

Towards Developing a Concrete Mix Design to Withstand Sulphuric Acid Attack in Concrete Sewer Pipes Using Rice Husks Ash as an Admixture

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Abstract

Concrete corrosion from sulphuric acid generated from the sewage content is one of the main causes of infrastructure failure in concrete sewer works in many cities of the world. This has raised the demand for sustainable concrete for such aggressive environments. A number of mitigation interventions have been developed but have not been sustainable given the cost implications.

The effect of incorporating varied quantities of fine burnt rice husk ash (RHA) in cement as a binder system with two water cement ratios for concrete exposed to a simulated acidic sewer environment was investigated. The objective was to evaluate the effect of the two on the strength, mass loss porosity and surface texture of concrete exposed to acidic environment and thus develop a mix design with the right % RHA in cement and W/C that can withstand corrosion.

The experimental study entailed preparation of 150mm x 150mm x 150mm concrete cubes with varying percentages of RHA in cement with two water cement ratios. The cubes were then cured for 28 days, allowed to dry off for 7 days then fully exposed to acidic sulphuric acid solution for 12 weeks.

The effect the acidic solution had on the surface roughness, mass loss, porosity and compressive strength of the cubes was then evaluated. Samples with 0.35 W/C were observed to have slightly more compressive strengths and also performed better in terms of surface texture, mass loss and porosity than those with 0.4 W/C. The highest compressive strengths, for the two water cement ratios, were achieved with 5% RHA in cement and thereafter the strengths reduced with increasing presence RHA. The mass loss and porosities, for both water cement ratios, decreased with increasing presence of RHA in cement an indication that incorporation of RHA in cement lead to a more impermeable concrete. A compressive strength of 35.29N/mm² slightly higher than the design characteristic strength by 0.8% was achieved with 0.35 W/C and 10% RHA in cement after the specimen were exposed in acidic solution.

Keywords: Concrete, Aggressive Environment, Corrosion, Rice Husk Ash, Compressive Strength, Porosity.

1.0 introduction

Concrete enjoys a wide use as a construction material mainly due to its ease of production, strength and moderate maintenance cost. However, concrete as a structural material in certain aggressive environments such as sewers suffer deterioration as they interact with the

aggressive media. Concrete corrosion has been identified as affecting sewer systems in many cities of the world. Figure 1 shows a corroded sewer pipe chamber. This has led to costly maintenance interventions as the works are not able to be utilized to their full design life.

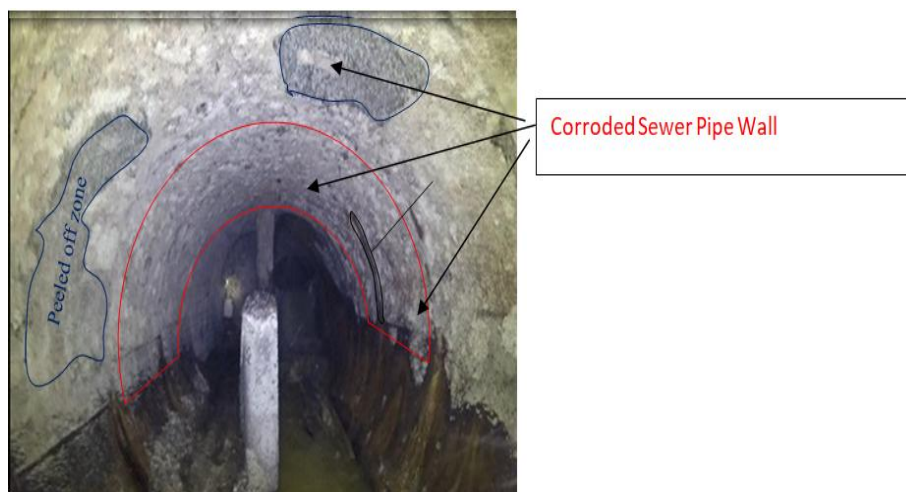


Figure 1: Corrosion Conditions in a Chamber in Edmonton, Canada

1.1 FACTORS THAT INFLUENCE CORROSION OF CONCRETE IN SEWER WORKS

A number of factors have been determined to influence corrosion in concrete sewer pipes. These mainly include air temperature, pH of the sewer, Biochemical Oxygen Demand (BOD), Flow characteristics of the sewage and the sewer pipe materials.

