Fire resistance evaluation of rice husk ash concrete

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Abstract

This paper studied the fire resistance of rice husk ash concrete. An experimental method was adopted as the research design in this work, which produced one hundred and eighty four (184) concrete specimens with the addition of rice husk ash in weighted percentages of 5%, 10% and 15% respectively. They were cured and tested at 7 days, 28 days, 30 days, 60 days, 90 days, 120 days, 150 days and 200 days. After the targeted curing days, the specimen were exposed to temperatures of 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C and 700 °C for 2 hours in a muffle electric furnace.

The results show that the pozzolanic concrete and control concrete fire resistance ranged between (60%-96%) for (200 °C-400 °C), (41%-55%) at 500 °C, and (13%-26%) for (600 °C-700 °C). It is concluded that 5% weighted RHA concrete performs better in fire than others.

Keyword: Civil Engineering

1. Introduction

Fire resistance is defined as the ability of the structural member to withstand exposure to a fire without loss of load bearing function or ability to act as a barrier to spread a fire (Ashley, 2007). The fire resistance of concrete can also be defined as the residual compressive strength of the concrete after exposure to high temperature for specific time duration. According to BS 8110 part 1 (1997), Table 3.4 specifies the fire rating of up to four hours.
Two zones can be determined. The normal zone with one hour fire resistance and the safe zone with two hours fire resistance (www.besix.com). Structures need to be designed so that in case of fire, safety of the structure is guaranteed and that there is enough time for the users to escape or help can be given (www.besix.com). Understanding the behaviour of real fire in buildings and their correlation with experimental and standard fire tests has improved recently.

Saad et al., (1998); Xu et al., (2001); Savva et al., (2005); Morsy et al., (2008); reported in their studies that high temperatures will affect concrete compressive strength, elasticity, density and surface appearance. However, concrete fire resistance improvement has become an interesting field for many researchers. According to the studies of Demirboga et al., (2007); Aydin (2008); Wang (2008), they reported that one of the methods of improving fire resistance of concrete is by cement replacement with pozzolanic materials. Kalifa et al., (2007); Xiao and Falkner (2006) reported in their studies that blended concrete is used extensively throughout the world because of their good performance. Limestone powder, rice husk ash, fly ash, ground granulated blast furnace slag and silica fume are the commonly used mineral additives in concrete (Aydın et al., 2008; Morsy et al., 2008).

Umran (2002) reported on the temperatures effect on some mechanical properties of concrete. Three temperature levels of 400 °C, 500 °C, 700 °C were chosen with four different exposure duration of 30 minutes, 1 hour, 1 hour 30 minutes, and 2 hours without loading it during heating. The specimens were heated and cooled under the same regime and tested after exposure to temperature at ages 30 days, 60 days, and 90 days. He found out that the fire resistances of the concrete were between 70%-85% at 400 °C, 59%-78 % at 500 °C and 43%-62 % at 700 °C respectively.

This was further collaborated by Habeeb (2000) who studied the effect of high temperatures on some mechanical properties of high strength concrete. The samples were exposed for periods one hour, two hours and four hours without imposing loads during exposure to temperature. The specimens were then cooled and tested for one day or one month after heating. He also concluded that the fire resistance of the concrete were between (90%-106 %) at 100 °C, (72%-103 %) at 300 °C, (55%-87 %) at 500 °C and (22%-66 %) between (600 °C-800 °C). The study concluded that exposure time beyond one hour had a significant effect on the residual compressive strength of concrete; however, the effect was diminished as the level of temperature increased.

Khoury (2000) studied the effect of fire on concrete and concrete structures. He found out that within 200 °C evaporable water were lost, between 200 °C-400 °C siliceous aggregates starts to weaken, between 400 °C-600 °C, Ca(OH)2 decomposes, between 600 °C-800 °C, the C-S-H decomposes and the load bearing capacity were lost. Above 1000 °C the concrete melts and exist as liquid.
However, depending upon the intended purpose of a structure, materials employed for both ordinary and high strength concrete, must satisfy certain fire resisting requirements as set out by the various standards (Mohammad et al., 2011). Li et al. (2004) pointed out that the retained compressive strength can be inferred primarily when combining changes in colour and temperature during fire.

