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**Progress on the Use of Rice Husk Ash (RHA) as a Construction Material in Nigeria**

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**ABSTRACT.** *Research on the use of Rice Husk Ash (RHA) in cement, concrete and mortar has been explored in different fronts in Nigeria with encouraging results. RHA is composed of silica, alumina, iron oxide, calcium oxide and some traces of other compounds. The combustion of RHA at optimum temperature established by researchers produces either amorphous or crystalline ash depending on the combustion temperature and type of burning. This paper tries to bring under one umbrella documented research reported in literature on the use of RHA in construction in Nigeria. Physical and chemical properties; consistency, setting time and flow of mixed paste are reported. Combustion process and optimum temperature has also been exclusively reported. Cement replacement with RHA, strength results on concrete, mortar, bricks and blocks; other properties reported are flexural and tensile strength, sorptivity and coefficient of water absorption. It is seen from literature that optimum replacement level of RHA with cement is about 10 – 20% and with longer curing duration, as there is a sharp decrease in mechanical properties beyond this level.*

**Keywords:** Rice husk ash, amorphous, crystalline, optimum temperature, concrete, construction.

1. **INTRODUCTION**

 Global production of rice, the majority of which is grown in Asian is approximately 550 million tons/year. The milling of rice generates a waste material, while husk is the material surrounding the rice grain. The annual worldwide output of the rice husk is approximately 80 million tons, which corresponds to 3.2 million tons of silica/year globally Natarajan *et al.,* (1998) [1]. According to FAO (2010) [2], Nigerian rice husk generation could be estimated at 748,000 – 990,000 tonnes, since there is no commercial Rice Husk Ash (RHA) production in the country. This quantity of rice husk is mostly disposed of by open air burning that possess environmental hazard. It was reported that approximately 100 million tons of rice husk are generated annually worldwide, while about 2 million are generated in Nigeria annually Oyetola and Abdullahi (2006) [3]. Out of the total rice produced, the husks constitute approximately 20%. In Oluremi (1990), as reported in [3], that a survey by Raw Materials Research and Development Council of Nigeria on available local building materials reveals that certain building materials deserve serious consideration as substitute for imported ones. These materials include cement/lime stabilized bricks/blocks, sundried (Adobe) soil bricks, burnt clay bricks/blocks, rice husk ash (RHA), lime and stonecrete blocks.

 The possibility of substituting Ordinary Portland Cement (OPC) with RHA pozzolan for the production of cement bonded composites (CBCs) was investigated using the hydration technique by Fabiyi (2013) [4]. A pozzolan has been defined as a siliceous or aluminosiliceous material that in finely divided form and in the presence of moisture chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds Detwiler *et al.,* (1996) [5]. According to Papadakis and Tsimas (2002) [6], despite lower early strength, the addition of natural pozzolana (up to 20-30%) could also improve the compressive, splitting and flexural strength of the concrete. Pozzolanas can be divided into two groups; natural pozzolana such as volcanic ash and diatomite, and artificial pozzolana such as calcined clay, pulverized fuel ash, and ash from burnt agricultural waste [7].

 According to Saraswathy and Ha-Won (2007) [8], the addition of RHA to Portland cement does not only improve the early strength of concrete, but also forms a calcium silicate hydrate (CSH) gel around the cement particles which is highly dense and less porous, and may increase the strength of concrete against cracking. In the works of [9-10], the use of rice husk ash reduces the effects of alkali-silica reactivity as well as drying shrinkage. Also, the work of Saraswathy and Ha-Won (2007) [8] on normal strength concrete shows that at w/c ratio of 0.53, up to 25% replacement of OPC with RHA could lead to increase in compressive strength and decrease in effective porosity and coefficient of water absorption in concrete at 28 days. Rice husk ash is known to reduce the porosity of concrete at the interface between cement paste and aggregate, and improve strength Bui *et al.,* (2005) [11].

 The work of Abalaka and Okoli (2013b) [12] investigated the effect of RHA on normal strength concrete at water-binder ratio of 0.45, 0.50 and 0.55. The result showed that RHA with a low specific surface could be used to replace 25% OPC in concrete at w/b ratio of 0.55. Burning in the open air is likely to cause environmental pollution as carbon dioxide (CO2) and carbon monoxide (CO) would be released into the atmosphere as a result of insufficient oxygen in the heap of the rice husk. Also, the aerobic decomposition of the rice husk in the landfills could be a major source of methane emissions. The release of these gases into the atmosphere changes the climate, thereby resulting in global warming which is now one of the greatest threats to our world Fabiyi (2013) [4].

