Mechanical properties of cement mortar with Lime & Rice husk ash

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Abstract: Hardening of cement-based mortars along with rice husk ash and lime in various formulations was studied using mechanical strength. As cement is partially substituted with RHA; the combined hydration of (OPC) cement, carbonation reaction, and pozzolanic reaction result in hardening. Although hydration of cement contributes to boost the mortar early strength, at the later stages, carbonation becomes much greater as its cement level decreases and the mortar's porosity increases. The long-term strength growth of cement–rice husk Ash mortars is below that of the reference cement (OPC) mortar due to its higher porosity resulting from high demands of water in Rice husk ash grains. For cement-Rice-husk Ash – lime mortars with 10 percent cement weight, the reduction in strength is observed at an early stage. It has been clarified that the current phase of calcium silicate hydrate (C–S–H) is insufficiently cemented and carbonated.

Keyword: Mortar, Rice husk ash (RHA), Cement (OPC), Lime, Mechanical Properties.

1. Introduction

The use of artificial pozzolana as part of cement replacement was suggested on mortar and concrete, with a view to producing better, inexpensive, and sustainable mortar and concrete [1]. The benefit of alternate cement mixing containing waste materials such as rice husk ash, Ground granulated furnace slag GGBS, silica fume and fly ash as manufactured pozzolana is to recycle waste, reduce costs and slash energy savings in CO₂ emissions when processing cements [2]–[6]. It was given a prominent position among these products because rice husks are abundant as agricultural waste & because capacity for use as additional binder material in mortar & concrete is burnt to the full delicacy under controlled conditions and terrain [7]–[9]. This pozzolanic reactivity of the Rice-husk (RHA) ash comes from its high amorphous silica content (approximately 90 percent), low carbon C content & the porous nature of the ash. The combustion temperatures, degree of grinding and burning period are the key parameters that affect the pozzolanic reactivity of the Rice-husk (RHA) Ash [10]–[14].

Cement is a substance that blends durable and adhesive properties with water, allowing it to bind pieces of material to a compact whole [15]. Cements are graded as silicate calcium and cement aluminium calcium. Furthermore, cement is divided into Slag and Portland, while calcium aluminium is divided into Pozzolona cements and High Alumina [16]. There has been a lot of research on the RHA production, RHA reactivity and its application in mortar and concrete [17]–[20]. A growing
A number of studies have concentrated on the use of waste materials. The production & use of mixed cements is fast growing for the construction sector [21]. The attention now paid to pozzolans of agricultural and industrial by-products such as RHA & fly-ash, as their use typically improves the quality, costs and mitigation of harmful effects on our environment. Rice Husk is a significant by-product of agriculture and is available worldwide [22]–[25]. Rice husk with a cellular micro-structure is formed when burnt at temperatures below 700 °C [26]. High silicate content as amorphous silica or non-crystalline silica is present in the rice husk (RHA) ash [27]. It is thus a pozzolan-like material and can therefore be used as additional cement material. Mehta gave an insight on the effects of husks care on the pozzolan reactivity of the Rice husk (RHA) Ash [28]–[32]. The function of husk ash in high performance mortar/concrete, which is created by using a water reduction agent with a low cement ratio (under 0.4), was mainly focused on. Many studies have been conducted [33]–[38]. The filler effect of rice husk ash on these concrete composites has been shown to be more pronounced than decreased porosity, highly durable, leading to increased strength, pozzolanic effect and increased bonding ability in the ITZ (Interfacial transition zone) [39]–[41].

Another area of application for Cement-Rice husk (RHA) ash is the development of low-cost & low-strength combinations for rural use in developing countries, where there's an abundance of rice husks and Portland cement is scarce and costly. The combination of RHA with cement or/and lime without any Admixture is accomplished because of its limited supply and economic demand [42]–[45]. This research analyzed these types of formulations and documented the findings of an experimental study into hardening the RHA mixes with lime and cement in various compositions in mortar. Results for hardening reactions & their effect on the production of strength & on the mortar microstructure are presented.