Mineral admixture concrete is one of the most significant new materials available worldwide for construction and for rehabilitation purposes. Bouzoubaa et al. (2002) have shown that mineral admixtures such as blast furnace slag, fly ash and silica fume enhance the strength and durability of concrete. When these pozzolans react with cement, they form additional calcium silicate hydrates (C-S-H), which improves strength and durability of concrete (Igarashi et al., 2005).

The by-product of rice milling industry is called rice husk ash (RHA). During the growth of rice plant, it takes in silica from the soil and absorbs it into its structure (Smith and Kamwanja, 1986). The ash is obtained when the rice husk is burnt between 500 °C and 800 °C to produce a non-crystalline amorphous rice husk ash (Mehta and Monteiro, 1993).

When the rice husk is burnt, it produces relatively large proportions of ash which contains around 90% silica (Swamy, 1986). Its excellent pozzolanic properties are due to its high surface area and high silica content. Bahrami et al. (2017) reported on the extraction of crystalline and amorphous silica powder from rice husk using water as a liquid medium. They found out that monoliths from crystalline rice husk ash showed higher mechanical strength while monoliths from amorphous rich husk ash possesses higher surface area.

The production of improved hardened properties and durability of concrete was possible with rice husk ash (Safiuddin et al., 2012). Porosity decrease and improve compressive, tensile and flexural strengths of concrete were possible using rice husk ash blended concrete. Corrosion resistance and freeze-thaw durability of concrete were also enhanced (Zhang and Malhotra, 1996). Givi et al. (2010) reported in their studies that rice husk ash blended concrete and mortars have good workability. Rice husk ash was used to produce high-strength concrete (Ismaila and Waliuddin, 1996). In another study carried out by Zhang and Malhotra (1996) rice husk ash was also used to produce high performance concrete, using rice husk ash as one of the cementing material. Nehdi et al., (2003) reported further that rice husk ash can be used to produce normal-strength self consolidating concrete.

However, the mechanical properties of rice husk ash concrete exposed to elevated temperatures have not been widely studied. Most of the investigations have been focused on the effects of exposure time, cooling methods and loading conditions (Husem, 2006; Sancak et al., 2008; Balogun, 1986; Arioz, 2007; Chan et al., 2000). Unlike previous studies, this study tends to examine the performance of the binary blend of OPC/RHA.
pozzolanic blended concrete obtained from Edo State, Nigeria and also to evaluate its residual compressive strength characteristics when exposed to high temperatures.

2. Materials and methods

2.1. Research design

The study uses the experimental (quantitative) research design method to carry out this work. The laboratory work includes the experimental part and the control part. The experimental part contains the rice husk ash (RHA) in weighted percentages (wt %) of 5%, 10% and 15% replacement of cement in concrete called the pozzolanic part while the control part contains only the ordinary Portland cement (OPC) in concrete called the OPC control part. The experimental design is concerned about the investigation of the effect of high temperature (independent variable) on the residual compressive strength (dependent variable) of the pozzolanic part and the (OPC) control part.

The material used in the study comprises rice husk ash, Portland cement, 20 mm size of crushed coarse aggregate, fine aggregate and water. The tools used consisted of steel moulds (100 mm × 100 mm size), shovel, head pans and muffle electric furnace. The 100 mm × 100 mm steel moulds were used which conforms to the minimum standard of BS 1881-124: 1988 for concrete making. The rice husk was obtained in Ekpoma, Edo state, Nigeria.