a) Air Temperature

An increase in temperature leads to an increase in biochemical reactions, impacts on growth rate of microorganisms hence has a significant influence on microbial population in the sewers (Neethling et al., 1989). Increased temperatures in the sewage chamber lead to increased bacterial activity and thus production of H_2S and eventually oxidation to H_2SO_4 . Variation in air temperature therefore determines the time of corrosion.

b) pH of the Sewer

Optimal conditions for the generation of sulphide in the sewage exist when the pH is between 6.5 and 8 (Mara and Horan, 2003), while the tolerance of SRB is between a pH of 5.5 and 9 (Barjenbruch et al., 2008), and a decrease in the pH of the sewage from 7.9 to 7.2 corresponds to an increase in hydrogen sulphide gas generation in the sewer headspace (Nielsen et al., 2006). According to Wells and Melchers (2011), when the pH of the surface of the sewer pipe falls to below 6, significant conversion of sound concrete to a corroded product (mostly gypsum) begins.

c) Biochemical Oxygen Demand (BOD) of the Sewage

In typical municipal sewage, the organic nutrients available for generation of H_2S are proportional to the BOD of the sewage (Davy, 1950). A higher BOD therefore leads to an increase in the rate of generation of H_2S and production of H_2SO_4 in the sewage chamber thus reduced concrete corrosion initiation time and increased rate of corrosion.

d) Flow Characteristics of the Sewage

Flow velocity and turbulence have a significant impact on the biogenic corrosion since they determine whether there is deposition on the sewer invert (Kiliswa, 2016). At high flow velocities, most solids are carried in suspension throughout the sewer, while at low velocities, solids are deposited on the sewers invert. Also, at low velocities, solids are deposited on the sewers invert in form of sludge and silt to form additional habitat for bacteria responsible for reducing nitrates and sulphates in the sewage. Very low velocities therefore mean a higher rate of H_2S generation in the sewage chambers.

e) Sewer Pipe Materials

Concrete sewer pipes corrodes when it comes in contact with the aggressive sulphuric acid generated from the sewage. The acid reacts with the concrete to form a pulpy material that disintegrates and collapses with time. A concrete product with physiochemical properties that can inhibit corrosion will therefore mean extended life of the structure. Concrete sewer pipes are manufactured from raw materials namely; cement, aggregates, water and admixtures that are supposedly engineered to be able to withstand

the aggressive sewer environment. A concrete mix from these ingredients that is able to withstand corrosion would therefore increase the design life of the sewer structure.

1.2 Interventions To Mitigate Concrete Corrosion In Sewer Works

Two main broad categories of interventions have been used to manage corrosion in concrete sewer pipes. These are:

a) Controlling Environmental Factors

This approach attempts to modify the sewer environment by dosing chemicals such as magnesium hydroxide, sodium hydroxide, iron salts, and nitrate into the sewage to reduce the emission of H₂S in the liquid and gas phase [Zhang L et al, 2008, Ochi T et al, 1998, Park K et al, 2014]. Even though these methods can effectively decrease the sulphide level, they have high operating and maintenance cost over the service life of the system and may sometimes result in the formation of unwanted by-products [Vaidya S, et al, 2010]

b) Improving Corrosion Resistance of Concrete

i) Coatings on Existing Structures

One of the methods used in protecting concrete structures is isolation of the concrete from contact with the aggressive environments. Coating and lining are the most common methods to prevent corrosion of concrete tanks and other structures used in wastewater treatment plants. The interior of the concrete pipes is usually lined or coated to create a low-permeable and acid-resistant durable physical barrier between concrete and corrosive environment [Piotr et al 2022].

Despite the wide application of protective coatings, their functional characteristics such as strength, elasticity, and adhesion might be affected by microbial activity, i.e. production of aggressive metabolites, enzymatic attack, and physical penetration and disruption [Cappitelli F et al, 2008]. Over the last three decades, numerous cases of coating failures in wastewater treatment plants have been reported [Piotr et al 2022].

ii) Admixtures in New Concrete

Prevention of concrete corrosion can primarily be achieved in the design phase by modification of

concrete mixture so as to develop an acid resistant concrete by either improving the microstructure of concrete or provision of barriers against acids [Khitab A et al, 2013].

Alteration of mix design parameters, incorporation of supplementary cementitious materials and mineral admixtures such as silica fume, fly ash, limestone, and blast furnace slag has been employed to increase the durability and the acid resistance of concrete [Goyal S et al, 2009].

Incorporation of growth inhibitory compounds, i.e. bacterial and fungicidal admixtures, into concrete mix have also been applied to mitigate deterioration.

