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Utilization of Groundnut Shell Ash as Cement Replacement in Stabilized Earth Blocks

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K e y w o r d s

Stabilized earth blocks
Cement
Groundnut shell ash
Strength
Durability
Sustainability

A B S T R A C T

This study analyzes the feasibility of using groundnut shell ash (GSA) obtained as the byproduct of agriculture in the manufacturing of stabilized earth blocks. Solid masonry blocks were casted with a mix proportion of 1:6 cement and sand. Cement blocks, at four different GSA as partial replacement levels of 0, 10%, 20%, 30%, and 40% were prepared as a fraction of cement weight. Experimental setups were conducted on the earth blocks including determining physical parameters such as densities and water absorption rates; mechanical characteristics including compressive strength and flexural strength; durability aspects such as sorption, and resistance against severe environmental conditions. Additionally, the cost, embodied energy, and CO_2 emission for the production of earth blocks were estimated in order to assess the cost-benefit and sustainability of GSA incorporation in cement-sand blocks. Results from this test indicate that even though the mechanical properties of GSA cement blocks do not vastly improve the strength properties the durability characteristics of GSA cement blocks are slightly better and improve the sustainability of block production.

1. INTRODUCTION

Masonry is the oldest building material in residential and commercial construction. Masonry was frequently employed as the primary building material in Sri Lankan residences and other structures. For developing nations, building using masonry is particularly cost-effective since it requires far less material and technical expertise than building with concrete or steel. Masonry offers several benefits, including low cost, uncomplicated building methods, and superior thermal and acoustic insulation. The two main building materials used to create houses in Sri Lanka are fired clay brick and cement sand blocks, both of which have drawbacks due to their environmental impact and a lack of resources (Poorveekan et al. 2021). The usage of agricultural soils and high emissions from burning are problems in the manufacturing of fired clay bricks. River sand and cement were needed for the production of cement sand blocks. However, the depletion of river sand has resulted in a severe scarcity of sand, and the manufacturing of cement is very energy-intensive and CO_2 emission. So, earth-based building materials have just become famous for building houses (Yogananth et al. 2019).

By utilizing as much locally accessible soil as possible, earth-based construction materials encourage the development of regional supply chains with additional value. Compressed Stabilized Earth Block (CSEB) and Earth Cement Block (ECB) are the two main building techniques that are generally suggested, depending on the local soil qualities and equipment availability. Even if the manufacturing of masonry units may now use local soil instead of the long-standing lack of river sand, the need for cement to make compressed stabilized earth blocks and earth cement blocks still has a negative impact on the environment because of CO_2 emissions (Seevaratnam et al. 2020).

On the other side, waste creation contributes to increased environmental contamination due to population growth. Finding reusable materials from generated waste and raw material substitutes from generated waste is vital to reduce environmental pollution and lowering raw material consumption (Sathiparan and De Zoysa 2018). Agricultural waste products, including rice husk ash, sugar cane bagasse ash, and sawdust ash are utilized, particularly in the building sector, as a partial replacement for cement.

Shell from groundnuts is one of these wastes. Groundnut shell ash (GSA) is produced when groundnut shells are burned. Large amounts of groundnut are created, which is organic waste. The peanut industry produces a lot of it as a by-product. Due to its classification as a highly reactive pozzolan, GSA has been utilized as a partial substitute for cement.

Published literature shows that the slump of the fresh concrete mix decreases with GSA replacement (Karthikeyan et al. 2018, Abro, et al. 2021). This indicates that water demand for consistent mix increases as more cement is replaced with GSA. Also, published literature showed that reduction in density with the increase in GSA content as cement replacement. In the case of compressive strength of concrete and cement mortar, there were two types of trends observed from the published literature (i) compressive strength increased up to an optimum amount of GSA as cement replacement and reduced thereafter (Buari et al. 2019, Abro et al. 2021) (ii) compressive strength decreased with the increase in GSA as cement replacement (Alabadan et al. 2005, Karthikeyan et al. 2018). In overall, desirable mechanical qualities are attained when GSA is employed as a cement substitute in concrete and cement mortar at a replacement level between 10 and 15%. Higher GSA content provides an adverse effect on the mechanical properties of concrete and cement mortar (Anomugisha 2020).

