Effect of Ground Granulated Blast Furnace Slag in Limecrete with Added Natural Admixtures

Basithali E. K.[1*], Sajeeb R.[1], K. P. Ramaswamy[1], Biju Bhaskar[2]

[1]Department of Civil Engineering, TKM College of Engineering, APJ Abdul Kalam Technological University, India

[2]Thannal Natural Homes, Tiruvannamalai, Tamil Nadu, India

*Corresponding Author: basithalieks@gmail.com

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ABSTRACT

Portland cement is typically used as the binder in concrete, which is a widely used building material. The high energy required as well as the CO_2 emissions associated with the production of cement are considered to be serious environmental issues. The present paper considers concrete with lime binder (limecrete) which completely avoids the usage of cement. Mineral admixtures (pozzolanic materials) such as ground granulated blast furnace slag (GGBS), Rice Husk Ash, and Surkhi are used along with fermented organic admixtures such as Kadukkai and Jaggery. Brickbats are used as coarse aggregate and M-sand is used as fine aggregate. The focus of the present study is on finding the effect of GGBS on the properties of the limecrete considered. Compositions with different percentages of GGBS are used with lime along with natural admixtures. The different compositions of GGBS considered are 40, 60, 80, and 100 percentages by dry weight of lime. The liquid-fines ratio is fixed at 0.58 by trial and error. Four combinations of limecrete specimens are cast in standard cubic and cylindrical moulds. To assess the influence of the GGBS on various properties of the mix, specimens are tested for mechanical strength using destructive and non-destructive testing. Increase in GGBS content has found to increase the workability of limecrete. However, the 28th day compressive strength of limecrete is found to be low for structural applications.

Keywords: Sustainability, Limecrete, Ground granulated blast furnace slag, Surkhi, Natural Admixture

1 Introduction

The materials which are used most frequently worldwide are concrete and derivatives of cement. It is not unexpected that one of the largest sources of air pollution is the concrete sector [1]. Having said that, the concrete industries have a duty to society and the environment to support sustainable growth. It is significant to highlight that the aforementioned industry utilizes large amounts of water in addition to other natural resources. Each ton of cement produced results in the emission of one ton of CO_2 and other greenhouse gases into the atmosphere, which are among the factors contributing to global warming. Around 1.4 billion tons of CO_2 are produced by the cement sector, which is equivalent to a little under 7% of world CO_2 output [2]. Cement-based construction can produce hazardous waste as well, and its improper disposal can lead to contamination that not only harms the environment but also the health of the local population [3].

From earlier research on natural hydraulic lime (NHL) mortars, it was concluded that the performance of these mortars depends on the type of natural hydraulic lime used, the binder-to-aggregate ratio, the water-to-binder ratio, the origin, composition, and grain size distribution of the aggregates, as well as the curing conditions taken into account [4]. The Lime pozzolana reaction is influenced by the characterization of the pozzolana, its fineness, temperature, and the presence of additives such as Kadukkai and Jaggery. The addition of pozzolanic materials to the lime matrix enhances the properties from both mechanical and durability points of view. It is practical and efficient to replace cement or fine aggregate with extra

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pozzolanic materials like fly ash and ground granulated blast furnace slag. According to reports, more than 900 million tons of fly ash are produced every year worldwide, while India produces annually at 169.25 million tons [5]. However, only around 65 percent of the 530 million tons of blast furnace slag produced year globally gets recycled [6].

Using low embodied energy binding agents such as lime along with pozzolanic materials such as ground granulated blast furnace slag [7], rice husk ash [2], and surkhi can reduce the use of high embodied energy materials such as cement and it is derivatives. Lime-pozzolanic mixes absorb CO_2 from the environment and lower the amount of greenhouse gases in the atmosphere, this action is termed as carbonation [8], [9]. Brickbats can be used as coarse aggregate to manufacture high performance concrete [10], [11]. Under high temperatures, brickbat aggregate concrete performs just as well as or even better than natural aggregate concrete [12], [13]. The use of crushed brick as an alternative source of coarse aggregate in concrete was supported by all of the above-mentioned research. Various natural organics, including curd, jaggery, cactus extract, bel pulp, lentils, and oil of margosa, were discovered in the literature to be put into the lime mortar to increase its strength and other qualities [14]. Amino acids were added to organically modified lime mortar to increase its mechanical resilience, water- resistance, and speed of carbonation [15], [16]. Herb addition improved mechanical characteristics because of the formation of whewellite crystals.