2. Research Methodology

2.1. Material Used

Rice husk (RHA) ash, cement & lime have been used as binder of mortar in this research. The physical & chemical properties of all these materials are shown in Table 1. The chemical properties of all these materials appear to be suitable for use as a binder for mortar and much research work has been done with these materials. Amount of calcium hydroxide content is 83.22% in lime hydration.

| properties            | Constituents | Lime | RHA | OPC |
|-----------------------|--------------|------|-----|-----|
| Physical Properties   | SBlaine cm²/g | 19464| 13047| 4856|
| Density g/cm³         | 2.23         | 2.14 | 3.12|
| Mean value PSD        | 4.40         | 7.83 | 22.80|
| Chemical Properties (%) | LOI          | 24.39| 2.49| 1.6 |
| SiO₂                  | 0.11         | 90.86| 17.2|
| MgO                   | 0.76         | 0.53 | 0.8 |
| CaO                   | 74.23        | 0.78 | 61.7|
| SO₃                   | 0.27         | 0.25 | 3.1 |
| K₂O                   | 0.09         | 1.13 | 0.77|
| Na₂O                  | 0.08         | 0.08 | 0.41|
| Al₂O₃                 | 0.15         | 0.08 | 5.7 |
| Fe₂O₃                 | 0.12         | 0.24 | 3.9 |
| CO₂                   | 1.15         |      |     |
| Ca(OH)₂               | 83.22        |      |     |
The reactivity of the Lime RHA is greatly determined by its specific surface region, regulated by unbranded porous carbon particles. The literature has mentioned the effect of the grinding cycle on the specific surface region of the Rice husk (RHA) ash [46]–[54]. Keeping this in mind, RHA used a lab vibration ring mill for several times to assess the optimal grind time to achieve sufficient pozzolan operations. The actual surface area was improved after initial grinding for 10 minutes as a consequence of the particle diameter reduction of the ashes. Further grinding, though, culminated in a decline in the basic surface area & the pozzolanic operation of the RHA while its fineness was about the same. The decline was due to the deterioration following further scraping of the brittle surface of the ashes. Using a laboratory batch-balls drill, the entire batch of RHA was ground until certain fineness and precise surface area \{13047cm^2/g\} was obtained. Many of the RHA grains on the field were circular and spherical grains, which had various particle sizes below 50 \(\mu m\).

![Fig. 2: Relationship between S_blaire surface area & conductivity of electrical variation](image)

2.2. Composition of Material

The compositions Rice husk (RHA) ash–lime mortar, cement–Rice husk (RHA) ash–lime & cement–Rice husk (RHA) ash mortar have been analyzed in three separate forms, respectively (Table 2). The mortar was produced with normal sand of quartz with a 2mm average grain size. Cement- Rice husk (RHA) ash-lime mortar & Cement- Rice husk (RHA) ash mortar were maintained at 1:3 by weight by binder to sand ratio. Cement–Rice husk ash Mortar, replacing cement with RHA by weight, is investigated with 3 formulations at 30 percent, 50 percent and 70 percent. There were two kinds of lime, RHA and cement mixed ternary mortar examined. A 1:3 binder – sand ratio for contrast of the data was tested with Rice husk ash–lime mortar, both by weight and volume.

2.3. Research Process

The hardening of the mortar has been tested with standardized beams of mortar (40 mm-40 mm-160 mm) that have been developed according to Western standards. Mortars have been repaired over the span of 360 days under usual laboratory conditions (20°C, 60 percent relative moisture). The hardening improvement was explored by mechanical strength analysis and thermal inspection. Mercury-intrusive porosimetry (Autopore IV Micromeritics) & a XL 30 S Philips (SEM) scanning electron microscope with an X-ray power dispersion method respectively were used for the delivery
and adjustment of the microstructure. Mechanical strength monitoring was conducted with regular mortar beams at 7 days, 28 days, 60 days, 90 days, 120 days, 180 days and 360 days of hardening with compressive pressure and flexural strength (3-point) tests. Upon vacuum drying at (0.025 mbar) and screening by 100 mm sieve, the temperature analysis was conducted on thin-ground mortar samples to provide the required binder fraction. Once the samples were dried at 45°C, scanning electron microscope processing was performed on fresh broken surfaces protected by gold.

