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Original Article

Performance of Groundnut Shell Ash as a Partial Replacement of Cement in Masonry Mortar

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Abstract *- Mortar is an important part of masonry construction worldwide. Presently, OPC remains the binder material of choice for mortar to develop structures for our socio-economic needs. The purpose of this study was to determine the feasibility of local groundnut shell ash being used to replace the PPC-32.5N cement in type M and N masonry mortars. The characterization of the local GSA found it to be pozzolanic, belonging to class C. The properties of type M mortar (17.2N/mm^2) and type N mortar (5.2N/mm^2) were evaluated with partial cement replacement with GSA intervals of 0%, 7.5%, 12.5%, 17.5% and 22.5%. The compressive strength of the type M mortar cubes did not achieve the required minimum compressive strength of 17.2N/mm^2 at 28 days of curing, but the mortar prism cured beyond 28 days achieved the minimum compressive strength of 17.2N/mm^2 at 56 and 90 days of curing at 7.5% GSA replacement. In contrast, in type N mortar, a minimum compressive strength of 5.2N/mm^2 at 28 days of curing was achieved at an optimum replacement of 17.5% GSA for cement. Similarly, mortar prism cured beyond 28 days achieved the same strength of 5.2N/mm^2 at 90 days of curing with 17.5% GSA replacement. The flexural strength for both mortars exhibited high strength compared with the corresponding compressive strength in the range of 10-40%. The reactivity of the mortar was achieved at 7.5% GSA replacement in both types of mortars. Both initial and secondary sorptivity values increased with an increase in GSA content and did not conform to the specified values. In conclusion, type M mortar is to be replaced up to 7.5% while type N mortar is to be replaced up to 17.5% GSA for optimum strength.*

Keywords *- Compressive strength, Flexural strength, Groundnut shell Ash, Mortar durability, Pozzolanic.*

1. Introduction

Mortar is an important part of masonry construction globally. Presently and in the conceivable future, Portland cement remains the binder material of choice for mortar and concrete to develop structures for our socio-economic needs. Cement production is characterized by high energy consumption and the emission of massive greenhouse gases [1].

Resource depletion, environmental pollution (air, surface and underground water contamination, etc.), disposal problems, and extinction of fauna and flora are some of the concerns associated with cement and agro-waste generation. These concerns contribute to economic and environmental sustainability burdens in the built industry. In order to deal with this phenomenon, pozzolanic materials are being sought to bridge the cost of construction. Groundnut shell ash is one of the pozzolans that has been tested to replace cement in concrete and masonry construction partly. Pozzolanas have been defined as silica and alumina materials that do not have self-cementitious qualities, but when finely grounded, they can react and bond together with reactive materials [2].

Groundnut shell is an agro-waste generated from milling or peeling of matured groundnut. Food and Agricultural Organization (FAO) and the United States Department of Agriculture (USDA) have both reported that global production of groundnut had reached 42.31 million tons in 2014 and 49.8 million metric tons in 2023, respectively. It is being projected to continuously increase annually [3, 4]. The same bodies have reported that China, India, and Nigeria are the leading countries in total global groundnut production, respectively. Groundnut produces approximately 40% plus of shells as waste. The production of ash is about 2.5% for every ton of shells generated [5].

Opined that GSA is a good pozzolanic material that reacts with calcium hydroxide forming calcium silicate hydrate, and its activity increases with time [6]. Further, research indicated that the presence of reactive silica can react chemically with calcium hydroxide and generate calcium silicate hydrate (C-S-H). The compressive strength of the GSA/OPC blended at 10% replacement performed better. It could be considered as an alternative substitute for cement in mortar for the construction of masonry walls and mass concrete foundations in low-cost housing.

This study looked into the potential of replacing portions of PPC-32.5N cement in the production of type M and N mortar using locally produced groundnut shell ash with the view to minimize the cost of masonry works, increase the groundnut production and also characterize the same as a possible construction material.

2. Literature Review

The boundless increase in the cost of cement has prompted researchers to investigate the viability of other pozzolanic materials as alternatives, which would be used as partial replacements for cement and subsequently lower the cost incurred in the usage of cement alone. Masonry mortar is used as a binding agent in masonry works, and it is composed of fine aggregate and cementitious materials. According to the research, [7] mortar performance could be achieved by adopting alternative materials different from convectional cement-sand mortar [8]. Research has shown that the use of glass powder as a binder and aggregate in concrete by replacing cement up to 30% did not result in strength loss in mortar.

Conclusions have been drawn that the compressive strength at 15% replacement of cement with brick powder was satisfied with a 7% and 9% increase in compressive and split tensile strength, respectively, compared to control concrete [9]. Investigation into the usefulness of Peanut Husk Ash (PHA) in mortar found that the compressive strength of mortar with 15% substitution of cement at a w/c ratio of 0.5% gave 70% and 80% of target strength at 7 and 28 days, respectively. The researchers further suggested a longer curing period to achieve the required strength [10]. Analysis of Sudanese GSA concluded that reactivity at 20% replacement showed low pozzolanas contrary to the standard requirement. However, at 10% replacement, the requirement was met [11]. Examination of compressive strength, flexural strength, water absorption, and concrete density made with the replacement of cement by groundnut shell ash resulted in a raft of recommendations.

First, the recommendation was that replacement at 5% and 10% is adequate for load-bearing external walls; secondly recommended that 20% and 25% replacement was adequate for non-load-bearing interior walls; and finally, at 15%, replacement was adequate for non-load-bearing exterior walls, [12]. The combination of GSA and OPC ought to be regarded as an environmentally pollution-free construction material.

However, it will not afford an economic gain to the contractors, that is according to a study employing GSA in the production of concrete [13]. A study to evaluate the effect of coconut and groundnut shell ash concluded that 5% of CSA and GSA achieved results close to the control specimen. However, regression modelling of CSA-GSA showed results that can be used in the prediction of strength at different ages, with optimum results at 3.29 and 4.45%, respectively [14].

3. Materials and Methods

3.1. River Sand

The river sand was sourced from river Ewaso Nyiro at Archer's post, Isiolo County, Kenya. The grading was carried out as per the specification of BS 812:103-1:1985, and results were plotted and compared against the nominal envelopes. The silt content in river sand was determined according to BS812-2:1984.

A sample of 50g air-dried river sand passing through a 4.75mm sieve was mixed with a 1% solution of salt and water with the content reaching 100ml mark in a 250ml cylinder. To determine the specific gravity of the river sand, a 500g saturated surface dried sample was used and the test was conducted according to BS 812-2:1975.

3.2. Pozzolanic Portland Cement

Pozzolanic Portland cement (32.5N) was used in this study. The cement was sourced from hardware in Juja, Kiambu County, Kenya. The physical characterization of the cement was conducted in line with EN 196-1:2005 and the conformity was according to EN 197-1. Similarly, the chemical characterization was conducted according to EN 196-2.

3.3. Groundnut Shell Ash

The groundnut shells were sourced from small-scale farmers located in Ramula village within Rachuonyo East Sub-County of Homabay County, Kenya. The shells were burnt in an uncontrolled incinerator for about two hours to produce the ash. The ash was collected after cooling and then sieved through a 75μm sieve.

The physical characterization of the GSA was conducted in line with EN 196-1:2005, and the conformity was checked as per EN 197-1. Similarly, the chemical characterization was conducted according to EN 196-2.

3.4. Water

The water used was sourced from the university's piped water supplied to the laboratories. The water conformed to the requirement of EN 196-1.