Mineral and natural admixtures are improving long and short-term property of lime-based concrete and mortar. Various studies have been done with different sustainable materials including industrial wastes and locally available natural herbal admixtures. But the combined effect of these materials is quite important to produce strong and durable building material. The research presented in this article focuses on the effect of GGBS in lime-based concrete with natural admixtures. This research comprises of three phases, determination of the mix design for lime-based concrete by trial-and-error method, Casting of Samples, and testing and analysis of strength and durability properties.

2 Materials and Methods

2.1 Materials

The current research is carried out on concrete specimens in which slaked lime powder (figure 1a) and pozzolanic materials are used as binding agents. The procured shell lime is slaked with distilled water and sieved through 600 micron IS sieve so that it conforms to IS 712:1984 [17]. Pozzolanic materials – GGBS (figure 1b), rice husk ash (figure 1c), and surkhi (figure 1d) are used in the form of fine powders with particle size less than 300 microns and conforms to IS 1344:1981 [18] and IS 3812:1981 [19]. Standard manufactured sand, which conforms to IS 383:1970 [20], is used as fine aggregate and saturated brickbat of 20 mm nominal size conforming to IS 3068:1986 [21] is used as coarse aggregate. Instead of distilled water four-day fermented Kadukkai-jaggery liquid is added to the limecrete. Figure 1 e and f shows raw Kadukkai seed and sugarcane jaggery respectively.

(a) Lime Powder

(b) GGBS

(c) Rice Husk Ash

(d) Surkhi *(e) Kaddukai Seed* *(f) Jaggery*

Figure 1: *Sustainable construction materials used in the study*

2.2 Methods

Limecrete considered in the present study comprises lime as a binder, brickbat as coarse aggregate, and manufactured sand as fine aggregate. To enhance the performance of the mix natural admixtures (Kadukkai and Jaggery) and pozzolans (GGBS, surkhi, and rice husk ash) are added. The mix adopted in the study consists of lime, surkhi, rice husk ash, fine aggregate, and coarse aggregate in the proportion 1:0.4:0.4:4:8 by weight. The effect of GGBS in the aforementioned mix is analyzed experimentally by adding GGBS from 40 to 100 percent by the dry weight of lime at an increment of 20%. As the quantity of fines in each mix is variable, water content to get a mix of the desired workability will correspondingly vary. Hence to achieve medium workability as per IS 6461:7-1973 [22] trials have been conducted and liquid to the fine ratio which is described as the ratio of liquid (weight of Kadukkai-jaggery water) to fines (weight of lime, GGBS, surkhi, and rice husk ash) is adopted as 0.58. Potable water with 8 % (by weight) concentration of Kadukkai and Jaggery that have undergone a four-day fermentation process separately and its extract are added in the desired liquid to fine ratio. Cylindrical (150 mm diameter and 300 mm height) and cubic (100×100×100 mm) specimens are prepared for the experimental studies (Figure 2). Within an hour of adding water, limecrete is laid and compacted. To obtain a uniform, high-quality limecrete, a mechanical mixer and table vibrator are utilized for mixing and vibration, respectively. The limecrete samples are demoulded after 72 hours and kept in a shade with relative humidity for curing until the day of the test. As the lime composite gains strength through the carbonation process by absorbing CO_2 from the atmosphere, air curing is used for the specimens.

Figure 2: *Samples Cast*

3 Results and Discussion

To examine the effect of GGBS in limecrete, test for workability on fresh mix as well as test for strength and durability on hardened specimens have been performed. The variation of various parameters of the limecrete with different percentages of GGBS is shown in figure 3.