Even though few scientific studies have focused on utilizing GSA to create earth cement blocks so far, a limited amount of research has been done on the impact of GSA on the mechanical properties and durability of stabilized earth cement blocks. This study aims to evaluate the outcomes with traditional earth cement blocks by examining the impact of partial substitution of cement by GSA on earth cement blocks' mechanical and durability qualities.

2. MATERIALS AND METHODS

2.1. Material Used

The following materials were utilized in this study to prepare mortar:

- Cement: The binding material for this study will be Ordinary Portland Cement (OPC) as specified in Sri Lankan Standard and ASTM C150 (ASTM-C150 2012).
- Soil: Locally available lateritic earth soil obtained from the Faculty of Engineering, Kilinochchi premises, Jaffna, SriLanka was used for the study. The soil was sieved to obtain a size of 5 mm. The soil is free from organic matter, such as dirt, leaves, roots, and hummus.
- Groundnut shell ash (GSA): For the investigation, groundnut shell from nearby farmers who grow groundnuts was used. After the groundnut traders had removed the groundnut seed from its shells, they gave away the shells for free. The shell was obtained, then it was sun-dried for three weeks. The shell was placed in an iron drum and burned to ashes outside after sun-drying. The groundnut shell that had burned was grounded and sieved through an 800-micron sieve. Glass-sealed bottles were used to preserve the groundnut shell ash in a dry atmosphere.

Figure 1 illustrates the particle size distribution of sand cement and ground nut shell ash used.

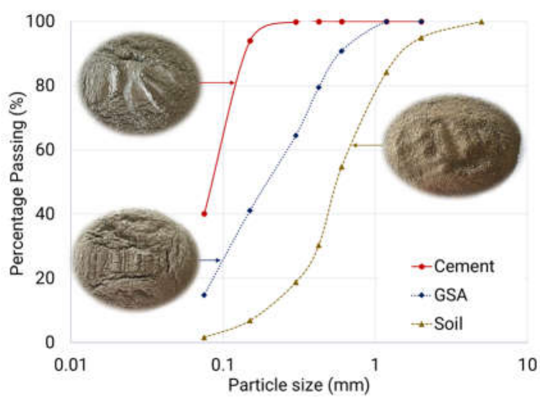

Figure 1 Particle size distribution of each raw material used.

2.2. Mix Design

On the basis of the volume %, the

appropriate ratio of the cement-soil mix was chosen. Cement and soil were mixed in a volume proportion of 1:6 for control blocks. Blocks with five different mix proportions were cast, including control earth cement blocks and blocks with 10%, 20%, 30%, and 40% GSA substitution in lieu of cement. For continuous workability, utilising a fixed water-to-binder ratio or fixed slump value is typically preferable. GSA is not distributed evenly in the wet mixture like cement since it has bigger particles than cement. As a result, the homogeneity of the mortar mix decreases, and particle-to-particle spacing increases. This meant that more water was needed to keep the mix homogeneous due to an increase in GSA replacement. Although even at a larger water-to-binder ratio, the slump remained zero because of the clay and silt content in the local soil. To achieve the highest dry density of the binder-soil mix, the water-to-binder ratio is chosen based on the optimum water content. Figure 2 displays the results of each mix's protector compaction test (cement, GSA, and local soil).

For the control mortar and GSA blended mortar, blocks with dimensions of 160 mm × 40 mm × 40 mm and cubes with dimensions of 50 mm × 50 mm × 50 mm were made. Casting was done using the wet mortar to get the right distribution mix. Manual compaction was carried out using a temping rod, 25 strokes in each of the three layers. Before being sent to the lab for testing, mortar blocks and cubes were allowed to dry for up to 28 days and each test used the six cubes.