1. **PHYSICAL PROPERTIES OF RHA**

 The work of Ephraim *et al.,* (2012) [13] presented a grading analysis of RHA, sand and coarse aggregates; rice husk ash is distributed from coarse to fine silt extending to clay. In Akeke *et al.,* (2013) [14], it was also reported that RHA is distributed from coarse to fine silt. The table below summarizes the physical properties of RHA as reported in literature:

**Table-1:** Physical properties of RHA

|  |
| --- |
| **Physical Properties of Rice Husk Ash** |
| **Reference** | **Specific Gravity** | **Bulk Density kg/m3** | **Fineness Modulus** |
| Oyetola & Abdullahi [3] | 2.13 | Uncompacted 460 | - |
| Compacted 530 |
| Akeke et al., [14] | 1.55 | - | - |
| Oyekan & Kamiyo 15] | 2.17 | - | - |
| Ettu *et al.,* [36] | 1.80 | 765 | 1.38 |
| Ettu *et al.,* [48] | 1.84 | 770 | 1.48 |
| Ettu *et al.,* [49] | 1.81 | 760 | 1.40 |

 Also, Oyekan and Kamiyo (2011) [15] reported a moisture content of less than 1.5% specified by BS 3892, specific gravity of 2.17; a density of 2170 kg/m3. In Abalaka and Okoli (2013) [16] they reported that the milled RHA used had a low specific surface of 235m2/kg; and 50% of the RHA particles are less than 46.451µm in diameter, and 90% are less than 178.521µm in diameter.

1. **CONSISTENCY, SETTING TIME & FLOW OF RHA MIXED PASTE**

 Setting refers to the stiffening of the cement paste, a change from liquid to a rigid stage. A minimum time of 60 minutes is prescribed by ENV 197-1: 1992 for cements with strengths up to 42.5MPa and ASTM C 150-94 prescribes a minimum time for the initial set of 45 minutes using Vicat apparatus. The European Standards (EN 450-1, 2005) require the initial setting time of fly ash paste should be at most 120 minutes longer than that of the reference without ash. According to Andrade (2004) [17] when he investigated the use of bottom ash as aggregate in concrete, studies have identified that the addition of bottom ash to cement materials increases the initial and final setting time in relation to the reference mix. This is due to the increase in quantity of water present in the mixes with bottom ash, resulting in the maintenance of a greater workability, consequently, increasing the time that the mix is in the fresh state. In Yetgin and Cavder (2006) [18], it has been reported on the effects of natural Pozzolan on properties of cement mortars that “Setting properties of cement matrix were affected by natural Pozzolan ratio substituted for cement. Experimental results show a proportional delay in the initial set time, depending on the natural Pozzolan addition ratio”. This implies that natural Pozzolan decrease rate of hydration by decreasing heat of hydration. Setting time, consistency and flow of RHA mixes as reported in literature is hereby reproduced and discussed.

**Table-2:** Setting time of RHA

|  |  |  |
| --- | --- | --- |
|  | **Dabai *et al.,* (2009) [19]** | **Oyetola & Abdullahi (2006) [3]** |
| **Cement (%)** | **RHA (%)** | **IST (mins)** | **FST (mins)** | **IST (mins)** | **FST (mins)** |
| 100 | 0 | 122 | 183 | 95 | 150 |
| 90 | 10 | 136 | 227 | 189 | 323 |
| 80 | 20 | 154 | 255 | 191 | 510 |
| 70 | 30 | 165 | 275 | 305 | 685 |
| 60 | 40 | 213 | 350 | 374 | 756 |
| 50 | 50 | 281 | 402 | 429 | 811 |

*IST= Initial Setting Time FST= Final Setting Time*

 In Dabai *et al.,* (2009) [19], the initial setting time of mixes with RHA percentages was within the range specified by EN 450-1 (2005) from 0 – 30%, that is mixes with additions should be at most 120 minutes longer than the mixes without additions. However, in Oyetola and Abdullahi (2006) [3],it was observed that only 10% replacement of OPC with RHA was slightly higher than the code requirement by 24 minutes. It is well known that as RHA replaces cement, the rate of reaction reduces, and the quantity of heat liberated also reduces leading to late stiffening of the paste. As the hydration process requires water, greater amount of water was also required for the process to continue. The delay in the setting time can be attributed to the reduction in the quantity of C3S in the paste.

**Table-3:** Slump measured

|  |  |  |
| --- | --- | --- |
|  | **Oyetola and Abdullahi (2006) [3]** | **Tsado *et al.,* (2014) [30]** |
| **% RHA** | **Slump (mm)** |
| 0 | 15 | 30 |
| 10 | 30 | 28 |
| 20 | 20 | 27 |
| 30 | 25 | 25 |
| 40 | 20 | - |
| 50 | 25 | - |

From Ephraim *et al.,* (2012) [13], it was reported that the workability test showed RHA concrete had a slump range of 50-90 mm, medium workability with a compacting factor of 0.90. Also, Abalaka and Okoli (2013b) [12] observed that the slump of fresh concrete mixes containing 5% RHA were higher than that of control at w/b ratio of 0.50 and 0.55. The result indicates that RHA content at this level resulted in better dispersion of cement particles thus causing increase in slump. They concluded that optimum OPC replacement with RHA at 25% by weight could be attained without strength reduction in normal strength concrete at w/b ratio of 0.55.