3.5. Chemical Characterization

The chemical composition analysis of GSA was conducted using X-Ray Fluorescence (XRF) analytical methods at the Ministry of Mining, Nairobi, Kenya.

3.6. Mortar Preparation

Two types of mortars were considered in this research (Type M and N). Conventional mortar nominal mix ratios were adopted, i.e., for Type N (1:6) and Type M (1:3) cement to fine aggregate ratios were used. Table 1 shows the replacement percentages.

Table 1. Material proportions for type M and N mortars

Mortar Type		
GSA mortar Sample	**Type M w/c Ratio**	**Type N w/c Ratio**
0.0%	3.42	1.95
7.5%	3.42	1.95
12.5%	3.42	1.95
17.5%	3.42	1.95
22.5%	3.42	1.95

3.7. Tests on Mortar

The consistency was determined following BS EN 1015-3. For compressive strength and flexural strength, a total of 90 mortar cubes of size 100x100x100mm were cast to be tested on days 7, 14 and 28. Further, 90 prisms of size 40x40x160mm were also cast for testing on days 28, 56 and 90 as recommended in EN 196-1.

The water absorption, porosity, and Sorptivity of mortar were conducted to determine the durability of the mortar, and its capacity to absorb water through capillary action was determined. The mortar prisms were covered with wax on the sides, except the side immersed in water. The prisms were weighed and placed in a water bath. The sample weight was taken at time intervals specified in ASTM C1585 by surface drying with a cloth towel within 30 seconds and back to the water bath.

4. Results and Discussion

4.1. Particle Size Distribution

As shown in (Figure 1), the grading of the Ewaso Nyiro river sand (BS 812-103-1:1985) fitted well within the limits prescribed in BS 882-1992 Table 4 and IS 383-1970. The fineness modulus of the river sand was found to be 2.9 which categorized it as medium-coarse grained sand. Other researchers have expounded that fine sand compromises the bond strength of the masonry [15, 16]. It can be, therefore, postulated that the particle size distribution of the Ewaso Nyiro river sand shall improve the bonding of masonry units.

4.2. Characterization of the River Sand

The river sand recorded a silt content of 6.1% (Table 2). The value is within the range of 3-8%, implying that the silt content will adequately occupy the voids present in the river sand (BS 812-101: 1988).

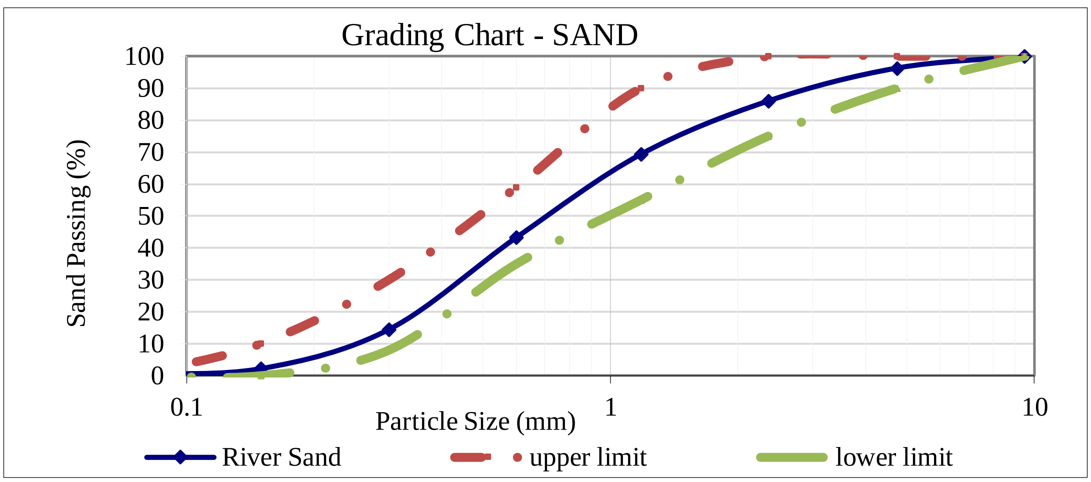


Fig. 1 Grading chart of river sand

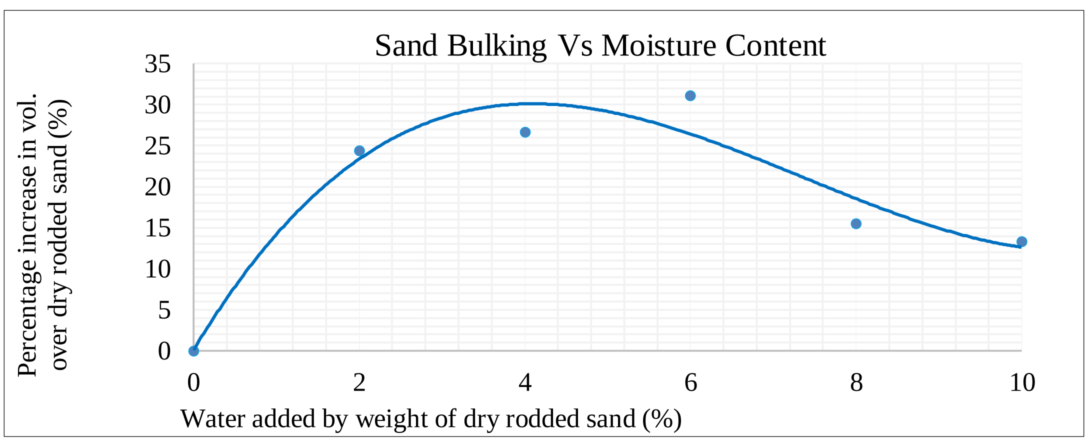


Fig. 2 Maximum bulking of Ewaso Nyiro River sand

Table 2. Characterization of Ewaso Nyiro River sand

Property	Value
Silt content (%)	6.1
Specific gravity, G	2.34
Water absorption	1.35
Percentage void	34.5
Bulk Density (ρ), Kg/m^3	1532
Apparent specific gravity	2.41

As indicated in Table 2, the specific gravity, the apparent specific gravity and water absorption were found to be 2.34, 2.41, and 1.35%, respectively. The low specific gravity (should range 2.5-3.0) value shows the presence of deleterious material as exhibited with slightly high silt content. The water absorption was within the limit provided (0.1-2.0%) (BS 8007 and BS 882).

For determining the bulking of sand, water was added at intervals of 2% in a range of 0-10% to a sample of 250g. As shown in (Figure 2), the maximum bulking of sand occurred with a moisture content of 4% and can be classified as medium (PCA major series 172 and PCA ST20). The bulk density of sand was within the limit of 1520-1680Kg/m^3 (ASTM C 29)

4.3. Particle Size Distribution for GSA

The groundnut shell ash was graded to check its particle size distribution and found to be very fine based on the Fineness Modulus (FM) value of 2.0, with more than 70% being finer than 0.42mm sieve (Figure 3) and, therefore, could not be used as a replacement of sand but be considered as a cementitious material.

However, as indicated in (Figure 3), the presence of particles greater than 0.5mm contributes to the reduction of the percentage of fines in the ash. The Groundnut shell ash was added at intervals of 5% (7.5, 12.5, 17.5 and 22.5%) in making the masonry mortar.

4.4. Physical Properties of Pozzolanic Portland Cement and Groundnut Shell Ash

As shown in Table 3, the addition of GSA increases the initial setting time of mortar paste as compared to that of PPC. Increasing GSA from 7.5% to 22.5% in the presence of PPC led to an 18.82% decrease in the initial setting time of the mortar paste. The soundness of the paste decreased with increasing GSA content. The specific gravity of 32.5N PPC (2.89) was slightly below the 2.90 mark for Portland-blast-furnace-slag and PPC (PCA, 1988).