### Table 2: Rice husk ash, lime and cement blended mortar composition

| Mix             | Sand | Lime | RHA  | Cement | Binder | Flow |
|-----------------|------|------|------|--------|--------|------|
| C Quote         | 1350 | -    | -    | 450    | 0.48   | 143  |
| C VII – RHA III | 1350 | -    | 135  | 315    | 0.60   | 149  |
| C V – RHA V     | 1350 | -    | 225  | 225    | 0.65   | 145  |
| C III – RHA VII | 1350 | -    | 315  | 135    | 0.70   | 146  |
| C I – RHA VII – L II | 1350 | 90  | 315  | 45     | 0.80   | 150  |
| C I – RHA VII – L IV | 1350 | 180 | 225  | 45     | 0.82   | 147  |

C- Cement, RHA- Rice husk ash, L- Lime

### Table 3: Rice husk ash and lime mortar composition

| Mix | Sand | Lime | RHA | Binder-sand (wt) | Binder-sand (vol) | Water-binder (wt) | Flow |
|-----|------|------|-----|------------------|-------------------|------------------|------|
| RHA-L Volume | 1350 | 87.5 | 87.5 | 1:7.7           | 1:3               | 1.25            | 125  |
| RHA-L weight  | 1350 | 225  | 225  | 1:3             | 1:1.2             | 0.80            | 133  |

3. Outcome

3.1. Mechanical Strength

Demonstrates the development in the compressive and bending power of cement–Rice husk (RHA) ash mortar & cement mortar {Figure 3}. These strengths were decreased when RHA substituted in part with cement mortar by weights of 30, 50 and 70%, although the comparison cement mortar provided the maximum intensity in all phases. Mortar C VII – RHA III and C V – RHA V also resulted in a further improvement in bending strength over 360 days while for mortars C III – RHA VII no change in intensity was reported in 120 days. Cement–Rice husk ash–lime mortar developed relative lower compression and bending strength values than cement-Rice husk ash mortar {Figure 4}. At the very early stage of Twenty eight days of hardening, the strength reduction for both mortar compositions was reported. With the C I – RHA VII – L II mortar after Twenty eight days, the intensity decline is slightly greater even though its original output is still higher than C I – RHA VII – L VI.

4. Discussion

4.1. Cement-Rice husk ash Mortar

The results of the analysis stated that during hardness of the cement reference mortar hydration, premature-stage cement hydration & pozzolanic reaction paired with carbonation reaction at later stages resulted in cement Rice husk (RHA) ash mortars. Scanning electron microscope images revealed that at 120 days the pozzolanic reaction was still underway because Rice husk ash particles unreacted, or partially reacted, could be detected in the cement–Rice husk (RHA) ash mortar matrix.
The secondary hydrated states of small RHA particles are a rainfall location arising from the pozzolanic reaction.

4.2. Cement–Rice husk (RHA) ash–Lime Mortar

Cement–Rice husk ash–lime mortar showed a slightly different hardening process and a comparatively decreased intensity relative to cement–Rice husk ash mortar. At the very earlier stage of twentyeight days, the intensity decrease was reported and held until three hundred sixty days of hardening {Figure 4}. Results of thermal analyzes indicate pozzolanic and hydration reaction before the maximum intensity rates are reported for twenty eight days.

4.3. Rice husk (RHA) ash–Lime Mortar
The combination pozzolanic reaction and carbonization culminated in a hardening of Rice husk (RHA) ash-lime mortar. The pozzolanic reaction culminated in the production of the C-S-H process, already detected in twenty eight days. Reaction led to the production of bending power of the Rice husk (RHA) ash-lime mortar until the bulk of lime was consumed for sixty days.

![Fig 5: Mechanical Strength of Rice Husk (RHA) Ash-Lime Mortar](image)

5. Conclusion

Cement-Rice husk ash mortars harden due to simultaneous hydration of cement, carbonation & pozzolanic reaction. The initial production of strength in these mortars was primarily motivated by concrete hydration, whilst the pozzolan reaction & carbonation led to the long-term growth of strength. The rise in porosity of the mortar attributed to the strong water-to binding relationship favored later carbonation. Throughout the exceptionally early process of cement- Rice husk (RHA) ash-lime & Rice husk (RHA) ash-lime-, a decline throughout intensity has been observed. This was shown by low cement content in Cement- Rice husk (RHA) ash-lime mortars, the damaging impact on the hydrated phases, & the limited carbohydrating of the hydrated states of the calcium carbonate stages. Such decrease can also be induced by an excess of unreacted Rice husk ash in the mixture, as excess silica may react to the originally formulated C-S-H state. This can in effect contribute to an extremely polymerized C-S-H state being developed.