Even though significant improvement in microbial induced corrosion resistance of concrete has been observed after addition of commercial admixtures, their effectiveness is generally temporary and in high dosages they might affect the structural properties of concrete [Sun X et al, 2015]. In addition to the high costs, another impediment to their use is that only a few of these agents have been tried. In this regard, a number of experiments have been carried out to explore the use of more locally available admixtures, such as RHA, with concrete in aggressive sewer environments. These have mostly been carried out through laboratory experimental studies.

1.3 The Effect Of Partial Replacement Of Cement With Rha

Rice husk is agricultural waste that is obtained from the milling process of paddy. This when burned and grounded produces Rice Husk Ash (RHA) which studies have shown that consists of up to 90% amorphous silica, depending on the nature of burning conditions, which can be used as pozzolana in making concrete [Ankit et al, 2019]. Research has shown that the silica content and the high specific surface area is responsible for increasing the durability of concrete when used in appropriate proportion with cement [Ayesha et al, 2017]. Table 1 below shows a summary of optimum percentage of RHA for maximum concrete strength as determined by a number of researchers.

Table 1: Summary of % RHA in cement for Maximum Compressive Strength at 28 days by Different Researchers

Year	Author	% Optimum RHA	Suggested Scientific Explanation for Increase in Strength
1996	Min-Hong Zhang et al	15%	Pozzolanic effect in RHA
2005	Gemma Rodríguez	10%	Filler and pozzolanic effect
2007	Ganesan et al.	20%	Pozzolanic reaction and high specific surface area
2010	Ghassan Abood et al	10%	Fineness of RHA. acting as a microfiller
2012	Godwin Akeke and Maurice Ephraim	10%	High pozzolanicity effect
2014	Thanh Le et al.	10%	Pozzolanic effect, large specific surface area and the high silica content.
2019	Karthik et al. 2019	10%	Increase in pozzolanic action
2019	Ankit et al. 2019	7.5%	
Average % RHA	10.5%		

The increased presence of RHA in cement therefore increases the compressive strength of concrete up to a maximum with a certain optimum % of RHA.

1.4 The Effect of Water Cement Ratio on Concrete

From durability perspective, a low water to cement ratio concrete is recommended for any construction because all the deterioration phenomena are directly related to the permeability of concrete which is inversely proportional to the water to cement ratio. A number of studies have been carried out to determine the effects of varying water cement ratio on the properties of concrete. The studies determined that porosity, permeability and absorption increased with increased water cement ratio while the compressive strengths of concrete and mortars decreased.

1.5 Focus of the Study

Sewer works are designed and built for a design life of 75 to 100 years. With standard maintenance, the concrete mix used should therefore have desired properties that make it durable to withstand the aggressive sewer environment while in use for this period of time. The BS 8500 is not specific on sewer environments but sets the characteristic compressive cube strength for such environments at 35N/mm^2 . Besides the compressive strength, such concrete should also be able to inhibit ingress of aggressive acidic compounds into its matrices with very minimal or no reaction of the binder material with these compounds.

The two variables, the presence of RHA in cement and water cement ratio have been determined to have significant influence on the durability properties of concrete. The previous studies considered the influence of these variables had on the properties of concrete but acting exclusively. The three objectives of the study were therefore to determine the effect of RHA on the properties of concrete, to determine the combined effect of RHA and W/C on the properties of concrete and to develop a concrete mix design with desired properties for aggressive acidic environment.

2. Materials And Methods

2.1 MATERIALS

a) Concrete

The experimental study prepared concrete samples size $150\text{mm} \times 150\text{mm} \times 150\text{mm}$. Crushed coarse aggregates of maximum size 20mm were used as per clause 5.3 of BS 5911-120: 1989, and grading done as per table 3 of BS 882:1992. Locally available naturally occurring building sand, conforming to table 4 of BS 882 for heavy duty concrete used in the experiment while Duracem Cement, a sulphate resisting cement from Bamburi Cement was used in the study as a requirement of tables A15 and A17 of BS 8500 Part I. Rice Husks were sourced from a local company Lake Basin Development Company, burnt in the laboratory to form ash and collected through BS sieve size $75\mu\text{m}$. Blended cements were produced in the laboratory by thoroughly mixing cement and RHA.

Available clean potable tap water was used in concrete mixing.

Table 3.1 below shows a summary of constituent materials to achieve the characteristic strength as

obtained from the BS 8500 Part 1. The BRE Mix Design Procedure was then used to calculate the quantities of cement, fine and coarse aggregates.

