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Mitigating Sulfate Attack in Concrete using Rice Husk Ash

Ponmile Ayanwale Taiwo, Catherine Mayowa Ikumapayi*, Musibau Ademola Agboola , Oluwaropo Kayode Ajayi and Emmanuel Olugbemiro Ajadi

Department of Civil Engineering, Federal University of Technology, Akure, Nigeria

***Corresponding author:** Catherine Mayowa Ikumapayi, Department of Civil Engineering, Federal University of Technology, P.M.B 704, Akure, Nigeria, Tel: 08037999597, E-mail of corresponding author: mayowaik@yahoo.com

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Abstract

This study investigates the outcomes of partially substituting ordinary Portland cement with rice husk ash (RHA) on the durability of the resulting concrete with respect to sulfate attack using sodium sulfate and magnesium sulfate environments of 30,000mg/L and 50,000mg/L concentrations for various days up till 90 days. The intense of the sulfate attack was appraised in terms of compressive strength, weight loss, water absorption and expansion of the concrete specimens among others and its mechanism is explained using Thermal analysis and thermal gravimetric analysis. The results establish that the use of RHA in concrete will significantly reduce concrete deterioration when subjected to sulfate attack.

Keywords: Rice Husk Ash; Durability of Concrete; Sulfate Attack; Expansion in concrete; Compressive Strength

Introduction

Concrete, one of the ultimate embraced building and construction materials worldwide suffers deteriorations from different angles either from its constituent's materials, service environment or production and placing technology. Unfriendly service environment can cut short the life span of concrete or make the concrete to perform below expectation. Unfriendly service environment for concrete can be due to sulfate attack, chloride ion attack, carbonation, alkali silica reaction, high ambient temperature, high humidity, freezing and thawing among others (Ikumapayi, 2019; Kozubal *et al,* 2019; Pathirage, 2019; European Standard 206, 2005; Maslehuddi, 1994). Sulfate attack effect on concrete structures can be destructive with negative outcomes like expansion, cracking, and other deteriorations. Many civil engineering structures such as docks, bridges, jetties, pipe and box culverts, pile and raft foundations can be seriously dilapidated by sulfate attack. Sources of sulfate attack in concrete could be traced to the type of cement used, sulfate content of the fine and coarse aggregates, sulfate content of the water used in the mix as well as water from the surrounding and underground soil. Sulfate compound varies but the common sulfates are sodium, potassium, magnesium, ammonium and calcium sulfates (Yan *et al*., 1997). Sodium and magnesium sulfates are the most common ones but the magnesium sulfates has been reported to be more destructive than others (Bentur and Cohen, 1992).

Mechanism of sulfate attack of Portland cement binder can be primary explained under two phases. The first phase of the cement hydration involves the reaction of calcium hydroxide with sulfates to generate gypsum ($CaSO_4 \cdot 2H_2O$) as shown in reaction Equations 1 and 2. The second phase involves reaction of gypsum with monosulfates or calcium aluminate hydrate to form ettringite ($3CaO \cdot Al_2O_3 . 3CaSO_4 \cdot 32H_2O$) as shown in Equation 3. Further breaking down of calcium silicate-hydrate (C-S-H) gel into a soppy paste shown in Equation 4 is another chemical reaction peculiar to concretes that are subjected to magnesium sulfate attack. The magnesium ions present can cause extra destructive reactions through the development of Mg $(OH)_2$ and ettringite (Santhanam, 2003; Hekal *et al.* 2002; Santhanam, *et al*., 2002). Formation of ettringite from sulfate attack causes expansion, softening, spalling and weakening of the concrete components thereby subjecting them to premature failure (Bonen and Cohen, 1992). The origins of the expansion can be from the pressure created by the ettringite crystal swelling or swelling resulting from water absorption. Therefore, in aggressive environment, the necessity of ensuring concrete durability in term of sulfate attack should be among the paramount considerations [1-10].

$$Na_2SO_4 + Ca(OH)_2 + 2H_2O = CaSO_4.2H_2O + 2NaOH \quad (1)$$

$$MgSO_4 + Ca(OH)_2 + 2H_2O = CaSO_4.2H_2O + Mg(OH)_2 \quad (2)$$

The sulfate ion + the calcium hydroxide components of hardened cement paste + water = gypsum (calcium sulfate hydrate)

$$3CaO.\ Al_2O_3.12H_2O + 3(CaSO4.\ 2\ H_2O) + 13H_2O \Rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \quad (3)$$

(Ettringite)

Hydrated calcium aluminate + gypsum + water = <u>ettringite</u> (calcium sulphoaluminate hydrate)

$$MgSO_4 + C\text{-}S\text{-}H \Rightarrow CaSO_4.\ 2\ H_2O + M\text{-}S\text{-}H \quad (4)$$

Various methods are already in place to mitigate sulfate attack in concrete. The use of low C_3A content cement to resist both moderate and high sulfates attack is already in use (ASTM C150, 2012). This method is not environmental friendly and such cement are not readily available. This further demands the use of environmental friendly and sustainable method which involve the use of pozzolanic materials (Hooton, 1993; Akhras, 2006) especially the biogenic pozzolans (Arum *et al,* 2013; Ikumapayi 2018). One of the identified biogenic pozzolans is rice husks ash. Rice husk is a worldwide agricultural waste from rice industry and it is available in significant quantities all over the world (Kapur *et al*., 1996; <u>Quispe</u> *et al, 2017;* Boateng and Skeete, 1990; Matsumura, 2005; Bamisaye, 2007). It is recently gaining attention because some of its properties like compressive strength, chemical composition, setting time, workability have been proved to be in accordance with specification. So many past researchers has been engaged in one or two of the aforementioned properties but few of these researches have been tailored towards durability especially sulfate attack (Ikumapayi and Arum, 2016; De sensale, 2006; Zain *et.al*, 2011). In this regard, the sulfate resistance of RHA needs to be deeply investigated so as to properly utilize all its benefits. Its chemical composition, replacement level, behavior under sulfate attack, behavior under temperature change among others will be useful weapons in achieving the proposed target (Nehdi *et al.* 2003; Ikumapayi, 2018). The capacity of the pozzolan in resisting sulfate attack depends on its ability to improve the concrete permeability (Mindess *et al.,* 2003). Based on the foregoing, this research focuses on investigating the effect of sulfate attack from sodium sulfate and magnesium sulfate on the compressive strength and other properties of RHA Pozzolanic concrete. Effect of temperature on the behaviour of RHA Pozzolanic concrete under sulfate attack was also studied. The extent and trend of deteriorations caused in concrete by sodium sulfate and magnesium sulfate were determine and discussed. The degree of mitigation offered by RHA was also presented [11-15].

Materials and Methods

Materials

The type of ordinary Portland cement employed in this research was Dangote *3X* brand, and its properties is in accordance with the specification of British standards BS 12 (1991). River sand was employed as fine aggregate while crushed granite of 25 mm maximum nominal size was employed as the coarse aggregate. In this investigation, the rice husk used in the research were gotten from Ado Ekiti in Nigeria with geographical coordinates of 7° 38’ 0” North and 5° 13’ 0” East. They were air dried, calcinated in a furnace and then sieved with 75 µm (No.70) in the Department of Civil Engineering at the Federal University of Technology Akure. The properties of the RHA in terms of physical and chemical analysis of the RHA were determined and documented under result.

Material testing

Rice Husk Ash: Chemical test on the RHA was carried out using Minipal 4 Energy Dispensing X-ray Fluorescence Spectrometer (EDXRF) to get the oxide composition.