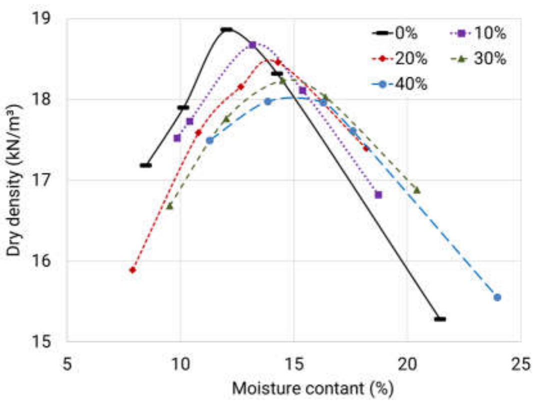

Figure 2 Proctor compaction test results for each mortar mix.

2.3. Testing

The following characteristics were obtained through tests on control blocks and blocks treated with GSA per the standard.

- Density: ASTM-C140 (2017)
- Water absorption: ASTM-C140 (2017)
- Compressive strength: ASTM-C109 (2020)
- Flexural strength: ASTM-C348 (2020)

To test for sorptivity, the cubes were dried for 24 hours at 105°C in an oven before being allowed to cool in a typical environment for another 24 hours. The water was maintained at a depth of 5 mm around the blocks. After draining the surface water, the mass of the cubes was measured at regular intervals (t=0, 5, 10, 15, 30, 60, and 90 min). Eq. (1) defines sorptivity as:

$$\Delta w/\rho A = s\sqrt{t} + I_0 \quad (1)$$

where Δw is mass gain due to capillary (kg), A is area exposed to the water (m^2), ρ is the density of water (kg/m^3), t is elapsed time (min), s is sorption coefficient ($mm/min^{1/2}$), and I_0 is initial sorption (mm).

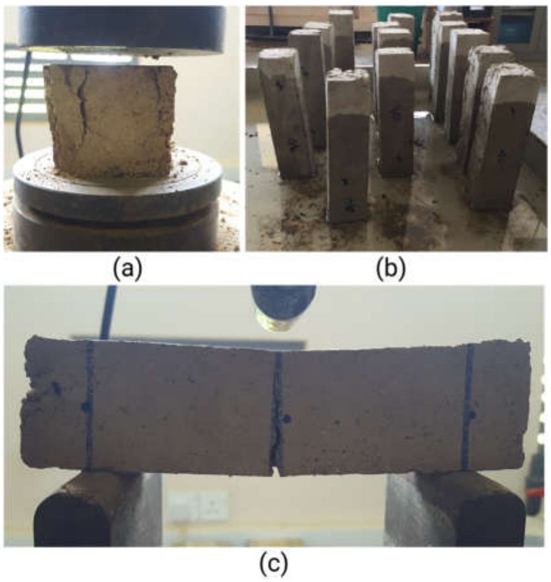

Figure 3 Test setup (a) compression, (b) sorptivity, and (c) flexural bending.

To investigate acidic and alkaline resistance, six specimens from each mix proportion were taken and their initial weights were measured. Then they were kept fully immersed in a fully immersed in 3% Sulfuric acid (H_2SO_4) solution and 3% NaOH solution according to ASTM C1152M (2020) and ASTM C289 (2007), respectively. After 28 days, specimens were taken out from acid and alkaline solution, air dried for seven days, and the new weights were measured.

3. RESULTS AND DISCUSSION

3.1. Physical and Mechanical Properties

3.1.1. Density and Water Absorption

Figure 4 shows the density and water absorption rate of hardened mortar made from various GSA compositions. It is evident that the density of the mortar reduced as GSA concentration rose. The decrease in density was anticipated since cement has a specific gravity of 3.1 whereas GSA has a specific gravity of 2.1. With a rise in GSA content, an increase in water absorption rate was seen. The hardened mortar may absorb more water as a result of the water-absorbent properties of GSA creating a channel through the mortar matrix. The maximum permitted water absorption should be 240 kg/m^3, following ASTM C90 (2016). The current investigation demonstrated that even mortar cubes containing 40% GSA were below the permitted water absorption limits suggested by ASTM C90.