The preparation of the rice husk test specimens follows the procedure as outlined by appropriate Standards (ASTM C311 2005). The ash was obtained by controlled burning of the rice husk with the help of a muffle furnace until the ash was produced at 500 °C for 5 hours. The standard sieves of 75 microns were used for the rice husk ash after grinding. The portion passing the sieve was adequate for the required degree of fineness that is 63 microns and below while the ash retained on the sieve were reground and sieved again. Setting time of the various mortar pastes were also carried out. The rice husk ash were now subjected to X-Ray Fluorescence (XRF) analysis to ascertain its chemical properties whether it conforms to ASTM C 618 (2008) minimum requirement for pozzolans usage in concrete.

However, the optimum blended cement concrete was exposed to temperatures ranging from 100 °C-700 °C for 2 hours duration in order to achieve a thermal steady state in the concrete specimen according to BS 8110 Part 1:Table 3.4 (1997). After the exposure to temperature, specimen were cooled at room temperature and crushed to obtain their respective residual compressive strength.

2.2. Population

The number of specimen produced for both the pre-test and post-test experiments were fifty six (56) concrete specimen and one hundred and twenty eight (128)
concrete specimen respectively totaling one hundred and eighty four concrete specimen altogether (184) of size 100 mm × 100 mm.

2.3. Data source

Data were sourced from various laboratory test conducted which includes the chemical analysis of rice husk ash (RHA) and ordinary Portland cement (OPC), specific gravity test, slump test, bulk density test, setting time test, compressive strength test and temperature test respectively.

3. Results and discussion

3.1. Chemical analysis of pozzolans using X-Ray Fluorescence (XRF)

Chemical analysis was carried out on samples of rice husk ash (RHA) and ordinary Portland cement (OPC) to reveal and compare their composition, and the results are shown in Table 1. The volumetric percentage compositions of the constituent compounds of rice husk ash (RHA) are compared to that of typical ordinary Portland cement (OPC). The results show that RHA contains most of the compounds known to have binding properties necessary for concrete work. The total percentages of iron oxide (Fe₂O₃), silicon dioxide (SiO₂) and aluminum oxide (Al₂O₃) in RHA were 89.6% which are more than the minimum of 70% specified for pozzolans by ASTM C618 (2008).

Table 1. Chemical volumetric composition of OPC and pozzolan using XRF analysis.

| S/N | Elemental Oxides         | Percentage composition by Volume |
|-----|--------------------------|----------------------------------|
|     |                          | RHA     | OPC     |
| 1   | Silica (SiO₂)            | 87.22   | 22.0    |
| 2   | Potassium oxide (K₂O)    | 1.12    | 0.4     |
| 3   | Calcium oxide (CaO)      | 2.12    | 62.0    |
| 4   | Aluminium oxide (Al₂O₃)  | 0.70    | 5.03    |
| 5   | Magnesium oxides (MgO)   | 1.18    | 2.06    |
| 6   | Iron oxide (Fe₂O₃)       | 1.68    | 4.65    |
| 7   | Sodium oxide (Na₂O)      | 0.20    | 0.19    |
| 8   | Manganese oxide (MnO)    | 1.06    | 2.06    |
| 9   | Sulphite (SO₃)           | 0.04    | 1.43    |
| 10  | Titanium oxide (TiO₂)    | 0.46    | -       |
| 11  | Loss on Ignition (LOI)   | 1.06    | -       |
3.2. Sieve analysis test

Sieve analyses were carried out in accordance with ASTM C136 (2014) methodology. The result of the sieve analysis of the fine aggregate, shown in Fig. 1 falls within zone 3 which makes it suitable for concrete.

3.3. Specific gravity test

The specific gravity test conducted were carried out in accordance with ASTM C127 (2015) methodology. The result of the RHA pozzolanic material shows 1.02 as stated in Table 2. This value is less than the value for OPC which is 3.15 which means RHA is lighter than OPC. However, the specific gravity of sand and granite were found to be 2.65 and 2.70 respectively which falls within the specific gravity range of 2.5–2.9 according to ASTM C127 (2015) standards for fine and coarse aggregate.