Reference

[1] A. P. Gursel, H. Maryman, and C. Ostertag, “A life-cycle approach to environmental, mechanical, and durability properties of ‘green’ concrete mixes with rice husk ash,” *Journal of Cleaner Production*, vol. 112, pp. 823–836, 2016.

[2] J. Payá et al., “Advantages in the use of fly ashes in cements containing pozzolanic combustion residues: Silica fume, sewage sludge ash, spent fluidized bed catalyst and rice husk ash,” *Journal of Chemical Technology and Biotechnology*, vol. 77, no. 3, pp. 331–335, 2002.

[3] G. Rodríguez de Sensale and I. Rodríguez Viacava, “A study on blended Portland cements containing residual rice husk ash and limestone filler,” *Construction and Building Materials*, vol. 166, pp. 873–888, 2018.
[4] E. Nimwinya, W. Arjharn, S. Horpibulsuk, T. Phoo-Ngernkham, and A. Poowancum, “A sustainable calcined water treatment sludge and rice husk ash geopolymer,” *Journal of Cleaner Production*, vol. 119, pp. 128–134, 2016.

[5] F. Celik and H. Canakci, “An investigation of rheological properties of cement-based grout mixed with rice husk ash (RHA),” *Construction and Building Materials*, vol. 91, pp. 187–194, 2015.

[6] E. Vejmelková, M. Keppert, P. Rovnaniková, Z. Keršner, and R. Černý, “Application of burnt clay shale as pozzolan addition to lime mortar,” *Cement and Concrete Composites*, vol. 34, no. 4, pp. 486–492, 2012.

[7] T. Sinsiri, W. Kroehong, C. Jaturapitakkul, and P. Chindaprasirt, “Assessing the effect of biomass ashes with different finenesses on the compressive strength of blended cement paste,” *Materials and Design*, vol. 42, pp. 424–433, 2012.

[8] A. Kumar and D. Gupta, “Behavior of cement-stabilized fiber-reinforced pond ash, rice husk ash-soil mixtures,” *Geotextiles and Geomembranes*, vol. 44, no. 3, pp. 466–474, 2016.

[9] L. P. Singh, S. R. Karade, S. K. Bhattacharyya, M. M. Yousuf, and S. Ahalawat, “Beneficial role of nanosilica in cement based materials - A review,” *Construction and Building Materials*, vol. 47, pp. 1069–1077, 2013.

[10] F. Pacheco-Torgal and S. Jalali, “Cementitious building materials reinforced with vegetable fibres: A review,” *Construction and Building Materials*, vol. 25, no. 2, pp. 575–581, 2011.

[11] A. Rashad, “Cementitious materials and agricultural wastes as natural fine aggregate replacement in conventional mortar and concrete,” *Journal of Building Engineering*, vol. 5, pp. 119–141, 2016.

[12] B. Chatveera and P. Lertwattanaruk, “Evaluation of sulfate resistance of cement mortars containing black rice husk ash,” *Journal of Environmental Management*, vol. 90, no. 3, pp. 1435–1441, 2009.

[13] P. Chindaprasirt and S. Rukzon, “Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar,” *Construction and Building Materials*, vol. 22, no. 8, pp. 1601–1606, 2008.

[14] V. Kannan and K. Ganesan, “Chloride and chemical resistance of self compacting concrete containing rice husk ash and metakaolin,” *Construction and Building Materials*, vol. 51, pp. 225–234, 2014.

[15] S. H. Sathawane, V. S. Vairagade, and K. S. Kene, “Combine effect of rice husk ash and fly ash on concrete by 30% cement replacement,” *Procedia Engineering*, vol. 51, pp. 35–44, 2013.

[16] A. Shukla, N. Gupta, and K. Kishore, “Experimental investigation on the effect of steel fiber embedded in marble dust based concrete,” in *Materials Today: Proceedings*, 2020, no. xxxx.