3.1 Compaction Factor

Compaction factor is the weights of partially compacted to fully compacted concrete. For concrete that is difficult to work with and for which the slump test is inappropriate, the compaction factor test is used. The variation of compaction factor with various percentages of GGBS is shown in figure 3a. Results show that

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there is an increase in compaction factor from 0.87 to 0.92 with an increase in GGBS content from 40 % to 100% by weight of lime. Thus, it becomes evident that the mixes which contain higher GGBS content need a lesser quantity of liquid to make a workable mix.

3.2 Unit weight

The weight per unit volume of a substance is its unit weight, sometimes referred to as its specific weight. Figure 3b shows how the unit weight of limecrete varies with different percentages of GGBS. It is observable that there is a slight increase in the unit weight of mixes from 17.66 kN/m^3 to 18.75 kN/m^3 with the addition of GGBS percentage from 40 % to 100 % in the mixes. When compared to cement concrete brickbat embodied limecrete is lighter.

3.3 Compressive Strength

This test gives us an idea about the strength parameter of limecrete. Compressive strength is the ability of a material or structure to carry the compressive loads on its surface without any crack or deflection. It is computed as the ratio of load at the failure to the surface area of the specimen. From 3c shows variation of compressive strength at different curing periods with the addition of GGBS. Cube compressive strength is increasing with time, 14^{th} day strength is equal to almost half the 28^{th} day strength. It is observed that the mix 1:1 lime-GGBS mix by weight gives the maximum compressive strength of 3.41 N/mm^2 on the14^{th} day which increases to 5.66 N/mm^2 on the 28^{th} day (66 % increment).

3.4 Split Tensile strength

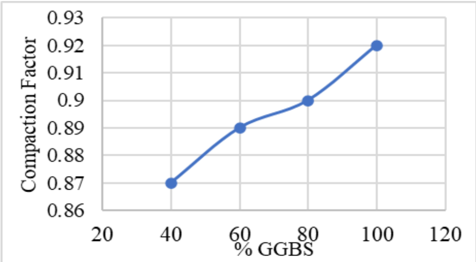
The split tensile strength test evaluates the concrete's tensile strength by failing a cylinder that splits along its vertical diameter. Due to its low tensile strength and fragile nature, concrete is not typically expected to sustain direct tension. The addition of GGBS in different percentages to limecrete shows improvement in the split tensile strength of the mixes as observable from figure 3d. It is seen that the mix with 1:1 lime-GGBS gives a maximum split tensile strength of 1.75 N/mm^2. Split tensile strength is approximately 30 percent of cube compressive strength.

3.5 Ultrasonic Pulse Velocity

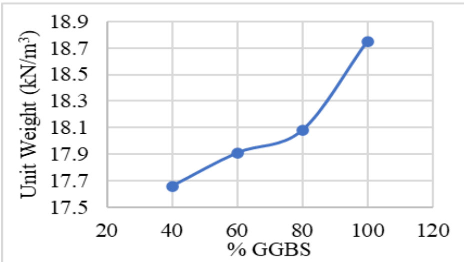
An in-situ, non-destructive test to examine the quality of concrete and natural rocks is the ultrasonic pulse velocity (UPV) test. By monitoring the speed of an ultrasonic pulse as it passes through a concrete structure or a naturally occurring rock formation, this test evaluates the quality and strength of rock or concrete. The ultrasonic pulse used in this test is passed through the concrete being tested, and the time it takes for the pulse to exit the structure is then recorded. Lower velocities could mean concrete with plenty of cracks or voids, whereas higher velocities suggest good quality and continuity of the material. The pulse generation circuit of ultrasonic testing equipment consists of an electronic circuit for generating pulses and a transducer for turning those pulses into mechanical pulses with oscillation frequencies between 40 and 50 kHz. The pulse reception circuit receives the signal. Figure 3e shows the variation of UPV with the percentage of GGBS added in limecrete. It is observed that the UPV increases from 0.46 km/s to 0.55 km/s as the GGBS content increases from 40% to 100%. The increase in UPV is attributed to the reduction in the micropores in limecrete with the addition of GGBS.

