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Experimental Investigation on Mechanical and Durability of Compressed Cement Stabilized Laterite Soil Blocks with Partial Replacement of Fly Ash and GGBFS

S. Sarath[1], K. Mahendran[2]

[1]*Research Scholar, Centre for Rural Technology, The Gandhigram Rural Institute – Deemed to be University, India, sarassarath@gmail.com*
[2]*Professor, Centre for Rural Technology, The Gandhigram Rural Institute – Deemed to be University, India, mahendran_gri@rediffmail.com*

Stabilized laterite blocks (SLBs) are produced by compacting a wetted combination of laterite soil, cement and industrial waste in a hydraulic machine into a high-density block. Such blocks are used for the construction of load-bearing masonry structures. This paper presents the results of an experimental investigation in characterizing the properties of partial replacement of cement stabilized laterite soil blocks using Fly Ash and Ground Granulated Blast furnace Slag (GGBS). The mix proportion are formulated by kept the laterite soil at constant of 90%, the binder 10%, which cement varying from 4 to 10%, Fly Ash and GGBFS varying from 2 to 6%. From the test results, it is observed that mix with 4% of GGBFS has attained better results in mechanical, microstructural and durability properties of cement stabilized laterite soil blocks in comparison to control mix.
Keywords: Laterite soil, Stabilized block, Fly Ash, GGBS, Mechanical, microstructural and Durability properties.

1. Introduction

Laterite soil, characterized by its peculiar indurated ferruginous clay composition, is predominantly found atop the highest mountains in Southern India. It forms as a result of the decomposition of ferruginous rocks in highly damp climates. It is the most common soil type across a wide area, spanning from approximately 100 kilometers south of Bombay to somewhere south of Quilon, extending deep inland in India. The discovery of laterite soil traces back to Angaddippuram, Kerala, where the predominant bedrock is dominantly Precambrian gneiss. The laterite of Angaddippuram is a mottled and vesicular variety of saprolite. Deep weathering with the partial stripping of weathered rock (saprolite), has given rise landscapes termed as etchplain. Numerous quartz veins can be observed in the weathered saprolite rocks which makes it easy to distinguish the saprolite from materials like disturbed soil [1-2]. There are variations in laterite profiles are based on the formation of bed rocks, depths and weathering processes. Laterite soil often displays shades of red, yellow, and grey. The remnants of earlier erosion surfaces form ridge summits containing detritus and boulders of primary laterite derived from the surrounding rocks. the crust of laterite soil may be indurated, but the underlying material is not excessively soft and can typically be cut only with tools like axes. This rocky pavement, originating from saprolite is used in construction. Quarrying involves cutting vertical grooves to isolate blocks, which are then separated, trimmed, and stacked for construction purposes. The degree of hardness may potentially increase with future exposures. Laterite soil has been commonly utilized in traditional homes, multi-story buildings, temples, cathedrals, as well as in roads, paths, and steps. Later, over years the weathered remnants of saprolite bed rocks were also used to produce compressed earth blocks. The laterite soil blocks involved various stabilization processes for the improvement of its properties [3-5]. Even, in road construction stabilization of soil improved the California bearing ratio (CBR) value of the subgrade. Various binders are used for stabilization process. One of the commonest stabilizing agents is cement. The need for cement stabilizes building blocks is increasing day by day due rapid development of urbanization. The use of billions of tons of cement throughout the world emits significant amounts of carbon dioxide (7%) during production of cement [6]. Accordingly, the partial replacement of cement is expected to meet increasing demand for cement stabilized mud block production [6-8]. The rapid urbanization has led to industrial waste generation, including Fly Ash and Ground Granulated Blast Furnace Slag (GGBS), contributing to land and groundwater pollution, which has produced during power generation and steel production. As construction activities increase, there is a growing demand for eco-friendly alternatives to cement. India's Fly Ash production reached 226.13 million tons in 2019-2020 and is estimated to reach 300-400 million tons by 2025. Accordingly, this study aims to address the environmental impact of Fly Ash disposal and converting the same to be a replacement for construction materials. In compressed cement stabilized earth blocks needs a low-carbon alternative to conventional cement, which was achieved through uses industrial by-products such as Fly Ash and GGBS [9-11]. However, the incorporation of GGBS and Fly Ash in compressed cement stabilized earth blocks presents unique challenges due to its complex chemical composition and physical properties. Understanding the combined behaviour of cement along with GGBS and Fly Ash based laterite blocks is crucial for assessing its feasibility and potential applications in real-time projects. This study mainly focuses on the effect of GGBS and Fly Ash on mechanical and durability properties of cement stabilized laterite soil blocks. The study includes;

