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Circularization of Agricultural Debris via Poly Lactic Acid Scrutiny, Revolutionary Investigation

Lucia Omolayo Agashua

Civil and Environmental Engineering Department, Federal University Otuoke Bayelsa State Nigeria

ABSTRACT

Agrarian wastes like eggshell are one of emergent issues in foodstuff industries owing to their disposal matter and cost. Nevertheless, it is also a prospect for the construction sectors if new usages of these unwanted materials can be ascertained. Poly Lactic Acid (PLA) approach is type of polymer that are eco-friendly with numerous benefits attached to its production if liked with other conventional polymers. Unambiguously, PLA needed about 65.5% lesser energy and created roughly 67.9% smaller greenhouse gases throughout its production period. Thus, this scrutiny utilized PLA approach in investigating Eggshell dust (ESD) and waste lactose (WL) impact on interlocking fired bricks mechanical strength. Scrutiny like X-Ray Diffractometer (XRD), FTIR and Surface Morphology categorization was carried out on the materials and the samplings, before performing strength analysis. Experimental outcomes from compressive strength activity index and ultrasonic pulse velocity (UPV) were utilized in predicting studies via machine learning and validated. The outcome shows that use of 10% ESD and 4% WL leads to maximum values of UPV and compressive strength from early to latter age of the interlocking fired bricks respectively. FTIR shows sharp peaks at 694.12 and 754.14 cm−1, while XRD reveals peaks of EGD main contents of greater crystalline as CaCO3, which in turn constitute hardness part of eggshell. Eggshell crystallinity index was 76.10% and CaCO3 peak was 2θ = 29.7° indicating rhombohedral. It was also ascertained from the SHapley Additive exPlanations (SHAP) scrutiny that eggshell dust amount had a more constructive and lesser negative correlation.

***Corresponding author**

Lucia Omolayo Agashua, Civil and Environmental Engineering Department, Federal University Otuoke Bayelsa State Nigeria.

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Introduction

The circularization is wall-defined as longer ways of preserving and uses resources, that is, be optimism that the resources can be reserved and reprocessed for longer period which is also termed the zero-waste economy [1-3]. Creation of waste is inexorable in all industrial circumstances, most especially agricultural settings. Nonetheless engineers must ponder on the way to eliminate, lessen or reuse wastes by creating something else [1, 4-6]. Through experimental intrusion, engineers can solve circular economic matters, a technique that cross across all engineering disciplines. Though, this method face backlots of criticism, but the ambiguity around the concept is forming a barrier, because a lot of people are left behind due to precision on how to continue [7, 8]. For instance, in South Africa, Cape Town to be precise, the engineers recently start a waste to energy plant. This plant uses all wastes such as municipal, domestic, agricultural and industrial waste to produce liquid petroleum for the city [9-12]. This plant got 500 tons of the wastes per day which makes the city greener and in turn lessens number of landfills in city, apart from employment opportunity for the populous. This is one of the means engineers through circular economy changes waste to innovative economy materials. Circular economy that was green waste management create closed loop system from linear system when PLA composite technique is amalgamated.

PLA is well recognized as polymer of the 21st century and served as most capable polymer concurrently usable in biobased, biocompatible and biodegradable matters (Figure 1). It is an aliphatic bio-created gotten from dual hydroxypropionic acid from agricultural wastes. Nowadays it appears to be pleasantest eco-friendly polymer with ever rising applications in construction works. The construction firms are among the fields that utilizes momentous number of natural resources which awkwardly create adverse impacts on the immediate environment. Subsequently, efforts have been intensified so as to counter the impacts, through partial stand-in of some of natural materials like cement with wastes material [2, 13-17]. Since few years ago, PLA composites is gaining momentous as substitute construction materials owing to its renewable nature and compatibility with nearly manufacturing deeds for structural usages [18-21]. Ranges from green amalgamates to thermal insulation natures have find usage in construction services. PLA matrix needed agricultural wastes like eggshell and waste lactose that possess superior physiognomies for creating eco-friendly composite [4, 7, 22-25]. Eggshell is the available worldwide and is a left-over gotten from poultry businesses (Figure 2). It contains enrich materials such as calcite form of 95.3% calcium carbonate and 4.7% organic substances like sulfated polysaccharides, collagen and others, but still regarded as one among foulest environmental contaminant [1, 25-29]. Eggshell is a left-over that can be gotten from cafeterias, bakeshops, households, eateries and so forth. The focus of this scrutiny is how circularization of eggshell PLA composite with varying proportion can enriched and predict strength of interlocking fired bricks.