1. **CHEMICAL ANALYSIS**

 The chemical composition of rice husk ash varies from rice husk to rice husk which may be due to geographical and climatic conditions, type of rice and quantity of fertilizer used Gavindarao (1980) [20]. The result of the chemical analysis conducted by different researchers in Nigeria (table below) revealed that the major components are silica, alumina, iron oxide and calcium oxide.

**Table-4:** Chemical analysis of RHA

|  |
| --- |
| **Chemical Properties of Rice Husk Ash** |
| **Reference** | **SiO2** | **Al2O3** | **Fe2O3** | **CaO** | **MgO** | **SO3** | **Na2O** | **K2O** | **LOI** |
| Dabai *et al* (2009) [19] | 68.12 | 1.06 | 0.78 | 1.01 | 1.31 | 0.14 | - | 21.23 | 18.25 |
| Oyekan & Kamiyo (2011) [15] | 76.00 | 3.00 | N.D. | 6.00 | 1.30 | N.D. | 1.18 | 0.10 | - |
| Abalaka & Okoli [16] | 95.41 | 0.00 | 0.82 | 0.00 | 1.24 | 0.07 | 0.22 | 1.65 | - |
| Tsado *et al* (2014) [30] | 48.44 | 23.31 | 4.89 | 8.12 | 1.25 | 1.92 | 0.35 | 0.83 | 7.53 |
| Usman *et al* (2014) [27] | 97.10 | 1.14 | 0.32 | 0.07 | 0.83 | 0.15 | 0.09 | 0.18 | 0.97 |
|  |
| **Chemical Properties of Ordinary Portland Cement** |
| Dabai *et al* (2009) [19] | 23.43 | 4.84 | 4.08 | 64.40 | 1.34 | 2.79 | - | 0.29 | 5.68 |

 The sum of SiO2 +Al2O3+Fe2O3 exceeding 70% (an indication of a Class N mineral admixture according to ASTM C618-03). SO3, maximum percentage of 4% as specified by the code, all the results presented are well below the threshold. A maximum Loss on Ignition of 10% is specified, however, only the result of Dabai *et al.,* (2009) [19] presented an excess of the requirement (18.25%). A high loss of ignition is indicative of prehydration and carbonation, which may be caused by improper and prolonged storage or adulteration during transport or transfer. Compounds such as calcium oxide and iron oxide responsible for strength, soundness and setting are present; magnesia which is responsible for unsoundness is less than 1.5%. Other compounds that might be found during XRF are due to geographical factors, year of harvest, sample preparation, and equipment used. Unburnt carbon existing in RHA is usually calculated by Loss on Ignition (LOI).

1. **COMBUSTION PROCESS AND OPTIMUM TEMPERATURE**

 Application of rice husk ash in concrete was patented in the year 1924. Up to 1978, all the researches were concentrated on utilizing ash derived from uncontrolled combustion Adisa (2013) [21]. Later, it was discovered that the type of RHA which is suitable for pozzolanic activity is amorphous rather than crystalline. In [22 - 23] they reported that the performance of these materials as pozzolans depends on the type and amount of amorphous silica content they contain which further depend on duration and calcination temperature. Similarly, Ramezanianpour and Malhotra (1995) [24] suggested burning temperature of 650°c for 60 minutes in the case of rice husk ash. In Cisse and Laquerbe (2000) [25] it was reported that uncontrolled temperature burning of rice husk tends to produce crystalline silica and consequently poor pozzolanic properties. However, biomass ash production at temperature below 1000°c yields high amorphous silica content, which does not contain too many harmful forms of silica. So the conversion of rice husk to ash for the purpose of pozzolan production can be done below 1000°c.

 The chemical analysis conducted by Dabai *et al.,* (2009) [19] on RHA obtained from Arkilla, Wamakko LGA in Sokoto State using a muffle furnace for 2 hours at 1100°c to obtain a finely divided ash revealed a silica content of 68.12%, alumina 1.01% and oxides such as calcium oxides 1.01% and iron oxide 0.78% responsible for strength, soundness and setting of the concrete. It also contain high amount of magnesia 1.31%. From the study of Fabiyi (2013) [4] rice husk from a mill in Akure, Ogun State was collected, processed by air drying prior to conversion to ash. It was ashed at 800°c in an enclosed barrel until the entire husk turned to ash (approximately 2 hours).

 An investigation by Olamide and Oyewale (2012) [26], subjected rice husk to calcination for temperature range of 50 - 750°c to determine its characteristics temperature. Characterization was obtained via highest Specific Surface Area (SSA) and highest amount of silica were observed which was 700°c. They concluded that during conversion of rice husk to rice husk ash, optimal silica was produced at temperature of 700°c with highest specific surface area (see table 5). At 750°c, there was decrease in the amount of silica obtained.