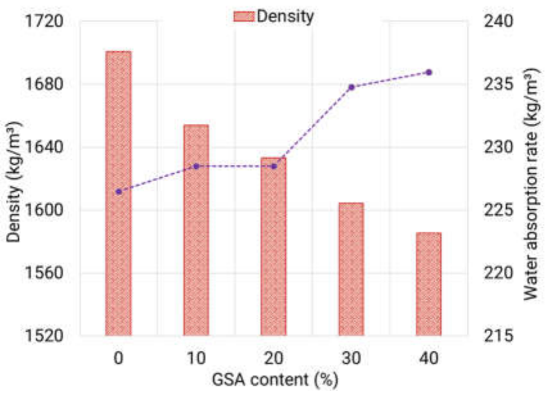

Figure 4 Density and water absorption rate of the blocks.

3.1.2. Compressive Strength

There are advantages and disadvantages in compressive strength when extra cementitious materials take the place of cement. On the plus side, calcium hydroxide ($Ca(OH)_2$), a by-product of cement hydration, and amorphous silica in GSA may react to generate calcium silicate hydrate (C-S-H) gel. This is known as the pozzolanic reaction, which occurs considerably more slowly than the hydration of cement. Equations (2) and (3) provide information on the cement hydration and pozzolanic process, respectively (Mayooran et al. 2017).

$$Ca_3SiO_5 + H_2O \rightarrow CaO.SiO_2.H_2O + Ca(OH)_2 \quad (2)$$

$$Ca(OH)_2 + SiO_2 \rightarrow CaO.SiO_2.H_2O \quad (3)$$

However, only a little quantity of GSA causes the extra C-S-H gel to develop. There wouldn't be enough $Ca(OH)_2$ to react with the silica to create C-S-H gel for a larger quantity of GSA owing to a drop in calcium hydroxide (due to a decrease in cement content in the mix) and an excessive amount of silica in the mix. As a result, the replacement of additional cementitious materials is only advantageous up to a certain amount of replacement. On the other hand, less cement is available for hydration when GSA is used in place of cement. As a result, it made cementitious materials less strong.

Figure 5 displays the control's dry and wet compressive strengths and GSA blended earth blocks after 28 days of curing. The earth blocks made of 100% cement have the highest average dry compressive strength. The substitution of GSA content results in a drop in average dry compressive strength. Figure 5 depicts the average wet compressive strength variation that was noted. The wet-to-dry compressive strength ratio is 0.58 for the control block and 0.58, 0.61, 0.68, and 0.73 for the GSA blended block with replacement levels of 10, 20, 30, and 40%, respectively.

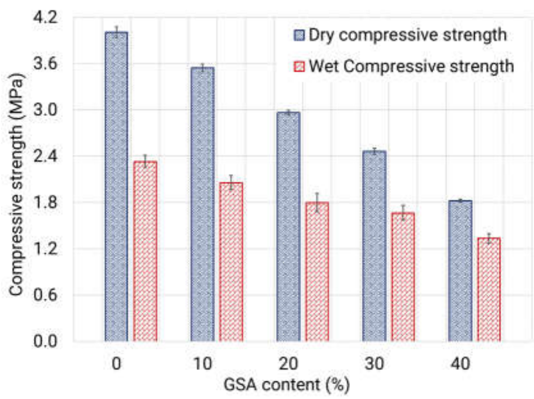

Figure 5 Wet and Dry Compressive strength of earth cement blocks after 28 days of curing.

As per SLS 1382 (2009), the minimum requirement for dry and wet compressive strength of stabilized earth blocks is 2.8 MPa and 1.2 MPa, respectively. Considering that, the mortar with up to 20% GSA satisfied this minimum limit for wet compressive strength.

3.1.3. Flexural Strength

Figure 6 displays the flexural tensile strengths of earth cement blocks. The flexural tensile strength of the blocks comprising GSA was lower than that of the control blocks. For GSA mixed earth blocks, decreased flexural strength is caused by a reduction of cement for pozzolanic reaction, same to how compressive strength is affected.

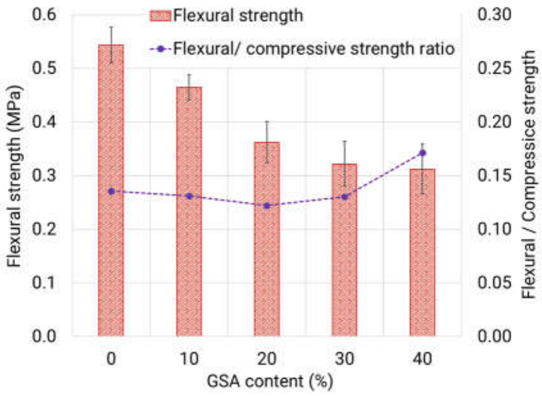

Figure 6 Average wet compressive strength variation and flexural strength.