Figure 1: Various Industrial Usage of PLA Globally

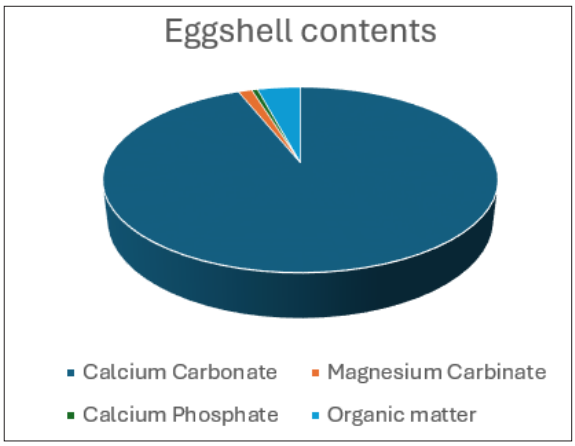

Figure 2: Various Proportion of Eggshell

Materials and Experiments Technique

Clay soils, Portland cement (PC) CEM 53, Blaine surface area of 444.8m^2/kg with density 3140kg/m^3 and aggregate (density of 2632 kg/m^3, sand fractions of 0/4 mm and naturally washed semi-crushed siliceous-calcareous) were gotten from a local supplier, while the eggshell was from waste dumping area in Nigeria, then converted and calcinated (Figure. 3). Sorts for purities of $CaCO_3$, eggshells in this scrutiny were between sorts B and C with 96.8%, as a mean $CaCO_3$ contents based on the DIN EN ISO 3262-5 standard and plasma-optical emission spectroscopy (POES). Fired bricks specimens were without and with ESD as PC substitutes. Two mixes of fired bricks were fabricated: without ESD (E-0%) and fired bricks with various proportion 2% - 10% by weight of cement. The ESD was processed and sieved via 63 µm mesh size. Samplings were vibrated for elimination of entrapped air and improved compaction purposes. All fired bricks compositions had PC substitute with ESD of 2% - 10% wt. %, using a water/(cement together with ESD) ratio of 0.5. Further, a mechanical mixer was utilized in blending the cement mortar components. After 7, 14, 21, 28 and 56 days, a uniaxial compression assessment based on ASTM C109/C109M-20 was carried out on all specimens [28].

Materials and Methods

Findings of FTIR Categorization

Outcome of FTIR for eggshell PLA composite were ascertain and shows in Figure 3(a-c). Figure 3a ascertained that there is ample carbon chain consistent with C=O sets. The pointed peaks at 694.01 and 752.98 cm^{-1}, likewise prohibitive transmittance pointed peaks at 1746.10 cm^{-1} were ascertained as C=O set stretching vibration, which validates that is of rich carbon origin. While, the topmost point at 1358.7 cm^{-1} is of C-H set. Figure 3b which was eggshell dust reveals topmost point at 1404.39 cm^{-1} means carbonate classes of stretching, i.e. enough quantities of carbonate. The topmost at 711.01 and 872.91 cm^{-1} means the calcium carbonate ($CaCO_3$) presence together with the in and out-plane distortion. Whereas, the peak at 3647.57 as well as 2514.02 cm^{-1} means availability of hydroxyl set stretching, while frail intensity specifies that the samplings possess lesser water molecule. Figure 3c which is 12% eggshell PLA composite ascertained that 10% eggshell PLA composite is correlated with the 12% eggshell PLA composite and no new topmost was noticed, demonstrating the prevalent physical interface eggshell dust and waste lactose via PLA. Nevertheless, the topmost at 3296.90 cm^{-1} that was noticed means –OH set bending as the elongating vibration after 10% extinct. The topmost at 1636.76 cm^{-1} of 10% was changes to a greater peak at 1648.01 cm^{-1} of 12% ESD-PLA composite meaning C=O set carbonyl elongation which can be as a result of hydrogen bonds [1,25].