The bulk density (454 kg/m^3) and specific gravity (1.57) of GSA shows how light the ash was. These properties led to a drop in compressive strength as the replacement increased. Similarly, the low reactivity of GSA was supported by wet sieving results (fineness = 44.3%). This fineness value exceeded the maximum limit of 34%, being retained as coarse.

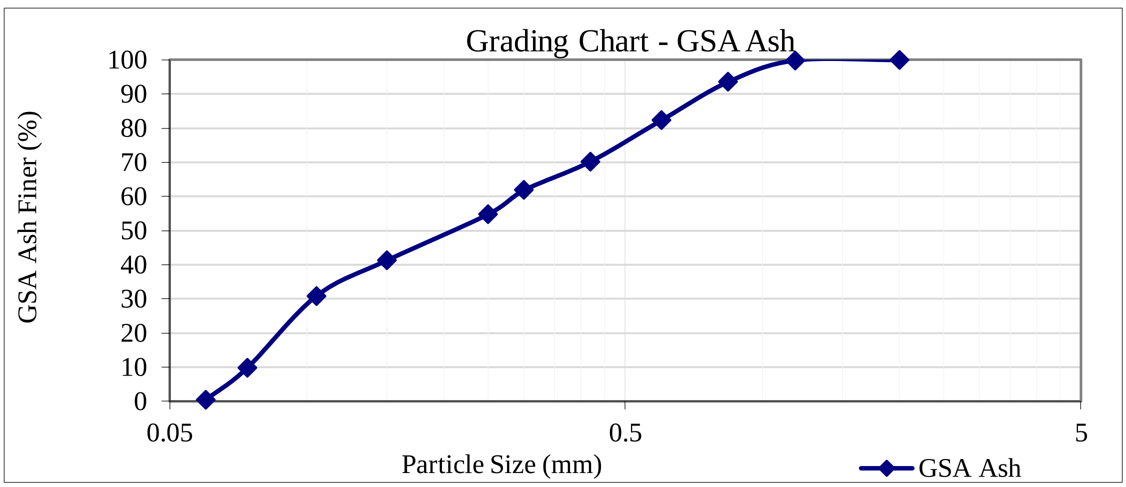


Fig. 3 Particle size distribution of groundnut shell ash

Table 3. Physical parameters of Pozzolanic Portland cement (32.5R) and groundnut shell ash on mortar

Parameters	PPC Cement	GSA	7.5% GSA	12.5% GSA	17.5% GSA	22.5% GSA
Consistency (%)	42.0	-	45.0	47.5	52.5	57.0
Initial setting time (min)	115	-	170.0	169.0	152.0	138.0
Final setting time (min)	288	-	382.0	390.0	375.0	388.0
Soundness (mm)	5.35	-	3.50	3.30	1.55	1.35
Specific gravity, G	2.89	1.57	-	-	-	-
Bulk Density (ρ), Kg/m^3	-	454	-	-	-	-
Fineness (%)	1.0	44.3	-	-	-	-

Table 4. Chemical composition of groundnut shell ash and Portland pozzolanic cement

Element	GSA (%)	PPC Cement (%)
Potassium (K_2O)	34.35	2.72
Calcium Oxide (CaO)	19.61	65.51
Silica (SiO_2)	18.14	18.56
Aluminium (Al_2O_3)	7.07	2.99
Magnesium (MgO)	5.98	-
Iron (Fe_2O_3)	5.86	5.72
Phosphorus (P_2O_5)	5.27	1.38
Sulphur (S)	1.23	2.08
Titanium (TiO)	0.96	0.56
Chlorine (Cl)	0.5	-
Manganese (MnO)	0.31	0.12
Strontium (Sr)	0.2	0.12
Zinc (ZnO)	0.15	0.04
Zirconium (Zr)	0.1	0.08
Barium (Ba)	0.09	-
SiO_2+Fe_2O_3+Al_2O_3	31.07	27.27

4.5. Chemical Characterization of Pozzolanic Portland Cement and Groundnut Shell Ash

The chemical analysis of Portland Pozzolana Cement (PPC) and Groundnut Shell Ash (GSA) was carried out using the XRF method (BS EN 196-2). As indicated in Table 4, the combined percentage of Silica oxide, Aluminum Oxide, and Ferrous oxide was found to be 31.07%. This was less than the minimum requirement of 70% and 50% for class F and class C Pozzolana classification as specified in ASTM C618 (2003), respectively. However, since the CaO (19.61%) in the GSA ranged between 10-30%, it was classified as class C pozzolana based on (ASTM C618, 1994; ASTM C618, 2012; ASTM C187, 2011 and [17]). The low reactivity action of the GSA was evident by the low percentage of the combined oxides of SiO_2+Fe_2O_3+Al_2O_3.

4.6. Properties of PPC-GSA Blended Mortar

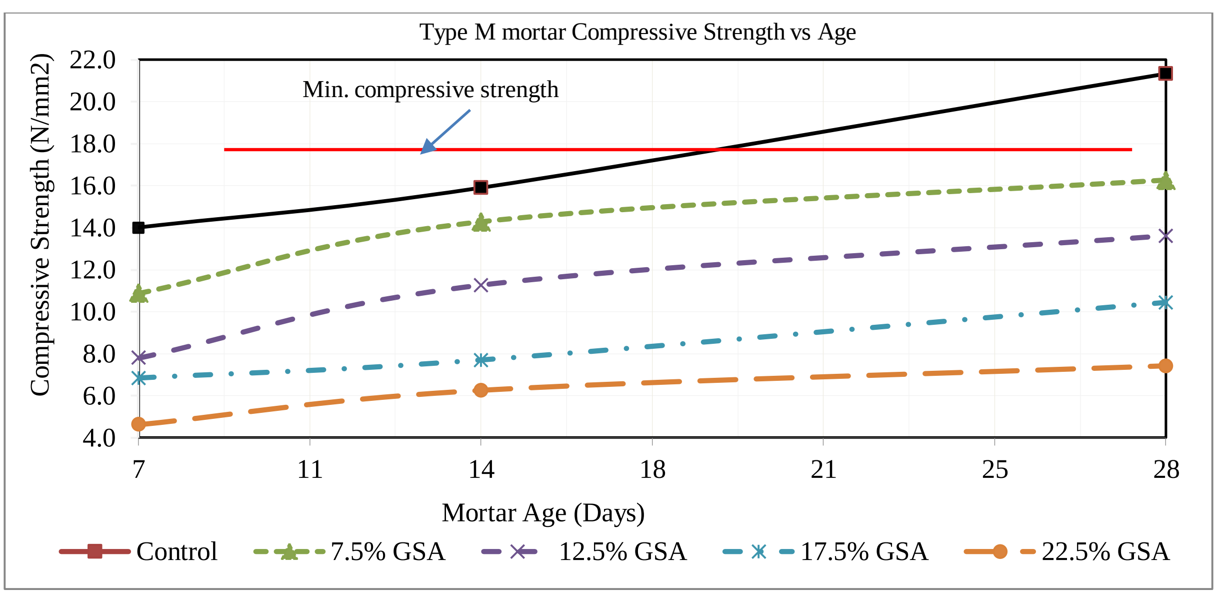
Table 5 shows the consistency values of Type M and N mortar at different percentages of GSA replacement. As seen in Table 5, the addition of GSA content does not lead to significant changes in the consistency of Type N mortar. On the other hand, an increase in GSA in Type M mortar leads to an increase in consistency. As recommended by BS EN 1015-3, the replacement of GSA at 22.5% provided the required value of 110±5%.