3.4. Densities of the binary blended concrete

The densities of the binary blended concrete were carried out according to ASTM C642 (2013) methodology and the results were presented in Table 3. Densities increased as curing ages increased for OPC concrete. However there was an increase for 5% to 15% RHA concrete between 30 days to 60 days and decreased at 90 days. It further increased between 120 days to 150 days for 5% and 10 % RHA concrete. These represent the filling of the pores in the concrete by the pozzolan making it denser than OPC concrete.

3.5. Discussion

3.5.1. Compressive strengths of binary blended concrete and OPC at different curing ages

The increase in percentages of rice husk ash (RHA) replacement reduces the compressive strength of concrete while increases in the curing ages increases the compressive strength of the concrete as shown in Table 4 and Fig. 2. When measured
with ordinary Portland cement (OPC) concrete, above 90 days of curing, the compressive strength for 5% weight of RHA and 10% weight of RHA replacements were 56.8% and 36.2% above the OPC concrete. These increases in compressive strength may be due to the hydration of more C-S-H and C-A-H between the OPC and the RHA pozzolan. Similarly Ettu, 2013 opined that pozzolans in concrete below 50 days has strength below normal concrete but above 50–90 days strength development is beyond normal concrete.

Table 4 and Fig. 2 have shown the results for the compressive strength in weighted percentages of 0%-15% RHA pozzolans replacement for the binary blended concrete
Table 4. Relationship between compressive strength and curing age of pozzolan at 23 °C.

| Age of Curing (Days) | Compressive Strength (N/mm²) |
|----------------------|-------------------------------|
|                      | 5% weight of RHA | 10% weight of RHA | 15% weight of RHA | Control (OPC) |
| 7                    | 8.5               | 7.2               | 1.2               | 9.4           |
| 28                   | 13.8              | 12.5              | 1.7               | 14.1          |
| 30                   | 15.5              | 21                | 2                 | 16            |
| 60                   | 18.5              | 21.5              | 3                 | 16.5          |
| 90                   | 29                | 25.2              | 5.5               | 18.5          |
| 120                  | 31                | 25.5              | 9                 | 18.5          |
| 150                  | 35                | 25.5              | 14.8              | 19.5          |
| 200                  | 40                | 27.2              | 24.2              | 22            |

Fig. 2. Relationship between compressive strength and curing period at 0%-15% weight of RHA replacement.

up to 200 days curing ages using 0.6 water/cement ratios. 5% weight of RHA concrete had a higher compressive strength when compared to OPC concrete above 60 days of curing. 10% weight of RHA concrete compressive strength was higher to the OPC concrete above 30 days of curing and lastly 15% weight of RHA concrete compressive strength was higher when compared to OPC concrete at curing periods above 200 days.

This behaviour may be due to the slow pozzolan-cement reactions according to Englehardt and Peng (1995). The optimum compressive strength of 40 N/mm² was obtained for 5% weight of RHA blended concrete at 200 days. The result shows that the compressive strengths of RHA blended cement composites increased with curing age and decreased with increase in percentage replacement of OPC with pozzolans. When compared to OPC concrete, the compressive strength of the RHA concrete is higher at longer curing durations. These results may have shown that cement
can be replaced up to 15% weight in binary pozzolanic concrete when cured up to 200 days.

However, the binary blend of rice husk ash at 5% weight replacement had the maximum compressive strength of 40.0 N/mm² at 200 days while the control (OPC) concrete compressive strength was 22.0 N/mm². This represents an increment of 81.8% of compressive strength over the control concrete at 200 days of curing. This depicts that the pozzolan-cement reaction increases at longer curing duration of the concrete thereby producing more C-S-H.