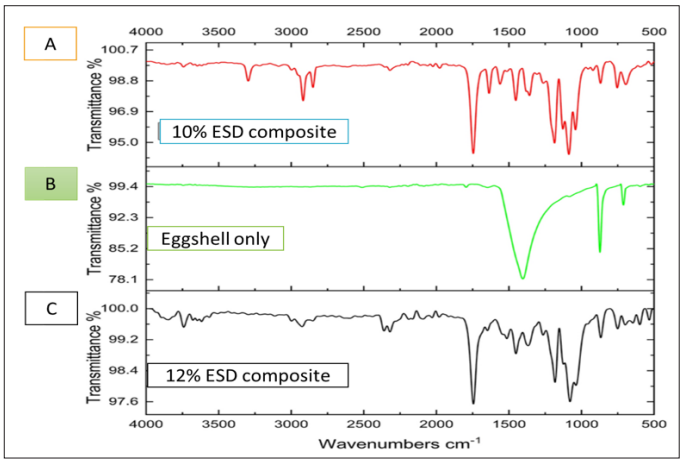

Figure 3: FTIR Bands of EGD-PLA Composite
(a) 10% EGD-PLA
(b) Eggshell
(c) 12% EGD-PLA

Findings of X-ray Diffraction (XRD) Scrutiny

Outcome of XRD for eggshell-PLA composite were discover and shows in Figure 4 (a&b). Figure 4a discovered that $CaCO_3$ with greater crystallite, which serves as hardness supporter were the key physiognomies of eggshell. The $CaCO_3$ topmost was seen at $2\theta = 29.5°$ together with resultant 104.2 plane specifies the trigonal constitute, while 76.08% was assessed as crystallinity index. Figure 4b displays optimum pattern of eggshell-PLA composite. Dual broad crests were ascertained at $2\theta = 16.89°$ and 19.31° demonstrating (110.1) as well as (203.2) planes together with the shrill peaks at $2\theta = 36.9°$, 44.03°, 64.19°, and 77.4° meaning a nebulous structure. The greater crystalline topmost plane at 110.1 ascertained the availability of α-form quartzes in the composites with 55.03% assessed as crystallinity index. It was ascertained that at the optimum intensity become punier with no any distinct crests in the eggshell-PLA composite owing to integration and

interaction of crystallite eggshell dust. The improved crystallinity index inveterate the availability of extremaly crystalline nature of eggshells in the eggshell-PLA composite. This also ascertain the eggshell dust fast-tracks the crystallization of the composite by stand-in as a nucleating substance [4-9].

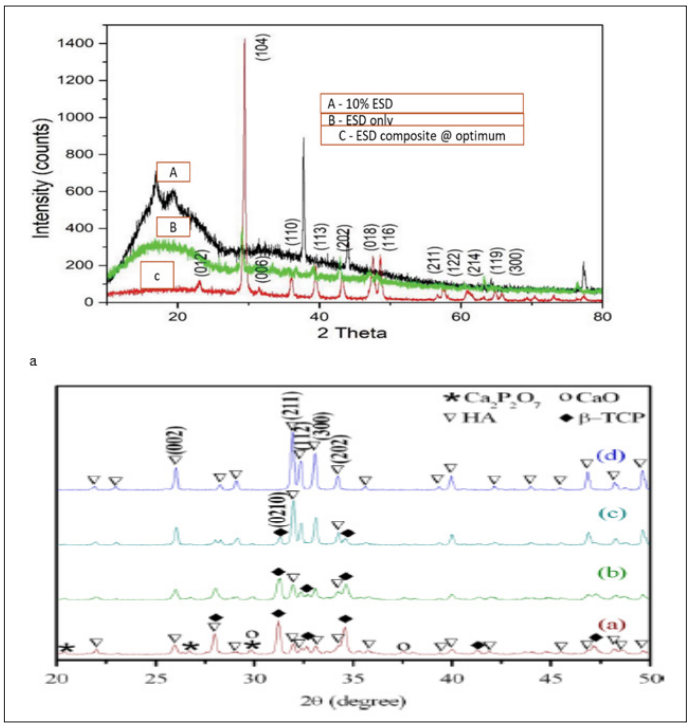

Figure 4: XRD Styles at Various Proportions Showing, (a) Eggshell-PLA Composite with Optimum (b) Some Parameters Noticed within Eggshell-PLA Composite

Findings of Surface Morphology through SEM

Outcome of SEM for eggshell-PLA composite was determined and displays in Figure 5 (a-d). Figure. 5a &b shown a tranquil surface with a wavy style owing to the material physiognomies disparities and perchance ascribed impurities occurrence. Figure. 5c &d. demonstrated that there is clean-cut on the outer surface which indicates the fragility of the composite owing to higher proportion of eggshell dust and waste lactose. While, fewer coagulation creates an undeviating spreading of the eggshell dust at moderate percentage addition with the waste lactose. A sturdy interfacial adhesion was also noticed as a result of spongy fibril make-up exterior of the eggshell dust, which was the reason for the beneficial adsorbing capability of eggshell as reacting agent with waste lactose [5, 10-15]. The PLA setting shows eggshell dust contents well covered with waste lactose with lesser slits signifying an improved interfacial adhesion between composites.