Table 2: Requirements for Characteristic Strength

Parameter	Requirement
Characteristic compressive strength f_c	35N/mm
Target Mean Strength, f_m	43N/mm ²
Crushed aggregates, maximum size	20mm
Cement Type	Sulphate Reducing Portland Cement, SRPC 42.5
Minimum cement content	400kg/m ³
Maximum water cement ratio, w/c	0.4
Slump	60 to 180mm

b) A Simulated Aggressive Solution

Sulphuric acid solution with a pH of 2.5 and a concentration of 5% was prepared to simulate this environment. This was used to accelerate degradation of the samples. The cubes were fully immersed in the solution for 12 weeks, with the solution being refreshed every 2 weeks. Commercially available sulphuric acid with a 35% concentration was used in the experiment. The acidic solution was prepared to a concentration of 5%.

2.2 METHODS

a) Concrete Mix Design

The BS 8500 part 1 used to obtain the characteristic concrete strength (Table 2) and mix design carried out according to Building Research

Establishment (BRE) to obtain the target strength and weight of constituent materials to produce 1m³ of concrete for each of the two water cement ratios. The quantities of cement, coarse aggregates, fine aggregates, RHA and water were determined for five cubes (0.017m³) for each category of % RHA in cement. 2 cubes were used to determine the compressive strength before exposure to aggressive solution while the strength of the other 3 were determined after exposure to aggressive solution. The quantities for preparation of 5 specimens, for each category of % RHA in cement are shown in table 3

Table 3: Calculated quantities for every % RHA category

% RHA in Cement	W/C	Cement (kg)	RHA (kg)	Water (Kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Total No of Cubes
0% RHA content	0.4	9.6	0	3.9	10.1	17.3	5
	0.35	10.9	0	3.9	9.6	15.9	5
5% RHA	0.4	9.1	0.5	3.9	10.1	17.3	5
	0.35	10.4	0.6	3.9	9.6	15.9	5
10% RHA	0.4	8.6	1.0	3.9	10.1	17.3	5
	0.35	9.8	1.1	3.9	9.6	15.9	5
15% RHA	0.4	8.2	1.4	3.9	10.1	17.3	5
	0.35	9.3	1.6	3.9	9.6	15.9	5
20% RHA	0.4	7.7	1.9	3.9	10.1	17.3	5
	0.35	8.7	2.2	3.9	9.6	15.9	5
Total No. of Cubes							50

b) Experimental Set Up

The cured concrete cubes were weighed then submerged in acidic solution for 12 weeks. The cubes were supported on a steel frame to ensure

the six surfaces are in constant contact with the solution. See the schematic diagram in figure 2 below.

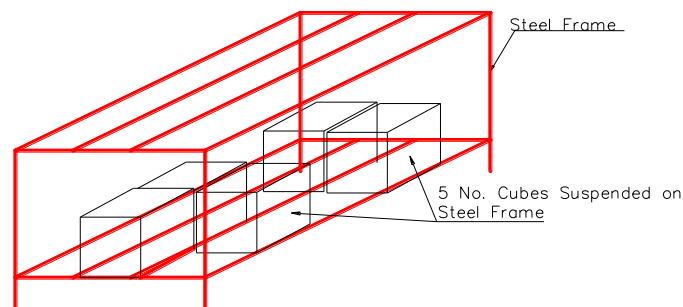


Figure 2: Schematic Diagram Showing 5 Cubes Supported on a Steel Frame. This Ensures all the Sides of the Cube are Exposed to the Aggressive Solution



Figure 3: Concrete Cubes Suspended on a Steel Frame, Ready for Immersion in Acidic Solution.



Figure 4: Samples Supported on a Steel Frame in 100 Liter Containers Containing Acidic Solution. The Black Containers Chosen to Absorb Thermal Radiation to Mimic Temperatures in Closed Sewer Pipes.

d) Measurements of Degradation

The following parameters were measured to evaluate the extent of corrosion which the cubes

had undergone while in contact with acidic solution.

i)

Compressive Strength

The compressive strengths of cubes were determined before and after exposure in acidic

solution using a compressive strength machine (see figure Below)



Figure 5: Compression Test on Cubes

ii) **Surface Roughness**

After curing for 28 days, the cubes were air dried for 7 days then immersed in acidic solution for 12 weeks. On removal from the aggressive solution the cubes were allowed to dry then their surfaces observed for any sign of deterioration and peeling off.