Fine and coarse Aggregate: Natural moisture content of the fine aggregate was determine using the oven-drying method. A weighed sample of the fine aggregates was dried to a constant mass at a temperature of 105 ± 5 °C and the moisture content was gotten using the mass of the total moisture in the sample expressed as a percentage of the mass of the dry sample in accordance with BS 812-109 (1990). Bulk density test for the fine aggregates was also carried out in accordance with the requirement of BS 812 – 2 (1995).. Grading of the coarse aggregates was done in accordance with BS EN 933-1 (2012).

***Setting time*:** This experiment was done in agreement with the standard specification of BSI EN 196 *(2016)*. The initial and final setting times were obtained for all the mixes of OPC and RHA

Concrete preparation

Five concrete mix proportions were prepared with cement partially substituted by RHA at a step side of 5%RHA. A control concrete (CRL) corresponding to 0%RHA was prepared alongside to serve as basic of comparison. The partial cement replacement by RHA was done by weight to achieve better accuracy taking cognisance of the differences in the material properties. Details of the mixed proportions is as shown in Table 1. Conplast SP430 superplasticizer was used at very small proportions to keep the slumps at a close range of 50mm-60mm. Concrete cube samples of 150×150×150 mm^3 dimension were produced to obtain the compressive strength, weight loss, length change and rate of penetration tests. These specimens were compacted and covered to prevent water evaporation. They were then demoulded after a duration of 24 hours and cured in lime saturated water at 23±2 °C temperature. This is to avoid leaching of $Ca\ (OH)_2$ from these specimens.

Table 1: Mix proportions of concrete

	Cement (kg)	RHA (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)	Water/ Cement binder ratio
CTL	399.12	0	798.24	1597.00	219.52	0.55
5% RHA	379.16	19.96	798.24	1597.00	219.52	0.55
10% RHA	359.21.	39.91	798.24	1597.00	219.52	0.55
15% RHA	339.25	59.87	798.24	1597.00	219.52	0.55
20% RHA	319.30	79.82	798.24	1597.00	219.52	0.55

Test on fresh concrete

The test procedure specified in BS EN 12350-2 (2019) was adopted for the slump test. Cement, sand, and coarse aggregates mix ratio of 1:2:4 was adopted and the batching was by weight with water cement ratio of 0.55. The difference between the slump cone's height and the concrete's final height was measured as the slump value. The compacting factor test was also done following the specification in BS EN 12350-2 (2019). The compacting factor was obtained as the ratio of the mass of the partially compacted concrete to that of the wholly compacted concrete. Air Entrainment (Porosity) test was done for the fresh concrete as specified by BS EN 12350-2 (2019). Air permeability of the produced mixes were obtained through pressure application.

Test on hardened concrete

Sulfate attack

Concrete specimens of various mix proportions removed from the lime-saturated water solution tank were immersed in sodium sulfate (Na_2SO_4) and magnesium sulfate (Na_2SO_4) solutions at 23±2 °C (ASTM C1012/1012M-18b, 2018). Two different concentrations of 30,000mg/L and 50,000mg/L of sodium sulfate and magnesium sulfate were used with 30,000mg/L representing moderate sulfate attack while 50,000mg/L represents severe sulfate attack. The control concrete specimens were not taken out of the lime-saturated water solution tank to give room for reasonable comparison.

Compressive strength deterioration test

The compressive strength of the concrete specimens at ages 7, 28, 56 and 90 days were carried out. The magnitude of deterioration caused by sulfate attack (Na_2SO_4 and $MgSO_4$ solutions) in relations to the percentage loss of compressive strength in the concrete were calculated.

Length change

The change in length observed for the concrete specimens were also considered as basis of measuring the sulfate resistance of RHA concrete (ASTM C1012/1012M-18b, 2018). The length change of the concrete cubes were determined after regular immersion periods of 7, 28, 56 and 90 days in 30,000 mg/L and 50,000 mg/L of Na_2SO_4 and $MgSO_4$ solutions as shown in Plate 1. The length changes were calculated using the formula in Equation 6 according to the standard and past researchers (Ash and John, 2017; ASTM C1012/1012M-18b, 2018)

$$\Delta L = \frac{L1-L2}{L3} \times 100 \qquad (6)$$

Where:
ΔL is percentage change in length of the sepecimen,
L_1 is length of specimen during assessment,
L_2 is length of specimen at immersion,
L_3 is innermost length of the moulds

Plate 1: Length change test

Water Absorption

Water absorption test was executed on the concrete samples at 7, 28, 56 and 90 days. These samples were dehydrated very well for 21 days by open exposure. The specimens were then weighed and soaked in water for a period of 24 hours, They were later brought out, cleaned by mopping and then re-weighed. The change in weight is the water absorbed. The water absorption can be expressed in percentage using Equation 7 (BS 1881, 2011) [16-22].

$$Wa = \frac{Mw - Md}{Md} \times 100 \quad (7)$$

Where:

W_a is water absorption (%)

M_w is mass of the wet specimen subsequent to 24 hours immersion in water

M_d is the mass of dry specimen prior to water immersion.

Weight Loss

The initial weights of the specified concrete specimens were measured before they were exposed to sulfate solution and the final weights of the concrete specimens after the exposure of concrete to sulfate solution were also measured. The weight loss were determined using the formula in Equation 8 according to some past researchers (Corral-Higuera., *et al.,* 2011).

$$W = \frac{W1 - W2}{W2} \times 100 \quad (8)$$

W symbolises the weight loss,

W_1 symbolises the initial weight of cube specimen submerged in water,

W_2 symbolises the weight of specimen submerged in sulfate solutions.

Depth of sulfate penetration

Concrete samples were investigated in terms of the sulfate penetration depth. The concrete specimens were sliced into two parts and the sulfate penetration depths were measured using phenolphthalein as indicator. The experiments were carried out at the 7, 28, 56 and 90 days specified time.

Results and Discussion

The outcomes of the chemical test of the RHA is presented in Table 2. The sum of the three chief oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) is 88.04% indicating that RHA is a pozzolans of class N, while the percentage of SO_3 is 0.36% which is less than 4.0 maximum. The loss on ignition is 3.18% which is less than the maximum 10. These results are in agreement with the standard requirement for a pozzolan (ASTM C618, 2019) and the result follows the same trend as past research outcomes (Raheem and Kareem, 2017).

Table 2: Oxide Composition of Rice Husk Ash (RHA)

S/N	Elements	Proportion (%)
1	SiO_2	87.23
2	Al_2O_3	0.35
3	Fe_2O_3	0.46
4	CaO	0.10
5	MgO	0.81
6	Na_2O	0.04
7	K_2O	2.97
8	SO_3	0.36
9	MnO	0.28
10	Pb_2O_5	2.62
11	TiO_2	0.05
12	ZnO	0.12
13	Cr_2O_3	0.03
14	BaO	0.06
15	LOI	3.18

Results of research materials testing

The results of the natural moisture content and bulk density of the fine aggregates shown in Table 3 are appropriate for making normal concrete.

Table 3: Physical Properties of Aggregate

Type of Test	River Sand
Natural moisture content (%)	11.34
Bulk density (kg/m^3)	2233.05

The grading of the coarse aggregates, fine aggregates, and rice husk ash are Table 4. The results indicate that the coarse aggregates are uniformly graded between 4 mm and 20 mm sizes. This establishes their suitability in any building and other structural works (BS EN 12620:2002+A1, 2008). The river sand also conforms to specification as it is well graded and very much suitable for any form of construction work (BS EN 12620:2002+A1, 2008). Furthermore, 1.0% of RHA was retained on BS 45 μm sieve as shown in Table 4, this indicates conformity with ASTM C618 (2019) that specifies a maximum of 5% retained for any pozzolan or other supplementary cementitious material [23-29].

