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A Review of Structures and Performance of Ternary Blends of Rice Husk Ash and Some Wastes in Concrete

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Abstract

The field of structural engineering has in recent times begun to widen its scope from the traditional analysis and design, into the development of new structural materials. This is because the use of non-renewable materials in forming and framing structural projects are raising serious environmental concerns bothering on sustainability of materials, especially cement, to produce structural concrete. Cement has been found to be a major contributor to greenhouse gases which affect the environment negatively. Waste from both the industrial and agricultural industries are gradually becoming sources of material to partly replace cement in concrete because of their pozzolanic properties. The agro-based pozzolanic materials include Rice husk Ash (RHA), Saw dust ash (SDA), Palm oil fuel ash (POFA) amongst others. To further widen the scope and resource base of pozzolanic materials for concreting, ternary blends consisting of agro-based pozzolans are being researched into. These research efforts however appear to be uncoordinated, and thus there is a need to juxtapose these efforts together to see the extent of work done on such ternary blends and present their relevant structural properties. This is with a view to helping identify gaps in such research as a means of preventing wastage of research energies. This paper presents a review of structural properties of some agro-based ternary blends used in structural concrete. It is concluded that more research effort is needed, especially in the development of practical and acceptable guidelines that will aid their application in concrete, for sustainable production of structural concrete.

Keywords

Agro-based, Pozzolan, Rice husk ash, Structural properties, Sustainability

1. Introduction

Of all the construction materials that are used in a built environment, none has matched concrete in terms of acceptability in all lands. Its acceptability was based on many factors, which include availability of materials of its production at every place, ability to be produced to have any desired specified strength, it enables builder and engineers to play with any geometric shapes, and excellent durability properties among others. However, this world-wide acceptability has its cost. Firstly, it leads to the exhaustion of the basic materials used for concrete production. These materials like sand, gravel, limestone for cement manufacture are all non-renewable natural resources (Ciccioli and Ragni, 2017, Fapohunda, 2020, Carretero-Gomez and Piedra-Munoz (2021). The depletion of these materials for concrete production is having global environmental consequences and it endangers the material existence of future generations. In addition to this, production of cement generates greenhouse gases like carbon dioxide (CO2), nitrous oxide (NO3), methane (CH4), etc. into the atmosphere which are released into the environment, and with have been attributed to contribute significantly to the global warming (Belaid, 2022). In the process of cement clinker production, CaCO3 (calcium carbonate) is converted into calcium oxide (CaO) by calcination inside rotary kiln, to emit car-bon dioxide (CO2) as byproduct as in equation 1.

$$CaCO_3 + Heat = CaO + CO_2 \quad (1)$$

According to Summerbell et al., 2016; Adesina, 2020; and Miller et al., 2021, the contribution of concrete industry into the global greenhouse gas emissions is between 7 – 9%. Also cement has a very high embodied energy, that is, the energy consumed for raw material mining, transportation, manufacture, assembly, installation, disassembly, and demolition for any product system over the duration of a product's life (Praseeda et al., 2017). Apparently, a material with low Embodied Energy is regarded more sustainable. It is against this background that researchers have been looking for ways to reduce greenhouse gas emissions attributed to concrete industry and embodied energy. One of the ways to achieve this is mass search for pozzolanic materials, especially from both industrial and agricultural wastes. These are to be used as partial replacement of cement to form binary blends. Some agricultural wastes in particular, that have been found to have pozzolanic properties are Palm Oil Fuel Ash (Jonida et al. 2023), Saw Dust Ash (Fapohunda et al., 2018), Rice Husk Ash (Fapohunda et al, 2017), Corn Cob Ash (Olafusi and Olutoge, 2012), Groundnut Husk Ash (Mahmoud et al. 2012), Banana Leaf Ash (Ndubuisi 2020), Sugarcane Bagasse Ash (Shuaibu et al. 2014 and Nasir Shafiq, et al. 2016), Palm Kernel Shell Ash (Ottos and Isaac 2018), and Bagasse Ash (Mrityunjay and Shivani, 2018) amongst others. While the usage of some of these as binary blends in concrete has resulted in improved structural and durability properties, others are inferior in quality and thus have limited or no application. It is in response to this that ternary blends were conceived by researchers as a strategy to compensate for inferior pozzolans. Ternary blends, contains cement with two other pozzolans with Portland cement, to form a binder in structural concrete as in equation 2.

$$Binder = Portland\ cement + 2\ pozzolanic\ materials \quad (2)$$

Equation 2 was based on the possibility of obtaining a combined chemical composition from the two (2) pozzolanic materials that will yield cementitious paste capable of impacting adequate strength and durability properties to the resulting concrete. The use of ternary offers a wide range of possibilities because the two pozzolanic materials in the blend could be sourced from any of at least the five (5) categories as in Table 1.