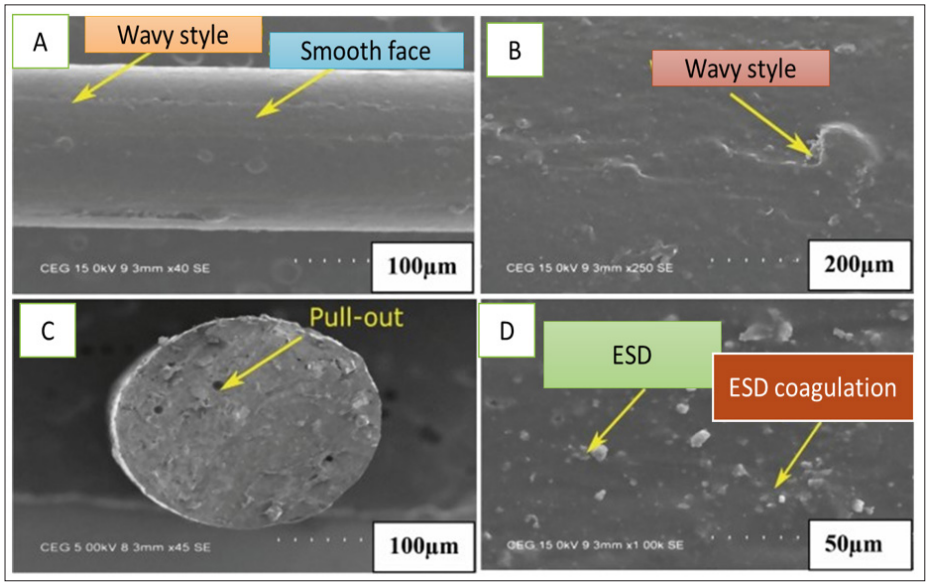

Figure 5: SEM Images of Eggshell-PLA Composite (a) and (b) Superficial of the Eggshell-PLA Composite at Optimum (c) Splintered Unit (d) Outward Revealing the Coagulation of Eggshell Dust

Findings of Compressive Strength Activity Indicator (CSAI)

Outcome of CSAI for eggshell-PLA composite were noticed and presented in Figure 6. As highlight by ASTM C311-18, strength deed indicator is utilized in ascertaining strength development of any concrete structures like interlocking fired bricks and others, that was incorporated with natural pozzolan.

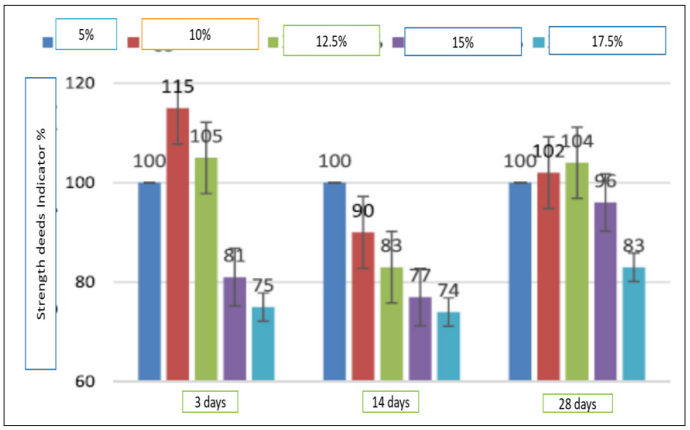

Figure 6: Strength Deed Indicator for Eggshell-PLA Composite

Figure 6 displays that the strength deed indicator of 2.5% and 5% was 117% and 106.5% respectively at three days. The greater index might be attributed to concrete gain strength very swiftly at timelier age. Eggshell dust serves as an accelerator to the hydration action owing to reaction amongst calcium oxide (CaO) in ESD and multifarious elements in cement that boost acceleration. But at 7 days, all samplings for 2.5% and 5% had lesser index of 73.9 and 91.02% respectively. Nevertheless, at 28 days, 10% had the greatest indication of 104.98%, then 7.5% with an indication value of 101,97%. But, from 12.5% blended with EGD there is 26.3% losses when compared with control. This specifies that greater amount stand-in of cement might wane the binding physiognomies of the interior structure, leads to a punier bonding of cementitious and aggregate contents [2, 20-24].