[17] J. Payá, J. Monzó, M. V. Borrachero, A. Mella do, and L. M. Ordoñez, “Determination of amorphous silica in rice husk ash by a rapid analytical method,” *Cement and Concrete Research*, vol. 31, no. 2, pp. 227–231, 2001.

[18] M. Aly, M. S. J. Hashmi, A. G. Olabi, M. Messeiry, E. F. Abadir, and A. I. Hussain, “Effect of colloidal nano-silica on the mechanical and physical behaviour of waste-glass cement mortar,” *Materials and Design*, vol. 33, no. 1, pp. 127–135, 2012.

[19] P. Nath and P. K. Sarker, “Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition,” *Construction and Building Materials*, vol. 66, pp. 163–171, 2014.

[20] H. Kizhakkumodom Venkatanarayanan and P. R. Rangaraju, “Effect of grinding of low-carbon rice husk ash on the microstructure and performance properties of blended cement concrete,” *Cement and Concrete Composites*, vol. 55, pp. 348–363, 2015.

[21] H. T. Le, M. Kraus, K. Siewert, and H. M. Ludwig, “Effect of macro-mesoporous rice husk ash on rheological properties of mortar formulated from self-compacting high performance concrete,” *Construction and Building Materials*, vol. 80, pp. 225–235, 2015.

[22] N. B. Singh and S. Rai, “Effect of polyvinyl alcohol on the hydration of cement with rice husk
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ash,” *Cement and Concrete Research*, vol. 31, no. 2, pp. 239–243, 2001.

[23] W. Xu et al., “Effect of rice husk ash fineness on porosity and hydration reaction of blended cement paste,” *Construction and Building Materials*, vol. 89, pp. 90–101, 2015.

[24] G. Rodriguez De Sensale, “Effect of rice-husk ash on durability of cementitious materials,” *Cement and Concrete Composites*, vol. 32, no. 9, pp. 718–725, 2010.

[25] A. Behnood, M. Modiri Gharehveran, F. Gozali, and M. Ameri, “Effects of copper slag and recycled concrete aggregate on the properties of CIR mixes with bitumen emulsion, rice husk ash, Portland cement and fly ash,” *Construction and Building Materials*, vol. 96, pp. 172–180, 2015.

[26] S. M. S. Kazmi, S. Abbas, M. J. Munir, and A. Khitab, “Exploratory study on the effect of waste rice husk and sugarcane bagasse ashes in burnt clay bricks,” *Journal of Building Engineering*, vol. 7, pp. 372–378, 2016.

[27] A. Shukla, N. Gupta, and A. Gupta, “Development of green concrete using waste marble dust,” in *Materials Today: Proceedings*, 2020, no. xxxx.

[28] A. Naji Givi, S. Abdul Rashid, F. N. A. Aziz, and M. A. M. Salleh, “Experimental investigation of the size effects of SiO2 nano-particles on the mechanical properties of binary blended concrete,” *Composites Part B: Engineering*, vol. 41, no. 8, pp. 673–677, 2010.

[29] A. Shukla, N. Gupta, “Study on the efficacy of natural pozzolans in Cement Mortar,” *Calcined Clays for Sustainable Concrete*, Rilem Publication, Springer, pp. 469-480, 2020.

[30] Q. Feng, H. Yamamichi, M. Shoya, and S. Sugita, “Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment,” *Cement and Concrete Research*, vol. 34, no. 3, pp. 521–526, 2004.

[31] M. R. Karim, M. F. M. Zain, and M. Jamil, “Strength of mortar and concrete as influenced by rice husk ash: A review,” *World Applied Sciences Journal*, vol. 19, no. 10, pp. 1501–1513, 2012.

[32] M. R. Shatat, “Hydration behavior and mechanical properties of blended cement containing various amounts of rice husk ash in presence of metakaolin,” *Arabian Journal of Chemistry*, vol. 9, pp. S1869–S1874, 2016.

[33] K. Kunchariyakun, S. Asavapisit, and K. Sombatsompop, “Properties of autoclaved aerated concrete incorporating rice husk ash as partial replacement for fine aggregate,” *Cement and Concrete Composites*, vol. 55, pp. 11–16, 2015.