- Durability performance of stabilized laterite blocks, including resistance to environmental wear.
- Mechanical properties of laterite blocks incorporating Fly Ash and GGBS as partial replacements for cement.

- Optimising mix design for achieving strength and durability while minimizing environmental impact.
- Addressing the environmental challenge of Fly Ash and GGBS disposal by repurposing them in construction materials.

2. Materials and Methods

The laterite soil collected from Kottayam district of Kerala is used for the production, which having Specific gravity of 2.01, Liquid Limit of 62%, Plastic Limit of 30% and Shrinkage Limit of 42%. The Ordinary Portland cement - 53 grade of cement was used conforming to IS 12269-2013 [13]. Fly ash and GGBS were used as supplementary cementitious material for laterite block production. Commercially available JSW GGBS was used in study. Fly ash was obtained from NLC private Limited India. Table 1 present the physical and chemical properties of binders. Table 2 shows the mix proportions of cement stabilized laterite mud blocks. The percentage of cement replacements were taken in the range of 2,4 and 6 % since replacing cement content with more than 60 % of supplementary cementitious materials considerably effects the strength and durability of the CSEB [8-9].The casting of laterite mud blocks was done using roller mixture and hydraulic press machine. Initially, the Laterite soil and binders were mixed in the pan mixture for 5 minutes. Then water is added to the dry mix. It is mixed thoroughly until it is uniform and lumps free. The fresh mix with optimum moisture content is batched to the hydraulic press. Mud block of size 300 x 200 x 150 mm is produced under 2000-3000 psi pressure. The blocks are left in ambient conditions for 24hours after that the blocks were cured with sprinkling of water and cover with plastic sheets. Laterite blocks were tested according to the standards of IS-1725:2023 [12] and the dry compressive strength and wet compressive strength were calculated at the age of 7, 14 and 28 days. The Ultrasonic Pulse Velocity of laterite blocks were calculated as per the IS 13311 (Part 1): 1992 codal provision [14], which is widely used for study homogeneity and voids on solid materials. The dry compressive strength of the mud blocks is determined by following the procedures given by IS 3495 (Part 1) codes [15]. The compression testing machine (CTM) was used to find the strength of mud blocks. The mud blocks were tested at a loading rate of 14 N/mm^2 per minute. The compressive strength of all blocks is noted and the average dry compressive strength is considered as the strength of mud block. The block efficiency test conducted by arranging the mud blocks one over another consisting of three numbers and also five numbers in each test. This test is particularly carried out to find out the efficiency of the blocks through the compressive strength of the blocks in a prism manner (Block Efficiency (η) = Masonry prism strength/Block Strength). Before wet compression testing, the mud blocks were immersed in water for 24 hours. Then the blocks were removed from the water, and moisture present on the surface was wiped out. The remaining test procedure for wet compressive strength is similar to that of dry compressive strength. Parallelly, the percentage of water absorption calculated was calculated as per the IS 3495 (Part 2):1992 [16] codal provisions in immersed laterite blocks. Spray erosion test was conducted as per IS 1725: 1982 to determine the erosion rate of each laterite block specimen. The water pressure was set to 50 kPa and the suitability of Mudbricks were assessed based on rate of erosion respectively in mm and mm/h.