$$\text{Bulk volume, } V_b = (W_{\text{sat}} - W_{\text{sub}})/\rho_w$$

$$\text{Porsity } \phi = (V_p / V_b) \times 100$$

W_{dry} is the dry weight of the sample,
W_{sat} is the saturated weight of the sample,
W_{sub} is the submerged weight of the sample and
ρ_w is the density of water.

iii) **Mass Loss**

The cubes were weighed before and after exposure in acidic solution and the mass loss due to deterioration by acidic solution determined for the different % RHA in cement. This is reported as percentage mass loss. % Mass Loss = $\frac{\text{mass of specimen before} - \text{mass of specimen after}}{\text{Mass of specimen before}} \times 100$

3. Results And Discussion

a) Compressive Strength Before and After Exposure in Acidic Solution

The compressive strengths before and after exposure were slightly higher with 0.35 w/c ratio than 0.4 w/c ratio for all the samples except one with 20% RHA. (See table 4). Previous studies already established that W/C has an important influence on the development and structure of pores in concrete hence contributing to permeability and durability of concrete. It was determined that generally a low water to cement ratio concrete is recommended from durability perspective because the deterioration phenomena are directly related to the permeability of concrete which is inversely proportional to the water to cement ratio. A less permeable concrete due to lower water cement ratio is therefore more

iv) **Porosity**

This is simply a measure of voids in a sample. This was carried out to establish the impermeability of samples in relation to its durability while in aggressive solution. Determination of porosities of samples of approximately 50mm x 50mm x 50mm were carried out using Archimedes principle as per the following procedure:

$$\text{Pore volume, } V_p = (W_{\text{sat}} - W_{\text{dry}})/\rho_w$$

durable and likely to exhibit superior durability properties. Hong 1996, Burak 2006, Hwang 2011 and Singh 2018 all demonstrated in their studies that samples with lower w/c ratios developed higher compressive strengths than those with higher w/c.

The compressive strengths for both water cement ratios reduced when the cubes were immersed in acidic solution, an indication of deterioration (See figures 6, 7, 8 and 9)

Both water cement ratios experienced the best strengths with 5% RHA in cement. The highest compressive strength after exposure to aggressive solution was obtained with 5% RHA in cement and

a 0.35 water cement ratio. The strengths then decreased with increased RHA in cement. With 10% RHA in cement and 0.35 w/c a compressive strength of 35.29 N/mm² that is higher than the characteristic strength as determined from the BS was obtained. The presence of RHA improved compressive strength due to the physical filler effect of the ash and the pozzolanic reaction of the available silica with C-H released from hydration process. The strengths reduced with increased presence of RHA in cement as the produced C-H probably not sufficient enough to react with all available silica in RHA.

Table 4: Compressive Strength of Cubes in N/mm² Before and After Exposure

% RHA in Cement	0.4 W/C		0.35 W/C	
	Average Strength Before Exposure	Average Strength After Exposure	Average Strength Before Exposure	Average Strength After Exposure
0%	38.8	36.8	39.7	38.6
5%	39.0	37.3	40.0	38.9
10%	36.3	35.0	36.4	35.3
15%	28.4	28.2	31.2	31.1
20%	25.7	25.5	24.7	24.1