Table 4: Particle size distribution for the constituent materials

Sieve size	Coarse aggregates % Passing	River sand % Passing	RHA % Passing
14.0mm	100.00		
12.0mm	68.42		
10 .0mm	32.70		
6.0 mm		100.00	
5.0 mm	1.96	93.94	
4.0 mm	0.36	92.24	
3.0 mm		90.46	
2.36 mm		88.10	
1.80 mm		86.58	
1.70 mm		83.23	100.00
600 µm		66.59	63.80
500 µm		63.57	55.10
212 µm		22.95	8.20
150 µm		12.25	1.70
0.75 µm		9.60	0.60
pan	0.00	0.00	0.00

Setting time of the OPC/RHA binder

The outcomes of the setting times for Ordinary Portland cement and blend mixes OPC/RHA are shown in Figure 1. There were reductions in the two setting times for OPC/RHA pastes in comparison to the OPC paste. But, both the initial and final setting times of the OPC/RHA falls within the recommended values of 45 minutes minimum and 600 minutes maximum specifies by BSI EN 196 (2016). Therefore, the setting times of OPC/RHA from 0% to 20% meets with specifications.

Tests on fresh concrete

Workability and air entrainment tests results are shown in Table 5. There is an improvement in the slump and air entrainment results of the blend mixes as the RHA content increases. This implies that effective use of RHA requires more water for workable fresh concrete. The use of superplasticizer can also be employed to improve the workability of such concrete. The outcomes of air entrainment indicates reduction in the void present within the OPC/RHA concrete thereby improving the packing morphology of the cement and making the concrete less permeable to aggressive substances like sulfate compound.

Compressive strength

Compressive strength results of the concrete specimens in water and those subjected to sulfate attack of different concentrations are shown in Figures 2 to 5. The result of concrete subjected to sodium sulfate moderate attack i.e. Na_2SO_4 moderate solution (30,000 mg/L concentration) in Figure 2 shows increase in strength throughout the 90 days attack. This is an indication that moderate sulfate aggressive environment has little negative consequence on the concrete compressive strength. Same results show improvement in the compressive strength as the percentage of RHA increases from 5% to 20% throughout the sulfate attack period, this implies that RHA improves the robustness of concrete thereby improving the compressive strength of such concrete. The result of concrete subjected to sodium sulfate severe

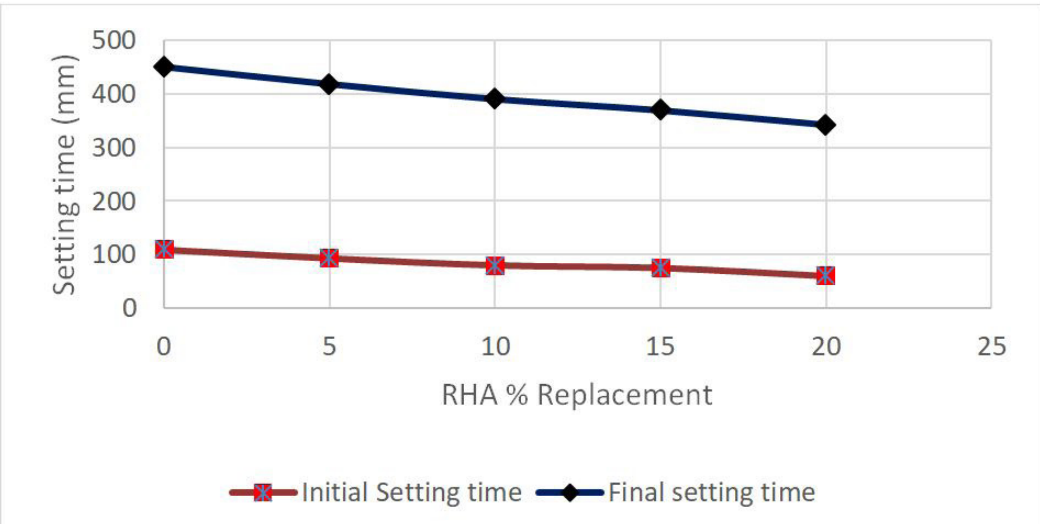

Plate 1: Length change test

Table 5: Compacting factor, Slump test and Air Entrainment values

Percentage replacement (%)	0	5	10	15	20
Compacting Factor m_p / m_f	0.81	0.86	0.89	0.91	0.93
Slump values (cm)	9.50	5.00	7.50	7.00	3.00
Air Entrainment (%)	2.45	2.00	1.80	1.75	2.30

attack i.e. Na_2SO_4 severe solution (50,000 mg/L concentration) shows increase in strength till 56 days and then decrease in compressive strength at 90 days, this further implies that the level of compressive strength deterioration in concrete is a function of the sulfate concentration. In Figures 4 and 5, for both concentrations of $MgSO_4$ solution (30,000 mg/L and 50,000 mg/L concentrations), the deterioration in strength commences after 56 days with $MgSO_4$ of 50,000 mg/L concentrations having the greater compressive strength reduction. It can also be observed from the results that $MgSO_4$ attack shows greater reduction in compressive strength than Na_2SO_4 attack. This is also an indication that the extent of compressive strength deterioration by sulfate attack is a function of the sulfate source. This further established that the presence of magnesium ions causes extra destructive reactions through the formation of Mg $(OH)_2$ and ettringite, a reaction that is familiar only to magnesium sulfate attack. This is in accordance with the results obtained and explanation proposed by some past researchers (Santhanam, *et al.*, 2002; Santhanam, 2003; Hekal *et al.* 2002) [30-35].

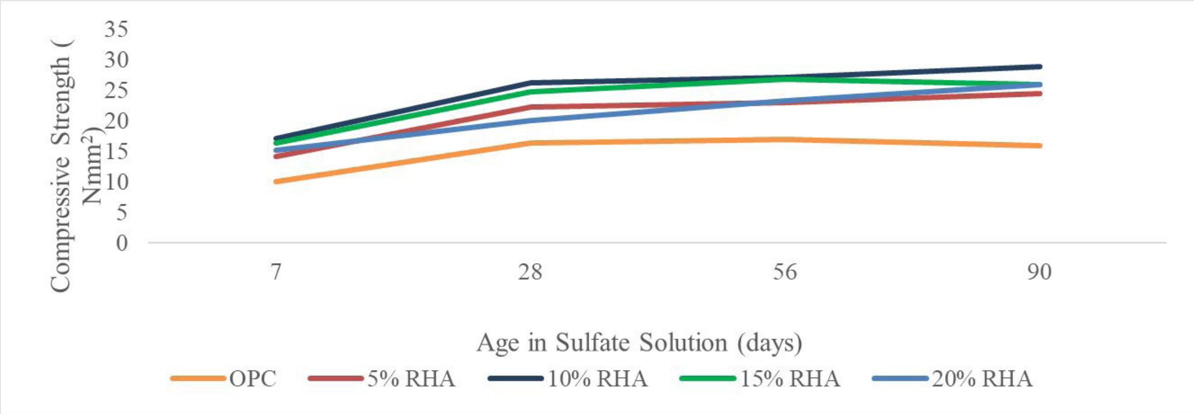

Figure 2: Compressive Strength Test Result for Concrete Immersed in Na_2SO_4 Moderate Solution (30,000 mg/L concentration)