Table 1. the physical and chemical properties cement and industrial wastes

Material	Chemical properties									Physical properties				
	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	SO_3	LOI	Specific gravity	Fineness (m^2/ Kg)	Average particle size (µm)	Initial setting time (min)	Final setting time (min)
Cement	4.87	61.5	2.36	-	2.73	-	22.3	1.9	1.78	3.12	328.6	7.46	45	325
FA	17.92	37.63	0.66	0.05	7.23	0.31	34.81	0.2	0.45	2.12	-	16.35	-	-
GGBS	10.12	4.56	2.98	0.70	1.37	0.32	72.12	0.24	0.51	2.79	-	19.04	-	-

Table 2. the mix proportion

Mix ID	Laterite Soil	Cement	Fly Ash	GGBS
C10CCA0	90%	10%	-	-
C8FA2	90%	8%	2%	-
C6FA4	90%	6%	4%	-
C4FA6	90%	4%	6%	-
C8GS2	90%	8%	-	2%
C6GS4	90%	6%	-	4%
C4GS6	90%	4%	-	6%

3. Results and Discussions

(i) Density of the Block:

The effect of Fly Ash and GGBS dosage on the density of laterite blocks is shown in Figure 1. It could be clearly understood from the results, the density of laterite blocks decreased with increasing content of Fly Ash, which reduced from 2035.93 to 1984.44 Kg/m^3 density of laterite blocks at age of 28 days. However, the increase of GGBS content leads to achieve higher density of blocks, which attained the maximum density is achieved in specimens containing 6% of GGBS as 2125.56 Kg/m^3, which is even higher than the control mix (C10) specimens density of 2035.93 Kg/m^3. This may be due to the formation of dense microstructure and enhances packing density of laterite blocks, which leads to increase particle packing density of the blended mixture [10].

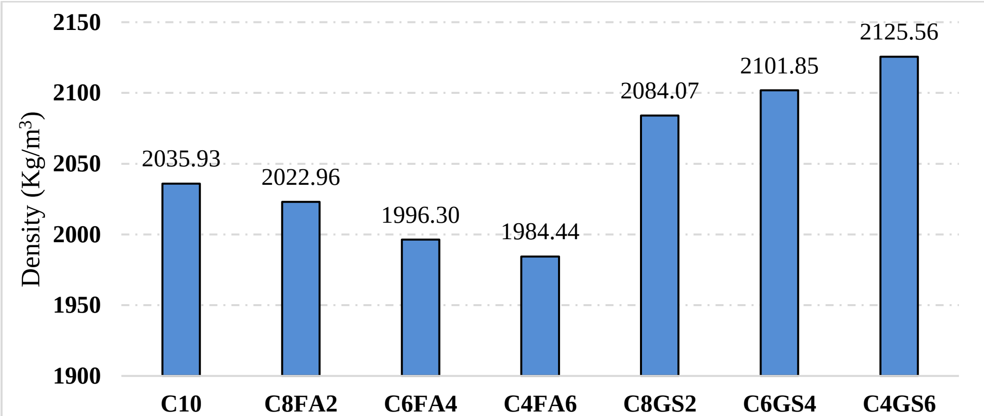

Figure 1. The effects of Fly Ash and GGBS replacement on density

(ii) Dry Compressive strength:

The dry compressive strength of laterite blocks specimens was calculated as per IS 1725: 2023 standard procedures after the age of 7, 14 and 28 days of curing. The Figure 2 shows the effects partial replacement of Fly Ash and GGBS on dry compressive strength of laterite blocks. The gradual increment in dry compressive strength of blocks is observed at intervals 7, 14 and 28 days, corresponding to their Fly Ash and GGBS replacement up 4%. Beyond that the dry compressive strength of cement stabilized laterite soil blocks was reduced. It clearly shows that's 4% of GGBS replacement found optimum for laterite soil blocks. The results clearly shows that the increase of GGBS replacement content up to 4% has increased the compressive strength from 1.91 N/mm^2 to 3.02 N/mm^2 in 7th day, 3.74 N/mm^2 to 6.21 N/mm^2 in 14th day, and 8.31 N/mm^2 to 9.26 N/mm^2 in 28th day, which increased the 28th day compressive strength about 11.43% with comparison to control mix C10. However, Fly Ash replacement content up to 4% has increased the compressive strength from 1.91 N/mm^2 to 2.93 N/mm^2 in 7th day, 3.74 N/mm^2 to 5.78 N/mm^2 in 14th day, and 8.31 N/mm^2 to 9.18 N/mm^2 in 28th day, which increased the 28th day compressive strength about 10.47 % with comparison to control mix C10. Figure 3 shows the microscopic images of laterite blocks surface is captured at the age of 7, 14 and 28 days as per the ASTM C1723–16. The absence of needle like formation clearly shows that the micrographs of C10 mix having high amount of unreacted cement particles in early age of hydration process at age of 7, 14 and days. On other hand, mixes with 4 % of Fly ash (C6FA4) and 4% of GGBS (C6GS4) are show that the presents of more amount of reacted cement particles due to its higher pozzolanic reaction in terms of formation of ettringite and calcium hydroxide during hydration and C-S-H gel formation also increased more in the mix with 4% of GGBS. Both Fly ash and GGBS has filled pores and it improved the microstructure of cement matrix of laterite blocks [11].

