gasket sample (popular commercial brand) shows very high tensile stress 435.579 MPa respectively. This can be due to the material (stainless steel).

Table 3: shows the tensile test result

Sample	Force at Peak (N)	Tensile Stress (MPa)	Elongation Percentage at Break (%)	Elongation at Peak (mm)
A	534.275	10.05	22.562	7.25
B	501.256	11.23	12.31	5.73
C	522.191	8.91	18.324	7.01
D	647.233	10.023	25.79	3.185
E	784.111	12.347	16.844	4.637
F	869.067	9.023	19.46	4.809
CR	1095.403	456.418	13.437	3.231

4. CONCLUSION

Development of a composite gasket using eggshell and glass powder in epoxy resin was carried out in this work. The eggshell was reinforced with glass fiber at different proportions, in the presence of epoxy resin and hardener to produce composite gaskets labelled A to F using the hand lay-up method. The mechanical tests carried out were tensile strength, impact strength, flexural strength, density, hardness, water absorption and the gaskets produced were compared with a standard gasket serving as Control. Density values for the samples ranged from 0.88 to 1.68 g/cm^3; Water Absorption values were in the range 0.53% to 7.84%; Flexural Strengths were in the range 2.88 to 64.02 MPa. Hardness values ranged from 21.67 to 28.91 VHN; Impact values ranged from 3.36 to 5.14 J while Tensile Strengths were 8.910 to 12.347 MPa. It could be observed that density increased with the addition of reinforced materials (both eggshell and glass powder), with the exception of Sample B that did not follow the trend. It could also be seen that Samples F and CR have about the same densities. Water absorption decreased with increase in reinforced materials except in Sample B that did not follow the trend. Sample E with 7.5% glass fibre gave the highest Flexure Strength. Flexure Strength generally decreased with increase in glass fibre except for Samples B, E and F that did not follow a particular pattern. The highest tensile strength of 12.347 N/mm^2 was given by Sample E with the composition of 7.5% eggshell powder and 7.5% glass fiber. Tensile strength increased with increase in glass fiber composition. Tensile strengths obtained for the Samples were generally lower compared with the Control (456.418 MPa), with the highest value (12.347 MPa) being given by Sample E. The Sample with the composition of 7.5% eggshell and 7.5% glass fiber gave the best performance. The gasket produced in the work will only be suitable for use in simple machinery because of the low flexural and tensile strength.

REFERENCES

[1] M. Nikzad, S.H. Masood, I. Sbarski, (2011). Thermo-mechanical properties of a highly filled polymeric composites for fused deposition modeling, Mater. Design, 32, 3448-3456. doi:10.1016/j.matdes.2011.01.056

[2] Feng, Y., Ashok, B. and .Madhukar, K. (2014). “Preparation and characterization of polypropylene carbonate bio-filler (eggshell powder) composite films,” International Journal of Polymer Analysis and Characterization, vol. 19, no. 7, pp. 637–647, 2014.

[3] Ngo, TriDung T.D. (2020). Fiber composites (Introduction to Composite Material). Alberta: Intechopen. doi:10.5772/intechopen.91285

[4] Lacovara B. (2008). The current and future trends of composite materials: an experimental study. *Journal of Composite Materials*, 45(20), 45-50. doi:10.1177/0021998311401066

[5] Rajak, D.K., Pagar D.D., Kumar R., Pruncu C.I.(2019). Recent progress of reinforcement materials: a comprehensive overview of composite materials, J. Mater. Res. Technol. 6354-6374. doi:10.1016/j.jmrt.2019.09.068

[6] Amir Lotfi, Huaizhong Li, Dzung Viet Dao, Gangadhara B Prusty. (2019). Natural fiberreinforced composites: A review on material, manufacturing, and machinability. Journal of Thermoplastic Composite Materials, 34(3), 6-9. doi:10.1177/0892705719844546

[7] Ilyas R. A, Sapuan S.M, Norizan M. N, Atikah M.S. N, Huzaifah M.R.M. (2019). Potential of natural fibre composites for transport industry. Prosiding Seminar Enau Kebangsaan, 211.