3.2. Durability

3.2.1. Sorption

Figure 7 displays the sorptivity values computed for earth cement blocks.

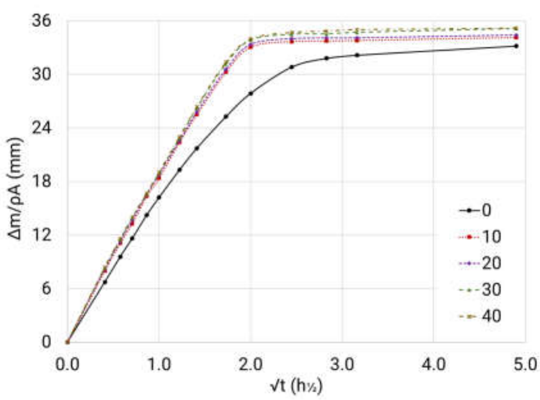

Figure 7 The sorptivity values computed for earth cement blocks.

As can be observed, as the amount of GSA content rises, so does sorptivity. This is because the GSA particle's presence in the mortar raises its void content, raising water absorption. This growth is, however, relatively modest. For mortar with GSA contents of 0, 10, 20, 30, and 40%, the sorptivity coefficient of earth cement blocks vary as 16.2, 18.3, 18.7, 18.9, and 19.0 mm/$h^{0.5}$, respectively.

3.2.2. Acid Resistance

Referring to the conventional masonry behavior, the traditional masonry blocks are vulnerable to acid and alkaline attacks due to their chemical nature but stabilized earth blocks with supplementary cementitious materials have developed less reactivity for acid and alkaline conditions rather compared to the conventional masonry blocks. Figure 8 portray the appearance of the mortar blocks after air drying.

When prepared mortar cubes were immersed in a solution of acid (H_2SO_4), $Ca(OH)_2$ and $3CaO.2SiO_2.3H_2O$ reacted with H_2SO_4 (sulphuric acid) and converted calcite to gypsum according to Eq. (4) and (5) (Hill et al. 2003, Min and Song 2018, Sundaralingam et al. 2022).

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 .2H_2O \qquad (4)$$

$$3CaO.2SiO_2.3H_2O + 3H_2SO_4 \rightarrow 3CaSO_4.2H_2O + 2Si(OH)_4 \qquad (5)$$

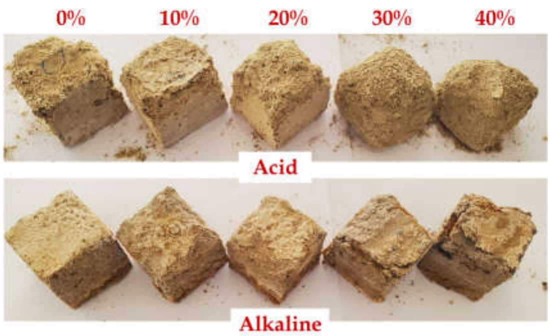

Figure 8 The appearance of air-dried mortar cubes after 28 days of curing in acid and alkaline solutions.

The loss of weight for each proportion is given in Table 1. Gypsum appears to be substantially formed in the area near the surfaces as a consequence of the sulfuric acid attack. The mono-sulfate hydrates then transfer into the ettringite phase due to the reaction between gypsum and calcium alumina hydrates to generate calcium monosulfide-alumina hydrate. Their precipitation in the pores and spaces caused induced internal stress when it formed in considerable amounts. Such stress can cause cracks on the surface, which diminishes the mortar's strength and causes weight loss. When groundnut shell ash is supplemented in some amount in the cement, the pozzolanic reaction between the groundnut shell ash and calcium hydroxide is enhanced, and the amount of calcium hydroxide that is susceptible to react with an acid solution is decreased (Sathiparan et al., 2022).