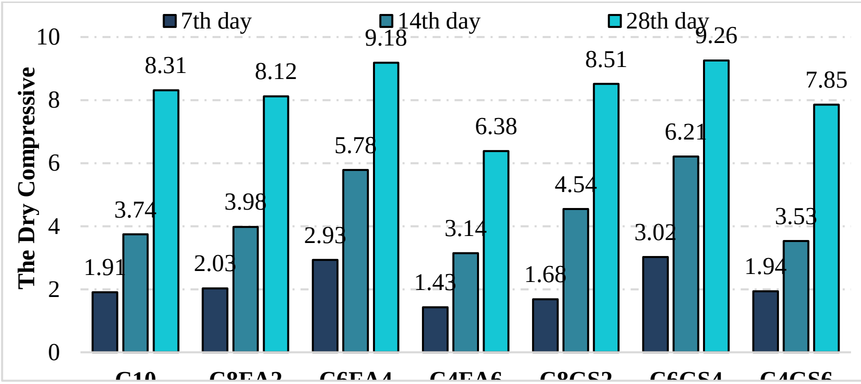

Figure 2. The effects of Fly Ash and GGBS replacement on dry compressive strength

(iii) Wet Compressive strength:

The wet compressive strength of laterite blocks specimens was calculated as per IS 1725: 2023 standard procedures after the age of 28 days of curing. The Figure 4 shows the effects partial replacement of Fly Ash and GGBS on dry compressive strength of laterite blocks. The gradual increment in wet compressive strength of laterite blocks is observed in both Fly Ash and GGBS replacement up 4%. Beyond that limit the wet compressive strength of cement stabilized laterite soil blocks was reduced drastically 29.95% in 6% of Fly ash and 6.71% in 6% of GGBS, which may due to higher dosage industrial waste material leads reduce reactivity of hydration process in laterite blocks. It clearly shows that's 4% of GGBS replacement found optimum for laterite soil blocks.