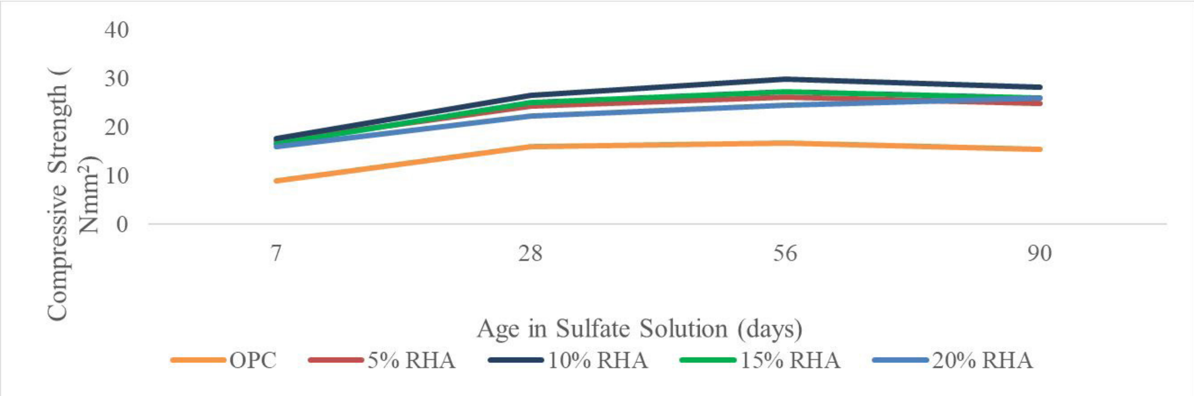

Figure 3: Compressive Strength Test Result for Concrete Immersed in Na_2SO_4 Severe Solution ((50,000 mg/L concentration)

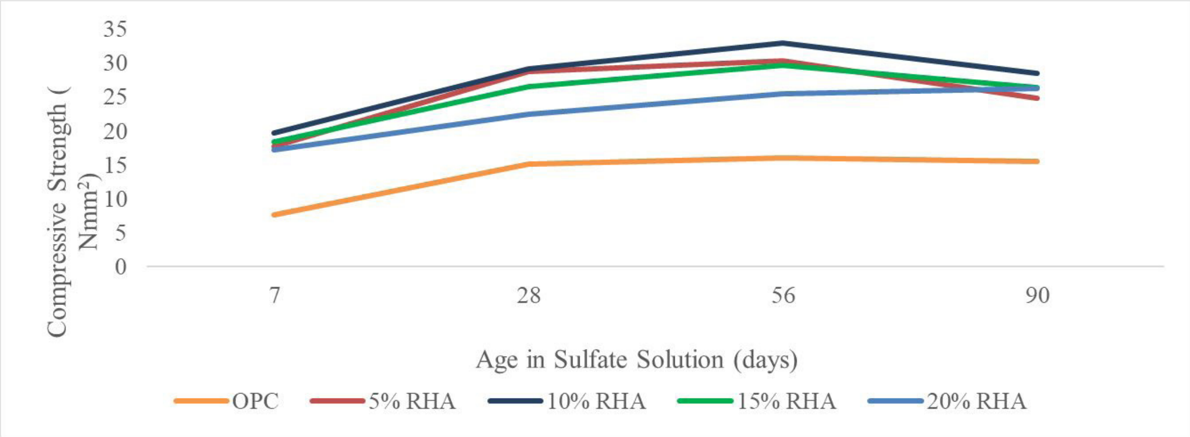

Figure 4: Compressive Strength Test Result for Concrete Immersed in $MgSO_4$ Moderate Solution ((30,000 mg/L concentration)

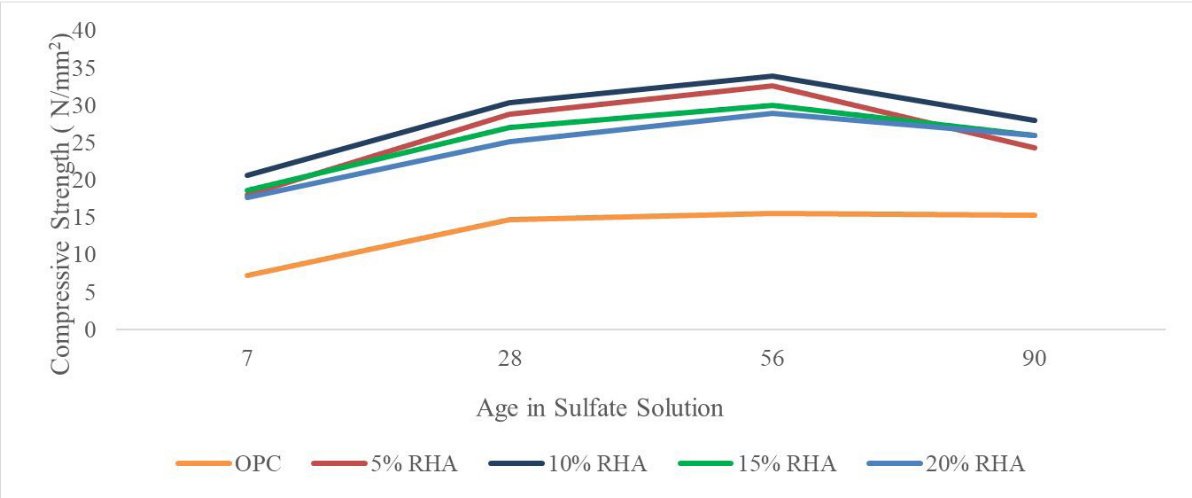

Figure 5: Compressive Strength Test Result for Concrete Immersed in $MgSO_4$ Severe Solution ((30,000 mg/L concentration)

Compressive strength deterioration

The magnitude of the compressive strength loss from sulfate attack by sodium and magnesium sulfate solutions are shown in Figures 6 to 9. At 7 days the graph shows that magnesium sulfate has more deteriorative effect on the concrete than sodium sulfate but this effect reduces with the addition of RHA which makes sodium sulfate attack more destructive to the concrete on addition of RHA. Same trend and relationship were also experienced after 28, and 56 days. After 90 days of attack, the control concrete have the highest strength loss, signifying lower resistivity of OPC concrete to OPC/RHA concrete. Magnesium sulfate also shows more deteriorative percentages than sodium sulfate throughout after 90 days of sulfate attack [36-40].

