

Effect of Rice Husk Ash on the Durability Properties of Concrete Subject to Aggressive Chemical Environment

Agboola Shamsudeen Abdulazeez¹, Bappah Hamza², Adamu Sani Abubakar³ and Tukur Mohammed⁴

¹Research Student, Abubakar Tafawa Balewa University Bauchi, Nigeria. ²Department of Building, Nigeria Army University Biu, Borno, Nigeria. ³Department of Building, Abubakar Tafawa Balewa University Bauchi, Nigeria. ⁴Tertiary Education Trust Fund (TETFUND) Nigeria.

Corresponding author: bldrshams@gmail.com

Abstract

One of the most common material used for construction purpose worldwide is concrete, with its major constituent being cement. The production of this cement leads to overburden on natural resources used in its production, and its production also results in environmental pollution as CO₂ gas is constantly emitted. The construction industry is increasingly finding an alternative to the use of environmentally friendly materials in order to meet the sustainable aspect required by modern technology. Consequently, for the last two decades, the increase global warming due to the extensive use of Portland cement have raised concerns and led to the expansion of this concept of alternative cementitious materials. However, too much emphasis is given to compressive strength as a measure for quality index with little or no consideration given to durability property. The concrete can be made strong but not durable especially when it is subjected to chemical aggressive environments. The main purpose of this study was to evaluate the durability properties of concrete produced with rice husk ash as partial cement replacement and cured in H₂O, H₂SO₄ and MgSO₄ curing environment and tested at 7, 14, 21, 28, 56 and 90 days. The water-cement ratios were maintained at 0.50, with variable RHA replacement ratio which range in between 0% to 30% of cement by weight. The results show that at 28 days' hydration period, 0% replacement shows higher strength while above 28 days 5% and 10% cement replacement with RHA shows improved strength. The result also shows an increase in compressive strength of about 1.35%, 2.11%, 2.15% for concrete samples with 10% RHA replacements than 0% replacements cured in normal environment (H₂O), H₂SO₄ and MgSO₄ respectively, at 90 days. Concrete samples made with 10% RHA replacements have high resistance to abrasion and less sorptivity than other replacements in both normal water and chemical aggressive environments at 90 days. Overall, the results showed that RHA is a highly water absorbing material, which also act as an internal curing agent concrete. The utilization of RHA in OPC production improves compressive, splitting tensile strength, flexural strength and durability of concrete. Therefore, it is recommended to be used to produce a strong, dense and durable concrete which can be used both in normal (H₂O) and chemically aggressive environments.

Keywords: Concrete; rice husk ash (RHA); MgSO₄, H₂SO₄; supplementary cementitious materials (SCM).

Introduction

The construction industry is increasingly changing and moving to the use of environmentally friendly materials in concrete production in order to meet the sustainability requirement of modern technology. Concrete refers generally to the use of Portland cement and other related materials, such as water, fine and coarse aggregates;

when mixed together, is capable of producing concrete with the desirable properties (Abdulazeez, 2019). Portland cement concrete is, after water, is the most utilized material in the world. Concrete is also the most versatile construction material in the world due to its excellent properties and advantages. It can be modified, engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used as they are. Concrete is a composite material made up of various constituents. The properties and characteristics of the composite are functions of the properties of the constituent materials' as well as the various mix proportions (Meyer, 2013). Concrete is termed as an artificial stone which is obtained after the hardening of the homogenous mixtures of cement, water, aggregates and sometime additives and or admixture to modify the fresh and hardened properties of concrete. The material composition of concrete need to be established in order to assure the performance and durability of building elements. Since last decades, the increasing issue of global warming have raised concerns on the extensive use of Portland cement due to the high emission of carbon dioxide gas associated with its production. According to Mccaffrey, (2002), the production of one ton of Portland cement generates and releases approximately one ton of carbon dioxide gas into the atmosphere. This generation of carbon dioxide can be explained as cement is composed of clinker, gypsum, and clay; and in order to make cement, these ingredients are "cooked" at temperatures up to 1500°C, which is responsible for the majority of the CO₂ emission. Basically, during the "cooking" time, calcium is de-carbonated while releasing CO₂ that represents 60% of the quantity freed throughout the production of Portland cement. Obviously, the production of ordinary Portland cement is responsible for two ecological problems: it consumes a lot of energy and as mentioned earlier, the process depends on cooking the constituents of gypsum and clay, at high temperature, and these releases a large amount of carbon dioxide. Consequently, designing environmentally friendly concrete structures using basically OPC, in which the generation and emission of CO₂ can be limited during their life cycle, seems quite difficult.

The use of supplementary cementitious materials offers promising signs for a change in the way of producing concrete. Supplementary cementitious materials such as fly ash, rice husk ash, corn cob ash, volcanic ash, metakaolin, etc., are alternative binders to cement in concrete production. One of the practical solutions to economize cement is to replace it with industrial by-products and agricultural wastes as supplementary cementitious materials. A considerable amount of work has been reported in the literature on how to use agricultural waste products as supplementary cementitious materials (Mehta, 2000). Ideally, the development SCM serves three separate purposes simultaneously. On one hand, waste have an inherent negative value, as they require disposal, typically in landfills, subject to tipping fees that can be substantial. When used in concrete, the material's value increases considerably. The increase in value is referred to as "beneficiation". As this supplementary cementitious material (SCM) replaces a certain fraction of the cement, its market value may approach that of cement. The use of SCM reduces the cost of

construction and could make it more affordable to poor masses. Another benefit is the reduction of environmental costs of cement production in terms of energy use, depletion of natural resources, and air pollution. Also, the tangible as well as intangible costs associated with landfilling the original waste materials are eliminated. Of the SCMs available in cement replacement, rice husk ash is a highly pozzolanic material which is rich in amorphous silica and have shown some high utilization in concrete application.

Different researchers made study on RHA effect on concrete and it was concluded that RHA increases compressive strength. The performance of RHA in concrete is strongly influenced by its physical, mineralogical and chemical properties. Rice, Paddy (*Oryza sativa*) is grown on every continent except Antarctica and the extent of paddy cultivation covers about 1 percent of the earth's surface. More than half of the world's population depends on rice as a staple food and it ranks second to wheat in terms of cultivation area and production. The quantum of global production of paddy is close to 650 million tons per annum. Rice is an important food crop produced in large quantity in the savannah belt of Nigeria and West Africa. It ranks amongst the three major grain crops growing particularly in the northern states of Nigeria. Rice husk is a potential material, which is amenable for value addition. The usage of rice husk is either in its raw form or in ash form. Most of the husk from the milling is either burnt or dumped as waste in open fields and a small amount is used as fuel for boilers, electricity generation, bulking agents for composting of animal manure (Bonzeoak, 2003). The exterior of rice husk is composed of dentate rectangular elements, which themselves are mostly composed of silica coated with a thick cuticle and surface hairs. The mid region and inner epidermis contain little silica (Bonzeoak, 2003).

Researches have shown that small amounts of SCM have always been acceptable as cement replacements, what more if the SCM have high pozzolanic properties, in which it will not only impart technical advantages to the resulting concrete but also enable larger quantities of cement replacement to be achieved. There are many advantages in using pozzolans in concrete, which include improved workability at low replacement levels, and with pozzolans of low carbon content reduces bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack at later ages (Krishna, 2008). Pozzolanic reactions are silica reactions that take place in the presence of calcium hydroxide and water to produce calcium silicate hydrates (C-S-H). This C-S-H creates a denser microstructure that increases strength, reduces the permeability of concrete and improves its resistance to chemical attack (Osei and Jackson, 2012). According to Joergensen (2014) use of pozzolan to replace cement in concrete lower heat development during hardening and improve durability of the final concrete structures.