**Table-5:** Chemical Constituents of Raw Rice Husk Ash using AAS Analysis at 400-750°c [26]

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Temp (°C) | SiO2 (%) | Fe2O3 (%)  | Zn (%) | Mn (%) | CaO (%) | MgO (%) | Na2O (%) | K2O (%) | LOI (%) | SSA (m2/g) |
| 400 | 97.425 | 0.370 | 0.003 | 0.059 | 0.203 | 0.180 | 0.880 | 0.880 | 1.71 | 150 |
| 500 | 97.386 | 0.400 | 0.015 | 0.034 | 0.185 | 0.180 | 0.900 | 0.900 | 0.67 | 75 |
| 600 | 97.464 | 0.460 | 0.003 | 0.004 | 0.029 | 0.260 | 0.890 | 0.890 | 1.33 | 125 |
| 700 | 97.504 | 0.410 | 0.009 | 0.038 | 0.039 | 0.110 | 0.880 | 1.010 | 2.33 | 216.6 |
| 750 | 97.397 | 0.390 | 0.007 | 0.038 | 0.038 | 0.290 | 0.920 | 0.920 | 0.92 | 100 |

 Similarly, Usman *et al.,* (2014) [27] carried out determination of silica potential using Girei rice husk ash Adamawa State at temperatures of 500, 600, 700, 800 & 900°c. The ash was found to contain highest percentage of silica (97.10%) at 700°c. Increase in ash content with an increase in temperature can be attributed to the effect of shrinkage of the burning husk due to reactivity and its pozzolanic properties. Also, the carbon content present in the ash decreased with an increase in ash content Otaru *et al.,* (2013) [28].

 Combustion type (open air burning or using controlled combustion in a furnace) was also noted, [19] was conducted at a controlled temperature of 1100°c using furnace; Abalaka and Okoli (2013) [16] used charcoal fired incinerator at a temperature of 758°c while Usman *et al.,* (2014) [27] incinerated his rice husk ash at a temperature of between 600 - 900°c in a laboratory fabricated furnace. The work of [29 - 30], used open air burning to incinerate the rice husk ash. As it can be seen, there is a significant variation between the controlled burning using fabricated furnace and the open air burning. Open air burning produce less amount of silica, unlike the controlled burning where values as much as 97.1% was obtained by Usman *et al.,* (2014) [27].

1. **CHEMICAL REACTION OF RHA**

 When incinerated at right temperature, rice husk ash is primarily composed of amorphous silica; however, when burnt in an uncontrolled manner, the ash which is essentially silica is converted to crystalline forms and becomes less reactive. Reactivity is enhanced by increasing the fineness of the reacting materials. The work of Prasad *et al.,* (2001) [31] reported that the reactivity of RHA is attributed to its high content of amorphous silica and its porous nature. The filler effects of fine RHA particles also results in improvement in mechanical properties of concrete containing RHA Bui *et al.,* (2005) [11], The process of cement hydration starts as soon as water is added to cement and complex silicates are formed. C-S-H is the major hydration product responsible for the strength properties of concrete. According to Abalaka and Okoli (2013) [16], curing of concrete is important in promoting cement hydration by reducing moisture loss from the concrete to the atmosphere and providing water needed for the hydration of C-S-H gel. For curing to be beneficial to concrete, it should start as soon as concrete hardens, since the detrimental effect is irreversible (ACI, 1991). In addition to increasing the strength of concrete, proper curing reduces the porosity and provides a fine pore size distribution in concrete microstructure Alamri (1988) [32]. However, when a mineral admixture like RHA is added to concrete, curing conditions could affect strength and concrete microstructure differently.

 Chemical effect of RHA is mainly due to the pozzolanic reactions between the amorphous silica of RHA and calcium hydroxide (C-H) produced by the cement hydration to form calcium silicate hydrate (C-S-H). The lime in the cement reacts with the silica in the RHA to produce C3S and C2S, the hydration products of these two compounds are tobermorite gel and calcium hydroxide. The tobermorite particles are responsible for the cementing properties as well as other important engineering properties such as strength and shrinkage

 CaO+H2O→Ca(OH)2 [Eq. 1.]

SiO2+Ca(OH)2→CaO.SiO2.H2O [Eq. 2.]

 The physical effect which can also be considered as filler effect is the RHA particles increase the packing effect of the solid materials by filling the spaces between the cement grains in much the same way as cement fills the spaces between fine aggregates. Moreover, small particles of additions generate a large number of nucleation sites for the precipitation of the hydration products. This will accelerate the reactions to form smaller C-H crystals. RHA reduces the number of large pores and increases the probability of transforming the continuous pores into discontinuous ones, making the microstructure of the paste more homogeneous and denser.



**Fig-1:** BSE photomicrograph of raw RHA (x250) [16]

 According to Birnin-Yauri (2009) [33] as reported in [19], when water is added to cement the hydration starts, and in the presence of RHA, there is competition for the added water between SiO2 and other cement materials. Since the SiO2 is finer, it absorbs the water first before the commencement of the hydration of the other cement materials. This therefore, explains the retardation effect of the RHA on the setting time. Also, Oyetola and Abdullahi (2006) [3] when they investigated the use of rice husk ash in low-cost sandcrete blocks concur that as rice husk ash replaces cement, the rate of reaction reduces, and the quantity of heat liberated also reduces leading to late stiffening of the paste.