### 3.5.2. Effect of temperatures on the compressive strength of the blended concrete

Table 5 and Fig. 3 above show the results in weight percentages of 5%-15% RHA replacement of cement in concrete at 200 days of curing exposed to temperature of 100 °C-700 °C. The binary residual compressive strength decreases as the temperature increases for curing age of 200 days. The RHA concrete and OPC concrete fire resistance ranged between (60%-96%) for (200 °C-400 °C), (41%-55%) at 500 °C, and (13%-26%) for (600 °C-700 °C). However, 5% weight of RHA blended concrete showed good fire resistance ability up to 500 °C with a residual compressive strength of 21.8 N/mm² over the OPC concrete. Even at temperatures up to 700 °C, the 5% weighted RHA concrete still had an advantage in compressive strength over the OPC concrete. This may be due to the additional calcium silicate hydrates (C-S-H) produced from the cement-pozzolan reactions which improves strength and durability of concrete (Igarashi et al., 2005).

The 10% weight of RHA binary residual compressive strength decreases as the temperature increases at curing age of 200 days except for the 10% weight of RHA blended concrete which increased to 31.0 N/mm² at 100 °C. The increase in

### Table 5. Relationship between 200 days RHA residual compressive strength and temperature.

| Temperatures (°C) | 200 Days residual compressive strength (N/mm²) |
|-------------------|-----------------------------------------------|
|                   | 5% weight of RHA | 10% weight of RHA | 15% weight of RHA | OPC |
| 23                | 40.0                | 27.2                | 24.2                | 22.0          |
| 100               | 41.0                | 28.5                | 25.3                | 20.9          |
| 200               | 38.5                | 25.2                | 20.1                | 19.2          |
| 300               | 31.7                | 19.5                | 18.9                | 18.5          |
| 400               | 29.1                | 17.9                | 14.6                | 17.9          |
| 500               | 21.8                | 13.5                | 11.6                | 9.0           |
| 600               | 6.7                 | 4.1                 | 4.1                 | 5.8           |
| 700               | 5.4                 | 3.5                 | 3.3                 | 4.9           |
Compressive strength of the blended cement concrete specimens up to 200 °C may be due to the reaction of the admixture (RHA) with the free lime to produce more Calcium Silicate Hydrate (C-S-H) and Calcium Aluminate Hydrate (C-A-H) which deposit in the pore system (Adefemi et al., 2013). The 10% weight of RHA blended concrete showed good fire resistant ability only between 100 °C-200 °C, before it collapses above 200 °C. There was a gradual decrease of the residual compressive strength at 15% weight of RHA pozzolanic concrete as the temperature increases, at curing age of 200 days except at 100 °C, which increased from 24.2 N/mm² to 25.3 N/mm².

The control’s residual compressive strength decreased steadily from 22.0 N/mm² to 4.9 N/mm² when exposed to temperatures ranging from 100 °C-700 °C. The residual compressive strength’s decrease with temperature may be due to the dehydration of Calcium Carbonate (CaCO₃) at about 600 °C producing Calcium Oxide (CaO) and water (H₂O) (Khoury, 2000).

4. Conclusion

The following conclusions can be made from this study:

1. The agricultural ash used in this work which was rice husk ash (RHA) is reasonably pozzolanic since they contain silica which reacts with calcium to produce extra calcium silicate hydrate (C-S-H) paste which is the strength compound of concrete.

2. The compressive strength values of the binary blended cement concrete consistently decrease with increase in percentage replacement of OPC with pozzolans.

3. The 200 days compressive strength of 5% weight of RHA and 95% weight of OPC binary blended cement concrete gave the optimum value of 40.0 N/mm² when compared to other percentages replacement of RHA.
4. OPC can be replaced with RHA pozzolans up to 15% by weight in the binary blended cement concrete of grade 20 when cured up to 200 days without reducing its compressive strength.

5. 5% weight of RHA binary blended cement concrete shows its fire resistant ability when exposed up to 500 °C at 200 days curing age.

6. Rice husk ash (RHA) can find its usefulness in industries where productions of fire insulating materials are of a great concern.

7. The 5% weighted RHA blended concrete still had an advantage in compressive strength, over the OPC concrete when subjected to temperatures up to 700 °C for two hours.

**Declarations**

**Author contribution statement**

Richie I. Umasabor: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

John O. Okovido: Analyzed and interpreted the data.

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The authors declare no conflict of interest.

**Additional information**

No additional information is available for this paper.

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