Many concrete structures have shown serious deterioration, way before their intended service life, especially those constructed in a corrosive environment (Mehta, 1997). That is to say, they should be able to sustain various actions, usually the freeze-thaw cycles, chloride intrusion, and exposure to other aggressive chemical attacks. One of the disadvantage of concrete is that it is a porous material, while the prime target of concrete

structures is the ability to resist mechanical, physical, and chemical aggressions from their immediate environment throughout their lifetime. Recently researches on concrete technology is focused on durability rather than strength, this is due to the increase of pollutants in the environment which affect the performance of built facilities. Despite the ability of concrete to last hundreds of years in many applications and to resist environment attacks from aggressive agents, it has been proven that Portland cement concrete poses problems such as durability, when exposed to aggressive agents. Shetty (2009) stated that concrete was earlier deemed to be very durable material which demands less or no maintenance but at later age it was discovered that when exposed to aggressive environment where there is presence of chemicals, failures would occur and this can cost huge amount of money to renovate the affected concrete structure. Therefore, the impression that concrete is a very durable material is being threatened and hence the durability properties need to be considered

Durability is the ability of a product to physically remain in its functional state without requiring any excessive maintenance during its operational service life. Durability includes a series of properties required for the particular environment to which concrete will be exposed during its service life. Durable concrete is a form of concrete which resists the forces in that environment that tend to subject it to deteriorate prematurely without requirement for excessive effort in maintenance (Kalharime & Bryant, 2013). Penetration of aggressive substance into concrete via micro cracks or pores leads to deterioration of concrete and this tend to reduce the structures useful service life. This type of deterioration can be reduced by the introduction of Supplementary Cementitious Materials (SCMs) in concrete mixes. These SCM's reduce the pores in concrete as well as increase its density (Agboola, Idi, Tapgun & Bappah, 2020). Different concretes require different degrees of durability depending on the level of exposure and properties desired. A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement.

Durability of concrete is independent of its intrinsic characteristics, and it varies with the type of exposure and the degree of immersion. However, Concrete subject to aggressive attack can lead to total deterioration of the concrete element. Many researchers have attempted to improve the properties of concrete in terms of durability in various ways, of which the addition of groundnut husk ash, waste glass powder, and millet husk ash has shown to be effective (Adole, Dzasu, Umar, A. & Oraegbune, 2011; Agboola, Usman, Mamman, and Ushie, 2020; and Job & Adole, 2011). Abalaka (2007) studied the effects of sulphuric acid on compressive strength of concrete produced with ordinary Portland cement at 0.2%, 0.4% and 0.6% as concentrations of H_2SO_4 . The results show that there is loss in strength of concrete samples at 28 days curing days. Gambo (2014) also assessed the durability properties of ternary cementitious matrix concrete containing rice husk ash and sawdust ash as partial replacement of cement where the concrete samples were exposed to 1% concentration of $MgSO_4$. The results show that there is insignificant effect of

magnesium sulphate on the concrete samples at 56 days. This research tends to evaluate the effect of rice husk ash on the durability properties of concrete subject to aggressive chemical environment.

Materials and Methods

All the materials used for laboratory experiment were procured from the immediate environment. The relevant standards were used in the process of conducting the experiments.

Materials

The materials used for this study include, coarse aggregate, fine aggregate, cement, rice husk ash and water, magnesium sulphate and tetra oxo sulphate (vi) acid. Rice husk ash was gotten from farmers within Bauchi, Bauchi state, Nigeria. The coarse aggregate was obtained from a quarry site within Bauchi metropolis. The fine aggregate was also obtained from Yelwa River-flow in Bauchi state. The ordinary Portland cement is the brand of Dangote of Grade 42.5 which was procured from vendors within Bauchi metropolis. The chemical was procured from chemical vendors within Bauchi, metropolis.

Methods

Mix Ratio

A 1: 2: 4 mix ratio was designed using a water cement ratio of 0.5. Rice husk ash was used to replace cement from 5% to 30%.

Curing

The specimens were removed from mould after 24hours and taken to the curing tanks for the required curing days. Three types of curing medium were used which include; 0% concentration of H_2O (control), 1.2% concentration of H_2SO_4 and 1.2% concentration of $MgSO_4$. 1.2% concentration of $MgSO_4$ and H_2SO_4 used for this research were severe concentration range as used by (Abdulazeez, 2019). The curing periods include 7days, 14days, 21days, 28 days, 56days and 90 days. After the required curing period, tests were conducted on the hardened concrete. Curing process is used in enhancing the hydration of cement in concrete and also improve performance of concrete.



Figure 1: $MgSO_4$ and H_2SO_4 chemicals used for curing

Setting Time Test

As described in BS-EN 196-3, (1995) setting time test was conducted. Consistency, initial setting time and final setting time were carried out using Vicat apparatus with the plunger and needle. Seven different mixes with 0%, 5%, 10%, 15%, 20%, 25% and 30% replacement of OPC with RHA paste was prepared for setting time test.



Figure 2: Setting Time Test

Consistency

Consistency was determined using equation 1

$$\text{Consistency} = \frac{\text{water consumed}}{\text{weight of cement cement sample}} \times 100\% \quad (1).$$

Density Test

This was carried out prior to crushing of the concrete specimen. At the end of each curing period, the concrete specimens were weighed using an electric weighing machine balance and recorded. Density is calculated as mass of concrete specimen in (kg) divided by volume of concrete cube (m^3) and expressed in kg/m^3 , the density was determined using equation

$$2. \text{Density} = \frac{m}{v} \quad (2).$$



Figure 3: Measuring Specimen for Density Test

Compressive Strength Test of Concrete

The compressive strength test was conducted in accordance with (BS EN 12390-3, 2002). The cubes were cast and cured for 3 days, 7 days, 14 days, 21 days, 28 days, 56 days and 90 days respectively. For each mix, 3 cubes were crushed to obtain the average strength for the concrete samples. The compressive strength is the ratio of the weight of cube and the cross-sectional area.



Figure 4: Compressive Strength Test

Splitting Tensile Strength Test

The split strength test was conducted in accordance with (BS 1881 – 117, 1983). Tensile strength of concrete is determined by indirect method since it was very difficult to apply uniaxial tension to a concrete specimen. The splitting tensile strength was carried out using the compressive universal testing machine of 2000 KN capacity. The splitting tensile strength was calculated using the formula below;

$$f_t = \frac{2P}{\pi Ld} \text{ --- (3).}$$

Where:

f_t = splitting tensile strengths (N/mm²)

P = failure load (KN)

d = diameter of cylinder (mm)

L = length of cylinder (mm)



Figure 5: Split Tensile Strength Test

Flexural Strength Test of concrete

The flexural strength test was conducted in accordance with [13]. The beams were cast and cured for 28 days, 56 days and 90 days respectively. For each mix, 3 beams were placed and subjected to breaking machine to obtain the average strength of the concrete samples and the maximum load was recorded. Result were then calculated with:

$$R = \frac{Mc}{I} = \frac{PL}{bd^2} \text{ --- (4).}$$

R= flexural strength (n/mm²), I= moment of inertia (mm⁴), P= failure load (n)

M= max. bending moment (nmm), L=length (mm), B= average width (mm), C = D/2 (mm), D = average depth (mm).



Figure 6: Flexural Strength Test

Abrasion Resistance Test

The concrete samples (cubes) were removed from the container and allowed to surface dry. The surfaces of the concrete cubes were subjected to brushing by means of a wire brush with an applied weight of 3.5kg. The brushing consists of one forward and backward motion per second for one minute i.e. 60 cycles. The mass of the cubes before brushing was recorded and named W_1 and after brushing the mass was recorded and named W_2 . The mass of the detached matter i.e. $W_1 - W_2$ was recorded and the percentage weight loss of all the specimens were recorded and compared as stated by (Gambo, 2014) using equation 5.

$$\text{Abrasion resistance test} = \frac{W_1 - W_2}{W_1} \times 100\% \quad (5)$$

Water Absorption Test

The concrete samples (cubes) were removed from the curing tank and allowed to dry, and then placed in the electronic oven to oven dry at 105°C for 24 hours. The samples were removed from the oven and allowed to cool at room temperature then weighed to determine the initial weights (W_1). The final weights were determined after immersing the concrete samples in the curing medium for 30 minutes and then removed to cloth dry and re-weighed again as (W_2). The values obtained were recorded and the results calculated to assess the rate of absorption of the concrete specimens in accordance to (BS 1881-122, 1983). The equation 6 was used to compute the absorption capacity for the specimens:

$$\text{Abrasion resistance test} = \frac{W_2 - W_1}{W_2} \times 100\% \quad (6)$$

Results and Discussion

Setting Time and Consistency of OPC and RHA

Figure 7 and 8 shows the setting time and consistency of Portland cement and RHA paste. The setting time and consistency result conforms with (ASTM C187-98, 1991), and correspond to the research carried out by Abdulazeez, (2019) and Ogunbiyi, Olawale, Alabi & Thanni, (2017) on pozollanic cement.