1. **CEMENT REPLACEMENT WITH RHA**

 The work of Oyekan and Kamiyo (2007) [29], replacing cement with high volume of RHA could be economically counterproductive for local sandcrete block manufacturers, thereby defeating the aim of the substitution which is to reduce the unit cost of the block. Their research investigated the effect of partially replacing cement with Nigerian RHA on the structural, thermal and hygrothermal properties of sandcrete blocks in the percentage range 5 - 30% at intervals of 5%. From Cisse and Laquerbe (2000) [25], they observed that on sandcrete block, the mechanical resistance obtained when unground ash was added increased in performance over the classic mortar blocks. Their research lead to the production of lightweight sandcrete blocks with insulating properties at a reduced cost.

 The work of Okpala (1993) [34] partially substituted cement with RHA in the percentage range of 30 - 60% at intervals of 10%. His results revealed that a sandcrete mix of 1:6 (cement/sand ratio) required up to 40% cement replacement and a mix of 1:8 ratio required up to 30% to be sufficient for sandcrete block production in Nigeria. In Ettu *et al.,* (2013c) [35],it was reported that the compressive strength of OPC-RHA blended cement composites at all percentage replacements of OPC and RHA were much lower than the control values at 3 - 21 days, but increased to become comparable to even greater than the control values at 50 - 90 days.

1. **STRENGTH RESULTS IN CONCRETE**

 Addition of RHA in concrete has been reported in various literatures in Nigeria with the optimum percentage in the range of 15 – 30% rice husk ash for OPC. The work of Dabai *et al.,* (2009) [19] on concrete mixes involves the replacement of cement by RHA at five levels (0, 10, 20, 30, 40, and 50%) at a curing age of 3, 7, 14 and 28 days. The compressive strength of cubes at 10% replacement ranged from 12.6 MPa - 36.3MPa and increased with age of curing, but decreased with increase in RHA content for all mixes. In Akeke *et al.,* (2013) [14], their research experimentally carried out to investigate the effect of introducing rice husk ash as a partial replacement of OPC on the structural properties of concrete. It was found to have a compressive strength of 33 - 38.4MPa range at replacement percentages of 10 - 25% in a mix ratio of 1:1.5:3. Variation of compressive strength with RHA reported by Oyekan and Kamiyo (2007) [29] showed that the highest compressive strength for the concrete cubes was obtained at RHA content of 5% in the mix; strength of 29.35 N/mm2, representing a 16.8% increase over the strength obtained at zero percent ash content in the mix. As RHA content increased, the compressive strength of the concrete cubes decreased. Initial strength gain could be attributed to lime (CaO) in the cement reacting with silica in the RHA producing calcium silicate compounds. As the percentage of RHA increased, the amount of cement available for the hydration process decreased with a consequent reduction in the strength of cubes.

 Tsado *et al.,* (2014) [30] found that the highest compressive strength obtained for replacement samples of RHA was in 10% RHA at 30.58N/mm2 while 26.51N/mm2 and 17.68 N/mm2 were obtained for 20% and 30% replacement of RHA for OPC respectively. Similarly, Abalaka and Okoli (2013) [16] reported that the compressive strength loss of uncured cubes was attributed to moisture loss and self-desiccation in the concrete cubes containing 5% RHA that were water cured at 90 days had compressive strength higher than control. Compressive strength of uncured cubes containing 0, 5, 10, 15% RHA at a w/c ratio of 0.45, 0.50 and 0.55 were less than control, water cured cubes had compressive strength higher than control. They concluded that, pozzolanic reactions in concrete results in the formation of CSH gels that requires more water to hydrate, these reactions inevitably resulted in higher demand for hydration water. This water is supplied by curing, hence, the higher compressive losses recorded for uncured specimen containing RHA when compared to specimens uncured without RHA.