3.6 Water Absorption Test

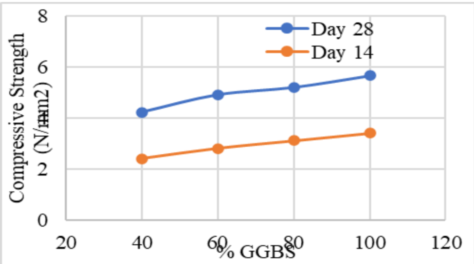
To calculate the quantity of water absorbed under particular circumstances, water absorption test is used. For the water absorption test, the specimens are dried in an oven at a predetermined temperature and time before being placed in a desiccator to cool. As soon as the specimens have cooled, they are weighed. The chemical is then immersed in water for 24 hours or until equilibrium at the predetermined temperature, usually 23 °C. Specimens are removed, dried using a lint-free cloth, and then weighed. A rise in weight % is how water absorption is measured. Figure 3f shows water absorption in percentage with the variation of GGBS content. It is observed that, with the addition of GGBS from 40% to 100%, the water absorption decreases from 3.32% to 2.81%. This is attributed to the reduction in the micro pores with the addition of GGBS in limecrete. Hence the durability of the limecrete is expected to increase with increase in percentage of GGBS.



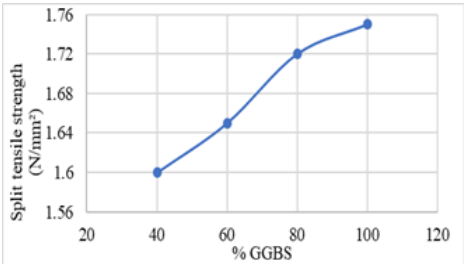
a) Compaction factor vs % GGBS



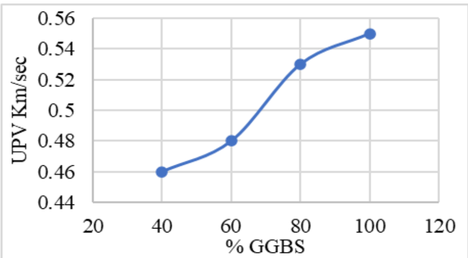
b) Unit weight vs % GGBS



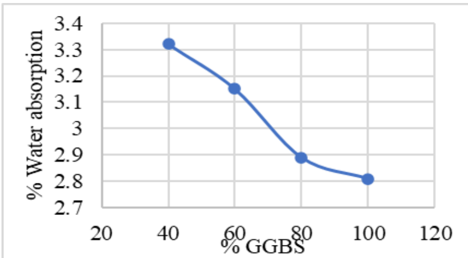
c) Compressive strength vs % GGBS



d) Split tensile strength vs % GGBS



e) UPV vs % GGBS



f) % Of water absorption vs % GGBS

Figure 3: *Effect of GGBS on various parameters of limecrete*

4 Conclusions

The present work focused on developing sustainable concrete using lime and waste materials from industry as well as construction. The usage of cement is completely avoided. The waste materials considered in the study are GGBS, surkhi, rice husk and brickbats. The mix adopted in the study consists of lime, surkhi, rice husk ash, fine aggregate, and coarse aggregate in the proportion 1:0.4:0.4:4:8 by weight. Brickbats of 20 mm nominal size are used as coarse aggregate. The natural admixture used in the present study is four-day fermented Kadukkai-jaggery liquid. The effect of GGBS on the properties of the mix is studied by adding it in percentages of 40, 60, 80 and 100 by weight of lime.