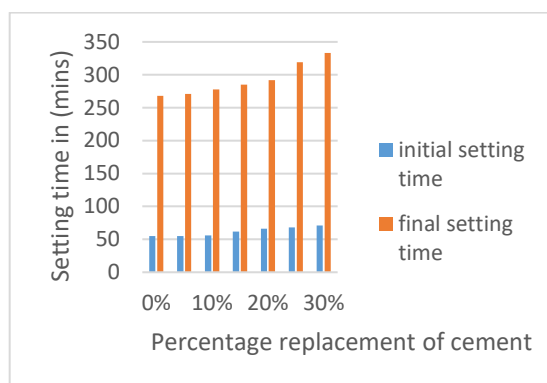


Figure 7: Setting Time Test

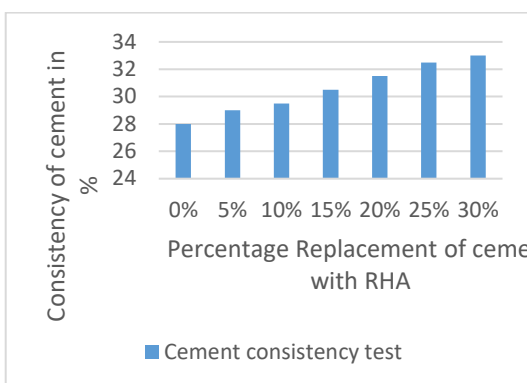


Figure 8: Setting Time Test

Visual Observation of Concrete specimen

There was little surface deterioration that is wear but no significant tear observed for concrete samples cured in MgSO_4 and H_2SO_4 at 90 days curing. Change of color was noticed which increases with increase in curing periods. Concrete samples that were cured in MgSO_4 discolored to white, while those cured in H_2SO_4 curing medium discolored to brownish. Loss of weight of concrete samples was also noticed with higher replacement percentages at later stages which can results to it not fully serving its functional requirement. The concrete samples cured in chemicals are shown in the figure 10 below:



Figure 10: Visual Observation of concrete specimens

Density of Concrete

The result of all the 7 mixtures for density of control concrete and concrete produced with RHA as partial replacement of cement, cured in water (H_2O), H_2SO_4 , and MgSO_4 of cubes, cylinder and beams test, is presented in Figure 11 to 17. Density values of concrete increase with increase in hydration period. Concrete cube, cylinder and beams produced with 0% control concrete, 5% and 10% cement replacement with rice husk ash produced higher density. The density of concrete cube samples cured in H_2O varies from 2405 kg/m^3 to 2510 kg/m^3 and it increase with increase curing periods. The density of concrete cube samples cured in H_2SO_4 varies from 2330 kg/m^3 to 2500 kg/m^3 and it increase with increase curing periods. The density of concrete cube samples cured in MgSO_4 varies from 2270 kg/m^3 to 2490 kg/m^3 and it increase with increase curing periods. Concrete samples with density higher than 2600 kg/m^3 are called as higher density concrete samples (Kazjonovs, Bajare, & Korjakins, 2010). The results favors higher durability as major values obtained exceeded the

2400 kg/m³ expected for a normal weight concrete, except for concrete with cement replacement at 30%. Therefore, concrete produced with RHA is a concrete with ordinary density, though samples with pozzolanic material replacements at 5% and 10% were denser than the control concrete samples. The density of concrete cylinder samples cured in H₂O varies from 2610 kg/m³ to 2690 kg/m³ and it increase with increase curing periods. The density of concrete cylindrical samples cured in H₂SO₄ varies from 2485 kg/m³ to 2585 kg/m³ and it increase with increase curing periods. The density of concrete cylindrical samples cured in MgSO₄ varies from 2450 kg/m³ to 2570 kg/m³ and it increase with increase curing periods. The density of concrete beam samples cured in H₂O varies from 2460 kg/m³ to 2530 kg/m³ and it increase with increase curing periods.