Table 1. Acid and alkaline resistance (weight loss given %).

GSA content (%)	0	10	20	30	40
Acid resistance	14.8	8.5	13.3	19.1	19.7
Alkaline	3.1	3.2	2.1	2.8	3.9

Therefore, it could observe less loss of weight for 10, 20% of ash replacement, but however, as the groundnut ash replacement in the cement exceeds 20%, the additional calcium hydroxide is not produced in the hydration reaction and the porosity of the mortar increases the pozzolanic reactivity decreases, leading to more significant textural damage as the acid ions penetrate deeper into the mortar and this cause more weight loss rather than the control mortar (Mayooran et al., 2017).

3.2.3. Alkaline Resistance

When mortar cubes are submerged in an alkaline solution, NaOH (sodium hydroxide) reacts with CO_2 from the atmosphere and formulates Na_2CO_3 (sodium carbonate). The chemical reaction mechanism that involves Na_2CO_3 formation is given by Eq. (6) (Allahverdi et al. 2015).

$$2NaOH\ (dissolved) + CO_2\ (dissolved) \rightarrow Na_2CO_3\ (solid) + H_2O\ (liquid) \qquad (6)$$

The sodium carbonate is also similarly white in color solid that gets settled on the mortar surface. The formation of carbonates in this chemical reaction forms a white color layer visible over the mortar cubes, which is why the white color precipitation over the surface. This precipitation is more visible on the control mortar and mortar with 10, 20% of groundnut shell ash replacement. This precipitation of carbonates on the pores of the surface causes excessive internal pressure as in an acidic medium and causes cracks on the surface. This causes weight loss in basic medium.

But as in acidic solution, the supplementary cementitious replacement up to some level reduces the weight loss and then after the trend seems to be increasing. However, in both acidic and basic mediums, the ground nut shell ash blended concrete shows more resistance than the conventional mortar up to a percentage replacement level.

3.3. Economical and Eco Benefit

3.3.1. Cost analysis

The entire cost for raw material consumption, transportation of raw materials, and manufacture for each mix composition was determined in order to assess the cost-benefits of using GSA as an alternative cementitious material in stabilized earth blocks. Cement, GSA, and soil requirements were used to determine the number of raw materials needed to produce one block with dimensions of 300 mm by 150 mm. Cement is sold at SLR 3000 per 50-kilogram bag on the local market. Despite the fact that groundnut shell is a waste product, transporting and processing it required direct costs. Based on excavation, loading and unloading, and transportation, the price of the soil is calculated. Based on these, the cost for 1 kg of cement, GSA, and soil are SLR 60.00, 13.17, and 0.28, respectively. Machine costs, and cost-per-strength are all included in the calculation of manufacturing costs.

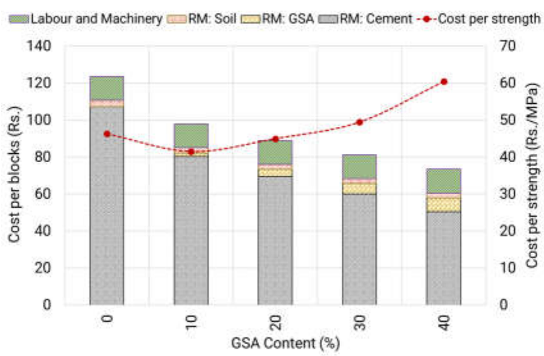

Figure 9 The total cost and cost-per-strength ratio for a single block.

Figure 9 shows the total cost and cost-per-strength ratio for a single block. Total cost decreased as GSA content % rose in the mix compared to the control mortar. However, when the cost-to-strength ratio was considered, it was found that 10% GSA content was cost-effective, with a 10.3% decrease in cost per strength compared to control blocks.

3.3.2. CO_2 Emission

The CO_2 emissions for producing one ton of mortar was computed to evaluate the environmental advantage of using GSA in producing earth blocks. For the computation, the CO_2 emissions from the manufacture of raw materials, their transportation, and manufacturing processes were taken into account. The Bath Inventory of Carbon and Energy (ICE) is the source of all information on CO_2 emissions (ICE 2011). The information needed to determine CO_2 emissions was condensed in Table 2.