The results of the current investigation led to the following conclusions:

1) From the experimental studies incorporating five different lime concrete mixes with varying GGBS content, it has been observed that with increase in GGBS content the properties of the mix are improving in both fresh and hardened state. Incorporation of higher finer particle and fermented natural admixture also helps to improve the workability at a low liquid to fine ratio.
2) Due to the inclusion of brickbat as coarse aggregate, the unit weight of limecrete is found to be less than typical cement concrete.
3) 1:1 lime-GGBS mix by weight gives a cube compressive strength of 3.41 N/mm^2 on the 14^{th} day which increases to 5.66 N/mm^2 on the 28^{th} day, exhibiting 66 % increase. Split tensile strength of 1:1 lime-GGBS mix by weight is observed to be 30% of 28^{th} day cube compressive strength.
4) UPV of limecrete mixes considered in the study varies from 0.46 to 0.55 km/sec as the percentage of GGBS increases from 40 to 100% by weight of lime. As per IS 13311(part 1): 1992 concrete quality grading is doubtful when compared to conventional concrete.
5) The micropores in limecrete reduces with increase in the content of GGBS as evident from the increase in UPV and reduction in the percentage water absorption with an increased percentage of GGBS. Increased GGBS content is expected to improves the durability of limecrete.

The limecrete developed in the present study results in a sustainable concrete with unit weight lesser than that of conventional concrete. As the limecrete has very low 28^{th} day compressive strength compared to ordinary concrete, its usage may be restricted to non-structural purposes only. It may be noted here that as the process of strength attainment of limecrete is slow, it can yield strength comparable with that of normal concrete with the passage of time. Methods to improve compressive strength of limecrete and long-term effect of lime-pozzolana interaction would be important elements for future research.

5 Publisher's Note

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References

[1] C. M. Hansson, "Concrete: The advanced industrial material of the 21st century," *Metallurgical and Materials Transactions B*, vol. 26, no. 3, pp. 417–437, May 1995, doi: 10.1007/BF02653859.

[2] E. Ozturk, C. Ince, S. Derogar, and R. Ball, "Factors affecting the CO2 emissions, cost efficiency and eco-strength efficiency of concrete containing rice husk ash: A database study," *Constr Build Mater*, vol. 326, p. 126905, Apr. 2022, doi: 10.1016/J.CONBUILDMAT.2022.126905.

[3] G. H. Nalon *et al.*, "Recycling waste materials to produce self-sensing concretes for smart and sustainable structures: A review," *Constr Build Mater*, vol. 325, p. 126658, Mar. 2022, doi: 10.1016/J.CONBUILDMAT.2022.126658.

[4] M. Apostolopoulou, D. J. Armaghani, A. Bakolas, M. G. Douvika, A. Moropoulou, and P. G. Asteris, "Compressive strength of natural hydraulic lime mortars using soft computing techniques," *Procedia Structural Integrity*, vol. 17, pp. 914–923, Jan. 2019, doi: 10.1016/J.PROSTR.2019.08.122.

[5] M. T. Marvila, A. R. G. de Azevedo, P. R. de Matos, S. N. Monteiro, and C. M. F. Vieira, "Rheological and the Fresh State Properties of Alkali-Activated Mortars by Blast Furnace Slag," *Materials 2021, Vol. 14, Page 2069*, vol. 14, no. 8, p. 2069, Apr. 2021, doi: 10.3390/MA14082069.

[6] A. Gholampour and T. Ozbakkaloglu, "Performance of sustainable concretes containing very high volume Class-F fly ash and ground granulated blast furnace slag," *J Clean Prod*, vol. 162, pp. 1407–1417, Sep. 2017, doi: 10.1016/J.JCLEPRO.2017.06.087.

[7] D. Nikhil Kumar and P. Rathish Kumar, "Investigations on alternate lime-pozzolana based mortars for repair of heritage structures," *Constr Build Mater*, vol. 341, p. 127776, Jul. 2022, doi: 10.1016/J.CONBUILDMAT.2022.127776.

[8] Z. Ghouleh, R. I. L. Guthrie, and Y. Shao, "High-strength KOBM steel slag binder activated by carbonation," *Constr Build Mater*, vol. 99, pp. 175–183, Nov. 2015, doi: 10.1016/J.CONBUILDMAT.2015.09.028.