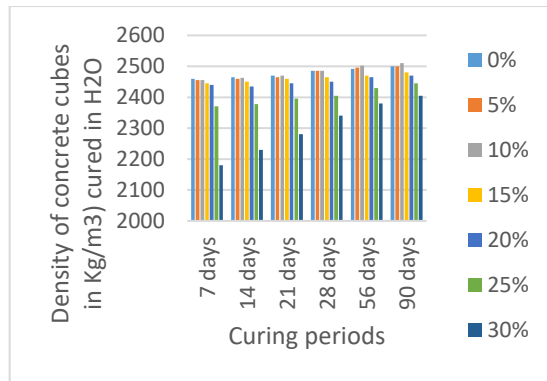


Figure 11: Density of Concrete Cubes cured in H₂O

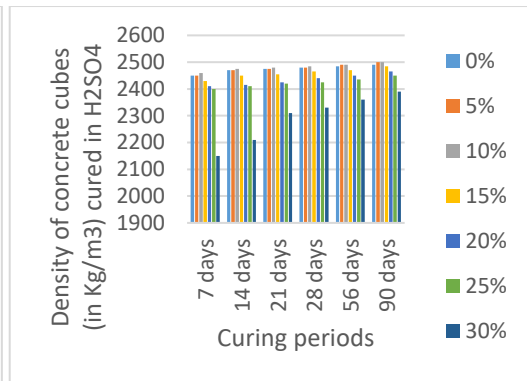


Figure 12: Density of Concrete Cubes cured in H₂SO₄

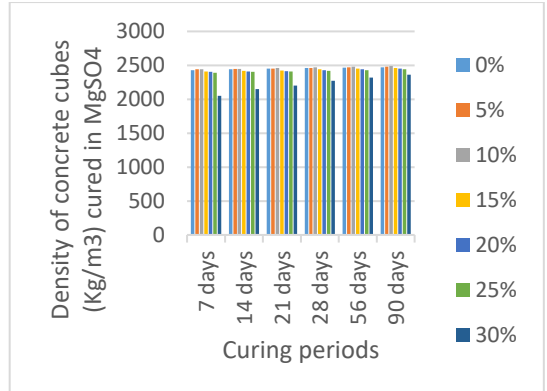


Figure 13: Density of Concrete Cubes cured in MgSO₄

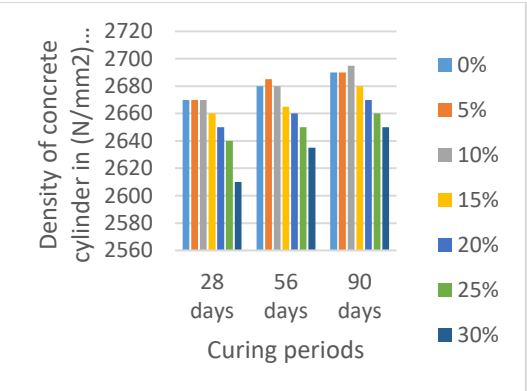


Figure 14: Density of Concrete Cylinder cured in H₂O

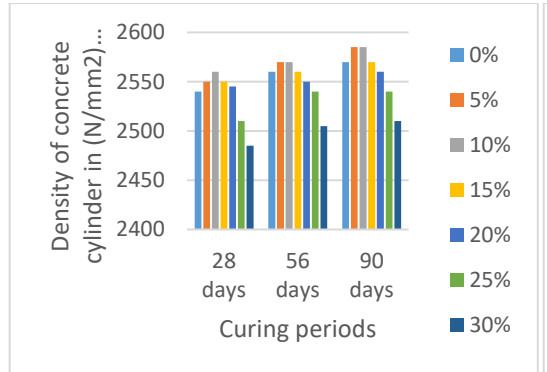


Figure 15: Density of Concrete Cylinder cured in H₂SO₄

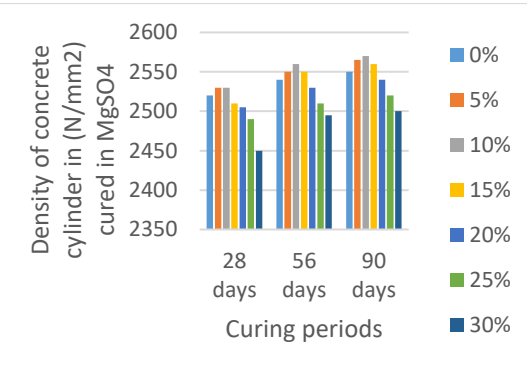


Figure 16: Density of Concrete Cylinder cured in MgSO₄

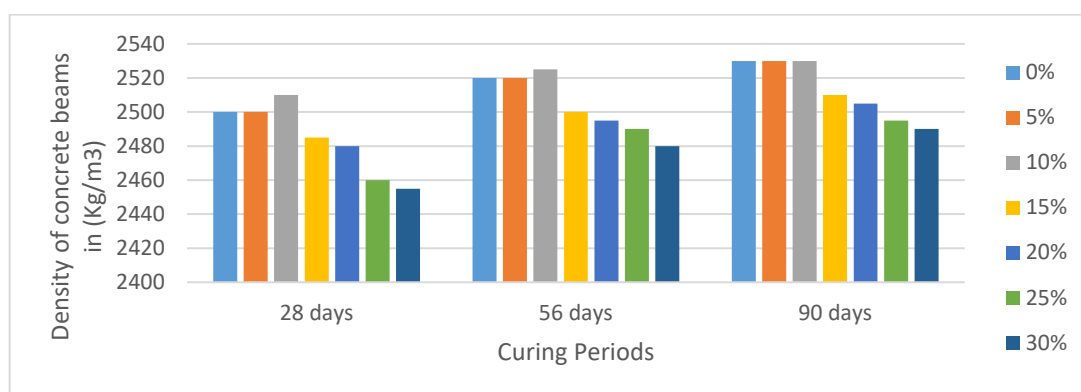


Figure 17: Density of concrete beams cured in H₂O

Compressive Strength of Concrete

The compressive strength of concrete produced with rice husk ash as partial replacement of cement in concrete cured in normal water (H₂O), H₂SO₄, and MgSO₄ environment was presented in Figure 18, 19 and 20. For concrete specimen cured in normal water, the maximum concrete strength at 28 days was observed at (0%) control concrete which shows better strength as compared to concrete specimen with partial replacements. At 56 days' hydration period, 0% concrete achieved 28.2 N/mm², while 5%, 10%, 15%, 20%, 25% and 30% achieved 28.3 N/mm², 28.6 N/mm², 25.2 N/mm², 22.1 N/mm², 17.4 N/mm² respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels. At 90 days' hydration period, 0% concrete achieved 29.2 N/mm², while 5%, 10%, 15%, 20%, 25% and 30% achieved 29.2 N/mm², 29.6 N/mm², 27.8 N/mm², 25.4 N/mm², 22.8 N/mm², 18.6 N/mm² respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels.

For concrete cured in H₂SO₄ environment, 10% cement replacement level attained 26.3 N/mm² as compared to 0% control concrete and 5% replacement of cement with rice husk ash in concrete which attained 26.1 N/mm² and 26.2 N/mm² respectively at 28 days' hydration period. From the result presented, it can be deduced that 10% cement replacement level shows better and improved strength as compared to control concrete and with other partial replacements at 28 days.

At 56 days' hydration period, 0% concrete achieved 27.4 N/mm², while 5%, 10%, 15%, 20%, 25% and 30% achieved 27.5 N/mm², 27.8 N/mm², 24.4 N/mm², 24.2 N/mm², 23.1 N/mm², 17.1 N/mm² respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels. Also at 90 days' hydration period, 0% concrete achieved 27.9 N/mm², while 5%, 10%, 15%, 20%, 25% and 30% achieved 28.1 N/mm², 28.5 N/mm², 25.7 N/mm², 25.1 N/mm², 22.1 N/mm², 18.2 N/mm² respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels. At 90 days 10% replacement of cement with RHA shows an increase in strength of 2.11% as compared to

control concrete. From the result presented it can be deduced that H_2SO_4 curing medium is more injurious to concrete samples, and more injurious to control concrete samples than at 5% and 10% replacements with RHA. This occurred due to the fact that the curing medium (H_2SO_4) is one of the strong acids that can harm concrete and strength development. RHA as a supplementary cementitious material is less susceptible to acid attack, due to filler material present in RHA which prevent the ingress of deleterious agent into the concrete. RHA retard the action of concrete damage which may be as a result of pozzolanic activity in the material and due to filler or binder present in RHA. This also tally with the assertion made by (Duggal, 2008) that the main product of pozzolana are less vulnerable to sulphate attack reason that there is less gypsum or ettringite in the formation of the product of many pozzolana.

Also, for concrete cured in MgSO_4 environment, 10% cement replacement level attained 26.1 N/mm^2 as compared to 0% control concrete and 5% replacement of cement with RHA which attained 25.7 N/mm^2 and 25.9 N/mm^2 respectively at 28 days' hydration period. The result shows that at 28 days' hydration period, 10% cement replacement level shows better and improved strength as compared to control concrete and other partial replacements. At 56 days' hydration period, 0% concrete achieved 26.7 N/mm^2 , while 5%, 10%, 15%, 20% 25 and 30% achieved 27.1 N/mm^2 , 27.5 N/mm^2 , 24.1 N/mm^2 , 23.8 N/mm^2 , 21.6 N/mm^2 , 16.2 N/mm^2 respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels. Also at 90 days' hydration period, 0% concrete achieved 27.3 N/mm^2 , while 5%, 10%, 15%, 20% 25 and 30% achieved 27.5 N/mm^2 , 27.9 N/mm^2 , 25.3 N/mm^2 , 24.2 N/mm^2 , 21.5 N/mm^2 , 17.5 N/mm^2 respectively, the result shows that 10% cement replacement shows better strength as compared to control concrete and other cement replacement levels. 10% replacement of cement with RHA shows an increase in strength of 2.15% as compared to control concrete at 90 days. From the result presented it can be deduced that MgSO_4 curing medium is more injurious to concrete samples generally, and more harmful to concrete than other curing medium. MgSO_4 is more injurious to control concrete samples than at 5% and 10% replacements with RHA. Also the result shows that 5% and 10% replacements can withstand exposure to magnesium sulphates compared to 0% replacement. This could be that the magnesium salt reacted with the cement mix in the control specimens. Gupta and Gupta (2012), affirm that magnesium sulphate (MgSO_4) decomposes calcium hydroxide $\text{Ca}(\text{OH})_2$ and hydrated tri-calcium aluminate (C_3A) present in cement which eventually form hydrated magnesium silicate that has no binding properties.

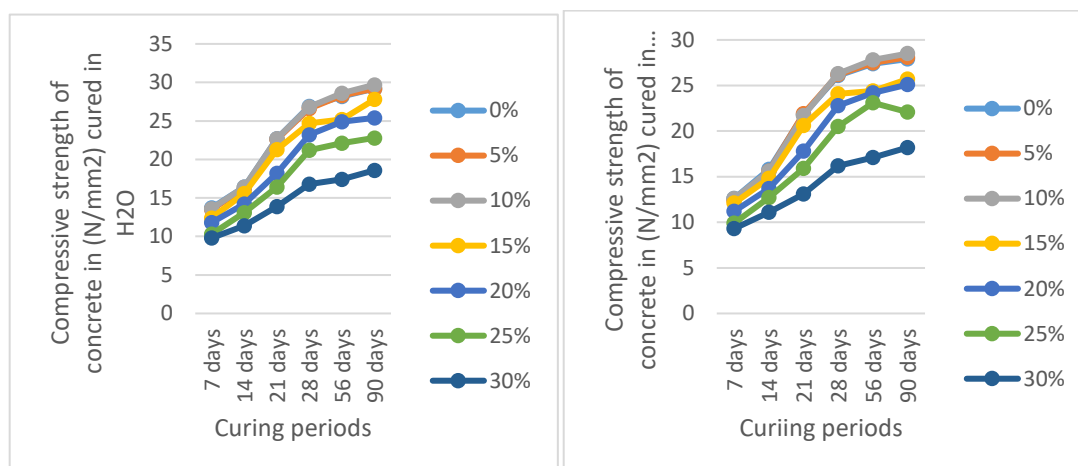


Figure 18: Compressive strength of concrete cured in H₂O Figure 19: Compressive strength of concrete cured in H₂SO₄

