Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Study on Mechanical, Durability and Microstructural Properties of Compressed Cement Stabilized Laterite Soil Blocks with Partial Replacement of Agro-Wastes

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

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

Stabilized Blocks are eco-friendly and cost-effective building materials made from a mix of mud and a stabilizer like cement. Compressed at high pressure, these blocks are high strength, durable and offer excellent weather-resistant properties. By using natural materials, SMBs minimize environmental impact and reduce construction costs. This paper presents the results of an experimental investigation in characterizing the properties of Stabilized laterite blocks (SLBs) using Bagasse Ash (BA) and Rice Husk Ash (RHA). The mix proportion are formulated by kept the laterite soil at constant of 90%, the binder 10%, which cement varying from 4 to 10%, Bagasse Ash and Rice Husk Ash varying from 2 to 6%. From the test results, it is observed that mix with 4% of RHA along with 6% of cement has attained better results than other mixes, which enhanced the mechanical, microstructural and durability characteristics of compressed cement stabilized laterite blocks.
Keywords: Stabilized laterite block, Bagasse Ash, Rice Husk Ash, mechanical and durability properties.

1. Introduction

The increasing demand for materials in the construction industry has led to increased prices and scarcity of resources, resulting in a need for sustainable materials with low energy consumption and environmental impact [1]. Earth, a sustainable raw material, has been used extensively for building construction since ancient times, offering environmental benefits such as lower embodied energy levels, high thermal mass, and increased use of locally sourced materials [2]. However, earthen building systems have been abandoned in parts of the world where they were once commonly used. Modern research has led to develop the new technology using earth in the form of rammed earth and unfired bricks, which known as Compressed Stabilized Earth Blocks (CSEBs). These blocks require the less energy and it leads to reduces carbon dioxide emission into the atmosphere [3-5]. Laterite soil, a unique type of soil found in Southern India, is primarily found in Kerala, where the predominant bedrock is Precambrian gneiss. This soil type is characterized by its indurated ferruginous clay composition and is commonly used in construction. The discovery of laterite soil dates back to Angadippuram - Kerala, where the saprolite is a mottled and vesicular variety. The underlying material is not excessively soft and can be cut only with tools like axes [6,7]. Laterite soil is used in construction, with ridge summits containing detritus and boulders of primary laterite derived from surrounding rocks [8]. The crust of laterite soil may be indurated, but the underlying material is not excessively soft. Laterite soil has been used in traditional homes, multi-story buildings, temples, cathedrals, roads, paths, and steps. Over time, the weathered remnants of saprolite bed rocks were also used to produce compressed earth blocks [9,10]. Laterite soil blocks undergo various stabilization processes to improve their properties, even in road construction, improving the California bearing ratio (CBR) value of the subgrade. 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. Accordingly, the partial replacement of cement is expected to meet increasing demand for cement stabilized mud block production [3]. Using agricultural wastes in mud block production is an eco-friendly way of disposing the large amounts of waste, which would otherwise damage air, land, and water [11-13]. The replacement of agricultural wastes 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. Agricultural wastes are used in different ways as aggregates, fibers and supplementary cementitious materials for cement-based composites [14-16]. The agricultural wastes such as rice husk, sugarcane bagasse and elephant grass ashes are silica rich biomass wastes, have been examined in recent years to understand their behavior as supplemental cementitious materials (SCM) in block production. Still only few studies available in BA and RHA based cement stabilized laterite blocks [17,18]. The rice and sugar are the world's most significant crop in terms of area of cultivation. In India, the rice and sugar are the most important crop, which are produced in huge quantity. Rice husk and sugarcane bagasse wastes, which pollutes the environment and creates health related problem by being dumped in land or open-air combustion [19,20]. Therefore, Bagasse and Rice Husk can be used into bio fuel for power generation in controlled environment and then waste ashes can be effectively utilized as a partial replacement for Portland cement. 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 [17-18].. This study explores the effects of partial replacement of 2, 4, and 6% of Agro-wastes such as BA and RHA. The study includes

- Promotes sustainable construction by utilizing agricultural wastes like BA and RHA as partial replacements for cement.

- Method to dispose of agro-wastes, minimizing environmental pollution caused by open-air combustion or land dumping.