[8] Ramesh M., L. Rajeshkumar, D. Balaji, (2021). Influence of process parameters on the properties of additively manufactured fiber-reinforced polymer composite materials: a review, J. Mater. Eng. Perform., 30, 4792-4807. doi:10.1007/s11665-021-05832-y

[9] Mahesh, Poornima, Venkateswara Rao. (2013). Elephant Grass-Glass Fiber Hybrid Composite. International Journal of Mechanical and Industrial Engineering, 3(1), 46-48. doi:10.47893/IJMIE.2014.1166

[10] Narendar, G and Sekhar, V.C., (2018). “Preparation and testing of composites with slag and egg shell powder filler,” International Journal of Engineering Research and Applications, vol. 8, no. 6,pp. 57–60, 2018.

[11] Betancourt, N.G.; Cree, D.E.(2017). Mechanical properties of poly (lactic acid) composites reinforced with CaCO3 eggshell based fillers. Adv. Mat. Rec. 2, 2545–2550.

[12] Owuamanam, S.; Soleimani, M.; Cree, D. (2021) Fabrication and characterization of bio-epoxy eggshell composites. Appl. 2, 694–713.

[13] Wasan A. Alkaron, Sameer F. Hamad and Mohammed M. Sabri (2023). Studying the Fabrication and Characterization of Polymer Composites Reinforced with Waste Eggshell Powder. Advances in PolymerTechnology. Volume 2023, Article ID 7640478, 9 pages https://doi.org/10.1155/2023/7640478

[14] Lorenz, B.; Persson, B.N. (2009). Leak rate of seals: Comparison of theory with experiment. Europhys. Lett. 86, 44006. doi: 10.1209/0295-5075/86/44006

[15] Zhang, Q.; Chen, X.; Huang, Y.; Zhang, X. (2018). An Experimental Study of the Leakage Mechanism in Static Seals. Appl. Sci. 8, 1404. https://doi.org/10.3390/app8081404.

[16] Singh, A.; Kumar, V.; Garg, A. (2023). Powertrain NVH CAE Predictions with Gasket Consideration. SAE Tech. Pap. 2023-01-0423. https://doi.org/10.4271/2023-01-0423

[17] Rudi Dungani, Myrtha Karina, Subyakto Subyakto, Sulaeman Aminudin. (2016). Agricultural waste fibers towards sustainability and advanced utilization: A review. Asian Journal of Plant Sciences, 15, 45-55. doi:10.3923/ajps.2016.42.55

[18] Oladele I.O. (2008). Development of automobile gaskets from local fibers. *Journal of Science and Technology*, 28(3), 152-158. doi:10.4314/just.v28i3.33115

[19] Koay Seong Chun, Tengku Maimunah, Chan Ming Yeng, Tshai Kim Yeow and Ong Thai Kiat. (2020). Properties of Corn Husk Fibre Reinforced Epoxy Composites Fabricated Using Vacuum-assisted Resin Infusion. *Journal of Engineering Science and Technology*, 31(3), 17-31. doi:10.21315/jps2020.31.3.2

[20] Fidelis Chigondo, Piwai Shoko, Benias C. Nyamunda, UpenyuGuyo, Mambo Moyo. (2013).Maize Stalk As Reinforcement In Natural Rubber Composites. *International Journal of Scientific and Technology Research*, 2(6), 263-269.

[21] Alkaron, W. A., Hamad, S. F., & Sabri, M. M. (2023). Studying the fabrication and characterization of polymer composites reinforced with waste eggshell powder. *Advances in Polymer Technology*, *2023*, 1–9. https://doi.org/10.1155/2023/7640478

[22] Hunton, P. (2005). Research on eggshell structure and quality: an historical overview. *Brazilian Journal of Poultry Science*, 2005, *7*, *2*, 67-71.

[23] Hassan, S. B.; Aigbodion, V. S.; Patrick, S. N. (2012) Development of polyester/Eggshell Particulate Composites. *Tribology in Industry*, 2012, *34*, *4*, 217-225.

[24] Widad, H. J. and Nadir, F. H. (2018). Preparation of epoxy chicken eggshell composite as thermal insulation. *Journal of the Australian Ceramic Society*, 2018,*54*, *2*, 231-235.