Table 5. Consistency of fresh PPC-GSA blend mortar by flow table method

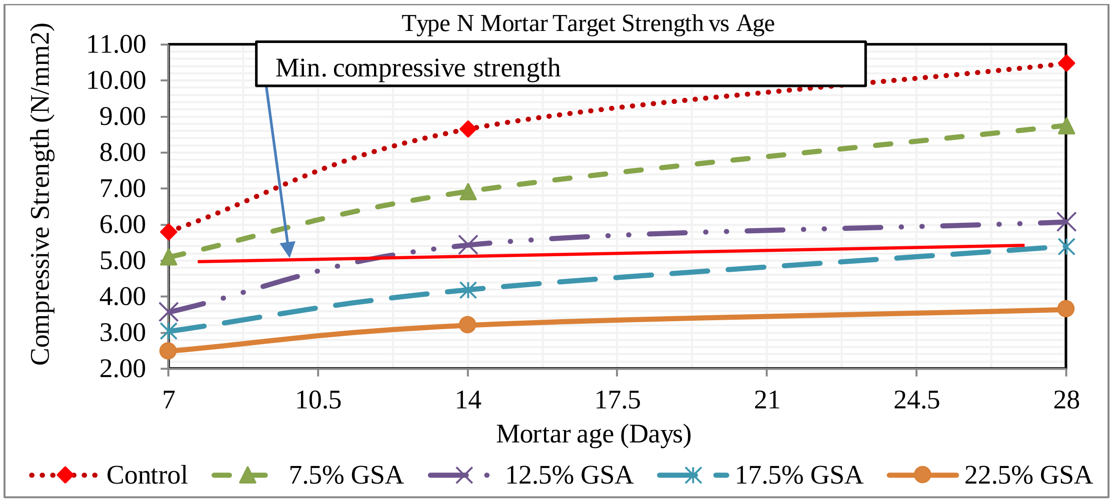
GSA Replacement %	Consistency of Mortar (mm)	
	Type M	Type N
0	115	075
7.5	079	076
12.5	101	067
17.5	101	076
22.5	109	076

4.7. Mortar Compressive Strength

The compressive strength of both Type M and N mortars increased with GSA content as the days progressed. As observed in Figure 4(a), the replacement of PPC with GSA makes Type M mortar not achieve the recommended minimum compressive strength (17.2N/mm^2). However, up to an optimum replacement of 17.5% GSA, Type N mortar can achieve a minimum compressive strength of 5.2N/mm^2 at 28 days of curing (Figure 4(b)).