Table 1. Possible categories of pozzolans in Ternary blends

Category	The two pozzolans
A	Both are industrial wastes
B	Both are agricultural wastes
C	One industrial waste + one agricultural waste
D	One industrial waste + others (geopolymer, quarry dust, metakaolin, etc.)
E	One agricultural waste + others (geopolymer, quarry dust, metakaolin, etc.)

In addition, using ternary blends will thus help to address some of the sustainability issues associated with cement consumption in concrete production.

Such concerns include reduction in CO_2 emission and embodied energy as well as cost reduction. More importantly, increasing use of pozzolan in concrete industry will be reduced its carbon dioxide emission significantly by 2050 and qualifies it to be classified as net-zero emission industry. This work is on concrete containing agricultural waste ternary blends. Much research energy has been expended to discover possible ternary blends that are of agricultural origin. The results of these research efforts, however, appear to be scattered and difficult, if not confusing, to track. Gathering such work together in form of a review will avail the researchers to know the extent of work done, the materials used, the scope covered, to uncover research gaps and al-so reveal where supplementary research works are needed to enable overall understanding for effective application of the material. However, observation from Table 1 shows that at least five (5) different categories of ternary blends. Reviewing all of them in one work will be very unwieldy. This work focuses on ternary blends involving rice husk ash. Thus, the aim of this paper is to carry out a critical review of works done by scholars on the potential usage of rice husk ash in ternary blends with other pozzolans in the production of structural concrete.

2. Materials and methods

The approach adopted for this work is to obtain all the scholarly works on concrete containing ternary blends of rice husk ash that are available on the internet. They were analyzed for structural relevance. The summary of the structural features of Rice husk ash (RHA), being the pivot of this review was addressed first and then followed by its ternary blends with some agricultural waste. The results are discussed in the sections following.

3. The Review

3.1 Summary of Structural properties of Rice Husk Ash (RHA) as Binary blends in Concrete

Rice husk ash (RHA) is produced from rice husk, an agrobased waste material that is abundant in many parts of the world, especially in rice cultivating countries. Fapohunda et al. (2017 and Siddika et al., 2021)) did extensive review on scholarly work done that has confirmed its suitability as partial replacement of cement in the production of concrete. Its pozzolanic oxide composition (SiO_2 + Al_2O_3 + Fe_2O_3) ranges from 73.13% to 95.77%; thus, in the category of Class F fly ash (ASTM C618, 2005). Other notable findings from the review and others are that: (i) the paste containing RHA requires more water to achieve the standard consistency in comparison with the samples without RHA, and the water.

demand increased with increase in cement replacement with RHA, (ii) the workabilities measured from both the slump and compacting factor tests decreased with increase in RHA, which means more that water is required to make the concrete workable (Neville, 2011). Other findings are decrease in the density of concrete specimens containing RHA with increase in the content of RHA at all water-binder ratios and development of densities with values of between 2200–2550 kg/m3 are in the range for normal concrete applications (Falade et al., 2011). Also, the compressive strength of concrete incorporating RHA developed later compressive strength that is higher than specimens without RHA as can be seen in Figure 1.