Findings of Ultrasonic Pulse Valocity (UPV) Conjunction with Strength

Outcome of UPV in collaboration with strength scrutiny for eggshell-PLA composite was investigated and presented in Figure 7. Figure. 7 shows that UPV and strength improved as the proportion of ESD enhanced up to 10%. But, after 10% greater and lesser values for UPV and compressive strength (CS) respectively was noticed, this might be owing to lessening of permeability activities in eggshell-PLA12.5 which caused greater pulse velocity. It can also be prescribed that further augmentation eggshell-PLA composite beyond 10% that weaken both UPV and CS, is impact of cement dilution that makes the composite become highly permeable. More so, the lessening of the porous structure of eggshell-PLA12.5 might be attributed to the impact of ESD consequential as calcium carbonate which serves as stolid filler which is in agreement with other investigators like [26]. From the charts presented R2 values displays that the correlation between UPV and CS was somewhat exponential to one another, which was also supported by prior scholars [17,23,29]. Meanwhile, both UPV and CV values were quite greater than control mix.

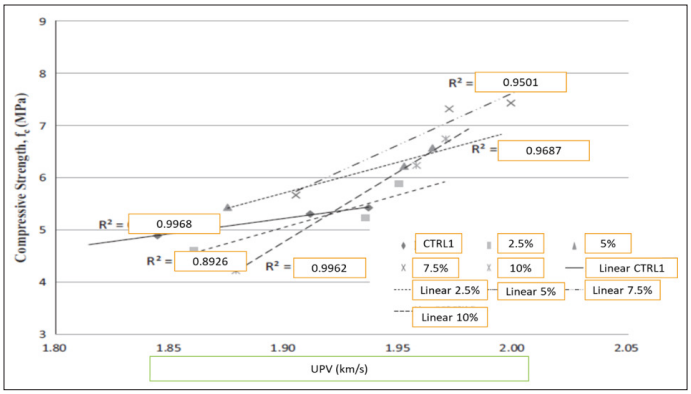

Figure 7: Impact of Both CS and UPV Scrutiny on Eggshell-PLA Composite

Machine Learning and S Hapley Additive Ex Planations (SHAP) Approach

Findings of SVM Modeler and Validation of Eggshell-PLA Composite

The SVM technique was utilized to ascertained the relationship between experimental and forecast percentage in CS (Figure 8). Figure 8 present R2 value of 0.89, which signifies that the SVM modeler fits the data-set appropriataly. Likewise, extreme error values noticed 6.27%, which characterizes the utmost deviation between the forecast and experimental values. Similarly, the least error noticed was 0.042%, signifying an extreme state of concord amongst the predicted and investigated values. Furthermore, modal's mean error was 1.47%, indicating wholly precision in forecasting CS, which can be conjectured that SVM modeler predict CS correctly. Further scrutiny on SVM modeler via statistical such as MAPE, RMSE, MAE and k-folds reveals 10.64%, 1.39%, 1.13% and 3.64% respectively. These checks also verdicts SVM modal as precise kind of modeler.

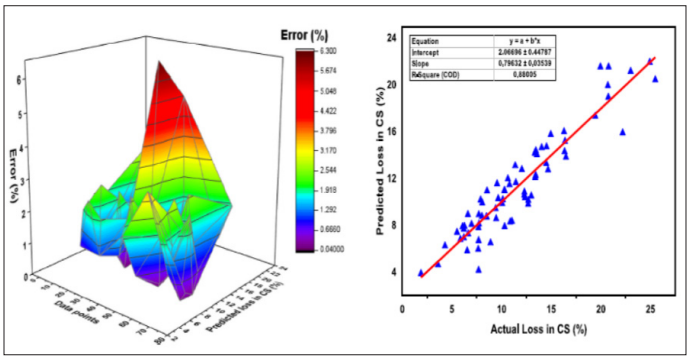

Figure 8: SVM Modeler (a) Guessing Errors for Forecast and Investigated Values, (b) Revealing Correlation Values