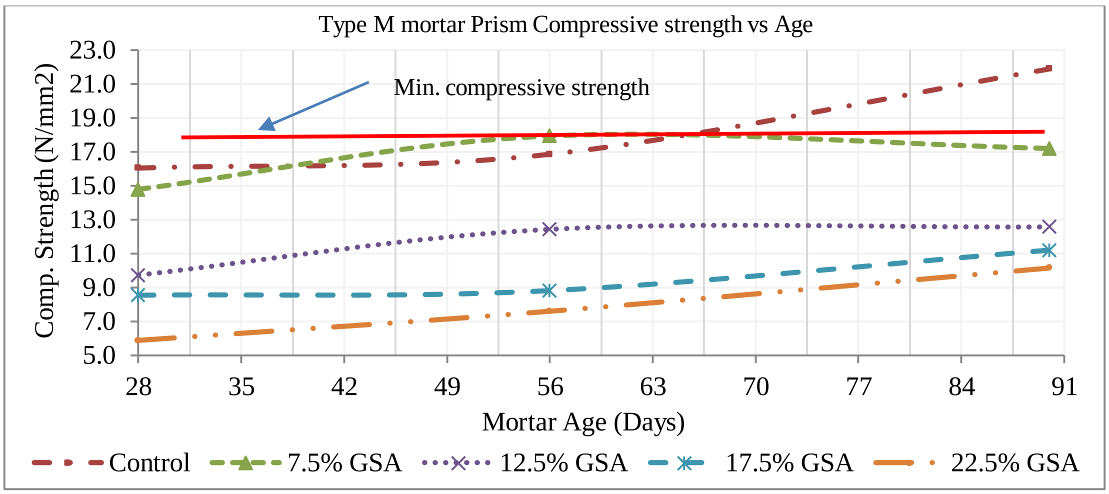


(a) Type M mortar cube strength

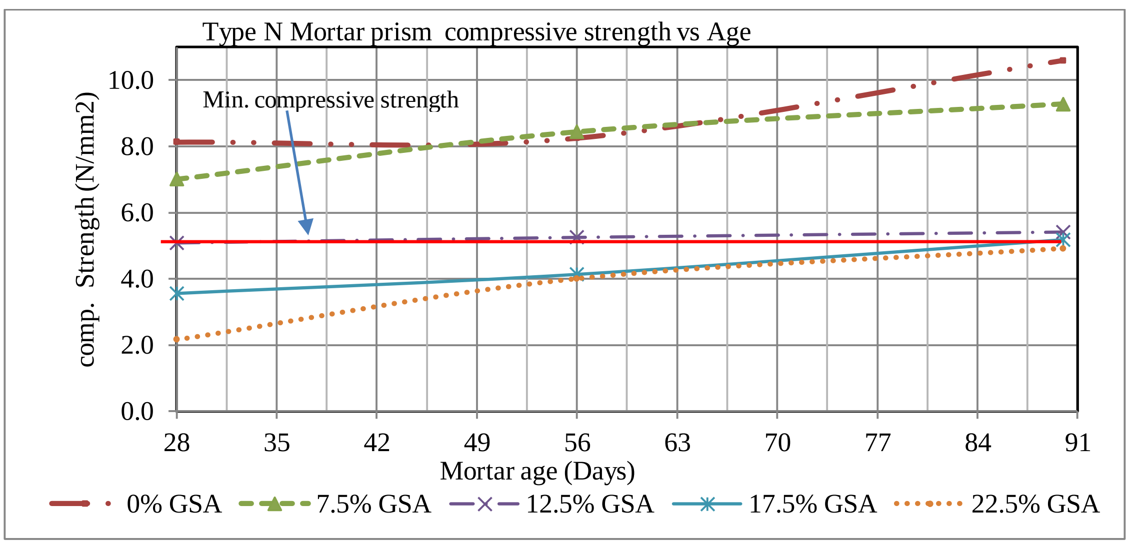


(b) Type N mortar cube strength

Fig. 4 Mortar cube compressive strength



(a) Type M has more prism strength



(b) Type N mortar prism strength

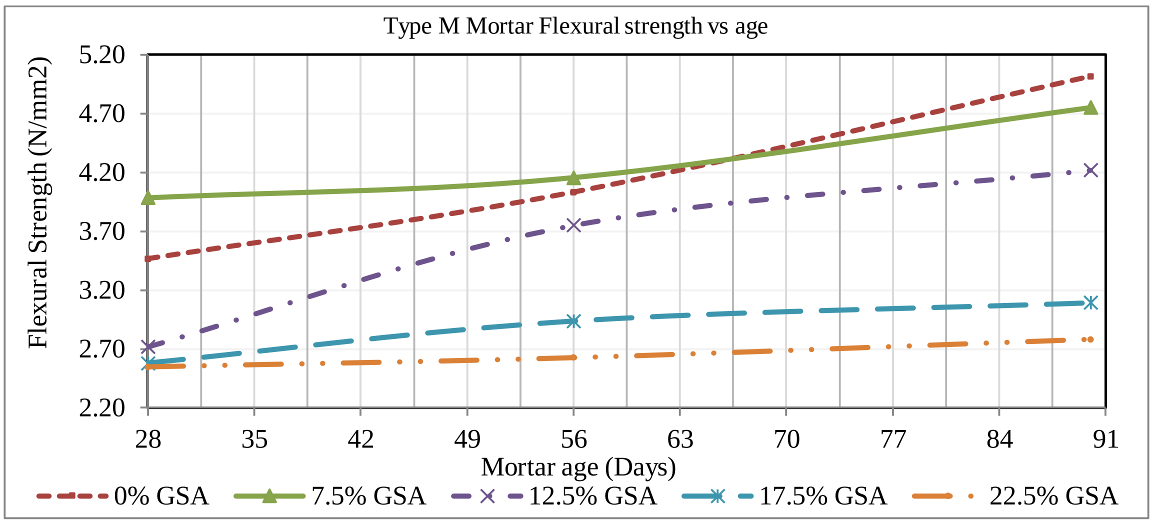
Fig. 5 Mortar prism compressive strength

The prism compressive strength for Type M and Type N mortars on days 28, 56 and 90 are presented in (Figure 5). Type M mortar only achieves the minimum compressive strength with 7.5% GSA replacement at 56 and 90 days of curing (Figure 5(a)). On the other hand, Type N mortars exhibited an increase in prism compressive strength up to 17.5% of GSA replacement, beyond which the mortars did not achieve the minimum required compressive strength even with curing beyond 28 days. The increment of prism compressive strength has been contributed by the continuous hydration of cement and GSA due to the presence of silica fumes, creating a stronger bond [18]. It was further observed that there was a consistent decrease in compressive strength with an increase in GSA content. A consistent pattern between compressive strength and salt scaling in different tested concrete samples was deduced.

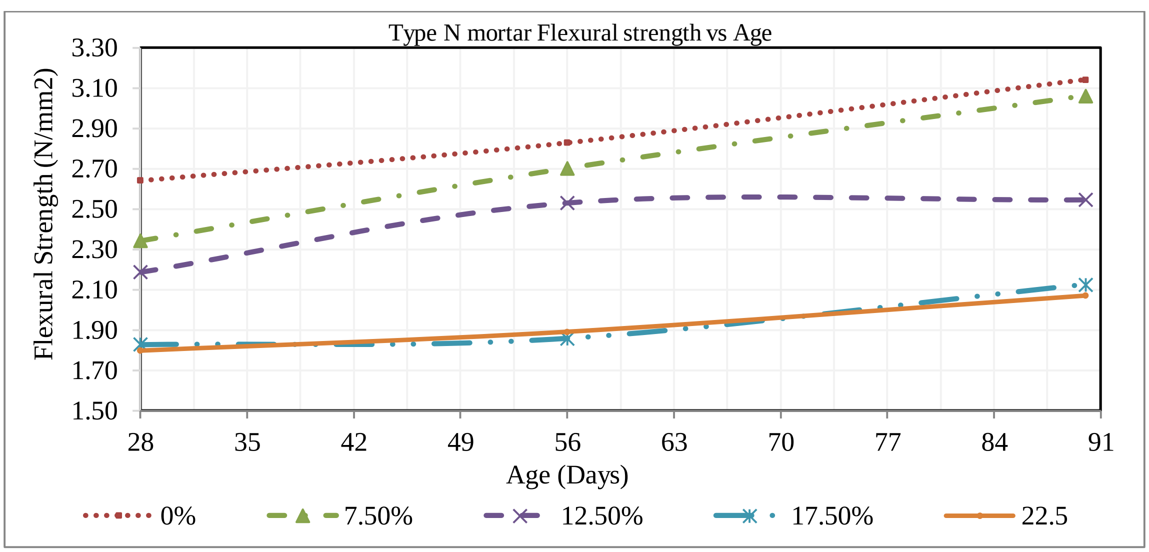
The research also found that the 28-day compressive strength had a strong negative correlation with alkali content (in particular, potassium oxide). This observation explains the observed trend in this study. The high content of potassium oxide (34.35%) in GSA, as compared to 2.72% in Portland pozzolanic cement, contributed to the reduction of prism compressive strength as the content increased [19].

4.8. Flexural Strength of Cement-GSA Mortar

The flexural strength increased with an increase in GSA content. At 28 and 56 days, type M mortar exhibited higher flexural strength than the control at 7.5% GSA replacement. The flexural strength for both mortars exhibited high strength compared with the corresponding compressive strength in the range of 10-40%.



(a) Type M mortar flexural strength



(b) Type N mortar flexural strength

Fig. 6 Flexural strength of mortar

4.9. Reactivity of Pozzolana

The best Strength Activity Index (SAI) occurred on day 56 of curing for Type M and N mortar (Figure 7). According to ASTM C618-08, a minimum strength activity index of 75% is recommended.

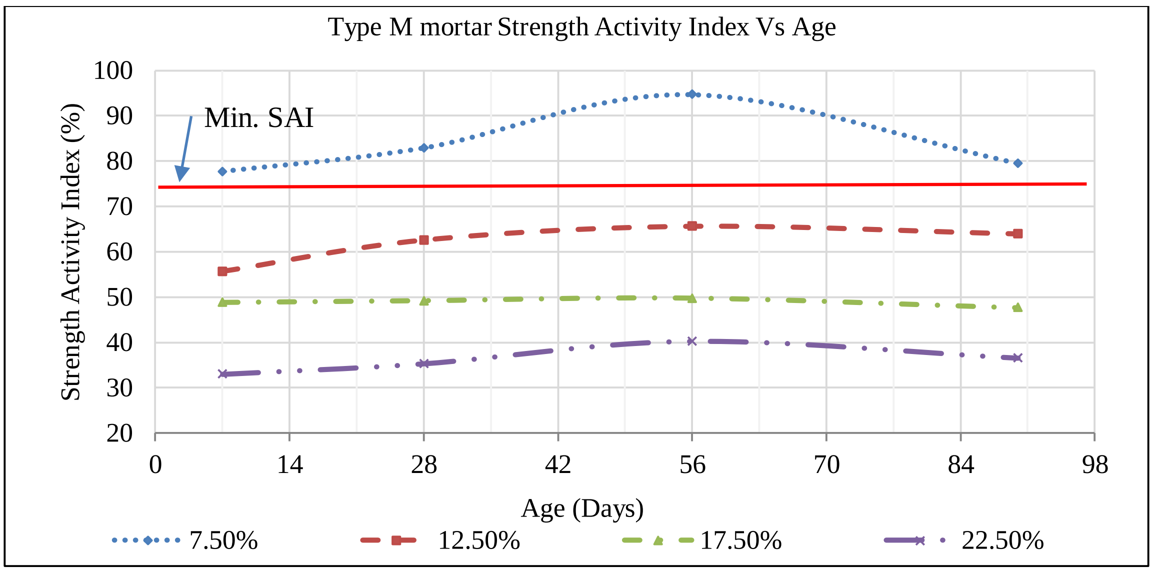
As indicated in (Figure 7), the optimum reactivity was achieved by adding 7.5% GSA for both Type M and N mortars. This means slow pozzolanic activity with the increase of GSA, leading to a decrease in compressive strength as the quantity of GSA increases.