[34] R. Siddique, K. Singh, P. Kunal, M. Singh, V. Corinaldesi, and A. Rajor, “Properties of bacterial rice husk ash concrete,” *Construction and Building Materials*, vol. 121, pp. 112–119, 2016.

[35] X. Chen, S. Wu, and J. Zhou, “Influence of porosity on compressive and tensile strength of cement mortar,” *Construction and Building Materials*, vol. 40, pp. 869–874, 2013.

[36] A. Najigivi, A. Khaloo, A. Iraji Zad, and S. Abdul Rashid, “Investigating the effects of using different types of SiO2 nanoparticles on the mechanical properties of binary blended concrete,” *Composites Part B: Engineering*, vol. 54, no. 1, pp. 52–58, 2013.
[41] H. T. Le and H. M. Ludwig, “Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete,” *Materials and Design*, vol. 89, pp. 156–166, 2016.

[42] A. Gupta, “Investigation of the strength of ground granulated blast furnace slag based geopolymer composite with silica fume” in *Materials Today: Proceedings*, 2020, no. xxx.

[43] A. Parasar, A. Gupta, “Investigation of the effect of bagasse ash, hooked steel fibers and glass fibers on the mechanical properties of concrete” in *Materials Today: Proceedings*, 2020, no. xxx.

[44] S. K. Antiohos, J. G. Tapali, M. Zervaki, J. Sousa-Coutinho, S. Tsimas, and V. G. Papadakis, “Low embodied energy cement containing untreated RHA: A strength development and durability study,” *Construction and Building Materials*, vol. 49, pp. 455–463, 2013.

[45] R. Madandoust, M. M. Ranjbar, H. A. Moghadam, and S. Y. Mousavi, “Mechanical properties and durability assessment of rice husk ash concrete,” *Biosystems Engineering*, vol. 110, no. 2, pp. 144–152, 2011.

[46] L. A. T. Bui, C. L. Hwang, C. T. Chen, K. L. Lin, and M. Y. Hsieh, “Manufacture and performance of cold bonded lightweight aggregate using alkaline activators for high performance concrete,” *Construction and Building Materials*, vol. 35, pp. 1056–1062, 2012.

[47] R. Madandoust and R. Ghavidel, “Mechanical properties of concrete containing waste glass powder and rice husk ash,” *Biosystems Engineering*, vol. 116, no. 2, pp. 113–119, 2013.

[48] A. Modarres and Z. Hosseini, “Mechanical properties of roller compacted concrete containing rice husk ash with original and recycled asphalt pavement material,” *Materials and Design*, vol. 64, pp. 227–236, 2014.

[49] E. Mohseni, F. Naseri, R. Amjadi, M. M. Khotbehsara, and M. M. Ranjbar, “Microstructure and durability properties of cement mortars containing nano-TiO2 and rice husk ash,” *Construction and Building Materials*, vol. 114, pp. 656–664, 2016.

[50] G. Sua-iam, P. Sokrai, and N. Makul, “Novel ternary blends of Type 1 Portland cement, residual rice husk ash, and limestone powder to improve the properties of self-compacting concrete,” *Construction and Building Materials*, vol. 125, pp. 1028–1034, 2016.

[51] B. M. Miyandehi, A. Feizbakhsh, M. A. Yazdi, Q. Feng Liu, J. Yang, and P. Alipour, “Performance and properties of mortar mixed with nano-CuO and rice husk ash,” *Cement and Concrete Composites*, vol. 74, pp. 225–235, 2016.

[52] D. Gupta and A. Kumar, “Performance evaluation of cement-stabilized pond ash-rice husk ash-clay mixture as a highway construction material,” *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 9, no. 1, pp. 159–169, 2017.

[53] M. Jamil, M. N. N. Khan, M. R. Karim, A. B. M. A. Kaish, and M. F. M. Zain, “Physical and chemical contributions of Rice Husk Ash on the properties of mortar,” *Construction and Building Materials*, vol. 128, pp. 185–198, 2016.

[54] E. Mohseni, M. M. Khotbehsara, F. Naseri, M. Monazami, and P. Sarker, “Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina,” *Construction and Building Materials*, vol. 111, pp. 429–439, 2016.