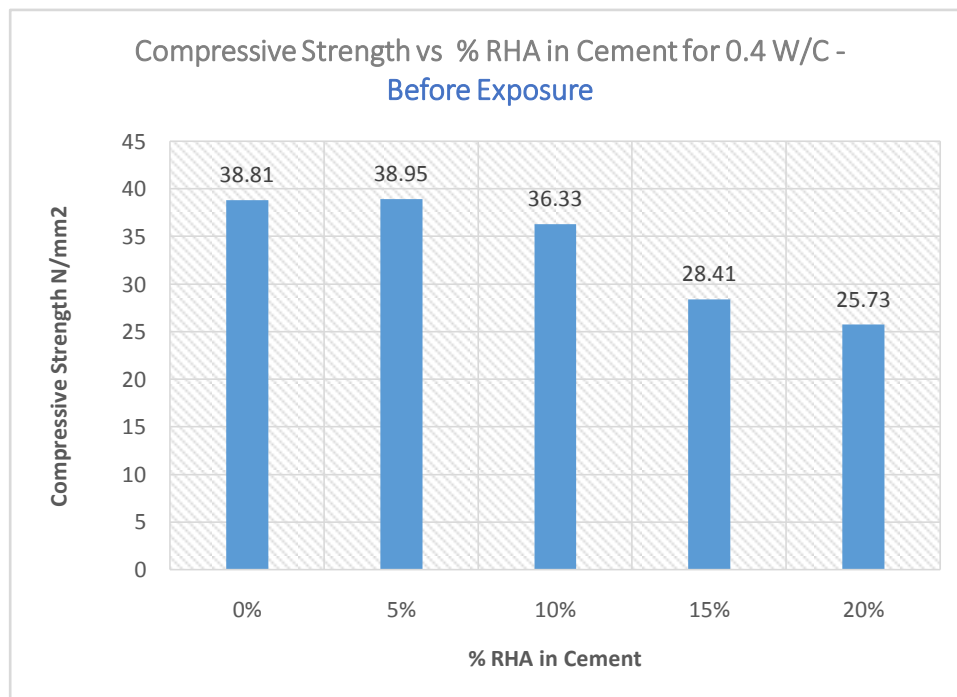


Figure 6: Compressive strength vs % RHA before exposure in aggressive solution, for 0.4 W/C

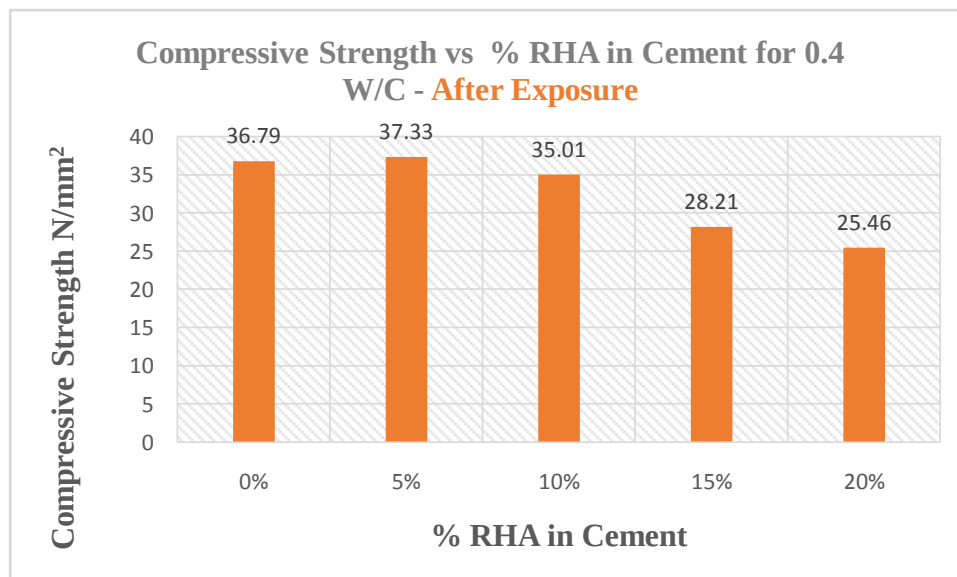


Figure 7: Compressive strength vs % RHA after exposure in aggressive solution, for 0.4 W/C

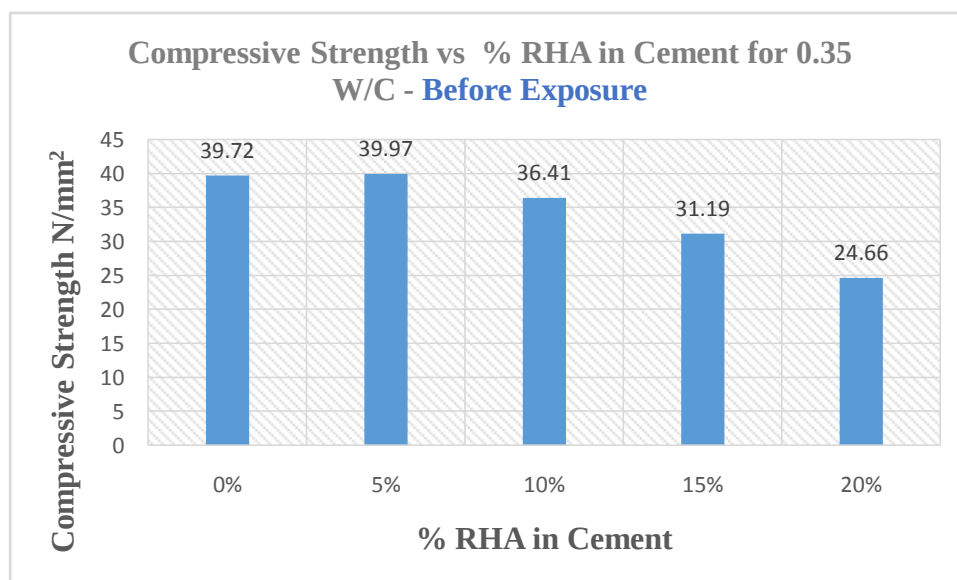


Figure 8: Compressive strength vs % RHA before exposure in aggressive solution, for 0.35 W/C