[25] Fadhel Abbas Abdulla, M S Qasim, Ahmed Ali Farhan Ogaili (2021) Influence Eggshells powder additive on thermal stress of fiberglass/polyester composite tubes. IOP Conf. Series: Earth and Environmental Science 877 (2021) 012039 doi:10.1088/1755-1315/877/1/012039

[26] Abdelmalik, A.A., Ogbodo, M.O., and Momoh, G.E., (2019), Investigating the mechanical and insulation performance of waste eggshell powder/epoxy polymer for power insulation application. SN Applied Sciences (2019) 1:1238 | https://doi.org/10.1007/s42452-019-1259-9

[27] Abbas Ibrahim Hussein (2021). Investigation the Egg-Shell Particles Reinforcement on the Mechanical Properties of PMMA Composites. Journal of Research in Medical and Dental Science. *9 (1):251-253*

[28] Stephen, O. S.; Duncan, E. C. (2021). Fabrication and Characterization pf Bio-Epoxy Eggshell Composites, *Appl. Mech*. *2*, 694-713

[29] Aveen Ansaif Jassim and Widad hamdi Jassim (2023). Preparation of Polyester/ Micro Eggshell Fillers Composite as Natural Surface Coating. Ibn Al-Haitham Journal for Pure and Applied Sciences. IHJPAS. 36(1)88-99. doi.org/10.30526/36.1.2889

[30] Ahmad Nadzri, S. N. Z., Hameed Sultan, M. T., Md Shah, A. U., Safri, S. N. A., & Basri, A. A. (2020). A review on the Kenaf/glass hybrid composites with limitations on mechanical and low velocity impact properties. *Polymers*, *12*(6), 1285.https://doi.org/10.3390/poly m12061285

[31] Mai, V.-D., Shin, S.-R., Lee, D.-S., & Kang, I. (2019). Thermal healing, reshaping and ecofriendly recycling of epoxy resin crosslinked with Schiff base of vanillin and hexane-1,6-diamine. *Polymers*, *11*(2), 293. https://doi.org/10.3390/polym11020293

[32] Sun, Z., Xu, L., Chen, Z., Wang, Y., Tusiime, R., Cheng, C., Zhou, S., Liu, Y., Yu, M., & Zhang, H. (2019). Enhancing the mechanical and thermal properties of epoxy resin via blending with thermoplastic polysulfone. *Polymers*, *11*(3), 461. https://doi.org/10.3390/polym11030461

[33] Pankaj Chaupal and Prakash Rajendran, (2023). Flexural strength prediction of randomly oriented chopped glass fiber composite laminate using artificial neural network, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 45(131). https://doi.org/10.1007/s40430-023-04061-9

[34] ZainunAchmad, Al Emran Ismail, and Ahmad Hamdan (2021). The Effect of a Mixture of Epoxy Resin Matrix Composite Materials and Hardener by Varying the Stirring Speed on The Mechanical Properties. International Journal of Engineering Trends and Technology. Volume 69 Issue 11, 83-88. ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I11P210

[35] Samotu, I. A., Dauda, M., Anafi, F. O. A and Obada, D. O. (2015) Suitability of Recycle Polyethylene/Palm Kernel Shell-Iron Filings Composite For Automobile Application, Triobology Industry, Vol.7, (2), 142-153

[36] Opeoluwa Fadele · Ikechukwuka N. A. Oguocha , Akindele Odeshi, Majid Soleimani, Chithra Karunakaran (2018). Characterization of raffia palm fiber for use in polymer composites. Journal of Wood Science (2018) 64:650–663 https://doi.org/10.1007/s10086-018-1748-2

[37] Sreekala M.S., Jayamol G., Kumaran M.G., and Sabu T., (200).The mechanical performance of hybrid phenol–formaldehyde-based composites reinforced with glass and oil palm fibres, Composites Science and Technology, 62 (2002)339–353

[38] V.P. Arthanarieswaran, A. Kumaravel, M. Kathirselvam, (2014). Evaluation of mechanical properties of banana and sisal fiber reinforced epoxy composites: Influence of glass fiber hybridization, Mater. Des. 64, 194–202, https://doi.org/10.1016/j.matdes.2014.07.058

[39] Rajesh Mishra, Hafsa Jamshaid, and Jiri Militky (2017). Basalt Nanoparticle Reinforced Hybrid Woven Composites: Mechanical and Thermo-mechanical Performance. Fibers and Polymers 2017, Vol.18, No.12, 2433-2442. DOI 10.1007/s12221-017-7545-5

[40] J. O. Agunsoye, A. K. Odumosu & O. Dada (2019). Novel epoxy-carbonized coconut shell nanoparticles composites for car bumper application. The International Journal of Advanced Manufacturing Technology https://doi.org/10.1007/s00170-018-3206-0

[41] M. Chary and K. S. Ahmed, (2017) "Experimental characterization of coconut shell particle reinforced epoxy composites," Journal of Materials and Environmental Sciences", vol. 8, issue .5, pp. 1661-1667.