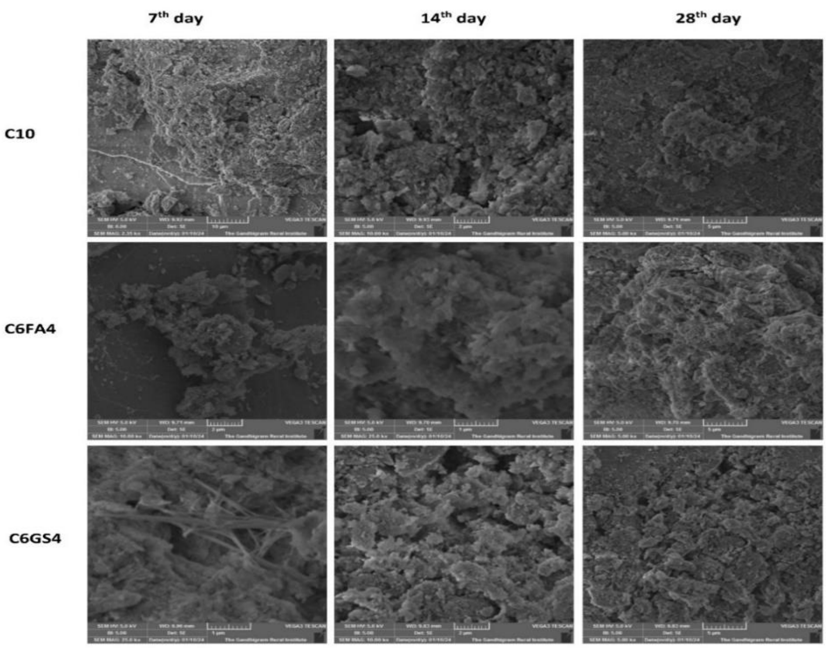

Figure 3. Scanning Electron Microscopic images of laterite blocks

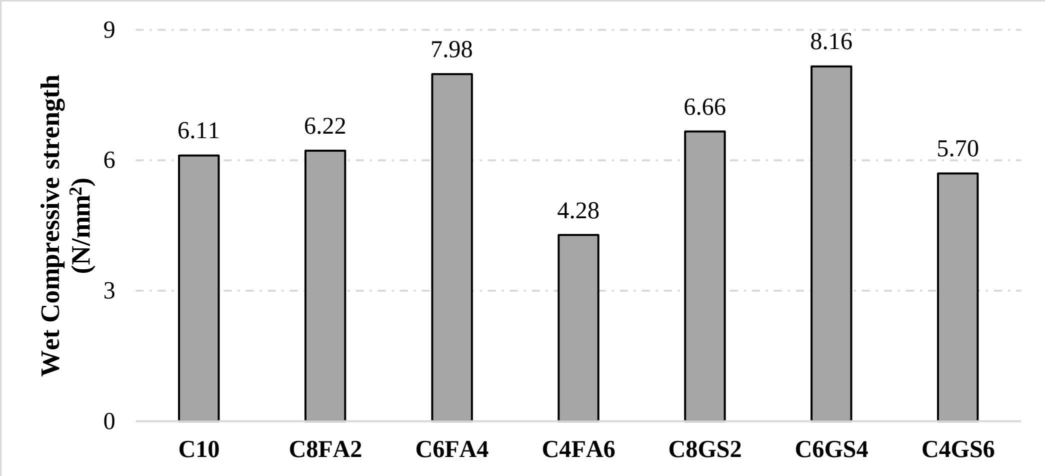

Figure 4. The effects of Fly Ash and GGBS replacement on wet compressive strength

(iv) Ultrasonic Pulse Velocity Test:

The ultrasonic pulse velocity was tested as per IS 13311 (Part 1) – 2004 and results are presented in Figure 5. It could be seen that the enhancement in ultrasonic pulse velocity of both Fly Ash and GGBS replaced laterite block at the age of 28 days, comparatively from the control mix. The velocity of laterite blocks the increases with increase of both Fly Ash and GGBS content up to 4%, beyond that gradually it is decreased. The mix having 4% of Fly Ash and 4% of GGBS has a maximum pulse velocity of 1.85 Km/sec and 1.91 Km/sec is noticed at 28 days, which enhanced the velocity of laterite blocks about 17.83% and 21.66%, respectively in comparison to control mix (C10 mix). This might be due to the reduction of voids in the mix and it leads to homogeneous matrix of laterite blocks, which could be verified from micrographs.

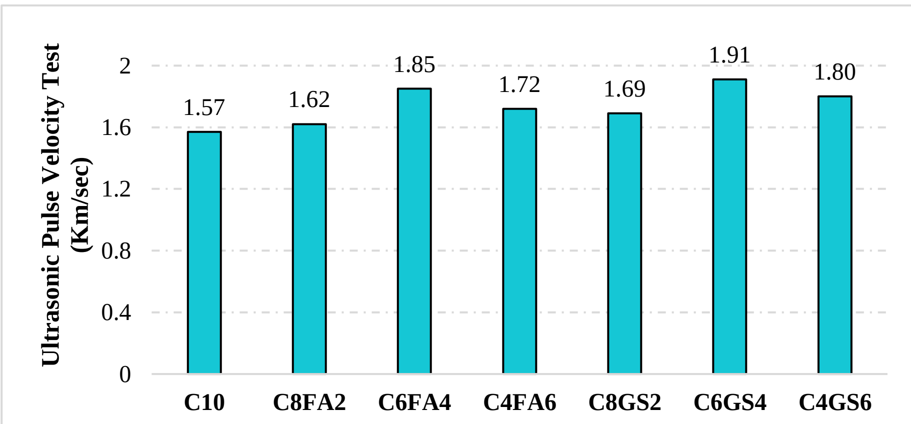

Figure 5. The effects of Fly Ash and GGBS replacement on ultrasonic pulse velocity