**Table-6:** Effect of curing conditions on compressive strength of concrete containing optimum percentage of RHA replacement [16]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Free w/c | RHA | Plasticizer (l/m3) | Slump (mm) | Uncured Compressive strength (N/mm2) | Water cured Compressive strength (N/mm2) |
|  |  |  |  | 3-D | 7-D | 14-D | 28-D | 90-D | 3-D | 7-D | 14-D | 28-D | 90-D |
|  | 0% | 8.3 | 30 | 29.43 | 30.85 | 31.91 | 32.84 | 32.95 | 36.04 | 40.02 | 47.38 | 49.49 | 49.95 |
| 0.30 | 5% | 10.3 | 7 | 21.13 | 23.83 | 22.69 | 27.14 | 27.19 | 30.93 | 38.43 | 41.39 | 44.12 | 50.42 |
|  | 0% | 6.7 | 73 | 29.03 | 34.24 | 36.64 | 38.86 | 39.50 | 35.42 | 41.68 | 45.73 | 52.71 | 61.71 |
| 0.35 | 5% | 7.2 | 106 | 37.63 | 41.60 | 48.25 | 48.33 | 49.08 | 22.55 | 37.97 | 38.64 | 50.84 | 51.98 |
|  | 0% | 2.5 | 120 | 28.79 | 30.36 | 33.60 | 34.78 | 35.01 | 32.49 | 34.95 | 40.42 | 44.53 | 49.96 |
| 0.40 | 5% | 2.7 | 137 | 28.45 | 32.71 | 33.13 | 35.51 | 38.75 | 30.39 | 35.93 | 39.04 | 40.72 | 45.01 |
|  | 0% | 1.2 | 200 | 22.13 | 29.96 | 31.00 | 33.40 | 33.34 | 23.82 | 27.68 | 33.69 | 33.94 | 40.11 |
| 0.45 | 10% | 1.7 | 130 | 23.42 | 28.93 | 31.55 | 34.30 | 34.60 | 28.30 | 34.24 | 37.51 | 41.06 | 46.09 |
|  | 0% | 0 | 200 | 19.19 | 20.45 | 25.54 | 25.79 | 26.76 | 20.89 | 24.18 | 28.13 | 30.39 | 34.85 |
| 0.50 | 15% | 0 | 20 | 20.32 | 22.99 | 25.47 | 29.94 | 31.38 | 22.10 | 27.58 | 30.05 | 35.85 | 42.42 |
|  | 0% | 0 | 200 | 13.29 | 16.25 | 18.56 | 20.39 | 21.21 | 15.20 | 16.99 | 21.01 | 21.34 | 26.37 |
| 0.55 | 5% | 0 | 200 | 13.55 | 16.34 | 20.70 | 23.28 | 22.15 | 15.57 | 17.91 | 22.85 | 25.33 | 28.39 |

 The work of Ettu *et al.,* (2013a) [36] investigated the strength characteristics of binary blended cement concrete made with OPC and agricultural by-products in south-eastern Nigeria. The result is presented in the table below:

**Table-7:** Result of compressive strength of concrete containing RHA

|  |  |  |  |
| --- | --- | --- | --- |
| **References** | **RHA: OPC** | **W/C ratio** | **Compressive strength (MPa) of RHA concrete in days** |
| **3** | **7** | **14** | **21** | **28** | **50** | **90** |
| **Ettu *et al.,* (2013a) [36]** | 00:100 | 0.6 | 8.00 | 14.10 | 21.60 | 22.30 | 23.20 | 23.70 | 23.80 |
| 05:95 | 5.40 | 10.00 | 18.30 | 22.40 | 25.70 | 28.50 | 30.20 |
| 10:90 | 4.90 | 9.50 | 18.00 | 21.80 | 22.90 | 25.20 | 27.30 |
| 15:85 | 4.40 | 8.40 | 15.80 | 19.30 | 21.20 | 24.30 | 26.40 |
| 20:80 | 3.70 | 7.50 | 12.00 | 16.00 | 18.30 | 22.10 | 23.60 |
| 25:85 | 3.50 | 7.30 | 11.30 | 14.40 | 16.40 | 20.50 | 22.50 |
|  |
| **Abalaka and Okoli (2013) [16]** | 00:100 | 0.55 | 15.75 | 19.91 | 21.82 | 24.20 | 24.83 | - | 28.84 |
| 05:95 | 15.26 | 18.80 | 21.46 | 24.02 | 26.56 | - | 30.75 |
| 10:90 | 16.29 | 19.72 | 23.24 | 26.09 | 28.36 | - | 32.28 |
| 15:85 | 17.56 | 22.58 | 25.71 | 28.26 | 30.77 | - | 34.34 |
| 20:80 | 17.54 | 20.68 | 26.29 | 28.31 | 32.28 | - | 37.20 |
| 25:85 | 15.65 | 17.19 | 23.69 | 25.47 | 25.61 | - | 30.19 |

 It can be seen that the OPC –RHA binary blended cement concrete consistently has higher strength, its value at 5% replacement of OPC becomes marginally greater than the control value at 21 days of curing and continue to increase more and more than the control at later ages of hydration. Also**,** Ettu *et al.,* (2013a) [36] reported that for concrete, at 90 days curing, 5% RHA attained 111% of the control strength, 15% RHA attained 98%, 35% attained 80% and 50% attained 62% of the control strength.

1. **STRENGTH RESULTS IN MORTAR, BRICKS & BLOCKS**

 The work of Oyetola and Abdullahi (2006) [3] investigated the potential utilization of RHA in sandcrete blocks in Minna, Niger State. 150mm x 450mm hollow sandcrete blocks were made with a mix ratio of 1:8 using absolute volume method mix design (to select the most suitable materials i.e. cement, RHA, sand and water) and tested at curing days of 1, 3, 7, 14, 21 and 28 days at 0, 10, 20, 30, 40 and 50% replacement levels. In Dabai *et al.,* (2009) [19] the results of compressive strength test carried out on six mortar cubes were presented, the strength of blocks for all the mix increases with age at curing and decrease as the RHA content increases. The best strength was obtained with percentages of cement replaced by 10% RHA and decreased appreciably as RHA increased. However, as they noted, the highest strength obtained was at 28 days curing with 10% replacement (36.3 MPa).