Table 2. Data used for calculation of CO_2 emission for the production of mortar.

Production stage	Description	CO_2 emission (kg)	Unit
Raw material production	Cement	0.73	per kg
	GSA	0.157	per kg
	Soil	0.0048	per kg
Transport		0.15	per ton.km
Manufacturing	Electricity grid mix	0.0008	per kg
	Water	0.001	per kg

Transportation distance for cement, factory → plant: 150 km, and for GSA and soil, site → plant: 20 km

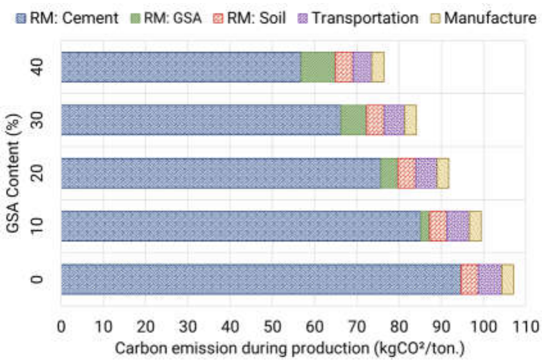

Figure 10 The carbon emission for each GSA content.

Using the data available the carbon emission during the production of the mortar was calculated in Kg per ton, including all 3 stages of the manufacturing process. Figure 10 illustrates the carbon emission for each proposition.

As the content of groundnut shell ash increased, the CO_2 emitted during mortar manufacturing decreased. Therefore, compared to the control mortar, the total CO_2 emission is less for mortars with ground nutshell ash as supplementary cementitious content. The total CO_2 emission for mortar incorporating 10, 20, 30, and 40% groundnut shell ash was 9.8, 9.2, 8.3 and 7.5%, respectively. This is less than the carbon emission from the control mortar. This trend was caused mainly by diminishing the cement content and transporting fine aggregate to the manufacturing plant.

4. CONCLUSIONS

The present study analysed stabilised earth blocks' mechanical and durability characteristics when groundnut shell ash is partially replaced. The salient conclusions which get understood from the research and analysis are as follows,

- The earth block's density reduces as the ash replacement percentage increases.
- The water absorption rate seems to be increased with the addition of the GSA content. However, the earth blocks with 40% GSA replacement are also less than the maximum permitted standard allowance.
- The substitution of GSA content results in a drop in average dry compressive strength and flexural strength. When cement is partially replaced by GSA, the less availability of cement for hydration causes the cementitious material to be less strength.
- The subsequent sorptivity values increased with the GSA replacement content in earth blocks as the availability of GSA particles in the earth blocks increases its void content.
- When GSA content increased in stabilized earth block the resistance for acid and alkaline attack was comparatively increased up to an optimum percentage of substitution level. But beyond 20% of GSA replacement, the weight loss for acid

attack was more than the control sample; beyond 30% of GSA replacement, the weight loss for the alkaline attack was more than the control mortar.

- GSA replacement for cement has positively impacted the environment by reducing carbon emissions. Since groundnut shell ash is a waste substance, cooperating with them in stabilized earth block production has promoted environmental sustainability. But considering the strength parameters, the amount of partial substitution of GSA on cement should be limited.

The study's findings emphasize that, although the higher replacement of ground nut shell ash for cement does not provide adequate compressive and flexural strength, GSA in cooperated earth blocks is strong enough in durability. As such blocks can be used in non-load-bearing and partition wall construction. In addition, the less cost and sustainable benefits promote the utilization of GSA in manufacturing cement-sand earth blocks. As GSA is a natural bio degradable material, so further study on long term durability have to perform to provide concrete idea of usage of GSA in real construction purposes.

REFERENCES

Abro, A., A. Kumar, M. Keerio and N. Bheel (2021). "An investigation on compressive strength of concrete blended with groundnut shell ash." Neutron 20(2): 123-127.

Alabadan, B., M. Olutoye and M. Zakariya (2005). "Partial replacement of ordinary portland cement (OPC) with bambara groundnut shell ash (BGSA) in concrete." Leonardo Electronic Journal of Practices and Technologies 6: 43-48.