4.10. Mortar Sorptivity

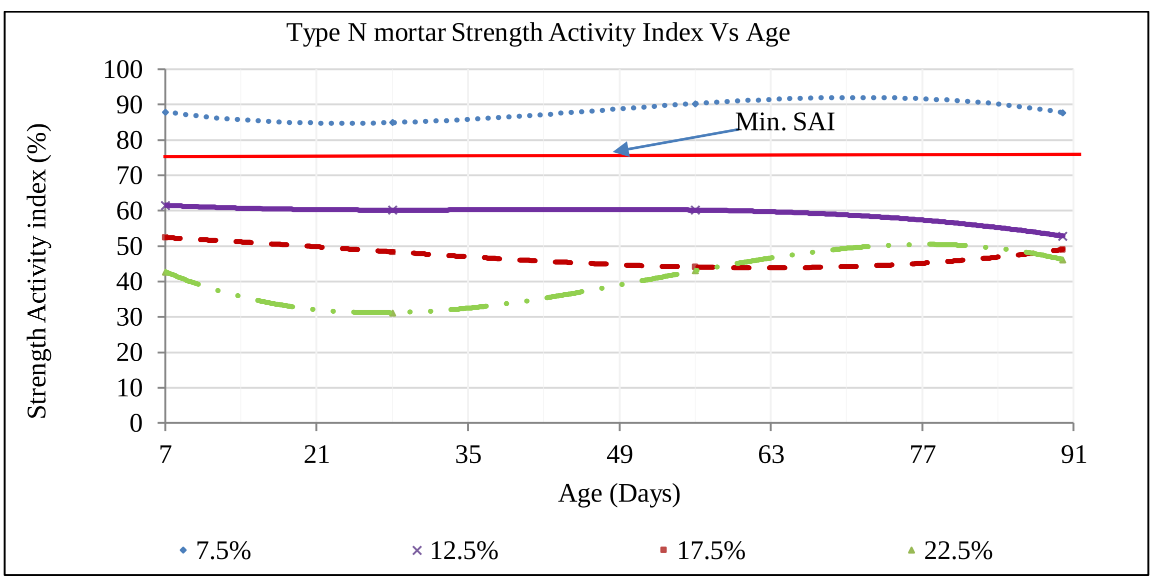
Both initial and secondary sorptivity values for Type M mortar increased with increased GSA content (Table 6). However, for Type N mortar the initial sorptivity value reduced to an optimum percentage of 12.5% GSA. The Initial Sorptivity (Si) value for both mortar types did not conform to the specified value of 3.5x10-4mm/√s. Similarly, the secondary sorptivity (Ss) value for both mortar types did not conform to the specified value of 1.1x10-4mm/√s [20-24].

4.11. Water Absorption and Porosity

Water absorption and porosity of the mortar prisms were conducted following BS EN 1015-18 and BS 1881-122:2011. According to results in (Figures 8 and 9), both type M and N mortar are highly porous, as indicated by high water absorption and porosity rate. The absorption and porosity increased with an increase in GSA replacement at 24 hours and 48 hours, respectively, as the curing period increased.



(a) Pozzolana reactivity for type M mortar

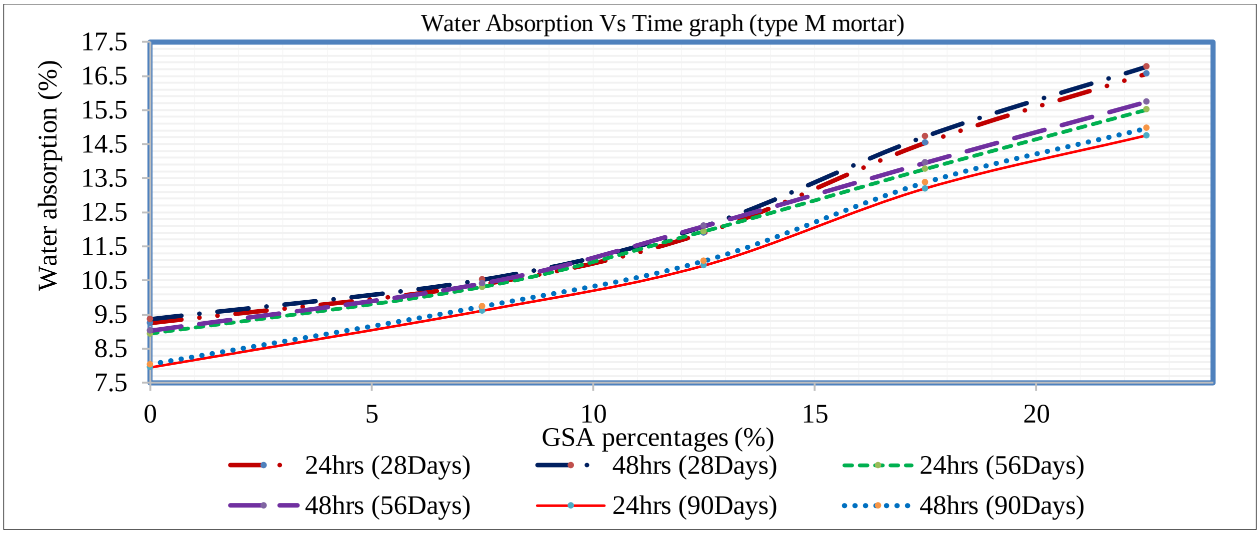


(b) Pozzolana reactivity for type N mortar

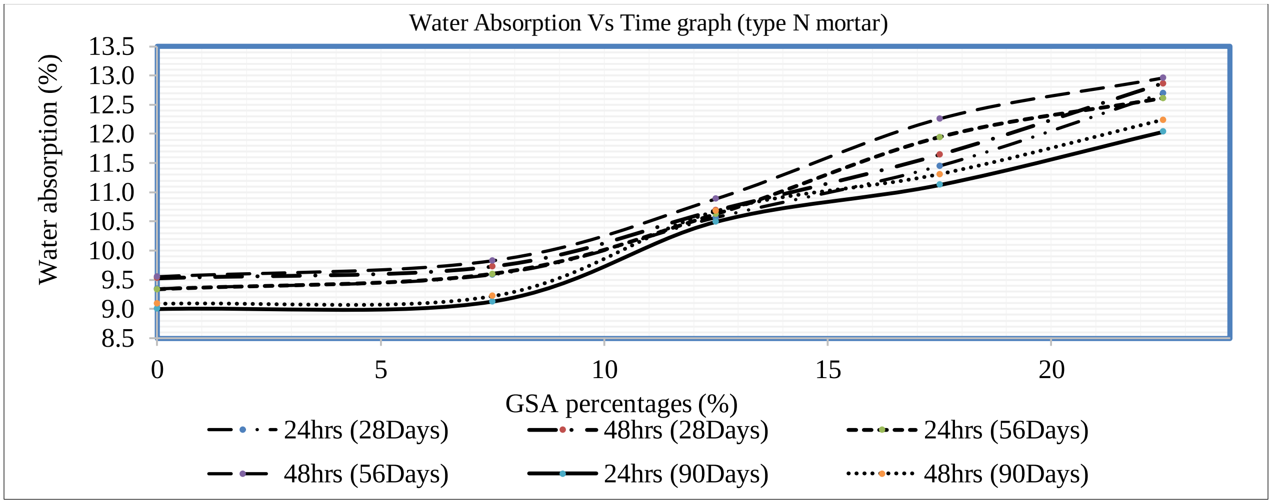
Fig. 7 Pozzolana reactivity of type M and N mortar