Findings of SHAP Technique on Eggshell-PLA Composite

SHapley Additive exPlanations (SHAP) scrutiny was employed in assessing the implication of raw materials constituents. This technique utilized byzantine non-linear deeds, and the series of input component effects with a premium facet for every parameter so as to unveil an in-depth perception during design of eggshell-PLA composite. The SHAP investigation ascertain both adverse and constructive effects demonstrating the use of ESD within the optimum value. Cement exhibited a constructive correlation with CS, while ESD and WL displayed both helpful and adverse correlations [3-5, 19-21]. These discoveries proposed that in order to moderate the CS values, it is essential to sustain moderate ESD amount with cement and waste lactose low.

Conclusions

This scrutiny ascertains impact of forecasting and prediction eggshell-PLA composite via SVM technique and validated the same using MAPE, RMSE, MAE and k-folds. Outcome of FTIR displays pointed peaks at 694.01 and 752.98 cm−1, likewise prohibitive transmittance pointed peaks at 1746.10 cm−1 were ascertained as C=O set stretching vibration, which validates that is of rich carbon origin. For XRD, dual broad crests were ascertained at 2θ = 16.89° and 19.31° demonstrating (110.1) as well as (203.2) planes together with the shrill peaks at 2θ = 36.9°, 44.03°, 64.19°, and 77.4° meaning a nebulous structure. The PLA setting shows eggshell dust contents well covered with waste lactose with lesser slits signifying an improved interfacial adhesion between composites. Outcome of CSAI for eggshell-PLA composite specifies that greater amount stand-in of cement might wane the binding physiognomies of the interior structure, leads to a punier bonding of cementitious and aggregate contents. R2 values displays that the correlation between UPV and CS was somewhat exponential to one another, and both UPV and CV values were quite greater than control mix. SVM modeler was precise and the verdicts also concord. Similarly, SHAP findings shows that cement exhibited a constructive correlation with CS, while ESD and WL displayed both helpful and adverse correlations [30].

