EXPERIMENTAL STUDY ON THE DURABILITY TO SALINE ENVIRONMENTS OF SELF-COMPACTING CONCRETE MADE WITH COARSE AGGREGATES COMBINATION

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This study focus on durability to saline environments of self-compacting concrete (SCC) made of granite-gravel combination as coarse aggregates in concrete production. In this study fine aggregates, water, superplasticizer and cement were kept constant. The percentages replacement of gravel in place of granite aggregates were 10, 20, 30, 40, and 50, while 100% granite serves as control. A total of 162 cubes of 100 × 100 × 100 mm concrete specimens were immersed over the initial curing in a water container and further cured in 5% sodium chloride (NaCl) and sodium carbonate (Na_2CO_3) solutions for 28, 56 and 91 days in line with ASTM C39 (2003). The tests results indicate that concrete cured in five percent (5%) of NaCl solution have compressive strength accelerating properties at early age that could not be sustained for long. While those cured in 5% of Na_2CO_3 solution reduced significantly the compressive strength of concrete.

Keywords: *Self-compacting concrete, concrete, durability, sodium chloride, cement, sodium carbonate, compressive strength.*

1. Introduction

Nik-Zafri [1] defined concrete as a mixture of cement, water, fine and coarse aggregates, the aggregates serve as the filler while water and cement form the paste. One of the most widely used construction materials is concrete. The importance of studying self-compacting concrete (SCC) is significant because of the ease of flow, placement and time of casting concrete can greatly lessen the costs and permit more flexibility in architectural and structural design [2]. Nilsson [3] reported that the use self-compacting concrete has the potential to decrease the emission of greenhouse gases and energy consumption by 20-30% and improved durability of the resultant concrete. The purpose of this study is to determine the adverse effects of substituting various percentages of washed gravel for granite as a coarse aggregate on self-compacting concrete (SCC) cured in both water and chemicals.

Xianming et al. [4] studied the chloride-based deicers effect of reinforcement on reinforced traditional concrete structures and discovered that the chemicals changes of concrete have no effect on other additives and corrosion inhibitors in deicers. Kejin et al. [5] studied damage caused by deicing chemicals on concrete materials, from the results obtained it was discovered that the rate of penetration of deicing chemicals and damage caused on concrete varying in respect to paste and concrete. On the other hand [6] discovered that the deterioration of concrete in chemicals may results from cement hydration decomposition and leaching. Also, the production of precipitation in concrete may results from the interaction between concrete materials and corrosion inhibitors [7]. Nazari & Riahi [8] investigated the strength assessment and coefficient of water absorption of high performance self-compacting concrete containing different amount of TiO_2 nano particles and reported that the addition of TiO_2 nano particles in the cement paste improved the strength and the resistances to water permeability of the specimens by 4.0%. Han et al., [9]; Wang et al., [10] and Siddique et al., [11] discovered that to achieve adequate flow of materials, strength and durability of concrete, factors such as composition of materials, chemical and mineral admixtures, aggregates, water to cement ratio and design method have significant effects on them.

It should be noted that the porosity of concrete as a result of crack is liable to expose the concrete to deleterious substance form the surrounding which will reduce the strength, durability and serviceability of concrete [12]. Therefore, to prevent both external and internal detrimental elements of concrete such as acid rain, temperature variation, sulfate ion, sunshine, seawater and sodium chloride (NaCl) which may

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lead to concrete cracks and pores, constituent materials selection, mixing and curing of concrete must be adequate [13]. However, Shi et al., [14] concluded that exposure of traditional concrete to chloride may cause detrimental effects on concrete infrastructure, which may result in reduction in strength and concrete integrity. Concrete that are exposed to concentrated $CaCl_2$ disintegrates in similar ways to those exposed to magnesium chloride ($MgCl_2$), but in a slower and less severe pace [15]. In addition, Haque et al., [16] reported that the long time use of deicer (NaCl) can accelerate the alkali silica reaction (ASR), while $CaCl_2$ and $MgCl_2$ do not have significant results impact on ASR.