- Evaluates the enhancement in mechanical strength and durability of blocks through the incorporation of silica-rich agricultural byproducts

- Investigates the changes in the microstructure of the blocks, leading to better understanding and optimization of material properties.

- Leverages locally available materials like laterite soil and agricultural residues, reducing transportation costs and supporting regional economies.

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 [21]. Table 1 present the physical and chemical properties of binders. The rice husk and sugarcane bagasse burned using incinerator at 700°C for 6 hours and cooled under room temperature. After that burned ash was sieved in 75µm sieve and only particles pass through 75µm sieve were used as supplementary cementitious material. Table 2 shows the mix proportions of cement stabilized laterite mud blocks. 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. Blocks were tested according to IS-1725:2023 [22] and the dry compressive strength and wet compressive strength were calculated at the age of 7, 14 and 28 days. Before the dry compressive strength, the Ultrasonic Pulse Velocity of laterite blocks were calculated as per the IS 13311 (Part 1): 1992 [23], 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) [24]. 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 [25] codal provisions in immersed laterite blocks. Spray erosion test was conducted as per IS 1725 to determine the erosion rate of each brick 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 agricultural wastes

Material		Cement	BA	RHA
Chemical properties	Al_2O_3	4.87	8.26	15.7
	CaO	61.5	6.25	22.4
	Fe_2O_3	2.4	3.5	0.1
	MgO	2.7	3.2	27
	Na_2O	-	-	0
	SiO_2	22.3	58.6	33.3
	SO_3	1.9	0.9	0.3
	LOI	1.8	0.6	1.1
Physical properties	Specific gravity	3.1	2.3	2.1
	Fineness (m^2/ Kg)	329	285	475
	Average particle size (μm)	7.5	72.5	9.35
	Initial setting time (min)	45	-	-
	Final setting time (min)	325	-	-

Table 2 Mix Proportion

Mix ID	C10CCA0	C8BH2	C6BH4	C4BH6	C8RH2	C6RH4	C4RH6
Laterite Soil	90%	90%	90%	90%	90%	90%	90%
Cement	10%	8%	6%	4%	8%	6%	4%
BA	-	2%	4%	6%	-	-	-
RHA	-	-	-	-	2%	4%	6%

3. Results and Discussions

3.1 Dry Density of the Block

The effect of BA and RHA 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 increased with increasing content of BA up to 4%, which increased from 1.69% and 0.16%, respectively for C8BA2 and C6BA4. After that the density of laterite blocks was reduced about 1.07%, in comparison to the C10 mix. On other hand, the increase of RHA content has reduced the density of laterite blocks about 1.60% in C8RH2, 3.31% in C6RH4 and 5.71% in C4RH6 in compression to C10 mix. The lower density and higher surface area of RHA leads to reduction of dry density of laterite blocks [16-18].