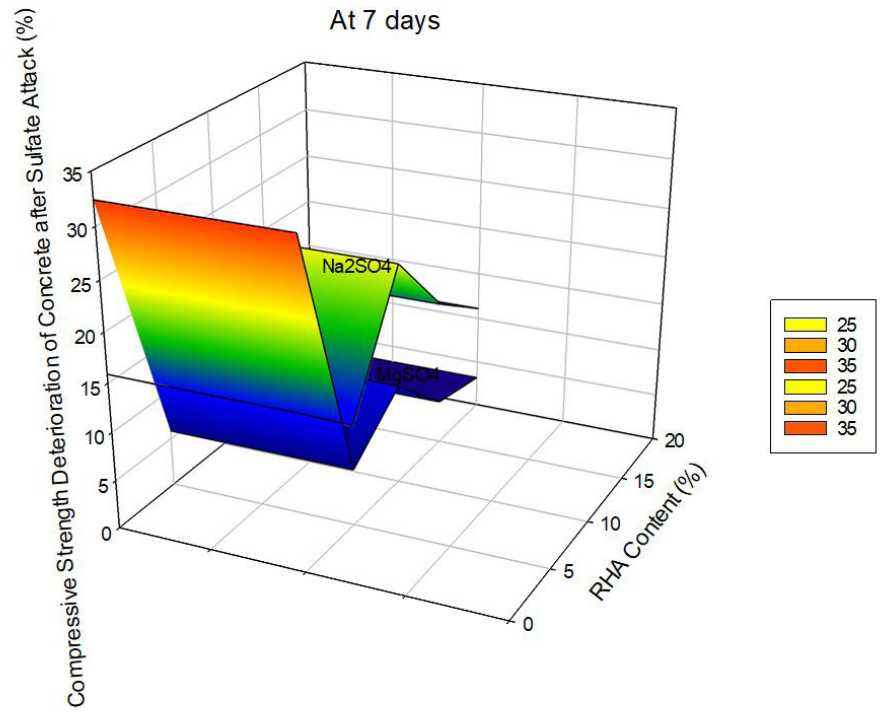

Figure 6: Percentage of Compressive strength deterioration of concrete after 7 days immersion in sulfate

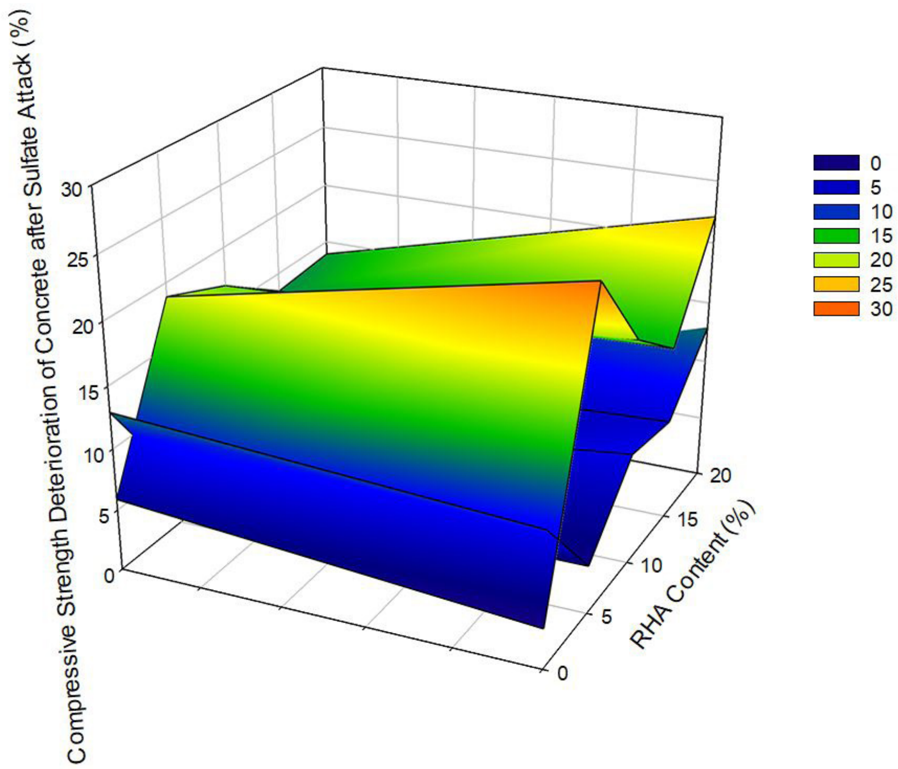

Figure 7: Percentage of Compressive strength deterioration of concrete after 28 days immersion in sulfate

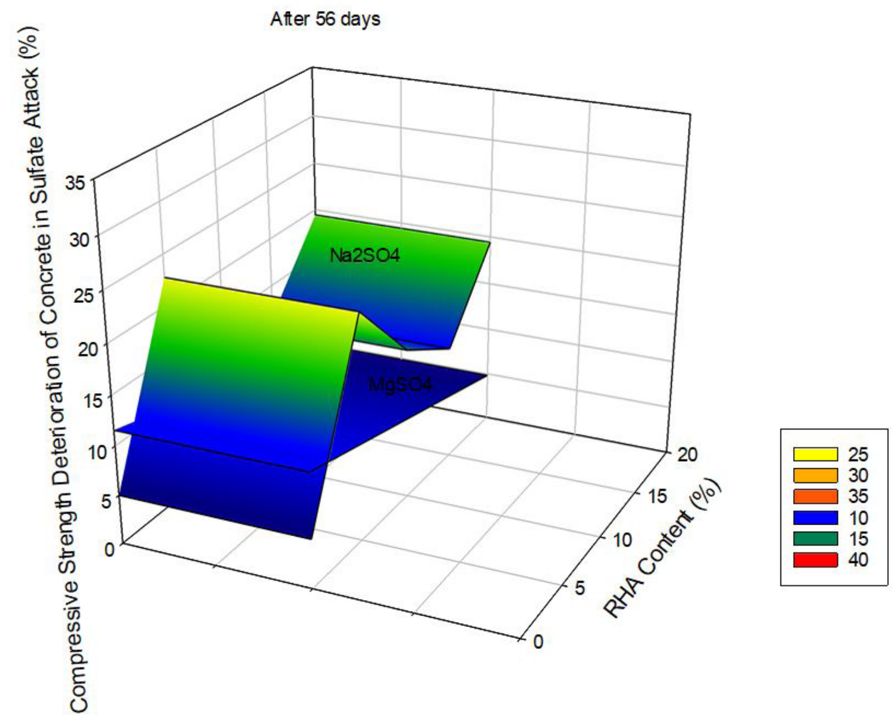

Figure 8: Percentage of Compressive strength deterioration of concrete after 56 days immersion in sulfate

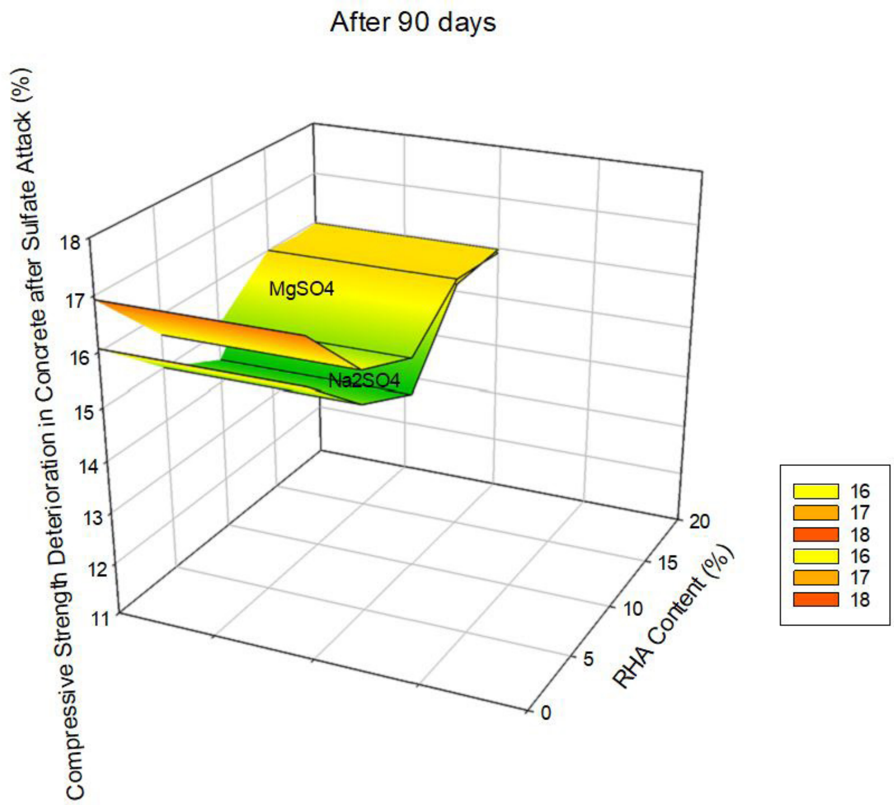

Figure 9: Percentage of Compressive strength deterioration of concrete after 90 days immersion in sulfate