Table 6. Average initial and secondary sorptivity of type M and N mortars

GSA mortar	Type M			Type N		
Sample	Type M-IS	Type M-SS	R = 0.99	Type N-IS	Type N-SS	R = 0.99
0.0%	6.31E-02	3.57E-03	0.98	7.74E-02	8.30E-03	0.98
7.5%	6.30E-02	6.73E-03	0.99	7.56E-02	9.30E-03	0.98
12.5%	7.95E-02	6.47E-03	0.99	6.88E-02	8.93E-03	0.98
17.5%	9.26E-02	8.67E-03	0.99	8.49E-02	9.20E-03	0.97
22.5%	1.11E-01	9.00E-03	0.99	8.64E-02	9.33E-03	0.98



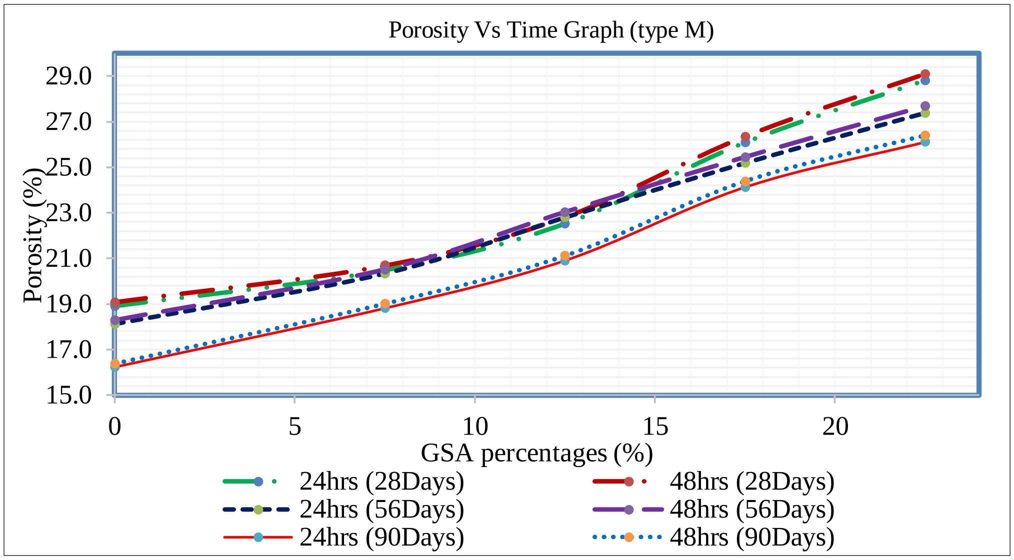
(a) The water absorption rate of type M mortar



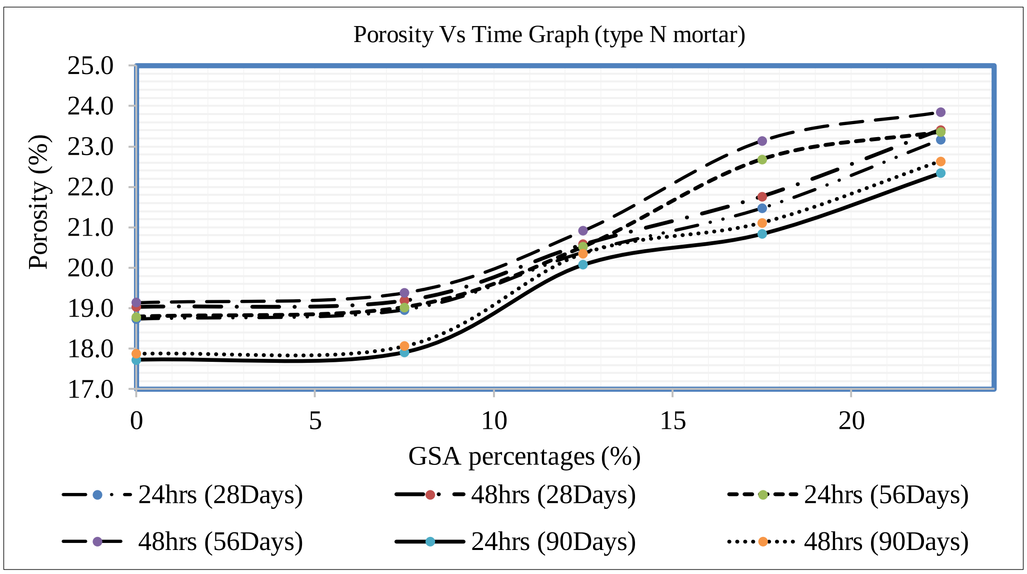
(b) The water absorption rate of type N mortar

Fig. 8 Water absorption rate of type M and N mortar

The comparison of compressive strength to water absorption shows that the compressive strength reduces with an increase in water absorption percentages. This could be deduced from the effect of GSA that increases the pore sizes due to the increased surface area of the ash [25, 26]. So far, there is no standard specifying the limit for water absorption of masonry mortar. However, ASTM C55-17 specifies a maximum of 8% and 11.3% for normal and medium-weight masonry units, respectively. Since mortar is part of the masonry, the same limit could be considered for mortar mixes. Thus, type M mortars comfortably comply with the specification of up to 7.5% GSA replacement at all the curing periods but only comply with the same standard at 12.5% for a 90-day curing period when tested after 24 and 48 hours. Similarly, type N mortar complied with the specification of up to 12.5% GSA replacement at all the curing periods. However, it only complied with the same standard at 17.5% for a 90-day curing period when tested after 24 and 48 hours.



(a) Porosity rate of type M mortar



(b) Porosity rate of type N mortar

Fig. 9 Porosity rate of type M and N mortar

5. Conclusion

In this study, the strength development and durability properties of two types of mortar were evaluated using PPC cement (32.5N) and Groundnut Shell Ash (GSA). The properties of type M mortar (17.2N/mm^2) and type N mortar (5.2N/mm^2) were evaluated with partial cement replacement with GSA intervals of 0%, 7.5%, 12.5%, 17.5% and 22.5%. The following conclusions were drawn from the experimental results;

- The local GSA material was analyzed for the composition of CaO (19.61%), which fell between the ranges of 10-30%; it could therefore be classified as class C pozzolana (ASTM C618, 1994; ASTM C618, 2012; ASTM C187, 2011).
- The compressive strength of the type M mortar cubes produced using the 32.5N PPC cement and GSA ash did not achieve the recommended minimum compressive strength of 17.2N/mm^2 at 28 days of curing. On the other hand, mortar prism cured beyond 28 days achieved the minimum compressive strength of 17.2N/mm^2 at 56 and 90 days of curing at 7.5% GSA replacement. In contrast with type N mortar, a minimum compressive strength of 5.2N/mm^2 at 28 days of curing was achieved at an optimum replacement of 17.5% GSA for cement. Similarly, mortar prism cured beyond 28 days achieved the same strength of 5.2N/mm^2 at 90 days of curing with 17.5% GSA replacement. In conclusion, the effect of curing duration was very minimal on the changes in the strength of the type N mortar.

- The flexural strength for both mortars exhibited high strength compared with the corresponding compressive strength in the range of 10-40%. However, it was observed that at 28 and 56 days, type M mortar exhibited higher flexural strength than the control at 7.5% GSA replacement.
- The reactivity of the two types of mortars was checked, and the optimum reactivity was achieved by adding 7.5% GSA in both types of mortars. This indicated slow pozzolanic activity as revealed by a decrease in compressive strength with an increase of GSA. However, the compressive strength increased with an increase in the curing period, indicating the possibility of achieving the minimum strength over a long period.
- Both initial and secondary sorptivity values for both mortars increased with an increase in GSA content and did not conform to the specified values (ASTM C1585-04). In conclusion, the material could be used for interior masonry works.
- ASTM C55-17 specifies maximum water absorption of 8% and 11.3% for normal and medium-weight masonry units, respectively. Thus, type M mortar comfortably complied with the specification of up to 7.5% GSA replacement at all the curing periods but only complied with the same standard at 12.5% for 90-day curing periods when tested after 24 and 48 hours. Similarly, type N mortar complied with the specification of up to 12.5% GSA replacement at all the curing periods. However, it only complied with the same standard at 17.5% for the 90-day curing period when tested after 24 and 48 hours.