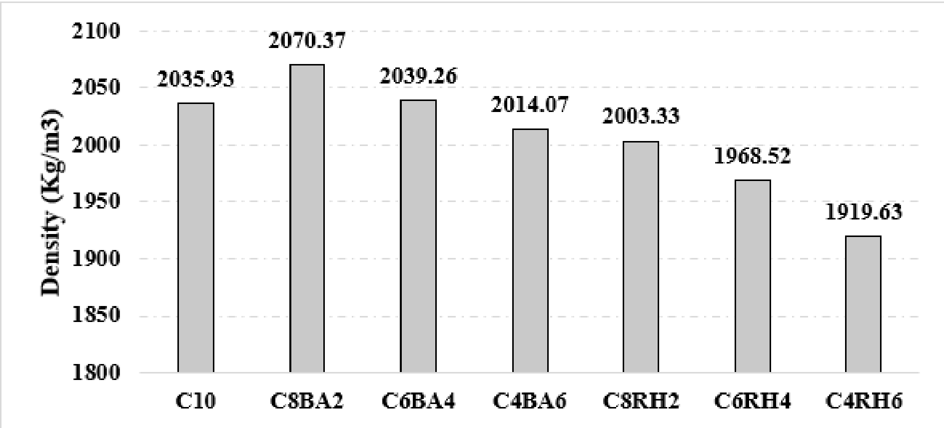

Figure 1. The effects of BA and RHA replacement on dry density

3.2 Dry Compressive strength

The laterite blocks dry compressive strength of was calculated as per IS 1725: 2023 at age of 7, 14 and 28 days of curing. The Figure 2 shows the effects partial replacement of BA and RHA on dry compressive strength of laterite blocks. The gradual increment in dry compressive strength of blocks is observed in mixes with partial replacement of RHA up to 4% at intervals 7, 14 and 28 days. It clearly shows that's 4% of RHA replacement found optimum for laterite soil blocks. The results clearly shows that the increase of RHA replacement content up to 4% has increased the compressive strength about 45.18% in 7th day, 56.73% in 14th day, and 3.73% in 28th day in comparison to control mix C10. Beyond that 6% of RHA, the dry compressive strength of cement stabilized laterite soil blocks was reduced about 41.20%, 24.53% and 29.24%, respectively for 7, 14 and 28 days. On other hand, 4 % of BA replaced mix has increased the compressive strength about 5.81% in 7th day, 22.87% in 14th day, and 28th day dry compressive strength has decreased about 13.60% in comparison to control mix C10. The scanning electron microscopic images of C10, C6BA4 and C6RH4 are captured at the age of 7, 14 and 28 days is shown Figure 3. It clearly shows that the micrographs of C10 mix and C6BA4 mixes having high amount of unreacted cement particles in hydration process at all ages. But C6RH4 mix with 4 % of RHA has more formation of calcium hydroxide and Ettringite during the early of hydration process on 7th and 14th days. Subsequently in 28th day micrographs shows that more homogenies microstructure was formed in C6RH4 mix, which might be due to its higher pozzolanic reactivity and C-S-H gel formation. Also, RHA has filled pores and it improved the microstructure of cement matrix of laterite blocks [18-20].

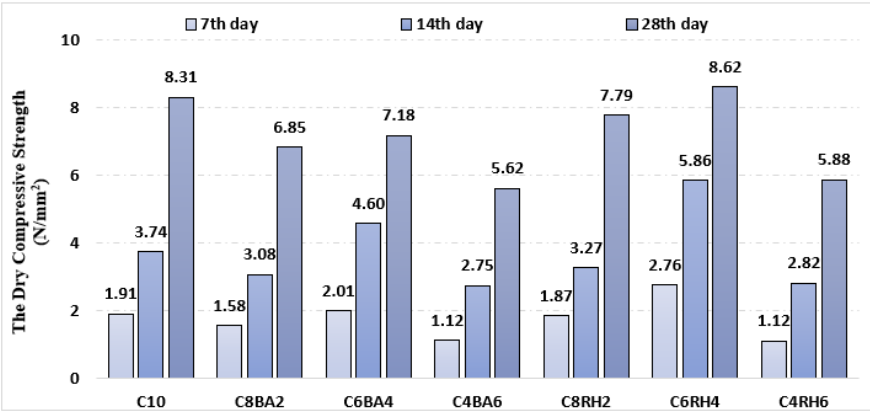

Figure 2. The effects of BA and RHA replacement on dry compressive strength

3.3 Wet Compressive strength

As per IS 1725: 2023 standard procedure wet compressive strength of laterite blocks specimens was tested at age of 28 days. The Figure 4 shows the effects partial replacement of BA and RHA on dry compressive strength of laterite blocks. The gradual increment in wet compressive strength of laterite blocks is observed in both BA and RHA replacement up to 4%. It clearly shows that the 4% of RHA replacement found optimum for laterite soil blocks, which enhanced the maximum dry compressive about 23.08%, in compression to the control mix (C10). Beyond that limit the wet compressive strength of cement stabilized laterite soil blocks was reduced drastically 42.39% in 6% of BA and 38.95% in 6% of RHA, which may due to higher dosages leads reduce the pozzolanic reactivity of cement particles in laterite blocks [16,18].