Length change of concrete specimen

The result in Figures 10 and 11 shows the length change of the various specimens. The length change of the OPC concrete is higher than the RHA concrete throughout the percentage replacement. Control specimens demonstrated higher length change at all ages than RHA concrete cubes, and the length change decreases with increase in the RHA replacement level. The length change also rises with an increase in the age of immersion, showing that length change in concrete subjected to sodium and magnesium sulfates attack is a function of time of attack. These findings are in accordance with Moon *et al.*(2003) and Chindarprasit, *et al.* (2007), who also reported that RHA exhibits better performance than OPC in reducing gypsum and ettringite formation in concrete. Another researcher reported that generally, SCMs help in mitigating sulfate attack by altering the pores arrangement, reduce C_3A concentration and get rid of $Ca(OH)_2$ by changing it into C-S-H, thus decreasing the magnitudes of gypsum formed (Bapat, 2012) [28-43].

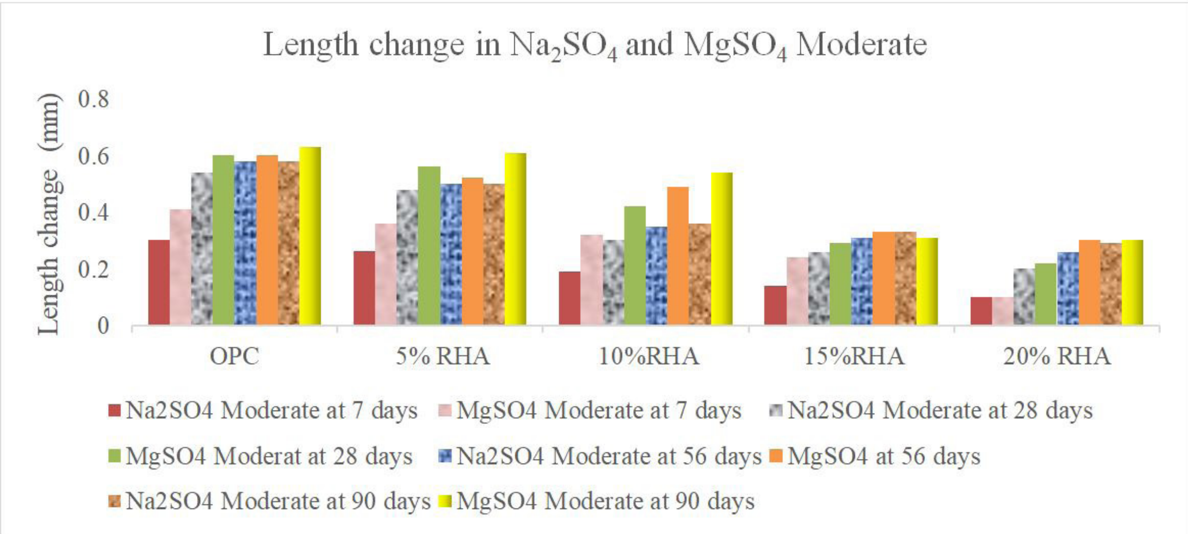

Figure 10: Length change for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Moderate Solutions

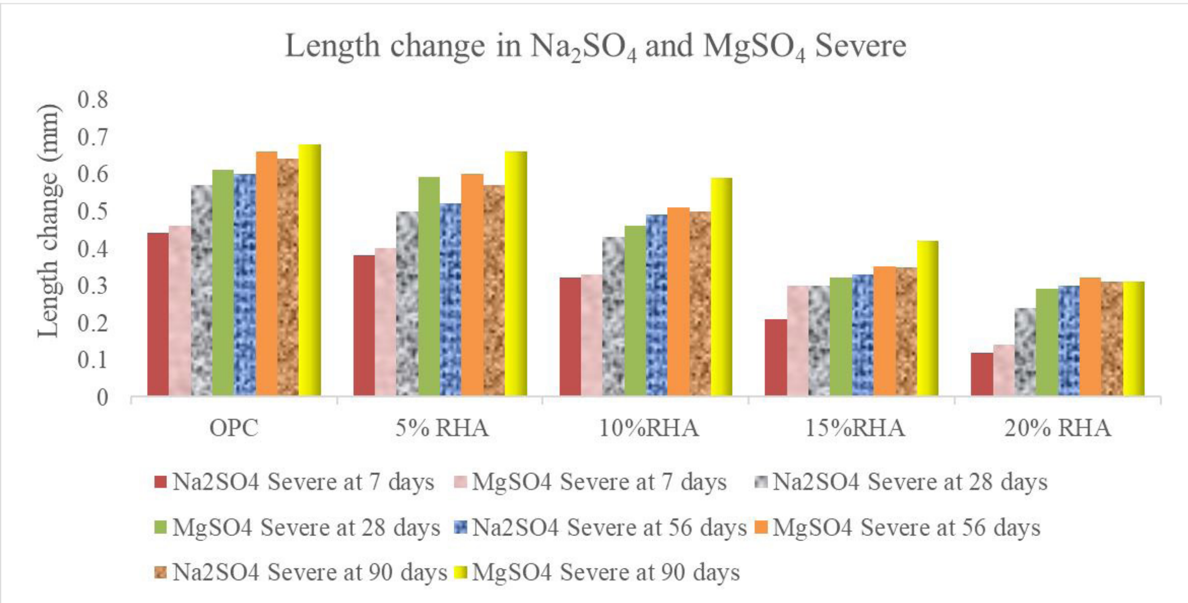

Figure 11: Length change for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Severe Solutions

Water absorption

Water absorption of OPC/RHA concrete cubes results are shown in Figures 12 and 13, an overall reduction in the percentage weight of water absorbed was detected as the RHA percentage replacement increases. The water absorption of the RHA blended cement concrete reduces as the RHA specimens increases. The concrete cubes subjected to Na_2SO_4 attack was found to exhibit a lower water absorption rate than the concrete cubes subjected to MgSO4 attack when all other conditions are the same.