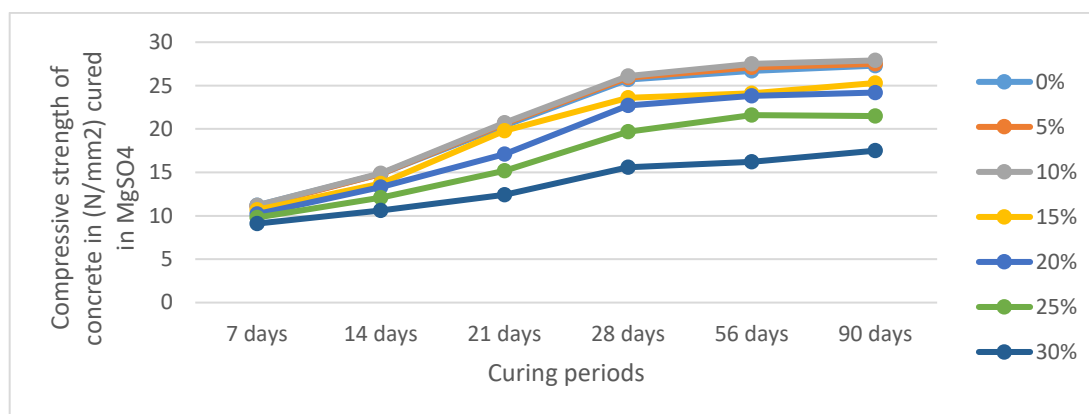


Figure 20: Compressive strength of concrete cured in MgSO₄

Split Tensile Strength of Concrete

Figure 21 present the tensile strength of concrete produced with RHA as partial replacement of cement and cured in normal (H₂O) environment, maximum strength achieved at 10% cement replacement which attained 3.54 N/mm² as compared to 0% control concrete and 5% cement replacement which both attained 3.51 N/mm² and 3.52 N/mm² respectively at 28 days. While 15%, 20%, 25% and 30% attained 3.48 N/mm², 3.46 N/mm², 3.33 N/mm², and 2.61 N/mm², respectively. At 56 days', maximum strength was achieved at 10% cement replacement which attained 3.56 N/mm² as compared to 5% cement replacement with RHA and 0% control concrete, which attained 3.56 N/mm² and 3.55 N/mm² respectively, concrete with 10% cement replacement shows improved and enhanced strength. At 90 days', maximum strength was achieved at 10% which attained 3.68 N/mm² as compared to 5% replacement of cement and 0% control concrete, which attained 3.66 N/mm² and 3.63 N/mm² respectively. Concrete with 10% replacement shows an increase of 1.36% as compared to the control concrete.

Figure 22 presents the tensile strength of concrete produced with rice husk ash as partial replacement of cement and cured in (H_2SO_4) environment, with maximum strength achieved at 0% and 10% which attained 3.46 N/mm² respectively, as compared to 5% cement replacement which attained 3.44 N/mm² at 28 days. While 15%, 20%, 25% and 30% attained 3.41 N/mm², 3.35 N/mm², 3.28 N/mm², and 2.53 N/mm², respectively. At 56 days', maximum strength was achieved at 10% cement replacement which attained 3.54 N/mm² as compared to 5% cement replacement and 0% control concrete, which attained 3.53 N/mm² and 3.51 N/mm² respectively, concrete with 10% cement replacement showed improved strength. At 90 days' curing period, maximum strength was achieved at 10% which attained 3.64 N/mm² as compared to 5% cement replacement and 0% control concrete, which attained 3.62 N/mm² and 3.61 N/mm² respectively. Concrete with 10% replacement shows an increase of 0.82% as compared to the control concrete.

Figure 23 also presents the tensile strength of concrete produced with RHA as partial replacement of cement and cured in ($MgSO_4$) environment, with maximum strength achieved at 10% cement replacement which attained 3.43 N/mm², as compared to 0% control concrete and 5% cement replacement which both attained 3.41 N/mm², at 28 days. While 15%, 20%, 25% and 30% attained 3.38 N/mm², 3.31 N/mm², 3.22 N/mm², and 2.46 N/mm², respectively. At 56 days', maximum strength achieved was at 10% replacement level which attained 3.52 N/mm² as compared to 5% cement replacement and 0% control concrete, which attained 3.51 N/mm² and 3.48 N/mm² respectively, concrete with 10% cement replacement showed improved strength. At 90 days', maximum strength was achieved at 10% replacement level which attained 3.56 N/mm² as compared to 5% cement replacement and 0% control concrete, which attained 3.54 N/mm² and 3.52 N/mm² respectively. Concrete with 10% replacement shows an increase of 1.12% as compared to the control concrete. However, 10% cement replacement shows improved strength. From the result presented, it can be deduced that magnesium sulphate curing condition is more deleterious to concrete specimen.

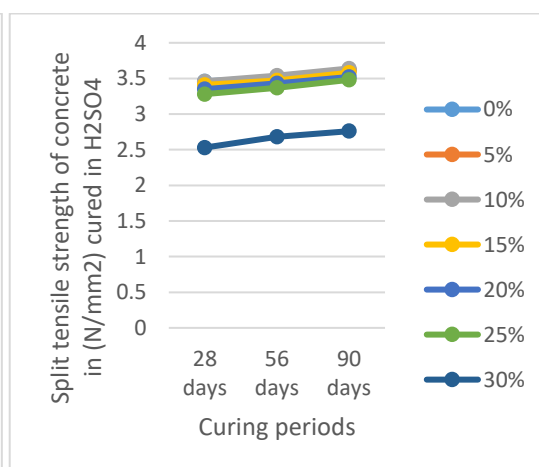
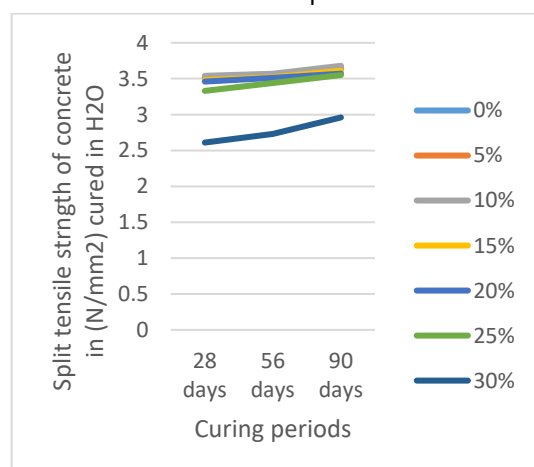


Figure 21: Split Tensile strength of concrete cured in H₂O Figure 22: Split Tensile strength of concrete cured in H₂SO₄

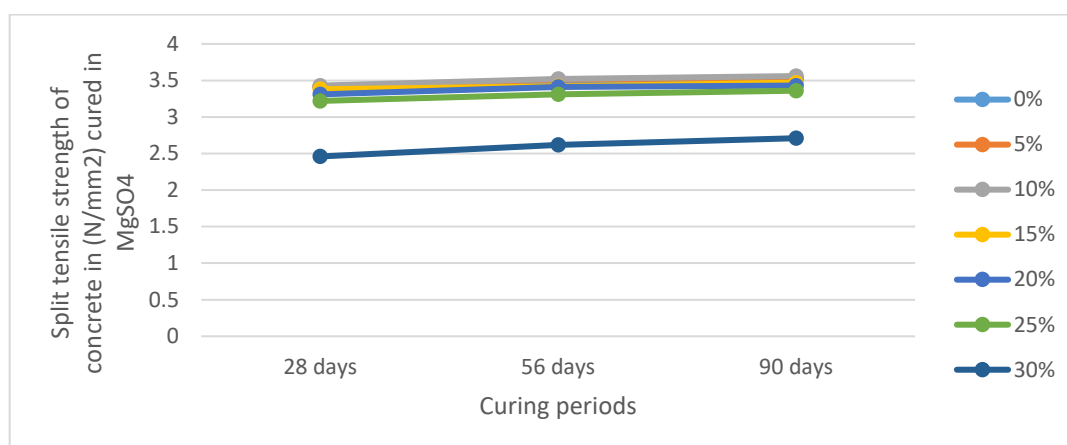


Figure 23: Split Tensile strength of concrete cured in MgSO_4

Flexural Strength of Concrete

From the results of the flexural strength test shown in figure 24. The values of flexural strength were 4.47 N/mm², 4.49 N/mm², 4.49 N/mm², 4.33 N/mm², 4.26 N/mm², 3.73 N/mm², and 3.51 N/mm² for concrete produced with RHA as partial replacement of cement at 0%, 5%, 10%, 15%, 20%, 25% and 30% respectively at 28 days' hydration period. The 5% and 10% cement replacement shows better strength as compared to the control concrete. At 56 days curing period, the result of the flexural strength was, 4.53 N/mm², 4.57 N/mm², 4.58 N/mm², 4.47 N/mm², 4.33 N/mm², 3.83 N/mm², and 3.57 N/mm² for 0%, 5%, 10%, 15%, 20%, 25% and 30% RHA as cement replacement. 10% replacement level shows higher strength as compared to other replacement levels. While, at 90 days' the strength of concrete achieved was 4.61 N/mm², 4.64 N/mm², 4.66 N/mm², 4.57 N/mm², 4.41 N/mm², 3.97 N/mm², and 3.64 N/mm², for concrete produced with 0%, 5%, 10%, 15%, 20%, 25% and 30% RHA as cement replacement respectively. The 10% cement replacement shows better strength as compared to the control concrete and other cement replacement levels. It was observed that as compressive strength increases, it results in a corresponding increase in flexural strength. In essence as compressive strength increase with increase hydration period, flexural strength increase with increase in hydration period. This conforms to the relationship of Linear proportionality between flexural and compressive strength described by (Neville & Brooks, 2010).