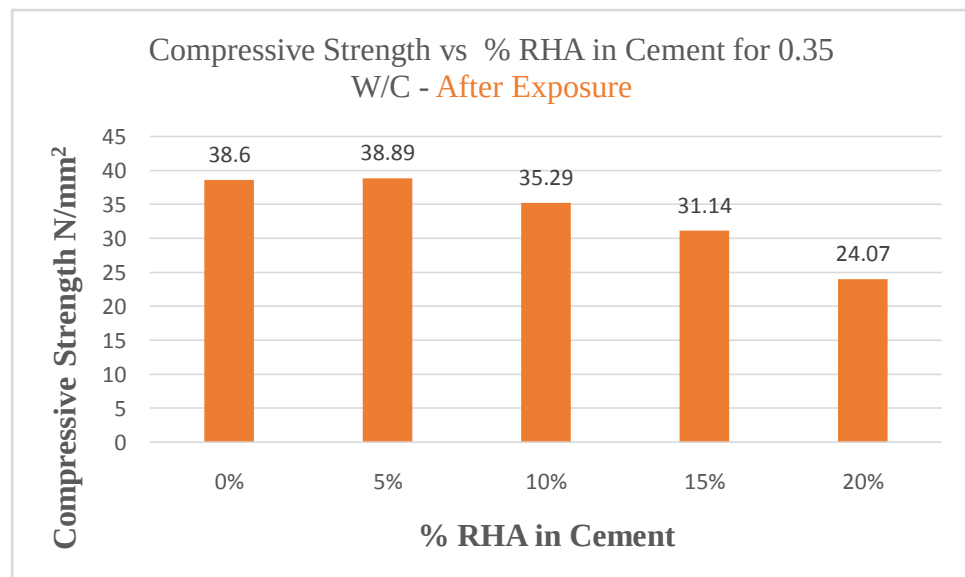


Figure 9: Compressive strength vs % RHA after exposure in aggressive solution, for 0.35 W/C

b) Surface Texture

The surface texture of the surface after interaction with the acidic solution is an observable sign of possible deterioration. The most affected samples had their surfaces easily peeling off upon removal from the acid solution leaving a very rough surface. The least affected samples however had very firm, smooth and compact surfaces that indicated their surfaces inhibited ingress of aggressive media into their matrices (See table 5).

Table 5: Surface Appearance of Cubes after Exposure in Aggressive Acidic Solution

% RHA in Cement	0.4 W/C	0.35 W/C	Remarks
0			Samples with 0% RHA in cement most affected, surfaces easily peeling off.
5			An improvement on surface appearance, surfaces affected but not so much
10			Significant improvement on surface appearance, surfaces indicate very minimal degradation

15			Surfaces showed very little indication of mass loss.
20			Surfaces are firm, smooth and compact. Surfaces of samples least affected by aggressive media.

Samples which had 0% RHA in cement had their surfaces most affected when exposed to aggressive solution while surfaces of samples with 10%, 15% and 20% RHA in cement were less affected in that order.

c) Mass Loss

Figures 10 and 11 show the trend in mass loss for the two W/C of samples incorporating different percentages of RHA in cement. The study determined that the presence of RHA in cement contributed to compactness and durability of the

concrete matrix. Samples with 0% RHA experienced the highest mass loss. There was reduction in mass loss as the presence of RHA increased from 5% to 20%. This could be attributed to the micro filler effect of RHA and the inert property when in contact with the acidic solution. It was established from literature that lower water cement ratios produced more impermeable concrete.