References

1. HM Al-Baghdadi (2021) Experimental study on sulfate resistance of concrete with recycled aggregate modified with polyvinyl alcohol (PVA), Case Stud. Constr Mater 14: e00527.
2. AA Bahraq J Jose, M Shameem, M Maslehuddin (2022) A review on treatment techniques to improve the durability of recycled aggregate concrete: Enhancement mechanisms, performance and cost analysis. J Build Eng 55: 104713.
3. S Nazar, J Yang, M Ashraf, F Aslam, MF Javed, et al. (2023) Formulation and characterization of cleaner one-part noval fly ash/lime-based alkali-activated material. J Mater Res Technol 23: 3821-3839.
4. MH Akeed, S Qaidi, HU Ahmed, RH Faraj, AS Mohammed, et al. (2022) Ultra-high-performance fiber-reinforced concrete. Part IV: Durability properties, cost assessment, applications and challenges. Case Stud Constr Mater 17: e01271.
5. Oloke D (2022) A conceptual framework for integrated Designers risk Assessments- a Casestudy of an insulated concrete formwork framed project. IOP Conference Series Earth and Environmental 1101: 032021.
6. AL Ayodale, OM Oketope, OS Olatunde (2019) Effect of sawdust ash and eggshell ash on salected engineering properties of lateralized bricks for low cost housing. Niger J Technol 38: 278-282.
7. RL Hill, AJ Boyd, JE Dongall, G Hichborn, RE Neal, et al. (2008) Guide to Durable Concrete. Reported by ACI Committee 201 https://0901.nccdn.net/4_2/000/000/050/773/ACI_201.2R01_Guide_to_Durable_Concrete.pdf.
8. S Sahoo, TR Mahapatra, N Priyadarshini, S Mahapatra, S Naik, et al. (2020) Influence of water binder ratio on strength and acid resistance of concrete made up of mineral admixture as supplementary cementitious material. Mater Today Proc 26: 796-803.
9. OE Oluwatuyi, BO Adeola, EA Alhassan, ES Nnochiri, AE Modupe, et al. (2018) Amaliorating effect of milled eggshell on cement stabilized lateritic soil for highway construction. Case Stud Constr Mater 9: e00191.
10. Sivagnanamani GS, Ramesh P, Kumar MH, Arul Mozhi Salvan V (2021) Fracture Analysis of Fused Deposition Modalling of Bio-composite Filaments. In Fracture Failure Analysis of Fiber Reinforced Polymer Matrix Composites 71-84.
11. MN Akhtar, M Jameal, Z Ibrahim, NM Bunnori (2022) Incorporation of recycled aggregates and silica fume in concrete: an environmental savior-a systematic review. J Mater Res Technol 20: 4525-4544.
12. Okeyinka OM, Oloke D (2020) A Review on Recycled Use of Solid Wastes in Building Materials. International Journal of Civil and Environmental Engineering 9: 1578-1587.
13. RA Ayyappa, RB Sandeep, GS Yadav, SS Dara (2020) Partial replacement of cement and coarse aggregate by egg shall powder and coconut shalls. Int J Innovat Technol Explor Eng 9: 1242-1246.
14. Huang YZ, Ji YR, Kang ZW, Li F, Ge SF, et al. (2020) Integrating Eggshell-Derived CaCO3/MgO Nanocomposites and Chitosan into a Biomimetic Scaffold for Bone Regeneration. Chem Eng J 395: 125098.
15. Faridi H A Akbar (2018) Application of eggshell wastes as valuable and utilizable products: a reviewApplication of eggshell wastes as valuable and utilizable products: a review. Res Agr Eng 64: 104-114.
16. M Amiri, F Hatami, EM Golafshani (2021) Evaluating the synergic effect of waste rubber powder and recycled concrete aggregate on mechanical properties and durability of concrete. Case Stud Constr Mater 15: e00639.
17. WL Baloch, H Siad, M Lachemi, M Sahmaran (2021) A review on the durability of concrete-to-concrete bond in recent rehabilitated structures. J Build Eng 44: 103315.
18. OF Nnaemeka, NB Singh (2020) Durability properties of geopolymer concrete made from fly ash in presence of Kaolin. Mater Today Proc 29: 781-784.
19. Khan, M Cao, SH Chu, M Ali (2022) Properties of hybrid steal-basalt fiber reinforced concrete exposed to different surrounding conditions. Constr Build Mater 322: 126340.
20. Jhatial (2019) Eggshell powder as partial cement replacement and its effect on the workability and compressive strength of concrete. Int j adv appl sci 6: 71-75.
21. A Brahimi, M Meghachou, H Abbad, A Rahmouni, M Balbachir, et al. (2020) Analysis of experimental data of environmental cement prepared by fly ash of eggs shall and sand dune for reduction of carbon dioxid. Data Brief 30: 105407.
22. H Bhaskaran, L John, PM Neethu, T Sebastian (2016) Study on egg shall concrete. Int J Eng Res Technol 4: 4-6.
23. Barkhad MS, Abu Jdayil B, Iqbal MZ, Mourad AHI (2020) Thermal insulation using biodegradable poly (lactic acid)/date pit composites. Constr Build Mater 261: 120533.
24. Z Liu, Q Lei, S Xing (2019) Mechanical Characteristics of Wood, Ceramic, Metal and Carbon Fiber-Based PLA Composites Fabricated by FDM. J Market Res 8: 3741-3751.
25. V Hembrick Holloman, T Samual, Z Mohammed, S Jealani, VK Rangari (2020) Ecofriendly Production of Bioactive Tissue Engineering Scaffolds Derived from Egg-and Sea-Shalls. J Market Res 9: 13729-13739.
26. E Ferraz, JAF Gamalas, J Coroado, C Monteiro, F Rocha (2018) Eggshell waste to produce building lime: calcium oxide reactivity, industrial, environmental and economic implications. Mater Struct 51: 115.
27. YY Tan, SI Doh, SC Chin (2018) Eggshell as a partial cement replacement in concrete devalopment. Mag Concr Res 70: 662-670.
28. N Shiferaw, L Habte, T Thenepalli, JW Ahn (2019) Effect of eggshell powder on the hydration of cement paste. Materials 12: 2483.

29. ASTM C90 _ 16a (2016) Standard specification for loadbearing concrete masonry units. ASTM International https://spectraglaze.com/wp-content/uploads/2018/04/ASTM-C90-122117.pdf.

30. V Subathra Devi (2018) Durability properties of multiple blended concrete. Constr Build Mater 179: 649-660.