 The work of Ettu *et al.,* (2013c) [35] observed that for sandcrete blocks, at 90 days of curing, 5% RHA attained 105% of the control strength, 15% RHA attained 99%, 35% RHA attained 71% and 50% RHA attained 57% of the control strength.

**Table-8:** Compressive strength of blended OPC-RHA cement sandcrete [35]

|  |  |
| --- | --- |
| Age (days) | Compressive Strength (N/mm2) for RHA |
| 0%  | 5% | 10% | 15% | 20% | 25% |
| 3 | 2.70 | 1.90 | 1.80 | 1.60 | 1.50 | 1.50 |
| 7 | 5.00 | 3.00 | 3.00 | 2.50 | 2.30 | 2.20 |
| 14 | 7.10 | 4.40 | 4.00 | 3.50 | 3.20 | 2.80 |
| 21 | 8.00 | 5.20 | 4.80 | 4.00 | 3.80 | 3.20 |
| 28 | 9.30 | 7.60 | 6.40 | 5.80 | 5.00 | 4.10 |
| 50 | 9.70 | 9.80 | 8.90 | 8.00 | 7.10 | 6.20 |
| 90 | 10.30 | 11.30 | 10.80 | 10.10 | 9.50 | 8.80 |

 In Oyekan and Kamiyo (2007) [29] the strength test results clearly showed that RHA does not appreciably enhance the compressive strength of the conventional sandcrete block.



**Fig-2:** Plot of Compressive Strength against age of sandcrete blocks [29]

 The blocks actually decreased in strength as the RHA percentage content in the mix increased. For the 450mm x 150mm x 225mm blocks, compressive strength increased at 5% RHA content in the mix. This they attributed to the reaction between lime with silica in the presence of moisture; another possible reason they noted for the low strength is the type of burning used to produce the ash. The burning process has been known to affect the quality of the ash produced. Open field burning was used in the investigation and the ash obtained probably contained a high percentage of unburnt carbon with a consequent reduction in the pozzolanic activity.

1. **FLEXURAL & TENSILE STRENGTHS**

 The work of Akeke *et al.,* (2013) [14] performed studies on the flexural properties to determine their moduli of rupture as well as its tensile strength characteristics for the determination of cracking values. The values obtained at 28 days are 3, 2.5 and 2.4 N/mm2 while the tensile strength values are 1.94, 1.17 and 0.91 N/mm2 at replacement percentages of 10, 20 and 25%. In Abalaka and Okoli (2013) [16] the split tensile strength indicates only marginal increase for cylinder containing RHA at w/c ratio of 0.40, 0.45 and 0.50. For uncured cylinders, marginal tensile strength increase was recorded at w/c ratio of 0.50 only.

**Table-9:** Tensile strength and durability properties of air cured concrete containing RHA [16]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| w/c | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 |
| RHA (%) | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 10 | 0 | 15 | 0 | 5 |
| Tensile Strength (MPa) | 3.074 | 2.125 | 3.153 | 2.272 | 2.911 | 2.830 | 2.994 | 2.764 | 2.238 | 2.406 | 1.845 | 1.844 |
| Sorptivity | 1.524 | 2.099 | 1.605 | 1.465 | 2.209 | 1.296 | 2.319 | 2.135 | 3.829 | 3.284 | 5.449 | 5.431 |
| Ka (m2/s) x10-4 | 8.837 | 13.376 | 11.412 | 6.275 | 20.332 | 10.068 | 25.101 | 20.031 | 46.883 | 36.145 | 78.047 | 78.024 |

 However, tensile strength of water cured cylinders was recorded to be generally higher than that of uncured cylinders, due to improved hydration. Higher w/c ratio mixes generally recorded lower tensile strength compared to lower w/c ratio mixes.

**Table-10:** Tensile strength and durability properties of water cured concrete containing RHA [16]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| w/c | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 |
| RHA (%) | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 10 | 0 | 15 | 0 | 5 |
| Tensile Strength (MPa) | 4.274 | 4.024 | 3.978 | 2.823 | 3.557 | 4.200 | 3.760 | 4.267 | 3.516 | 3.567 | 2.953 | 2.749 |
| Sorptivity | 0.906 | 0.994 | 0.920 | 1.296 | 1.274 | 0.876 | 1.657 | 1.458 | 1.951 | 1.620 | 2.393 | 1.841 |
| Ka (m2/s) x10-4 | 4.016 | 4.358 | 4.134 | 4.016 | 4.786 | 5.466 | 9.036 | 6.875 | 11.950 | 9.545 | 11.955 | 9.649 |

1. **SORPTIVITY & COEFFICIENT OF WATER ABSORPTION**

 Sorptivity has been defined by Ganesan *et al.,* (2008) [37] as a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. The value of the sorptivity can be measure by

 І= $S/√t$ [Eq. 3.]