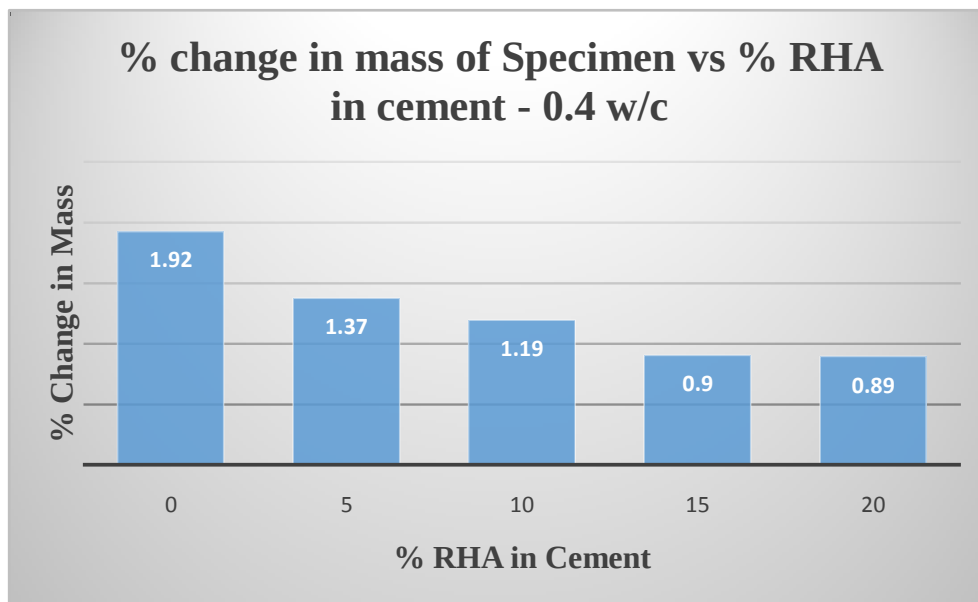


Figure 10: Percentage change in mass vs % RHA in cement with 0.4 w/c

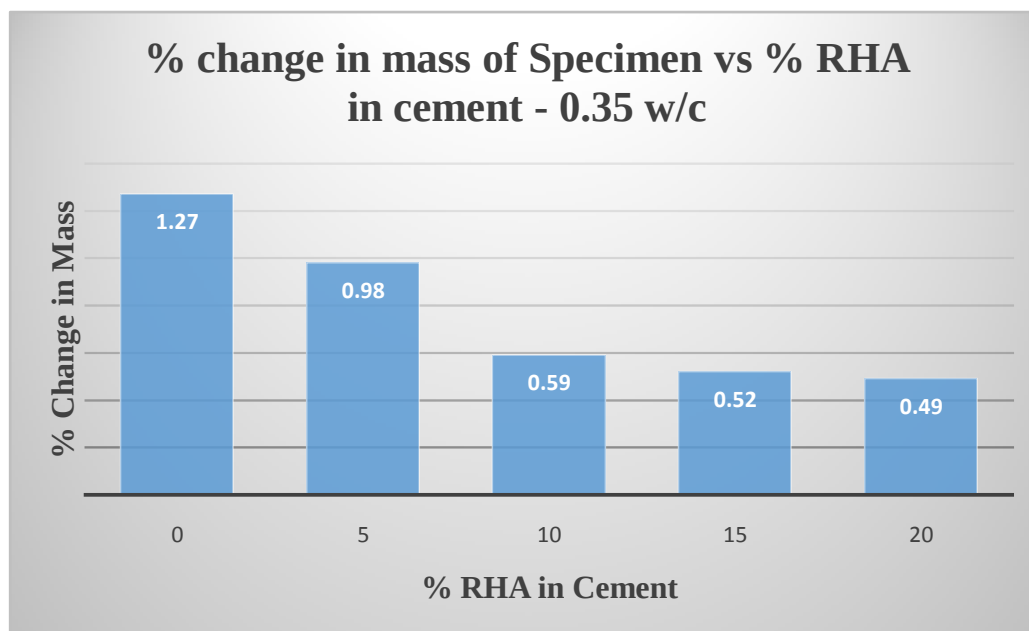


Figure 11: Percentage change in mass vs % RHA in cement with 0.35 w/c

d) Porosity

Porosities of the samples reduced with increasing presence of RHA in cement. With additional silica in excess that is not able to react with available C-H from hydration process, the inert silica acts as a micro filler creating a more compact and less porous matrix that inhibits ingress of deleterious material.

4. Conclusion

The findings from the study show that the combination of the presence of RHA in cement and varied W/C ratio in concrete has significant impact on the durability properties of concrete to be used in acidic environment. The study determined that with 10% RHA replacement in cement with 0.35 W/C ratio, we achieve a compressive strength of 35.3KN/mm^2 that is higher than the characteristic strength determined from the BS by 0.08%. This was after the samples were exposed in a simulated acidic environment for 12 weeks.

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