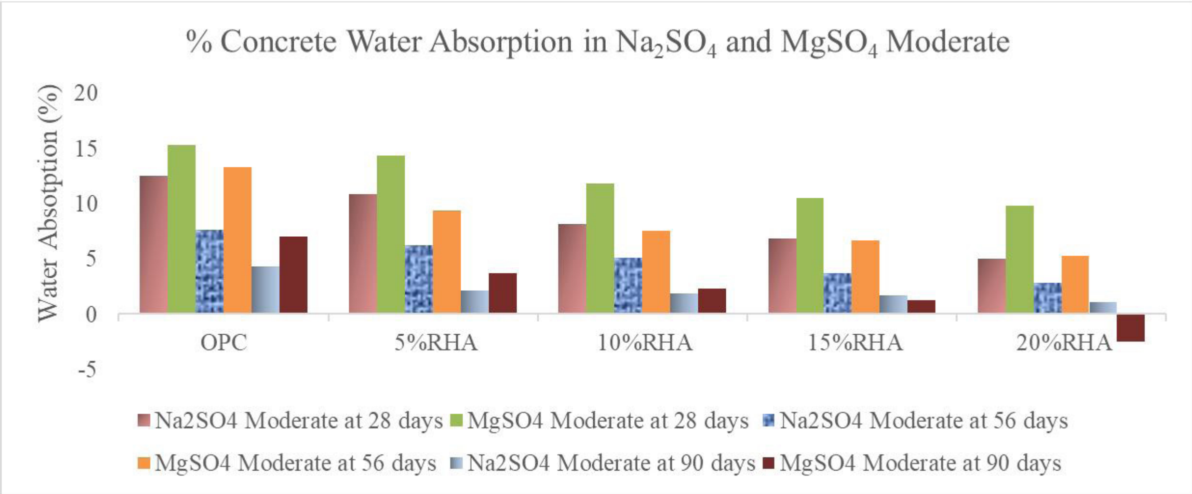

Figure 12: Percentage Water Absorption for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Moderate Solutions

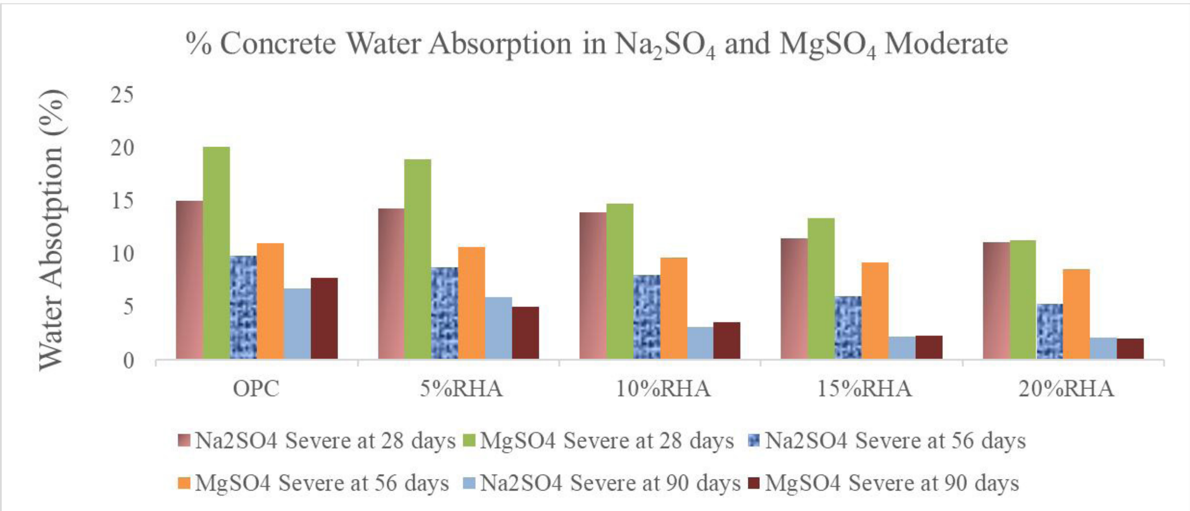

Figure 13: Percentage Water Absorption for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Severe Solutions

Weight loss

Weight loss results shown in Figures 14 and 15 for moderate solution and severe solution respectively displays an increase in weight loss as the sulfate attack days increases and as the concentration of the sulfate attack increases. 20% RHA concrete exhibits weight gain at 90 days for severe solutions.

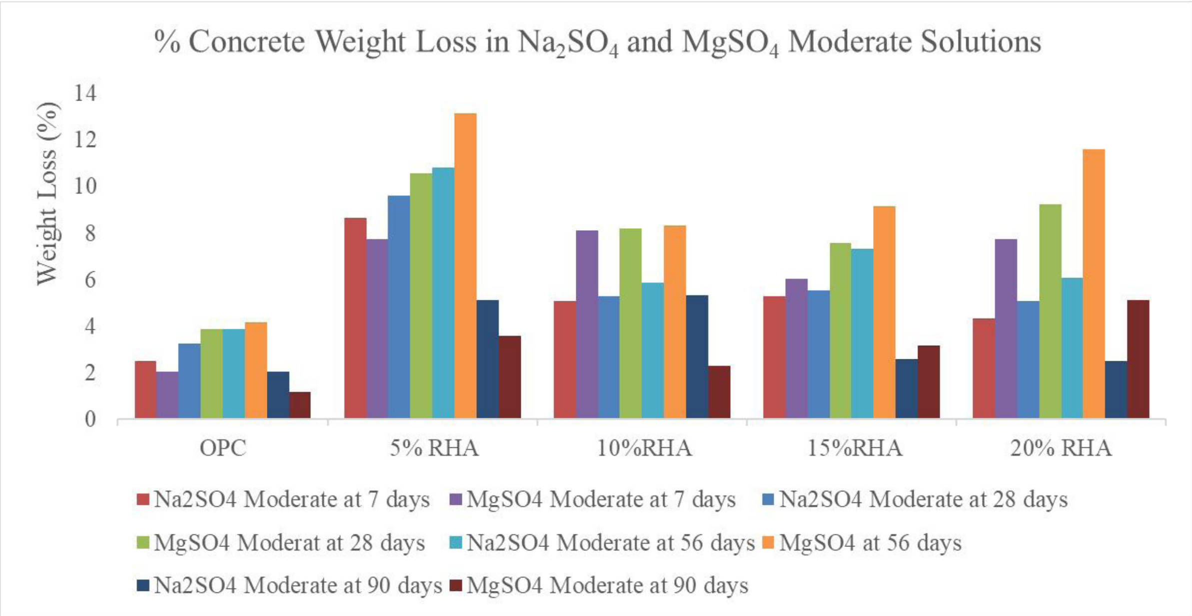

Figure 14: Percentage Weight Loss for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Moderate Solutions

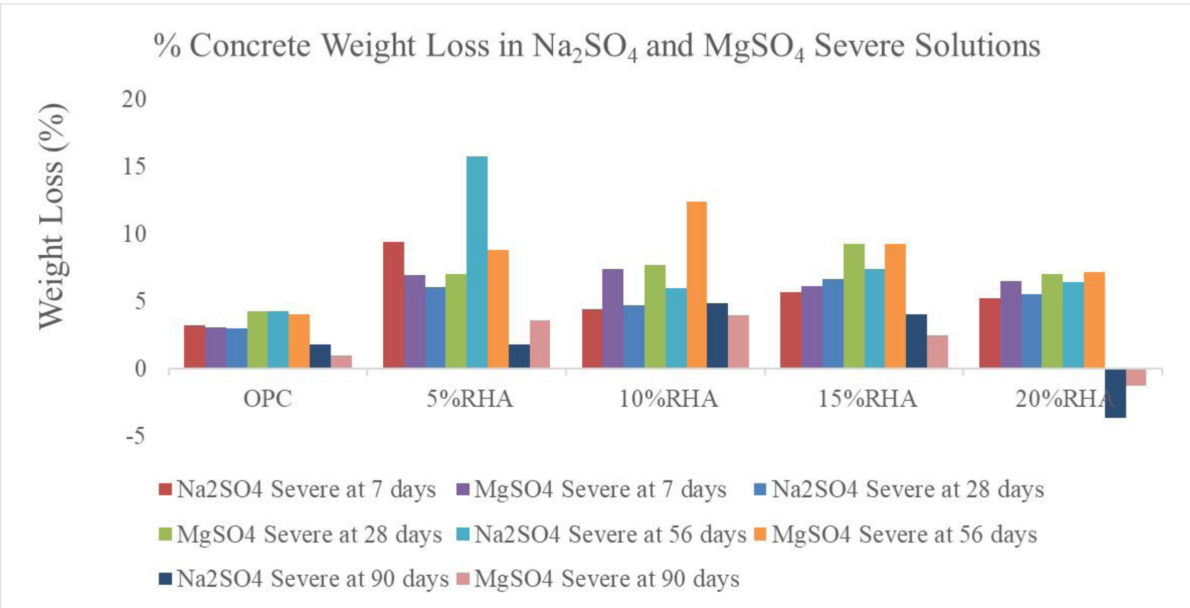

Figure 15: Percentage Weight Loss for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Severe Solutions