Allahverdi, A., E. Najafi Kani, K. M. A. Hossain and M. Lachemi (2015). 17 - Methods to control efflorescence in alkali-activated cement-based materials. Handbook of Alkali-Activated Cements, Mortars and Concretes. F. Pacheco-Torgal, J. A. Labrincha, C. Leonelli, A. Palomo and P. Chindaprasirt. Oxford, Woodhead Publishing: 463-483.

ASTM-C90 (2016). Standard specification for loadbearing concrete masonry units. West Conshohocken, PA, ASTM International.

ASTM-C109 (2020). Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens). West Conshohocken, PA, ASTM International.

Anomugisha, S. and A. Nicholas (2020). "Groundnut shell ash and fly ash ternary blended cement in making plaster for sustainable construction." International Journal of Advanced Research in Engineering Innovation 2(3): 44-57.

ASTM-C140/C140M (2017). Standard test methods for sampling and testing concrete masonry units and related units. West Conshohocken, PA, ASTM International.

ASTM-C150 (2012). Standard Specification for Portland Cement. West Conshohocken, PA, ASTM International.

ASTM-C289 (2007). Standard test method for potential Alkali-Silica reactivity of aggregates (Chemical method) West Conshohocken, PA, ASTM International.

ASTM-C348 (2020). Standard test method for flexural strength of hydraulic-cement mortars. West Conshohocken, PA, ASTM International.

ASTM-C1152/C1152M (2020). Standard test method for acid-soluble chloride in mortar and concrete. West Conshohocken, PA, ASTM International.

Buari, T. A., F. A. Olutoge, G. M. Ayinnuola, O. M. Okeyinka and J. S. Adeleke (2019). "Short term durability study of groundnut shell ash blended self consolidating high performance concrete in sulphate and acid environments." Asian Journal of Civil Engineering 20(5): 649-658.

Hill, J., E. A. Byars, J. H. Sharp, C. J. Lynsdale, J. C. Cripps and Q. Zhou (2003). "An experimental study of combined acid and sulfate attack of concrete." Cement and Concrete Composites 25(8): 997-1003.

ICE (2011). Embodied carbon: The inventory of carbon and energy (ICE). Bath, United

Kingdom, Sustainable Energy Research Team, University of Bath.

Karthikeyan, N., M. Saravanan and M. Deepika (2018). "Performance of groundnut shell ash as partial replacement of cement in concrete." International Journal for Scientific Research & Development 6(4): 525-528.

Mayooran, S., S. Ragavan and N. Sathiparan (2017). "Comparative study on open air burnt low- and high-carbon rice husk ash as partial cement replacement in cement block production." Journal of Building Engineering 13: 137-145.

Min, H. and Z. Song (2018). "Investigation on the Sulfuric Acid Corrosion Mechanism for Concrete in Soaking Environment." Advances in Materials Science and Engineering 2018: 3258123.

Poorveekan, K., K. M. S. Ath, A. Anburuvel and N. Sathiparan (2021). "Investigation of the engineering properties of cementless stabilized earth blocks with alkali-activated eggshell and rice husk ash as a binder." Construction and Building Materials 277: 122371.

Sathiparan, N. and H. T. S. M. De Zoysa (2018). "The effects of using agricultural waste as partial substitute for sand in cement blocks." Journal of Building Engineering 19: 216-227.

Seevaratnam, V., D. Uthayakumar and N. Sathiparan (2020). "Influence of Rice Husk Ash on Characteristics of Earth Cement Blocks." MRS Advances 5(54): 2793-2805.

SLS-1382, Sri Lanka standard specification for compressed stabilized earth blocks, Sri Lanka Standards Institution (SLSI), SriLanka, 2009.

Sundaralingam, K., A. Peiris, A. Anburuvel and N. Sathiparan (2022). "Quarry dust as river sand replacement in cement masonry blocks: Effect on mechanical and durability characteristics." Materialia 21: 101324.

Yogananth, Y., K. Thanushan, P. Sangeeth, J. G. Coonghe and N. Sathiparan (2019). "Comparison of strength and durability properties between earth-cement blocks and cement–sand blocks." Innovative Infrastructure Solutions 4(1): 50.