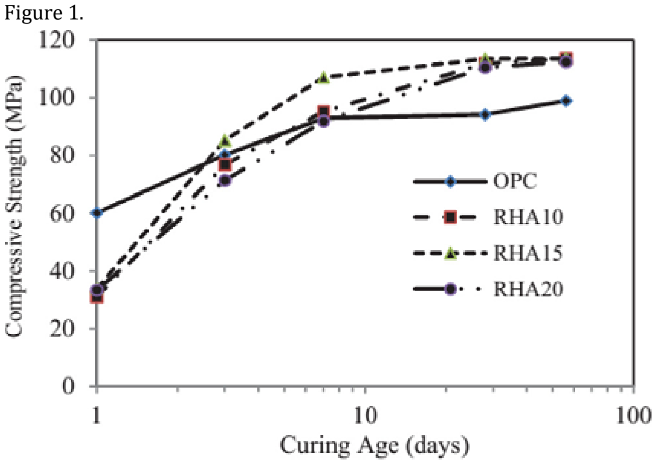

Figure 1. Effect of Rice husk ash on compressive Strength of concrete specimens

It was however found out that the strength development of concrete with RHA depends on the water-cement ratio (Al-Alwan et al., 2023), but at least up to 10% cement replacement with RHA resulted in strength development comparable to the control specimens. Further, RHA-concrete resulted in dense microstructure and thus impervious to agent of degradation like, sulphate attacks, chloride ingress, etc., as well exhibiting good shrinkage properties, giving it an overall structurally good and durable binary blends, when used with cement in concrete.

3.2 Ternary blends of Rice husk ash (RHA)

Rice husk ash and Corn cob ash ternary blends in Concrete

Corn cob is the hard thick cylindrical central core of corn (on which are borne the grains or kernels of an ear of corn). According to Adesanya and Raheem (2009a), corn cob is agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa. The documents from Food and Agriculture Organization (FAO, 2023) showed that 589 million tons of maize was produced worldwide in the year 2000. Corn Cob Ash (CCA) is obtained from the burning of corn cobs either by open burning or the use of an incinerator. The results of Alake (2020) showed that the pozzolanic oxide composition (SiO_2 + Al_2O_3 + Fe_2O_3) of CCA to be 78.34%, making it to be in the category of Class F fly ash (ASTM C618, 2005). In binary blends with cement, values of slump and compacting factor decreased with increase in CCA content, thus becoming less workable. Also, inclusion of CCA decreased the early age compressive strength but increase the latter ages compressive strength of concrete (Adesanya and Raheem, 2009b). Alake also researched into the structural characteristics of ternary blends of rice husk ash (RHA) and corn cob ash (CCA) in equal amounts in concrete. The findings showed that the compressive strength increased with increase in curing age but decreased as the RHA and CCA contents increased; and the compressive strength were lower at early stages but improved substantially up to 56 days (Figure 2). However, up to 10% RHA and CCA content was the limit for the development of adequate strength. However, Kumari et a., (2023) believed ternary blends of 10% RHA and 5% CCA to replace cement produced concrete with adequate structural strength. Kumari et al. (2023) carried out microstructural investigations with scanning electron microscopy (SEM) on ternary blends of RHA and CCA. Their analysis showed variation of behaviour with curing ages with

a porous structure at early age which later turned into denser matrix at 28 days of curing.

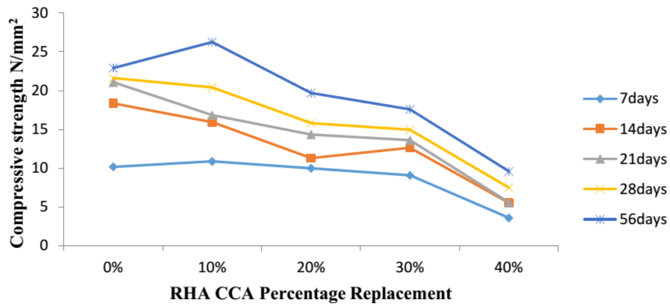

Figure 2. Strength development of Ternary blends of RHA and CCA in concrete

Rice husk ash and Sawdust ash ternary blends in Concrete

Sawdust ash (SDA) is obtained when saw dust, which is a waste material from the sawmill industry, is burnt into ashes. A review conducted by Fapohunda et al. (2018) revealed that SDA has a wide range pozzolanic oxide composition (SiO2 + Al2O3 + Fe2O3.), between 50 and 70%, and thus are in the same category with the Classes C and F fly ash. It was also found out that with appropriate mix design, SDA can be used to partly replace cement up to 20% in the concrete mix to develop structural concrete that satisfies codes requirements. The possibility of the combination RHA and SDA as ternary blends in structural concrete was investigated by Ettu et al., (2014). Equal proportions of RHA and SDA 5%, 10&, 15%, 20% and 25% were used in blends. They adopted curing days of 3, 7, 14, 21, 28, 50 and 90 days. Their results showed that compressive strengths at all the curing were higher than the control at 15% equal proportions of RHA and SDA in the mix. In his own investigation, James (2023) with equal replacement of RHA and SDA in the mix up to 15%, found out that the water requirement to achieve a standard paste increased with increase in the percent addition of RHA and SDA in the mix. He also found out the initial and final setting times followed the same trend. The results of James (2023) also confirmed earlier results by Ettu et al. (2014) that compressive strength increases with curing age.