Penetration depth

The results of the sulfate penetration depths of the various RHA blended cement concrete specimens are presented in Figure 16. The depth of penetration increases as the period of sulfate attack increases. The graph also shows that $MgSO_4$ exhibits greater attack than Na_2SO_4 throughout the sulfate attack period although at 90 days all the concrete specimens experienced total penetration though the concrete.

Statistical analysis of the compressive strength

The statistical analysis of the compressive strength at 90 day sulfate attack using SPSS software is as presented in Tables 6 to 7. The result of the LSD post hoc test shown in Table 7 showed that there was no significant different between the control i.e. OPC and all the other OPC samples when subjected to either of the sulfate attack at 90 days. On the other hands there were significant differences between the controls i.e. OPC and the other RHA concrete samples when subjected to either of the sulfate attack at 90 days. This implies that RHA mix is either more resistance to sulfate attack or vice versa. With reference to the result of compressive strength in (Figures 2 to 5), It can be deduced that RHA samples have better resistance to either of the two sulfate attack (i.e. sodium sulfate or magnesium sulfate) and this resistance to sulfate attack in terms of compressive strength is significant at 90 days sulfate attack.

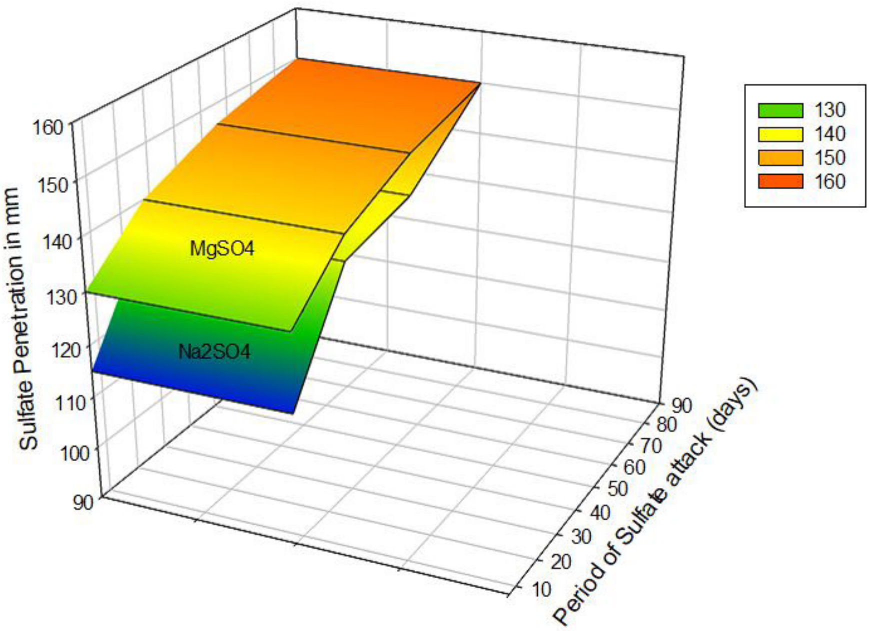

Figure 16: Penetration Depth for Concrete Immersed in Na_2SO_4 and $MgSO_4$ Moderate and Severe Solutions

Table 6: ANOVA Result of the Compressive strength at 90 days

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1868.579	24	77.857	17.051	.000
Within Groups	228.307	50	4.566		
Total	2096.886	74			

Table 7: LSD test for Compressive strength of concrete samples at 90 days sulfate attack

i	j	MD(i-j)	p	Remark
1	2	-10.43333*	.000	*
	3	-14.63333*	.000	*
	4	-12.60000*	.000	*
	5	-12.50000*	.000	*
	6	2.40000	.175	NS
	7	-6.46667*	.001	*
	8	-10.60000*	.000	*
	9	-7.66667*	.000	*
	10	-6.90000*	.000	*
	11	3.00000	.092	NS
	12	-6.53333*	.000	*
	13	-11.50000*	.000	*
	14	-7.86667*	.000	*
	15	-7.10000*	.000	*
	16	2.90000	.103	NS
	17	-6.50000*	.000	*
	18	-10.20000*	.000	*
	19	-8.10000*	.000	*
	20	-7.96667*	.000	*
	21	3.10000	.082	NS
	22	-5.93333*	.001	*
	23	-9.63333*	.000	*
	24	-7.63333*	.000	*
	25	-7.60000*	.000	*

*Mean Difference is significant at $p < 0.05$, NS= Not Significant, 1-OPCCRL90, 2 -RHA5CRL90, 3 -RHA10CRL90, 4 -RHA15CRL90, 5 -RHA20CRL90, 6 -OPCNa2SO4M90, 7 -RHA5Na2SO4M90, 8-RHA10Na2SO4M90, 9 -RHA15Na2SO4M90, 10 -RHA20Na2SO4M90, 11 -OPCNa2SO4S90, 12 -RHA5Na2SO4S90, 13 -RHA10Na2SO4S90, 14 -RHA15Na2SO4S90, 15 -RHA20Na2SO4S90, 16 -OPCMgSO4M90, 17 -RHA5MgSO4M90, 18 -RHA10MgSO4M90, 19 -RHA15MgSO4M90, 20 -RHA20MgSO4M90, 21-OPCMgSO4S90, 22 -RHA5MgSO4S90, 23 -RHA10MgSO4S90, 24 -RHA15MgSO4S90, 25 -RHA20MgSO4S90

Conclusions

This research is based on mitigating sulfate attack in concrete using rice husk ash for various mixed with cement partially replaced by 0%, 5%, 10%, 15% and 20%. From the study conducted on mitigating sulfate attack in concrete using rice husk ash, it can be concluded that;

i. Sulfate attack is a treat to concrete that is subjected to sulfate environment from the angle of expansion, weight loss, water absorption and loss of compressive strength.

ii. Blend OPC/RHA concrete is a potential expansion reducer caused by sulfate attack. This is in accordance with the result obtained by Akbar *et al.*(2020) that bagasse ash in finely grounded form produces a better structured geopolymer composites.

iii. OPC/RHA concrete can serve as compressive strength modifier and sulfate attack opposition in concretes.

iv. The results of the TG and DTA showed that greater percentage of the weight loss in all these specimens could be traced to the second step weight loss, which is due to carbon monoxide.

Recommendations

On the basis of this research findings, the potential of Rice Husk Ash to mitigate sulfate attack in concrete is high and goes along well with other properties of the concrete. Therefore, RHA should be adopted as cement admixture for sulfate resistance in concrete especially in aggressive areas.

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