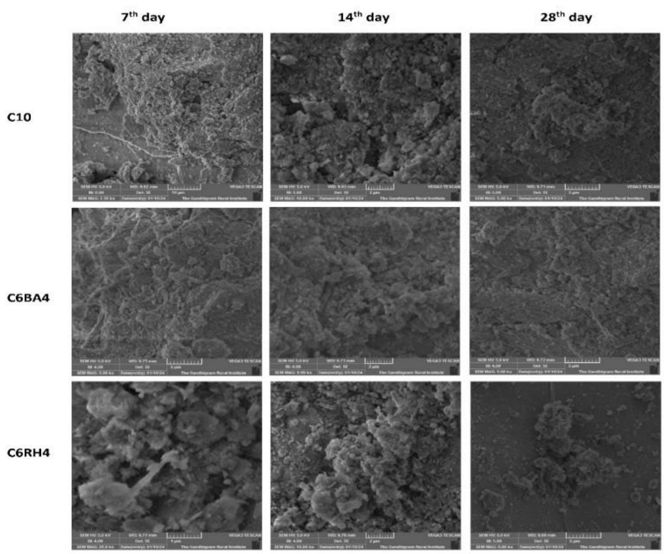

Figure 3. Scanning Electron Microscopic images of laterite blocks

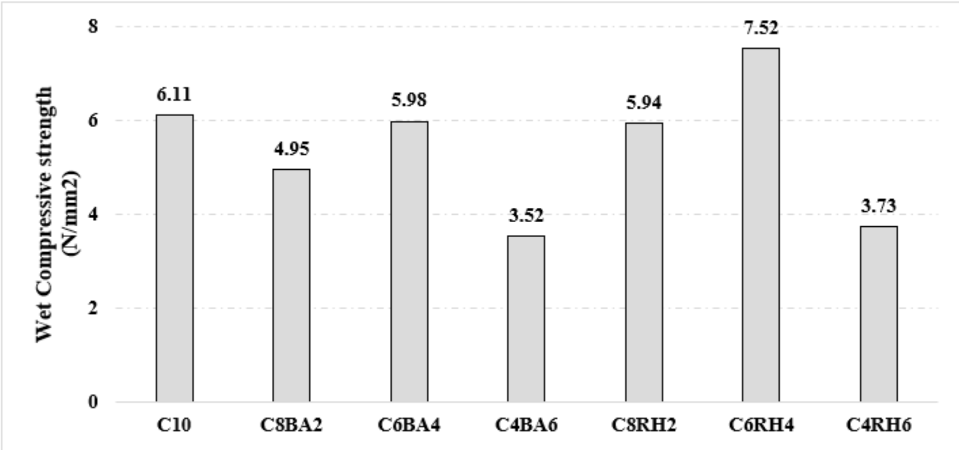

Figure 4. The effects of BA and RHA replacement on wet compressive strength

3.4 Ultrasonic Pulse Velocity Test

Figure 5 shows the ultrasonic pulse velocity of laterite block with BA and RHA. It could be seen that the enhancement in ultrasonic pulse velocity of both BA and RHA replaced laterite block at the age of 28 days, comparatively from the C10 mix. The velocity of laterite blocks the increases with increase of both BA and RHA content up to 4%, beyond that gradually it is decreased. The mix having 4% of BA and 4% of RHA has a maximum pulse velocity of 1.69 Km/sec and 1.79 Km/sec is noticed at 28 days, which enhanced the velocity of laterite blocks about 7.64% and 14.01%, respectively in comparison to control mix (C10 mix). This might be due to the pore reduction laterite block matrix and it leads to homogeneous blocks, which leads to enhanced the ultrasonic pulse velocity of laterite blocks [16,18,20].