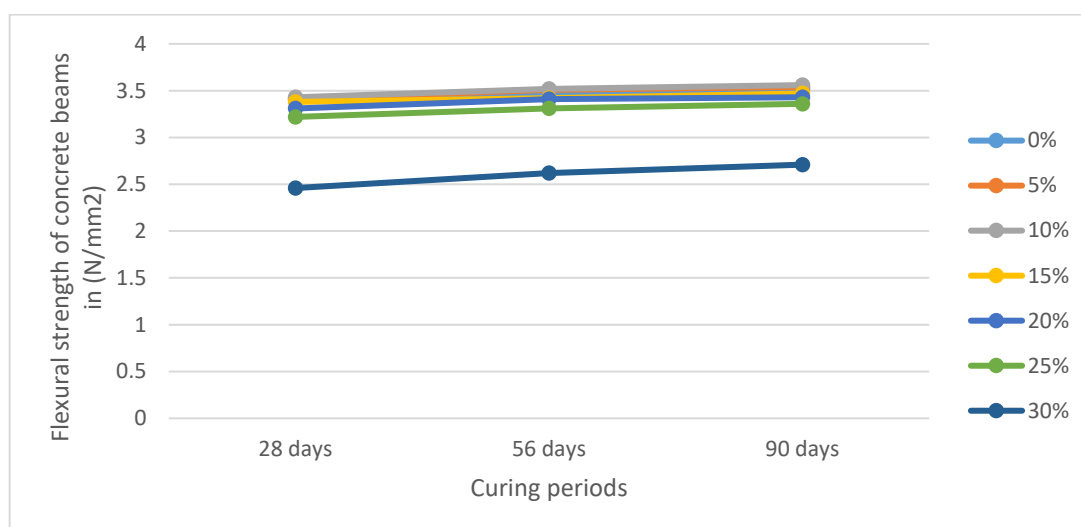


Figure 24: Flexural strength of concrete cured in H₂O

Abrasion Resistance Test of Concrete

Figure 25 presents the abrasion resistance of OPC-RHA concrete cured in (H₂O) and tested at 28, 56 and 90 hydration periods. There was high weight loss of 0.08% for 25% and 30% replacement as compared to 0% control concrete, 5% and 10% replacement, which all have 0.04% weight loss at 28 days, while 15% and 20% replacements have abrasion resistance of 0.05% respectively. Also at 56days it was discovered that 0%, 5% and 10% replacements have 0.05% with no difference noticed but better than at 15%, and 20%, with both having a weight loss of 0.08%, while 25% and 30% has higher loss of weight of 0.09% respectively for both. Thus at 90 days 25% and 30% replacement both have high loss of weight of 0.11 than at 0%, 5% and 10% having a loss of 0.08% and also less than 15% and 20% replacement with 0.09%. Thus 0%, 5% and 10% replacement generally resist abrasion more than other replacement levels in H₂O curing media.

Figure 26 presents the abrasion resistance of OPC-RHA concrete specimens cured in (H₂SO₄) and tested at 28, 56 and 90 hydration periods. There was high loss of weight of 0.11% for 30% replacement as compared to 0%, 5% and 10% replacement having 0.08% respectively at 28 days, while 15%, 20% and 25% replacements have abrasion resistance of 0.09% respectively. Also at 56days, it was discovered that 5%, 10% and 15% replacements had 0.09% with no difference notice but better than at 0%, and 20%, with both having a loss of weight of 0.11%, while 25% and 30% has higher weight loss of 0.12% respectively for both. Thus, at 90 days 30% replacement have high weight loss of 0.12% than at 5%, 10% and 15% having a loss of 0.11% and also less than 0%, 20% and 25% replacement levels with 0.12%. Thus, 5% and 10% replacement resist abrasion impact more than other cement replacement levels in H₂SO₄ curing media generally.

Figure 27 also presents the abrasion resistance of OPC-RHA concrete specimens cured in (MgSO₄) and tested at 28, 56 and 90 hydration periods. There was high loss of weight of 0.12% for 25% and 30% cement replacement levels as compared to 0%, 5% and 10%

replacements, with all having a weight loss of 0.09% respectively at 28 days, while 15%, and 20% replacements have abrasion resistance of 0.11% respectively. Also at 56 days' hydration periods, it was discovered that 0%, 5%, and 10% replacements had abrasion resistance of 0.11% with no difference notice but better than at 15%, and 20% having a loss of weight of 0.12% respectively, while 25% and 30% has higher loss of weight of 0.13% respectively for both replacement levels. Thus at 90 days 20%, 25% and 30% replacement have high loss of weight of 0.15% than at 5% and 10% having a loss of 0.12%; and also less than 0% control concrete having a weight loss of 0.13%. Thus 5% and 10% replacement resist abrasion better than other cement replacement levels in $MgSO_4$ curing media generally.

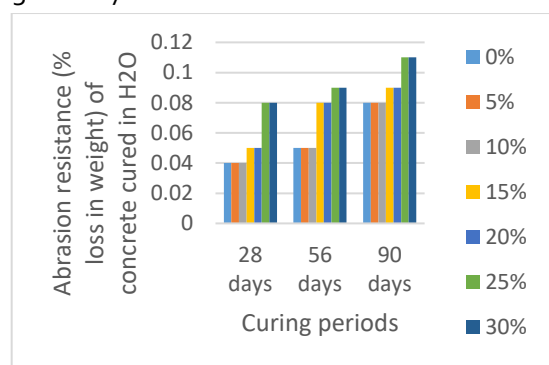


Figure 25: Abrasion Resistance test of concrete cured in H₂O

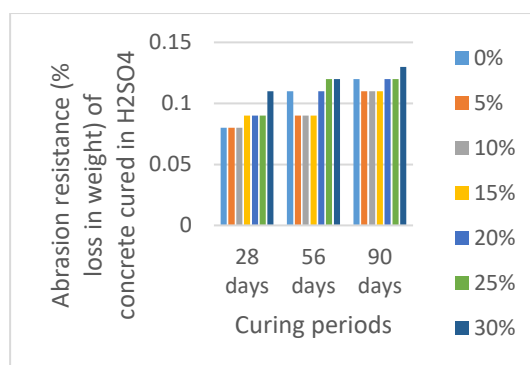


Figure 26: Abrasion Resistance test cured in H₂SO₄

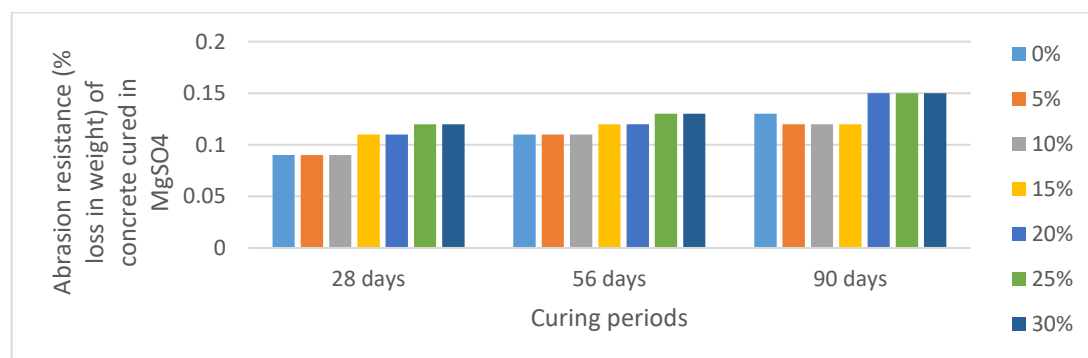


Figure 27: Abrasion Resistance test of concrete cured in H₂OSO₄

Water Absorption Test of Concrete

Figure 28 presents the water absorption of OPC-RHA concrete cured in water (H₂O) and tested at 28, 56 and 90 days' hydration periods. Sample cured in H₂O at 28 days, with 0% replacement absorbed 1.76% while 5%, 10%, 15%, 20%, 25%, and 30% replacement absorbed 1.81%, 1.84%, 1.96%, 2.08%, 2.12% and 2.16% respectively. Also at 56 days, concrete samples with 0% replacement absorbed 2.02% while 5%, 10%, 15%, 20%, 25% and 30% replacement absorbed 2.01%, 2.03%, 2.09%, 2.11%, 2.16% and 2.21% respectively. While at 90 days hydration period, concrete samples with 0% replacement absorbed 2.06% while 5%, 10%, 15%, 20%, 25% and 30% cement replacement with RHA absorbed 2.07%, 2.12%, 2.16%, 2.18%, 2.21% and 2.24% respectively. This means that control concrete