[9] J. S. Wang *et al.*, "A regional CO2 observing system simulation experiment for the ASCENDS satellite mission," *Atmos Chem Phys*, vol. 14, no. 23, pp. 12897–12914, Dec. 2014, doi: 10.5194/ACP-14-12897-2014.

[10] F. Bektas, K. Wang, and H. Ceylan, "Effects of crushed clay brick aggregate on mortar durability," *Constr Build Mater*, vol. 23, no. 5, pp. 1909–1914, May 2009, doi: 10.1016/J.CONBUILDMAT.2008.09.006.

[11] T. Manzur, S. Rahman, T. Torsha, M. A. Noor, and K. M. A. Hossain, "Burnt Clay Brick Aggregate for Internal Curing of Concrete under Adverse Curing Conditions," *KSCE Journal of Civil Engineering 2019 23:12*, vol. 23, no. 12, pp. 5143–5153, Oct. 2019, doi: 10.1007/S12205-019-0834-3.

[12] B. Debnath and P. P. Sarkar, "Characterization of pervious concrete using over burnt brick as coarse aggregate," *Constr Build Mater*, vol. 242, p. 118154, May 2020, doi: 10.1016/J.CONBUILDMAT.2020.118154.

[13] H. Böke, S. Akkurt, B. Ipekoğlu, and E. Uğurlu, "Characteristics of brick used as aggregate in historic brick-lime mortars and plasters," *Cem Concr Res*, vol. 36, no. 6, pp. 1115–1122, Jun. 2006, doi: 10.1016/J.CEMCONRES.2006.03.011.

[14] L. Ventol, M. Vendrell, P. Giraldez, and L. Merino, "Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone fabrics," *Constr Build Mater*, vol. 25, no. 8, pp. 3313–3318, Aug. 2011, doi: 10.1016/J.CONBUILDMAT.2011.03.020.

[15] L. Ventolà, M. Vendrell, and P. Giraldez, "Newly-designed traditional lime mortar with a phase change material as an additive," *Constr Build Mater*, vol. 47, pp. 1210–1216, Oct. 2013, doi: 10.1016/J.CONBUILDMAT.2013.05.111.

[16] S. Thirumalini, R. Ravi, and M. Rajesh, "Experimental investigation on physical and mechanical properties of lime mortar: Effect of organic addition," *J Cult Herit*, vol. 31, pp. 97–104, May 2018, doi: 10.1016/J.CULHER.2017.10.009.

[17] BUREAU OF INDIAN STANDARDS, "IS 712: Specification for Building Limes," New Delhi, 1984. Accessed: Mar. 24, 2023. [Online]. Available: https://bis.gov.in/wp-content/uploads/2020/05/PM-IS-712-MAY-2020.pdf

[18] Bureau of Indian Standards, "IS 1344: Specification for calcined clay pozzolana," New Delhi, 1981. Accessed: Mar. 27, 2023. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.1344.1981.pdf

[19] Bureau of Indian Standards, "IS 3812 Fly Ash For Use As Pozzolana And Admixture," 1981. https://www.services.bis.gov.in/php/BIS_2.0/bisconnect/knowyourstandards/Indian_standards/isdetails/ (accessed Apr. 12, 2023).

[20] BUREAU OF INDIAN STANDARDS, "IS 383: Specification for Coarse and Fine Aggregates From Natural Sources For Concrete," New Delhi, 1970. Accessed: Mar. 24, 2023. [Online]. Available: https://www.iitk.ac.in/ce/test/IS-codes/is.383.1970.pdf

[21] Bureau of Indian Standards, "IS 3068: SPECIFICATION FOR BROKEN BRICK (BURNT CLAY) COARSE AGGREGATE FOR USE IN LIME CONCRETE," New Delhi, 1986. Accessed: Mar. 24, 2023. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.3068.1986.pdf

[22] Bureau of Indian Standards, "IS 6461-7: Glossary of Terms Relating to Cement Concrete, Part 7: Mixing, Laying, Compaction, Curing and Other Construction Aspects," New Delhi, 1973. Accessed: Mar. 24, 2023. [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.6461.7.1973.pdf

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