(v) Prism test:

Figure 5 shows the efficiency of 3 blocks prism test at age of 28th day. It could be seen that the enhancement in prism efficiency in both Fly Ash and GGBS replaced laterite block at the age of 28 days, comparatively from the control mix. The mix having 4% of Fly Ash (C6FA4) and 4% of GGBS (C6GS4) has a maximum efficiency of 3 blocks prism test are 0.93 and 0.95 at 28 days, which enhanced the efficiency of laterite blocks about 2.20% and 4.40%, respectively in comparison to control mix (C10 mix). The prism efficiency of laterite blocks the increases with increase of both Fly Ash and GGBS content up to 4%, beyond that efficiency is rapidly decreased about 3.30-7.79%.

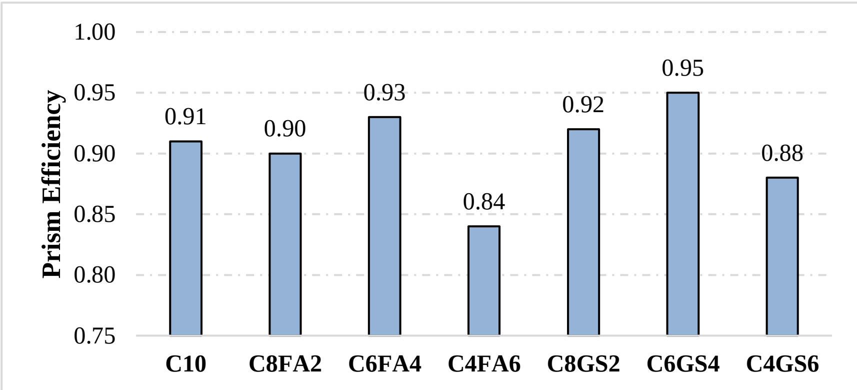

Figure 6. The effects of Fly Ash and GGBS replacement on 3 block prism efficiency

(vi) Water Absorption:

The water absorption was tested as per IS 3495 (Part 2):1992 and results are shown in Figure 6. It could be seen that the reduction in water absorption of both Fly Ash and GGBS replaced laterite block at the age of 28 days, comparatively from C10 mix. The water absorption of laterite blocks the decreases with increase of both Fly Ash and GGBS content up to 4%, after that it gradually increased, which may be due to non-reactivity of Fly Ash and GGBS. The mix having 4% of Fly Ash and 4% of GGBS has a minimum water absorption of 7.59% and 7.12% is noticed at 28 days, which reduced the absorption of laterite blocks about 14.04% and 19.37%, respectively in comparison to control mix (C10 mix).

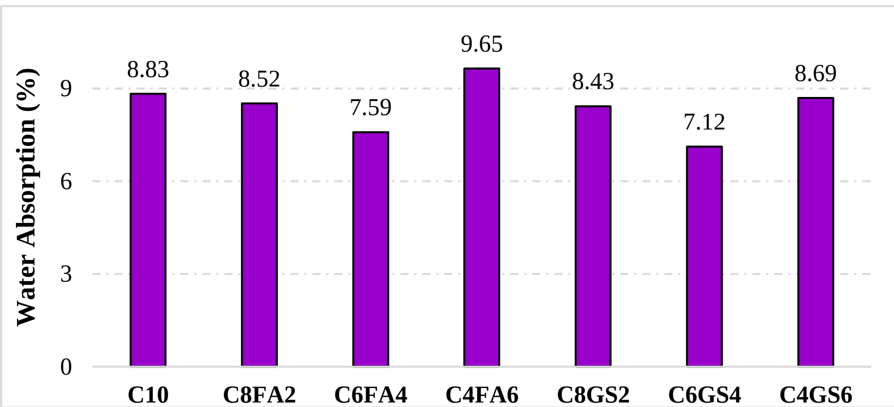

Figure 7. The effects of Fly Ash and GGBS replacement on water absorption

(vii) Spray Erosion Test:

Figure 7 shows the erosion rate of laterite block specimens was tested as per IS 1725: 1982. The gradual increment in resistance against the erosion rate of laterite blocks is observed in both Fly Ash and GGBS replacement up 4%. However, The Mix C6GS4 with 4% of GGBS was performed higher resistance in spray erosion test, which achieved the lowest rate of erosion 9 mm/hour and it was 43.33% reduction in compression to the C10 Mix. similarly, The Mix C6FA4 with 4% of Fly Ash reached 12 mm/hour and it was 25.00% reduction in the rate of erosion. This might be due to the reduction of voids in the mix and it leads to homogeneous matrix of laterite blocks, which could be verified from micrographs.

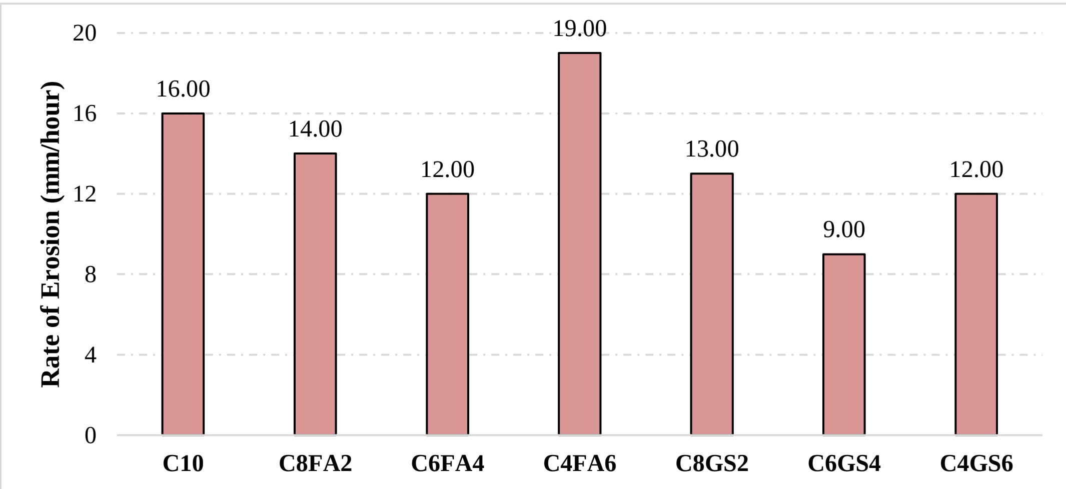

Figure 8. The effects of Fly Ash and GGBS replacement on rate of erosion

4. Conclusions

From the results of the various tests, the following conclusions can be drawn. The partial replacement of Fly Ash and GGBS in the blocks will not only controls the pollution and also it contributes to the economy, other than it will resolve the sustainability of natural nonrenewable material. The optimum level for partial replacement of Fly Ash and GGBS in laterite blocks about 4%, beyond that the mechanical and durability properties of laterite blocks was reduced rapidly. The mix with 4% of GGBS enhanced the density about 3.24%, dry compressive strength enhanced about 11.43%, wet compressive strength enhanced about 33.55%, ultrasonic pulse velocity enhanced about 21.55%, prism efficiency enhanced about 4.40%, water absorption reduced about 19.37% and rate of erosion in spray erosion test reduced about 43.75%. Similarly in C6FA4 mix with 4% of Fly Ash reduced the density about 2.53%, dry compressive strength enhanced about 10.47%, wet compressive strength enhanced about 30.61%, ultrasonic pulse velocity enhanced about 17.83%, prism efficiency enhanced about 2.20%, water absorption reduced about 14.04% and rate of erosion in spray erosion test reduced about 25.00%. Accordingly, the both 4% of GGBS and Fly Ash was effective replacement level for laterite soil blocks stabilized with strength and economical point of view along with 6% of cement. Research on optimizing the mix design for larger-scale applications, along with lifecycle assessments, can strengthen the case for widespread adoption in sustainable construction practices. Additionally, studies on the long-term durability of these blocks under varying environmental conditions, including freeze-thaw cycles and chemical exposure, can validate their applicability in diverse climates.