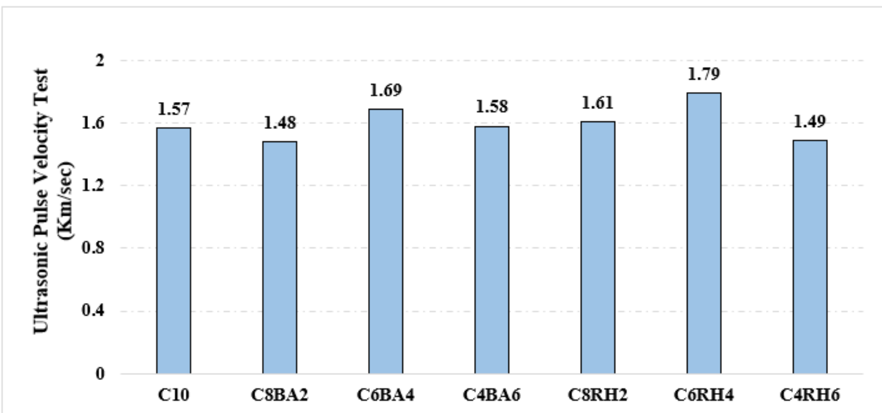

Figure 5. The effects of BA and RHA replacement on ultrasonic pulse velocity

3.5 Prism test

The efficiency of 3 blocks prism test is shown in Figure 6. It could be seen that the enhancement in prism efficiency in both BA and RHA replaced laterite block, comparatively from the control mix. The mix having 4% of BA (C6BA4) and 4% of RHA (C6RH4) has a maximum efficiency of 3 blocks prism test are 0.92 and 0.94, which enhanced the efficiency of laterite blocks about 1.10% and 3.30%, respectively in comparison to control mix (C10 mix). The prism efficiency of laterite blocks the increases with increase of both BA and RHA content up to 4%, beyond that efficiency is rapidly decreased about 8.79 -10.99%. The increase in efficiency is due to the improved compressive strength of individual units and the chances of getting a better mechanical interlocking may be also considered due to the visible texture of the surfaces laid upon.

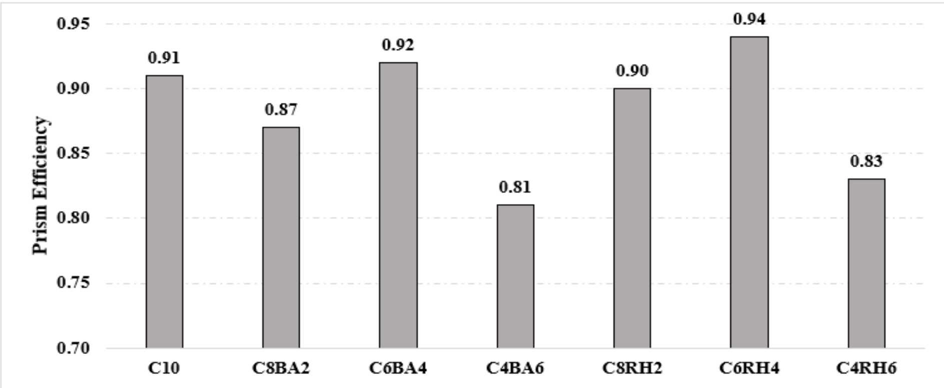

Figure 6. The effects of BA and RHA replacement on 3 block prism efficiency

3.6 Water Absorption

Figure 7 shows the water absorption results of laterite blocks with BA and RHA. It could be seen that the reduction in water absorption has observed only in RHA replaced laterite blocks. The water absorption of laterite blocks decreased with increasing content of RHA up to 4%, which decreased about 7.02% in C8RH2 mix, 4.08% in C6RH4, compression to the C10 mix. After that water absorption increased about 11.44% in C4RH6 mix with 6 % of RHA. On other hand, the increase of BA content increased the water absorption of laterite blocks about 2.15% in C8BA2 mix, 7.02% in C6BA4 mix and 15.74% mix in C4BA6 in compression to the control mix (C10) [16,17].

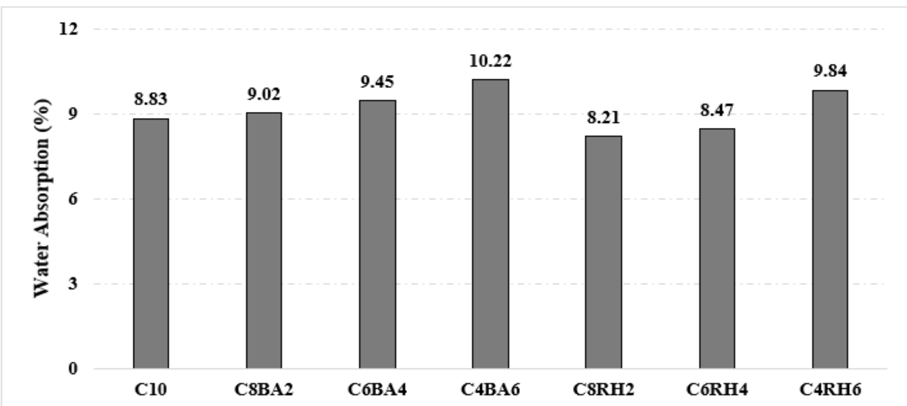

Figure 7. The effects of BA and RHA replacement on water absorption

3.7 Spray Erosion Test

The erosion rate of laterite block specimens with partial replacement of BA and RHA shown in Figure 8. The gradual increment in resistance against the erosion rate of laterite blocks is observed in both BA and RHA replacement up 4%. However, The Mix C6RH4 with 4% of RHA was performed higher resistance in spray erosion test, which achieved the lowest rate of erosion 13 mm/hour and it was 18.75% reduction in compression to the C10 Mix. similarly, The Mix C6BA4 with 4% of BA reached 14 mm/hour and it was 12.50% 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.