Haque et al., [16] worked on the strength and durability of lightweight concrete and discovered that the water permeability of a given concrete determine the penetration of chemicals like chlorine ions, sulphate and carbon dioxide into the concrete. Kore & Vyas [17] concluded that when traditional concrete is exposed to acid, the average reduction in compressive strength of control mix compared with the concrete containing marble, it was observed that there was not much adverse effect of acids on the marble concrete compared with the control.

Beeralingegowda & Gundakalle [18] reported the effect of addition of limestone powder on properties of SCC when 0-30% limestone powder were used to replace cement content in the SCC. The fresh and durability tests were studied. Regression analysis was used to analyze the results and found that limestone powder can be effectively used as a mineral additive in self-compacting concrete. However, Persson [19] investigated the frost resistance of SCC and found that damage is much less in SCC compared with traditional concrete, but they have similar scaling.

Zhu et al., [20] reported the transport properties and durability of SCC and found that the chloride migration in concrete depended much on the type of solid additives used in the mix. Hwang & Tsai [21] compared the performance of lightweight self-compacting concrete under different water-cement ratios and cement paste contents and found that, the packing of aggregates depend greatly on the amount of cement paste which increase strength efficiency of concrete and decrease the capacity of chloride ion to penetrate self-compacting lightweight concrete. Again, Makishima et al., [22] investigated self-compacting concrete frost resistance and found that self-compacting concrete has good resistance to thawing and freezing of concrete but there is need for entrained air to attain long term concrete frost resistance. Mortshall & Rodium [23] compared frost resistance of self-compacting concrete with conventionally-placed concrete and discovered that self-compacting concrete only showed at the skin surface better resistance to frost when subjected to varieties of durability tests.

Available literature reveals that just few studies exist on the durability of normal aggregate for SCC, of which aggregate makes up the bulk of concrete. Their properties largely determine the properties of concrete as a result of these. This current study focus on durability to saline environments of self-compacting concrete (SCC) made of granite-gravel combination as coarse aggregates in concrete production for both early and late ages.

2. Experimental

2.1 Materials and methods

The coarse aggregates used for this current study were granite and local gravel with maximum size of 12.5 mm; whereas river sand was used as fine aggregates in conformity with [24]. The Cement used was ordinary Portland cement CEM 42.5N, in line with the prerequisite of [25] standard. The super-plasticizer used for this research to achieve flow ability that is acceptable for self-compacting concrete was Complast SP 432 MS in conformity with [26]. The hydration process of the concrete was not controlled by any retarder agent. Natural odourless, colourless tap water was used for the concrete production. Fine aggregates, water, superplasticizer and cement were kept constant. The percentages replacement of gravel in place of granite aggregates were 10, 20, 30, 40, and 50, while 100% granite serves as control. Six concrete mixture samples based on the varying percentage proportions of gravel in place of granite were analyzed in this study. The mix samples were labelled SCC1 for 100% granite which serves as control, while granite replacement with gravel in the percentage proportions of 10, 20, 30, 40 and 50 are represented by SCC2, SCC3, SCC4, SCC5 and SCC6. The Batching and mixing of concrete with varying mix compositions of coarse aggregates are summarized in Table 1. A total of 162 cubes of 100 × 100 × 100 mm concrete specimens were immersed over the initial curing in a water tank and further cure in 5% sodium chloride and sodium carbonate solutions for 28, 56 and 90 days in line with [27] and the concrete cube specimens were used for compressive strength testing at the varying curing days in line with [28]. This testing procedure represents accelerated testing procedure which shows performance of concrete mixtures to chloride and sodium carbonate attack. The cubes were taken out of the acid water and the specimens were clean. The degree of chloride and sodium carbonate attack were evaluated by measuring the weight losses and concrete strength gains or losses due to chemical attack on the specimen at 28, 56 and 90 days, respectively. The microstructural analysis such as Scanning Electron Microscopy (SEM), Electron Dispersive Spectroscopy (EDX) and X-ray