absorbed less amount of curing agent than cement replacement levels. This happens as a result of filler material in the concrete which demand for more water. The degree of sorption of the concrete specimen tallies with the work carried out by Pitroda & Shah, (2014) which stated that the average absorption of the concrete specimens shall not be greater than 5%. The ratio of sorptivity of concrete reduced with increase in curing days.

Figure 29 presents the water absorption of OPC-RHA concrete cured in (H_2SO_4) and tested at 28, 56 and 90 days' hydration periods. For sample cured in H_2SO_4 at 28 days, concrete samples with 0% control concrete absorbed 1.92% while 5%, 10%, 15%, 20%, 25%, and 30% replacement absorbed 1.97%, 2.01%, 2.11%, 2.19%, 2.24% and 2.31% respectively. Also at 56 days, concrete samples with 0% replacement absorbed 2.12% while 5%, 10%, 15%, 20%, 25% and 30% replacement absorbed 2.15%, 2.22%, 2.27%, 2.32%, 2.36% and 2.51% respectively. While at 90days concrete samples with 0% replacement absorbed 2.26% while 5%, 10%, 15%, 20%, 25% and 30% replacement absorbed 2.31%, 2.34%, 2.42%, 2.47%, 2.51% and 2.59% respectively. This means that control concrete absorbed less amount of curing agent than cement replacement levels which is as a result of the SCM in the concrete which demand for more water. The degree of sorption of the concrete specimen tallies with the work carried out by Pitroda & Shah, (2014) which stated that the average absorption of the concrete specimens shall not be greater than 5%.

Figure 30 presents the water absorption of OPC-RHA concrete specimens cured in ($MgSO_4$) and tested at 28, 56 and 90 days' hydration periods. For sample cured in $MgSO_4$ at 28 days, concrete samples with 0% control concrete absorbed 2.11% while 5%, 10%, 15%, 20%, 25%, and 30% replacement absorbed 2.14%, 2.19%, 2.24%, 2.27%, 2.37% and 2.46% respectively. Also at 56 days, concrete samples with 0% replacement absorbed 2.23% while 5%, 10%, 15%, 20%, 25% and 30% cement replacement absorbed 2.25%, 2.28%, 2.33%, 2.36%, 2.44% and 2.53% respectively. While at 90days, concrete samples with 0% replacement absorbed 2.44% while 5%, 10%, 15%, 20%, 25% and 30% cement replacement absorbed 2.49%, 2.55%, 2.62%, 2.71%, 2.76% and 2.82% respectively. This means that control concrete absorbed less amount of curing agent than cement replacement levels which is as a result of SCM used in the concrete which demand for more water. The degree of sorption of the concrete tallies with the work carried out by Pitroda & Shah, (2014), which stated that the average absorption of the concrete specimens shall not be greater than 5%.

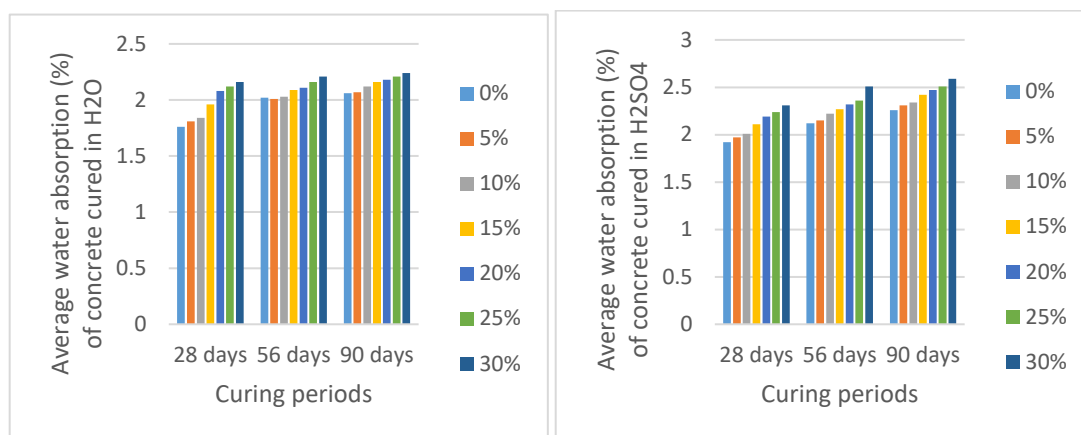


Figure 28: Water Absorption test of concrete cured in H₂O Figure 29: Water Absorption test cured in H₂SO₄

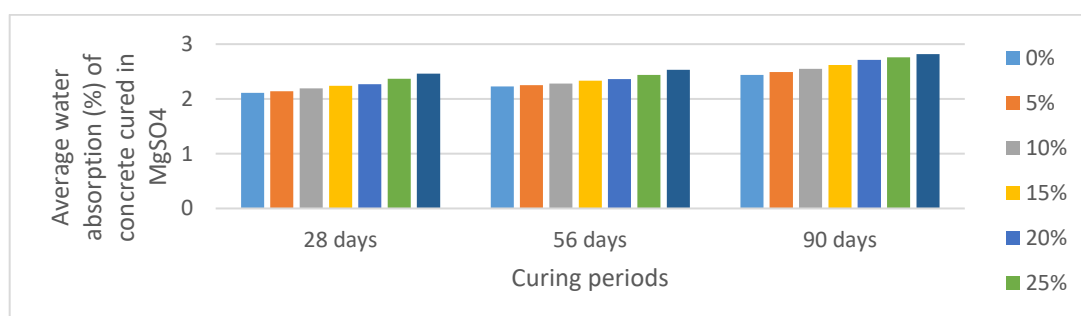


Figure 30: Water Absorption test of concrete cured in H₂OS₄

Conclusion

The RHA was used to replace cement at 5% - 30% in ratios. The density related values shows reduced density for concrete above 10% cement replacement with RHA in all curing conditions and beyond 28 days' hydration period. Visual inspection of samples cured in chemical solution, showed that as the percentage RHA content increases, the surface deterioration of the concrete increases. The compressive strengths declined at above 10% replacement level of cement with RHA at 28 days curing, it can also be deduced that at above 28 days curing period, concrete produced with RHA as cement replacement up-to 10% shows increase in strength above that of control concrete. As the percentage of RHA content in the concrete increases, the compressive strength decreases. 5% and 10% cement replacement with RHA in concrete resist aggressive chemical attack better than 0% control concrete. Durability test revealed that as the proportion of RHA in concrete increased the amount of weight loss in chemical solutions also increased. The result also indicates that cement replacement with rice husk ash up-to 15% meet the requirement of BS EN 206-1: 2000 for class C25/30 and C20/25 respectively for heavy weight concreting and LC25/28 and LC20/22 respectively for light weight concreting. In addition, at above 28 days' concrete test for cylindrical samples cured in different curing condition, 5% and 10% cement replacement with rice husk ash shows better and improved strength than control concrete sample for tensile strength, while 15% replacement level also shows promising result. Also,

5% and 10% cement replacement with rice husk ash shows improved strength beyond the control concrete sample for flexural strength. However, 10% replacement level presents the highest strength index both in normal curing and in aggressive chemical curing condition. Samples with the same percentage RHA content cured in water generally had a higher strength at the same age than those cured in chemical solutions. The study suggests that cement could be replaced with RHA up-to 15% with 10% replacement level having the best mix using W/C ratio of 0.5 and highest strength index. In essence, RHA is pozzolanic and is consequently suitable for concrete production. RHA utilization in the production of concrete will reduce the amount of waste in the environment. Setting time and consistency of cement rises with increase in rice husk ash percentages. The Water requirement of concrete rises as the proportion of rice husk ash increases in the concrete mix. The research concluded that RHA is a good pozzolanic material for use in concrete cured in normal water and in aggressive chemical agent, and 10% is the optimum replacement levels that can produce very strong, durable and workable concrete, but can be used up-to 15%.