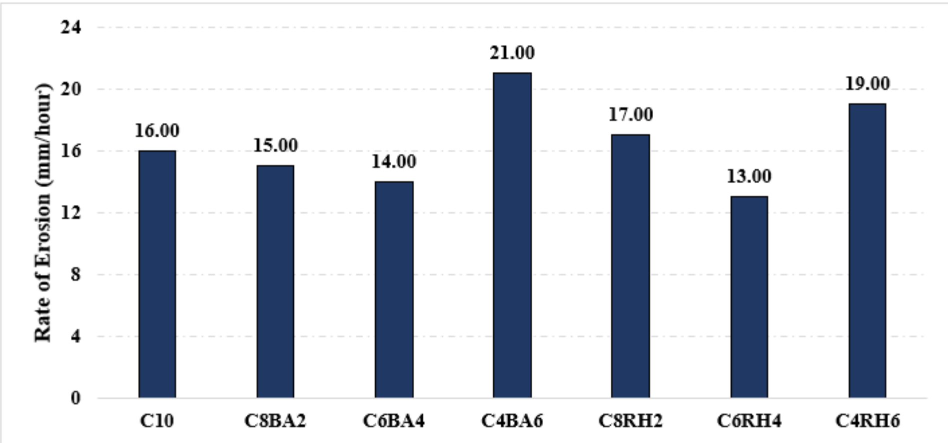

Figure 8. The effects of BA and RHA replacement on rate of erosion

4. Conclusions

From the results of the various tests, the following conclusions can be drawn. The partial replacement of BA and RHA 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 BA and RHA in laterite blocks about 4%, beyond that the mechanical and durability properties of laterite blocks was reduced rapidly. The mix with 4% of RHA has reduced the dry density blocks about 3.31%, dry compressive strength enhanced about 3.73%, wet compressive strength enhanced about 23.08%, ultrasonic pulse velocity enhanced about 14.01%, prism efficiency enhanced about 3.30%, water absorption reduced about 4.08% and rate of erosion in spray erosion test reduced about 18.75%. Similarly, in C6BA4 mix with 4% of BA increased the density about 0.16%, dry compressive strength retained about 86.40%, wet compressive strength retained about 97.87%, ultrasonic pulse velocity enhanced about 7.64%, prism efficiency enhanced about 1.10%, water absorption reduced about 7.02% and rate of erosion in spray erosion test reduced about 12.50%. Accordingly, the both 4% of RHA and BA 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. N. Kamaladasa and C. Jayasinghe, “Development of an efficient Construction Technique for Rammed Earth,” 2005.
2. J. C. Morel, A. Pkla, and P. Walker, “Compressive strength testing of compressed earth blocks,” Constr. Build. Mater., vol. 21, no. 2, pp. 303–309, 2007, doi: 10.1016/j.conbuildmat.2005.08.021.
3. C. Jayasinghe, “Comparative Performance of Burnt Clay Bricks and Compressed Stabilized Earth Bricks and Blocks,” Eng. J. Inst. Eng. Sri Lanka, vol. 40, no. 2, p. 33, 2007, doi: 10.4038/engineer.v40i2.7137.
4. A. G. Tennant, C. D. Foster, and B. V. V. Reddy, “Verification of Masonry Building Code to Flexural Behavior of Cement-Stabilized Soil Block,” J. Mater. Civ. Eng., vol. 25, no. 3, pp. 303–307, 2013, doi: 10.1061/(asce)mt.1943-5533.0000566.
5. H. B. Nagaraj, M. V. Sravan, T. G. Arun, and K. S. Jagadish, “Role of lime with cement in long-term strength of Compressed Stabilized Earth Blocks,” Int. J. Sustain. Built Environ., vol. 3, no. 1, pp. 54–61, 2014, doi: 10.1016/j.ijsbe.2014.03.001.
6. A. Y. B. Anifowose, “Stabilisation of lateritic soils as a raw material for building blocks,” Springer-Verlag, 2000.
7. Ishwar P. Sonar, “Laterite soil cement composite blocks,” J. Struct. Eng., vol. Vol. 37, No.01, no. 01, pp. 1–4, Apr. 2010.
8. J. O. Alao and Usep, “Performance Criteria Design Of Mixture Proportions For Laterite Cement Bricks Using The Schéffé Mixture Approach,” 2017.
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. 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.