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References

[1] Pierre-Claude Aïtcin, and Sidney Mindess, *Sustainability of Concrete*, 1st ed., CRC Press, pp. 1-328, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[2] G.L. Oyekan, "Crushed Waste Glass in Sandcrete Block Manufacture," *Proceeding on 32nd Conference on Our World*, Singapore, 2007. [Google Scholar]

[3] Pnut King, The Largest Peanut Producers in the World, Agrocrops, 2023. [Online]. Available: https://www.agrocrops.com/en/peanuts-blogs/the-largest-peanut-producers-in-the-world

[4] Faujdar Singh, and B. Diwakar, "Nutritive Value and Uses of Pigeon Pea and Groundnut," *Skill Development Series No. 14, Human Resource Development Program*, pp. 1-44, 1993. [Google Scholar] [Publisher Link]

[5] T.A. Buari, S.A. Ademola, and S.T. Ayegbokiki, "Characteristics Strength of Groundnut Shell Ash (GSA) and Ordinary Portland Cement (OPC) Blended Concrete in Nigeria," *IOSR Journal of Engineering*, vol. 3, no. 7, pp. 1-7, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[6] Navaratnarajah Sathiparan et al., "Potential Use of Groundnut Shell Ash in Sustainable Stabilized Earth Blocks," *Construction and Building Materials*, vol. 393, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Sumanth M. Kamplimath, and Ashwin M. Joshi, "Alternatives to Conventional Cement-Sand Mortar for Sustainable Masonry Construction," *Emerging Trends on Sustainable Construction – National Level Conference*, Christ University, Bangalore, pp. 1-7, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[8] B.G. Anand Kumar, and R. Ravindra, "Properties and Performance of Mortar and Concrete Made with Recycled Glass Powder as Binder and Aggregate," *IOP Conference Series: Materials Science and Engineering, First International Conference on Materials Science and Manufacturing Technology*, Coimbatore, Tamil Nadu, India, vol. 561, pp. 1-8, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] B.V. Ramamamurthy, and N. Himabindu, "Performance of Cement Mortar and Concrete with Partial Replacement of Cement with Clay Brick Powder-An Experimental Approach," *International Journal of Engineering Applied Sciences and Technology*, vol. 5, no. 2, pp. 385-389, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] J. Kreiker et al., "Study of Peanut Husk Ashes Properties to Promote its Use as Supplementary Material in Cement Mortars," *Revista IBRACON De Estruturas E Materiais*, vol. 7, no. 6, pp. 905-912, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[11] El-Sharif M. Ibrahiem, and Mutasim A. Ahmadai, "Pozzolanity Assessment of Sudanese Groundnut Shell Ash," *Conference Proceedings Civil Engineering*, no. 2, pp. 126-132, 2018. [Google Scholar]

[12] P.R. Fernando et al., "Evaluates Some Engineering Properties of Innovative Sustainable Cement Blocks as a Partial Replacement of Groundnut Shell Ash (GSA)," *Acta Scientific Agriculture*, vol. 2, no. 7, pp. 2-7, 2018. [Google Scholar] [Publisher Link]

[13] Victor Samuel, "Groundnut Shell Ash: A Local Construction Material in Concrete Production," *Fane-Fane International Multi-Disciplinary Journal*, vol. 5, no. 1, pp. 25-25, 2020. [Google Scholar] [Publisher Link]

[14] Sidi Yusuf Abdurrahman et al., "Compressive Strength and Optimization of Concrete Produced by Replacing Cement with Coconut Shell Ash (CSA) and Groundnut Shell Ash (GSA)," *Saudi Journal of Civil Engineering*, vol. 6, no. 8, pp. 207-214, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] C. Anderson, and L.C. Held, "The Effect of Sand Grading on Mortar Properties and the Tensile Bond of Brickwork Specimens," *Proceedings of the British Masonry Society*, vol. 1, pp. 1-5, 1986. [Google Scholar] [Publisher Link]

[16] Abbagana Mohammed, Tim G. Hughes, and Aliyu Abubakar, "Importance of Sand Grading on the Compressive Strength and Stiffness of Lime Mortar in Small Scale Model Studies," *Open Journal of Civil Engineering*, vol. 5, no. 4, pp. 372-378, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[17] Jamilu Usman, Nasiru Yahaya, and E. Mohammed Mazizah, "Influence of Groundnut Shell Ash on the Properties of Cement Pastes," *IOP Conference Series: Materials Science and Engineering*, *Postgraduate Symposium in Civil and Environmental Engineering*, Universiti Tun Hussein Onn Malaysia, vol. 601, pp. 1-8, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] Rushabh A. Shah, and Jayeshkumar Pitroda, "Effect of Water Absorption and Sorptivity on Durability of Pozzocrete Mortar," *International Journal of Emerging Science and Engineering*, vol. 1, no. 5, pp. 73-77, 2013. [Google Scholar] [Publisher Link]

[19] K. Rose, B.B. Hope, and A.K.C. IP, "*Factors Affecting Strength and Durability of Concrete Made with Various Cements*," Transportation Research Record 1234, Queens University, Kingston, Ontario, Canada, pp. 13-23, 1989. [Google Scholar] [Publisher Link]

[20] K. Gopi Shankar, and G.V. Rama Rao, "Variation of Sorptivity in Diverse Grades of Concrete Proportioned with Fly Ash, Woodhusk Ash and Rice Husk Ash," *International Research Journal of Engineering and Technology*, vol. 4, no. 12, pp. 1626-1633, 2017. [Google Scholar] [Publisher Link]

[21] D.W.S. Ho, and R.K. Lewis, "The Water Sorptivity of Concretes : The Influence of Constituents under Continuous Curing," *Durability of Building Materials*, vol. 4, no. 3, pp. 241-252, 1987. [Google Scholar] [Publisher Link]

[22] Nicos S. Martys, and Chiara F. Ferraris, "Capillary Transport in Mortar and Concrete," *Cement and Concrete Research*, vol. 27, no. 5, pp. 747-760, 1997. [CrossRef] [Google Scholar] [Publisher Link]

[23] ASTM C1585-04, "*Standard Test Method for Measurement of the Rate of Absorption of Water by Hydraulic-Cement Concretes*," ASTM International, 2010. [Google Scholar] [Publisher Link]

[24] C. Hall, "Water Sorptivity of Mortars and Concretes: A Review," *Magazine of Concrete Research*, vol. 41, no. 147, pp. 51-61, 1989. [CrossRef] [Google Scholar] [Publisher Link]

[25] R. Guru Lakshmi et al., "Experimental Study on Mechanical and Durability Properties of Mortar with Fly Ash and Copper Slag," *International Research Journal of Engineering and Technology*, vol. 3, no. 6, pp. 939-943, 2016. [Publisher Link]

[26] BS 1881-122: Testing Concrete - Method for Determination of Water Absorption, BSI.Knowledge, 2011. [Online]. Available: https://knowledge.bsigroup.com/products/testing-concrete-method-for-determination-of-water-absorption-1?version=standard