References

1. G. Byju1 and Thomas Varghese (2001), Influence Of Land Uses On Soil Acidity Parameters In A Typical Laterite Terrain From Kerala, Journal of Tropical Agriculture 39 (2001) : 124-127.
2. Raymahashay, B.C., Rao, K.S., Mehta, V.K. and Bhavana, P.R (1987). Mineralogy and geochemistry of lateritic soil profiles in Kerala, India. In: Y. Ogura (Guest-Editor), Proceedings of An International Seminar on Laterite, October 14-17, 1985, Tokyo, Japan. Chem. Geol., 60: 327-330.
3. C. Bishweka, M. B. Manjia, F. Ngapgue, U. J. M. P. Nana, and C. Pettang, “Contribution to the Characterization of Lateritic Soils for the Manufacture of Compressed Stabilized Earth Bricks,” Open J. Civ. Eng., vol. 11, no. 04, pp. 411–426, 2021, doi: 10.4236/ojce.2021.114024.
4. I. Obianyo, A. P. Onwualu, and A. B. O. Soboyejo, “Mechanical behaviour of lateritic soil stabilized with bone ash and hydrated lime for sustainable building applications,” Case Stud. Constr. Mater., vol. 12, Jun. 2020, doi: 10.1016/j.cscm.2020.e00331.
5. A. Lawane, J. R. Minane, R. Vinai, and A. Pantet, “Mechanical and physical properties of stabilised compressed coal bottom ash blocks with inclusion of lateritic soils in Niger,” Sci. African, vol. 6, Nov. 2019, doi: 10.1016/j.sciaf.2019.e00198.
6. P. Tiboti, J. B. Niyomukiza, M. Kiwanuka, J. W. Mbujje, J. Baiga, and A. F. Hadudu, “Optimizing laterite cement blocks in the construction of masonry using quarry dust,” in IOP Conference Series: Earth and Environmental Science, IOP Publishing Ltd, Jul. 2021. doi: 10.1088/1755-1315/802/1/012056.
7. P. E. Moses, M. P. Chockalingam, R. Venkatakrishnaiah, and P. Dayakar, “Advantage of Laterite over Clay in the Manufacture of Compressed Stabilized Earth Bricks (CSEBs),” Int. J. Adv. Res. Eng. Technol., vol. 11, no. 1, pp. 45–51, 2020.
8. N. A. Ibrahim, T. Magindran, M. I. Shahrin, and N. M. Yusof, “Sustainable use of laterite soil as compressed cement stabilized earth block for low cost housing construction,” in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, May 2020. doi: 10.1088/1757-899X/849/1/012027.
9. F. A. Olutoge, C. A. Booth, S. O. A. Olawale, and O. A. Alebiosu, “Lateritic cement- and lime-stabilised bricks and blocks for affordable housing,” Proc. Inst. Civ. Eng. Constr. Mater., vol. 171, no. 5, pp. 195–202, Oct. 2018, doi: 10.1680/jcoma.16.00062.
10. D. C. Sekhar and S. Nayak, “Utilization of granulated blast furnace slag and cement in the manufacture of compressed stabilized earth blocks,” Constr. Build. Mater., vol. 166, pp. 531–536, Mar. 2018, doi: 10.1016/j.conbuildmat.2018.01.125.
11. P. M. Touré, V. Sambou, M. Faye, A. Thiam, M. Adj, and D. Azilinon, “Mechanical and hygrothermal properties of compressed stabilized earth bricks (CSEB),” J. Build. Eng., vol. 13, pp. 266–271, Sep. 2017, doi: 10.1016/j.jobe.2017.08.012.
12. IS 1725:2023 Stabilized soil Block Used in General Building Construction Specification
13. IS 12269-2013 Ordinary Portland Cement, 53 Grade — Specification (First Revision)
14. IS 13311 (Part 1): 1992 Non-destructive testing of concrete Part 1: Ultrasonic pulse velocity
15. IS 3495 (Part 1) : 2019 Burnt Clay Building Bricks — Methods of Tests Part 1 Determination of Compressive Strength (Fourth Revision)
16. IS 3495 (Part 2): 2019 Burnt Clay Building Bricks — Methods of Tests Part 2 Determination of Water Absorption (Fourth Revision).