11. R. W. Salim, J. M. Ndambuki, and D. A. Adedokun, “Improving the bearing strength of sandy loam soil compressed earth block bricks using Sugercane Bagasse Ash,” Sustain., vol. 6, no. 6, pp. 3686–3696, 2014, doi: 10.3390/su6063686.
12. T. A. Abdalla, A. A. E. Hussein, Y. H. Ahmed, and O. Semmana, “Strength, durability, and microstructure properties of concrete containing bagasse ash – A review of 15 years of perspectives, progress and future insights,” Results Eng., vol. 21, no. January, p. 101764, 2024, doi: 10.1016/j.rineng.2024.101764.
13. M. H. R. Sobuz et al., “Assessing the influence of sugarcane bagasse ash for the production of eco-friendly concrete: Experimental and machine learning approaches,” Case Stud. Constr. Mater., vol. 20, no. November 2023, p. e02839, 2024, doi: 10.1016/j.cscm.2023.e02839.
14. K. P. Alvarenga and G. C. Cordeiro, “Evaluating sugarcane bagasse fly ash as a sustainable cement replacement for enhanced performance,” Clean. Eng. Technol., vol. 20, no. February, p. 100751, 2024, doi: 10.1016/j.clet.2024.100751.
15. N. Yaseen, “Exploring the potential of sugarcane bagasse ash as a sustainable supplementary cementitious material: Experimental investigation and statistical analysis,” Results Chem., vol. 10, no. June, p. 101723, 2024, doi: 10.1016/j.rechem.2024.101723.
16. R. Kishore, V. Bhikshma, and P. Jeevana Prakash, “Study on strength characteristics of high

strength Rice Husk Ash concrete," Procedia Eng., vol. 14, pp. 2666–2672, 2011, doi: 10.1016/j.proeng.2011.07.335.
17. E. A. Basha, R. Hashim, H. B. Mahmud, and A. S. Muntohar, "Stabilization of residual soil with rice husk ash and cement," Constr. Build. Mater., vol. 19, no. 6, pp. 448–453, 2005, doi: 10.1016/j.conbuildmat.2004.08.001.
18. G. Rodríguez De Sensale, "Strength development of concrete with rice-husk ash," Cem. Concr. Compos., vol. 28, no. 2, pp. 158–160, 2006, doi: 10.1016/j.cemconcomp.2005.09.005.
19. H. Chao-Lung, B. Le Anh-Tuan, and C. Chun-Tsun, "Effect of rice husk ash on the strength and durability characteristics of concrete," Constr. Build. Mater., vol. 25, no. 9, pp. 3768–3772, 2011, doi: 10.1016/j.conbuildmat.2011.04.009.
20. R. Kishore, V. Bhikshma, and P. Jeevana Prakash, "Study on strength characteristics of high strength Rice Husk Ash concrete," Procedia Eng., vol. 14, pp. 2666–2672, 2011, doi: 10.1016/j.proeng.2011.07.335.
21. IS 12269-2013 Ordinary Portland Cement, 53 Grade — Specification (First Revision)
22. IS 1725:2023 Stabilized soil Block Used in General Building Construction Specification
23. IS 13311 (Part 1): 1992 Non-destructive testing of concrete Part 1: Ultrasonic pulse velocity
24. IS 3495 (Part 1) : 2019 Burnt Clay Building Bricks — Methods of Tests Part 1 Determination of Compressive Strength (Fourth Revision)
25. IS 3495 (Part 2): 2019 Burnt Clay Building Bricks — Methods of Tests Part 2 Determination of Water Absorption (Fourth Revision)