Where I is the cumulative water absorption per unit are of the surface (m3/m2)

S is the Sorptivity $(\frac{m}{\sqrt{t}})$ and t is the elapsed time (s) as reported in Stanish et al., (1997)

 Coefficient of water absorption is a measure of permeability of concrete; this is determined by measuring water uptake in dry concrete in a time of 1 hour Ganesan *et al.,* (2008) [37]. It can be calculated using the following formula:

$Ka=\left[Q/A\right]$2 $1/t$[Eq. 4.]

Where Ka is the coefficient of water absorption (m2/s)

Q is the quantity of water absorbed (m3) by the dry oven in time t

t is 3600 seconds and A is the surface area (m2) through which water was absorbed.

 The work of Abalaka and Okoli (2013) [16] tested for Sorptivity at interval of 1, 2, 4, 8, 10, 20, 30, 60 and 90 minutes. In water absorption, the concrete was heated in an oven at 98°c until a constant mass was attained at 10 days, and then gradually allowed to cool for 24 hours at room temperature. The coefficient of water absorption of the specimen at 90 days was calculated. Sorptivity and coefficient of water absorption of cured specimens were lower than that of uncured specimens at the entire w/c ratio investigated. As curing improves hydration in addition to CSH gels other solid hydration products develop in concrete that tends to produce a more compact microstructure for water cured specimens compared to uncured specimens. Significant reductions in sorptivity and water absorption were recorded for cubes containing RHA at higher w/c ratio mixes.

 Also, Abalaka and Okoli (2013b) [12] observed increase in saturated water absorption over control for all the cubes containing RHA; they attributed that to the hygroscopic nature of the RHA. Compared to the control, coefficient of water absorption for concrete cubes containing RHA generally decreased at lower RHA content. Increase in water absorption and sorptivity values were recorded at higher RHA replacements. Significant reductions in Sorptivity were only recorded for specimens containing RHA at w/b ratio of 0.55.

**Table-11:** Effect of RHA on durability properties of normal strength concrete at w/b ratio of 0.55 [16]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RHA (%) | Slump (mm) | Saturated water absorption (%) | Coefficient of water absorption, Ka (m2/s) x10-10 | Sorptivity, I (m√t)x10-5 |
|  |  | 28 days | 28 days | 28 days |
| 0 | 7 | 6.08 | 5.98  | 3.06 |
| 5 | 12 | 6.72 | 3.36 | 3.40 |
| 10 | 5 | 6.47 | 3.67 | 1.77 |
| 15 | 4 | 7.20 | 1.91 | 1.69 |
| 20 | 2 | 7.11 | 4.00 | 2.20 |
| 25 | 0 | 6.52 | 10.00 | 2.71 |

 Similarly, Oyekan and Kamiyo (2011) [15] observed that the value of Sorptivity of the sandcrete blocks gradually increases with the percentage content of RHA. This implies that blocks made with cement partially replaced with RHA are not suitable for drainage channels construction, but could be useful for partitioning of building spaces.

1. **CONCLUSION**

 The use of RHA in cement, concrete and mortar has been experimented with some encouraging results.

* The initial and final setting time increased with increase in percentage replacement (Tsado *et al.,* 2014 [30]). Incorporation of RHA in concrete resulted in increased water demand and enhanced strength (Ephraim *et al.,* 2012 [13]).
* Partial replacement of cement by 15% RHA saves N70, 000 ($ 430.35) of the cost of construction and thus makes housing relatively affordable (Adisa, 2013 [21]).
* Rice husk ash as partial substitute of cement in the production of cement-based products will improve their performance, and 10 – 20 % replacement has been proposed as optimum replacement level (Dabai *et al.,* 2009 [19]; Oyetola and Abdullahi, 2006 [3]).
* In sandcrete blocks, compressive strength performance is only enhanced at 10 % replacement for improved structural performance. Concrete made with 20 - 25% RHA content is suitable for low-cost housing development (Oyekan and Kamiyo, 2007 [29]). Density of concrete decreased as percentage replacement of OPC increased (Tsado *et al.,* 2014 [30]).
* Compressive strength increases with increase in curing period and decreases with increase in all the ash substitution. There was a sharp decrease in compressive strength beyond 20% (Ephraim *et al.,* 2012 [13]).
* Strength variation of OPC-RHA composites suggests that with good quality control of the concreting process, 5% - 30% replacements could be suitable for reinforced concrete works, and 35% - 50% for minor works in concrete. Also, 5% - 20% OPC replacement with RHA could be used for light load-bearing sandcrete and soilcrete works, while 25% - 50% could still be suitable for non-load bearing works (Ettu *et al.,* 2013c [35])

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