Rice husk ash and Wheat straw ash ternary blends in Concrete

Wheat straw is obtained after harvesting the wheat crop on removal of stubbles. According to figures given by the Food and Agricultural Organization (FAO, 2022) of the United Nations, annual worldwide wheat production is about 734.5 million tons and for every production of kg of grain, about 1.3 to 1.5 kg of wheat straw is produced as waste on average (Pan and Sano, 2005). Its disposal either by indiscriminate dumping or uncontrolled burning is generating environmental hazard. Wheat straw ash (WSA) is obtained by the controlled burning of wheat straw. In the work done by Goyal et al. (2007) Bheel et al. (2021a) the pozzolanic oxide composition (SiO2 + Al2O3 + Fe2O3) of WSA was found to be between

78.14% and 80.03%, thereby falling into the category of Class F fly ash (ASTM C618, 2005). According to Babar et al. (2022), the use of WSA as binary blends in concrete resulted in increased compressive strength up to 10% replacement values and decrease in unit weight. Other findings are increased workability and water absorption with increased WSA content. Similar results were obtained earlier by Shar et al. (2019). The potential use of WSA with RHA, as ternary blends in concrete was investigated by Goyal et al. (2007). Three combinations of ternary blends of RHA and WSA in concrete were used, namely, (10+5) %; (5+10) % and (7.5+7.5) %. Their results showed that ternary' blend with (7.5 + 7.5) % combination of RHA and WSA developed better strengths characteristics than the control and other blends, and thus proved to be the optimum combination for achieving concrete with better structural features. In their own investigation, Bheel et al. (2021b) used ternary blends of RHA and WSA in equal proportions. Their results showed reduction in workability and density with increasing combined proportion RHA and WSA in the mix. The reported developed densities of between 2200 – 2300 kg/m3 makes the resulting concrete useful for normal concreting. The results also showed that up to 10% ternary blends (5% RHA + 5% WSA) in the concrete mix, the compressive strengths and the tensile strengths measured through splitting test and modulus of rupture, were significantly enhanced at 28 days of curing. The pattern of the strength performance is shown in Figure 3. It can be observed in Figure 3 that strengths increased up to 10% of combined equal proportions of RHA and WSA, suggesting that using RHA and WSA in equal proportions at 10% replacement of cement will produce concrete having improved strength characteristic.

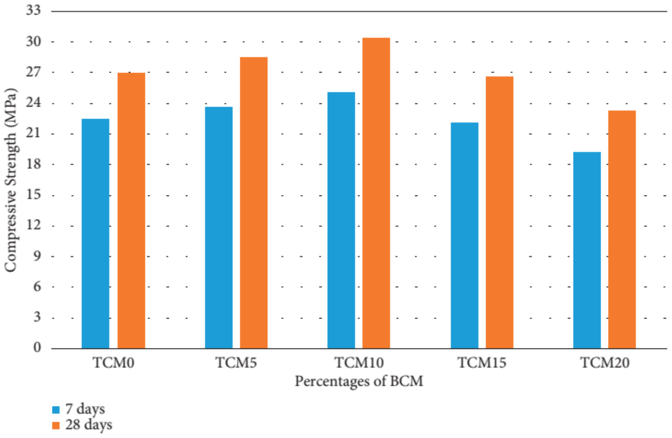

Figure 3. Pattern of Strength development for ternary blends of RHA and WSA in concrete.

Rice husk ash and ground granulated blast slag ternary blends in Concrete

Ground granulated blast furnace slag (GGBFS) is a waste product obtained from steel industries. It is rich in SiO2 and Calcium aluminates. Around 12 million tons of slags are produced by steel industries. The general trend of the effects of application of GGBFS in concrete from literature (Barnett et al., 2006; Srikanth et al., 2023; Rondón-Quintana et al., 2019) indicates that the partial replacement of OPC by GGBFS typically results in lower early strengths (7 to 28 days), but greater long-term strengths. There is also enhanced workability, less bleeding, and lower heat of hydration. Other results include lower chloride ion permeability, less creep, improved resistance to sulfate attack and alkali silica reactivity (ASR) durability and increased steel corrosion resistance. In furtherance to this, Dhinakaran and Sreekanth (2018) researched into the structural characteristics of ternary blends of RHA and GGBFG in concrete. They used 10 combinations of percentages of RHA and GGBFG in the mix as shown in Table 2