Recommendations

1. The research recommends the use of rice husk ash to replace OPC in concrete production to save environment and also improve the properties of concrete.
2. The research recommends the use of 1.2% magnesium sulphate and sulphuric acid as severe concentration range for concrete. However, higher concentration can be used for more severe conditions.
3. Rice husk ash can be used as an admixture to alter initial and final setting time of OPC-RHA concrete is recommended.
4. The use of 10% rice husk ash is the optimum OPC/RHA replacement level that can be used to produce concrete with the required strength for construction purposes in both normal and chemical aggressive environments.
5. Standardization of the use of rice husk ash pozzolana in concrete should be carried out.

Recommendations for Further Studies

1. Further studies are recommended on other properties such as shrinkage, chloride penetration, permeability, fire resistance, durability on mortars made with RHA as cement replacements.
2. Further studies are recommended on increasing the concentration of sulphate and acid solution to subject concrete to check more severe concentration.
3. Admixtures may be added to improve performance, also using a different mix and altering water cement ratio is also recommended.
4. The use of 10% rice husk ash is the optimum OPC/RHA replacement level that can be used to produce durable concrete for construction purposes in both normal and chemically aggressive environments.

5. It is recommended that evaluating properties of concrete produced with 5% to 30% rice husk ash as partial replacement of cement be extended to 180, 360 or possibly 720 days to further determine the pozzolanic ability of the concrete both in normal and chemically aggressive environments.
6. The effect of rice husk ash on the durability of OPC concrete at low water to binder ratio (w/b), should also be investigated.

References

- Abalaka, A. E. (2007). Effects of Sulphuric Acid on Compressive Strength of Concrete Produced with Ordinary Portland cement. *Nigerian Journal of Construction Technology and Management*, 8(1), 14-19.
- Abdulazeez, S. A. (2019). Durability Properties of Composite Waste Glass Powder and Volcanic Ash Concrete exposed to Aggressive Chemical Environment. Unpublished Master's Thesis. Department of Building, Faculty of Environmental Technology, Abubakar Tafawa Balewa University, Bauchi.
- Agboola S.A., Usman N., Mamman A.I., and Ushie G. (2020). Suitability of Waste Glass Powder as Partial Cement Replacement in Concrete Subject to Chemical Aggressive Environment. *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*. Vol. IX, Issue II, Pp. 45 – 52, ISSN: 2278-2540. February 2020.
- Agboola, S. A., Idi A.M., Taggun J., Bappah H. (2020). Strength Performance of Concrete Produced with Volcanic Ash as Partial Replacement of Cement. *International Journal of Engineering Research & Technology (IJERT)*, 9(3), 372-378. DOI: 10.13140/RG.2.2.13367.68002.
- Adole, M.A., Dzasu, W.E., Umar, A. and Oraegbune, O.M. (2011). Effects of groundnut husk ash-blended cement on chemical resistance of concrete. *ATBU Journal of Environmental Technology*, 4(1).
- ASTM C187-98 (1991). Determination of Normal Consistency of Hydraulic Cement. American Association State Highway and Transportation Officials Standard; AASHTO T129 STA.
- Bonzeoak Ltd. (2003). Rice husk ash market study (ESTU U/00/0061/REP). London UK: DTI publications.
- British Standard European Norm, (2002). Testing hardened concrete; Compressive strength of test. *BS EN 12390-3*, BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.
- British Standard, EN, (2000). Concrete- Specification, Performance, Production and Conformity. *EN 216-1*, BSI, 389 Chiswick High Road London. W4 4AL, U.K.
- British Standard; EN, (1995). Method of Testing Cement; Determination of Setting Time and Soundness. *EN 196-3*, BSI, 389 Chiswick High Road London. W4 4AL, U.K.
- British Standard Institution (1983) Method for Determination of Compressive Strength of Concrete Cube, BS 1881: Part 116, London, British Standard Institution.
- BS1881 - 117: (1983). Testing Concrete - Method for determination of tensile splitting strength. British Standards Institute, London
- British Standard Institution (1983) Method for Determination of Compressive Strength of Concrete Cube, BS 1881: Part 116, London, British Standard Institution.
- British Standard, (1983). Testing concrete; Method for determination of water absorption. BS 1881-122, BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.
- Duggal, S. K. (2008). Building Materials. *New Age International Publishers*, New Delhi, India. 142-300.
- Gupta, B. L. and Gupta A. (2012). Concrete technology, Published by A. K. Jain. For Standard Publishers Distributors. 1705-B, NaiSarak, Delhi-110006.
- Gambo, S. (2014). Assessment of Durability Properties of Ternary Cementitious Matrix Concrete Containing Rice Husk Ash and Saw Dust Ash as Partial Replacement of Cement. *Unpublished M.Sc*

- Thesis Work*, Department of Building Faculty of Environmental Design, Ahmadu Bello University Zaria, Nigeria.
- Job. F. O. and Adole, M. A., (2011). The Effects of Chemicals on the Properties of Millet Husk Ash Blended Cement Concrete. Paper presented on NIOB 41st Annual General Meeting/Conference 6-10 July, 2011. 46-53.
- Joergensen, S. W. (2014). *Grinding of Clinker Replacement Materials*. Special Report by General Manager Grinding Technology, 1-15.
- Kalharime & Bryant Mathen. (2013). *concrete durability*.
- Kazjonovs, J., Bajare, D. and Korjakins, A. (2010). Designing of High Density Concrete by Using Steel Treatment Waste. Paper Presented on Modern Building Materials, Structure and Techniques International Conference May 19-21, 2010. Vilnius, Lithuania, 138-142.
- Krishna, R., (2008). Rice husk ash an ideal admixture for concrete in aggressive environment. Recycling construction Waste for sustainable development. Organized by CREAM, UiTM, ACCI and CSM, Kuala Lumpur.
- Mccaffrey, R. (2002). Climate change and the cement industry, Global cement and lime magazine (environmental special issue), 15-19.
- Meyer, K. (2013). Non- destructive evaluating of Embedded Structures in concrete. *international symposium*.
- Mehta, P.K. (2000)., "Concrete Technology for Sustainable Development – An Overview of Essential Elements", in Concrete Technology for a Sustainable Development in the 21st Century, O.E. Gjorv and K. Sakai, eds., E&FN Spon, London.
- Mehta, P.K. (1997)., "Effect of cement composition on corrosion of reinforcing steel in concrete, in; Chloride Corrosion of steel. pp. 12-19. ASTM STP 629, West Conshohocken.
- Neville, A.M. and Brooks, J.J. (2010). Concrete Technology. 2nd edition. Long man Group United Kingdom Limited, 30-269.
- Ogunbiyi M., Olawale S., Alabi O. and Thanni M., (2017). Assessment of the Qualities of Dangote and Elephant (Portland) Cement Brands Commonly Used in the Nigerian Construction Industry. *International Journal of Innovative Research in Science, Engineering and Technology*, 6(3), 3888-3895. Retrieved from <http://www.ijirset.com>.
- Osei, D. Y. and Jackson, E. N. (2012). Compressive Strength and Workability of Concrete Using Natural Pozzolan as Partial Replacement of Ordinary Portland Cement. *Journal of Advances in Applied Science Research*, 3(6), 3658-3662. Retrieved from <http://www.pelagiaresearchlibrary.com>
- Pitroda, J. and Shah, D. S. (2014). An Experimental Study on Durability and Water Absorption Properties of Pervious Concrete. *International Journal of Research in Engineering and Technology*, 3(3), 439-444. Retrieved from <http://www.ijret.org>.
- Shetty, M. S. (2009). *Concrete Technology; Theory and Practice*, S Chad and Company, New Delhi, India, 174-418.