Table 2. Combination of RHA and GGBFS in Ternary blend with cement in Concrete (Dhinakaran and Sreekanth (2018)

Mix	Cement (%)	GGBFS (%)	RHS (%)
A	100.10	-	-
B	74.90	19.99	5.10
C	70.10	19.99	10.01
D	64.91	19.90	14.98
E	64.98	29.98	5.02
F	59.60	29.98	10.01
G	54.98	29.98	14.98
H	54.98	39.97	4.99
I	49.99	39.98	9.99
J	44.98	39.99	15.10

The strength parameters investigated for the 10 combinations were compression and flexural strengths. Durability properties like sorptivity, porosity, and freeze-thaw, were also studied. The analysis of the results showed that the mix with 30% GGBFS and 5% RHA exhibited better structural and durability performance in comparison with control concrete. In addition, it was also discovered that high-strength concrete, with 28-day compressive strength above 50 N/mm2, could be produced with 35% replacement of cement either with 20% GGBFS and 15% RHA or 30% GGBFS and 5% RHA.

Ternary Blends of Rice husk ash and other Wastes in Concrete

Ternary blends of rice husk ash (RHA) with other materials were also found to have the potential for strength development for structural application. For example, ternary blend of rice husk ash (RHA) and silica fume (SF), investigated by Ahmed et a., (2022) showed a concrete with comparable structural features with the control, as well as providing strong resistance to alkali aggregate reaction at 5% SF and 20%RHA. Amin et al. (2022) also carried out investigations on the ternary blends of RHA and SF. They concluded mix having 33% RHA along with 7% SF (RHA33SF7) produced the highest strength. They also observed that the microstructure at this mix was compact and dense. Similarly, ternary blends of rice husk ash (RHA) and coconut husk ash (CHA) were researched into by Obokparo and Arum (2020). Their results showed that at 10% replacement the maximum compressive strength of 32.9N/mm2 was obtained for the ternary blended concrete of RHA and CHA with cement at 56 days. This value, according to them, was 16.1% higher in strength than the control samples. In their own work, Al-Hashem et al. (2022) showed that ANN can be used to predict the 28-day strength of Rice husk ash (RHA) and Fly ash (FA) ternary blends in concrete. Alyami et al. (2023) investigated the possibility of producing sustainable ultra-high-performance concrete using the ternary blends of rice husk ash and sugarcane leaf (SLA) ash. Their results showed that ultra-high-performance concrete could be prepared if 50% of ordinary Portland cement (OPC) by weight is replaced with SLA 25% + RHA25%. At this mix, they produced a compressive, tensile, and flexural strength of more than 155, 19, and 27 MPa, respectively. All these values were in the range of ultra-high concrete (Vidya et al., 2017; Santhanam and Anbuarasu, 2020).

Economic Prospect of Using Ternary Blends of Waste materials in Concrete.

The problem of improper disposal of both industrial and agricultural wastes, especially in developing nations, constitutes some barriers to economic development of those nations. First, the environmental problems in the form of pollution, leading to unhealthy living conditions cannot result in productive workforce that is necessary for economic development (Adesina, 2020 and Amin et al., 2022). Secondly, the land space occupied by these wastes tied up land that could have been used for developmental schemes (Miller et al. 2021). Thirdly, unrestrained use of non-renewable materials in the concrete industry endangers the economic wellbeing of future generations. These barriers are removed if the use of ternary blends is promoted in the production of structural concrete, with concomitant economic benefits.

4. Conclusions

From the above brief review of rice RHA-based ternary blends usage in concrete, it is obvious that such usage has the capacity to develop concrete with strength and durability characteristics that are adequate for structural application. More importantly, the usage will help achieve the status of net-zero in relation to greenhouse gas emissions in concrete industry. However, the development of national or professional technical standards to guide the use of the reviewed wastes, for use as a component of concrete, which is not yet addressed, constitutes a major challenge that ought to be addressed by scholars. The research questions that should be resolved is whether the provisions of existing national codes, for example, the BS 8110 (1997), are adequate and sufficient for the design of structural elements in concrete containing rice husk ash as partial replacement of cement. This is recommended for further studies.

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