Table 1

Mix proportions of self-compacting concrete samples

S/N	Mix Samples	Mix Proportion (%)	Cement (g)	Fine Aggregate (g)	Coarse Aggregate (g)		Water (g)	Super-Plasticizer (%)
					Granite	Gravel		
1	SCC1	100	561	977	620	-	168.8	1.14
2	SCC2	90/10	561	977	558	62	168.8	1.14
3	SCC3	80/20	561	977	496	124	168.8	1.14
4	SCC4	70/30	561	977	434	186	168.8	1.14
5	SCC5	60/40	561	977	372	248	168.8	1.14
6	SCC6	50/50	561	977	310	310	168.8	1.14

Bamigboye et al. [2]

Table 2

Sodium carbonate (Na_2CO_3) test results for washed gravel

Mix Proportions of granite/gravel (%)	Na_2CO_3 Concentration (%)	Average reduction in weight (%)			average loss of Compressive strength (N/mm^2)		
		28 days	56 days	90 days	28 days	56 days	96 days
100/0	0	3.54	4.65	5.36	33.0	35.0	40.6
100/0	5	3.36	4.58	5.25	29.5	32.9	38.1
90/10	0	2.63	3.55	4.67	31.2	33.33	38.6
90/10	5	2.41	3.44	4.59	27.8	30.06	35.00
80/20	0	2.53	3.46	4.86	28.67	30.92	35.80
80/20	5	2.31	3.24	4.35	25.87	28.99	33.91
70/30	0	2.39	3.35	4.25	26.0	28.6	34.35
70/30	5	2.35	3.22	4.13	22.61	25.15	32.44
60/40	0	1.28	2.33	3.13	22.00	27.4	35.5
60/40	5	1.06	2.01	3.05	18.19	24.86	31.65
50/50	0	1.09	2.01	3.09	19.2	26.5	29.67
50/50	5	1.01	1.86	2.95	15.26	23.66	25.58

Table 3

Sodium chloride (NaCl) test results for washed gravel

Mix Proportions of granite/gravel (%)	NaCl Concentration (%)	Average reduction in weight (%)			average of compressive strength (N/mm^2)		
		28 days	56 days	90 days	28 days	56 days	96 days
100/0	0	3.89	5.65	6.22	33.0	41.1	46.81
100/0	5	3.90	5.67	5.89	34.1	41.1	42.02
90/10	0	3.35	4.72	5.31	31.9	36.69	45.6
90/10	5	3.41	4.88	5.01	32.4	37.05	40.07
80/20	0	3.09	4.25	5.09	30.10	32.50	43.00
80/20	5	3.11	4.36	4.99	31.9	33.9	38.15
70/30	0	3.19	3.35	4.87	28.30	30.9	41.50
70/30	5	3.25	3.46	5.07	30.95	34.15	43.00
60/40	0	2.12	3.05	3.34	24.33	29.2	38.95
60/40	5	2.14	3.09	3.14	26.05	30.2	36.82
50/50	0	1.02	2.99	3.01	22.33	28.9	36.02
50/50	5	1.16	3.05	2.95	24.52	29.95	30.07

Powder Diffraction (XRD) of the concrete produced were determined. Manuscript.

3. Results and discussions

3.1 Sodium Carbonate attack

The water quality plays a significant role in curing of concrete. The impurities in water may interface and affect the hardening and strength of concrete. However, when exposed to severe environments, its durability can drop significantly due to degradation. The chemical components existing in water can partake in the chemical reaction and therefore affect the hardening and strength growth of concrete. The effects of sodium chloride (NaCl) and strong alkaline substance like sodium carbonate (Na_2CO_3) are assessed under laboratory condition for granite-washed gravel aggregate combination in SCC in this study. The tested cubes specimens were of dimensions

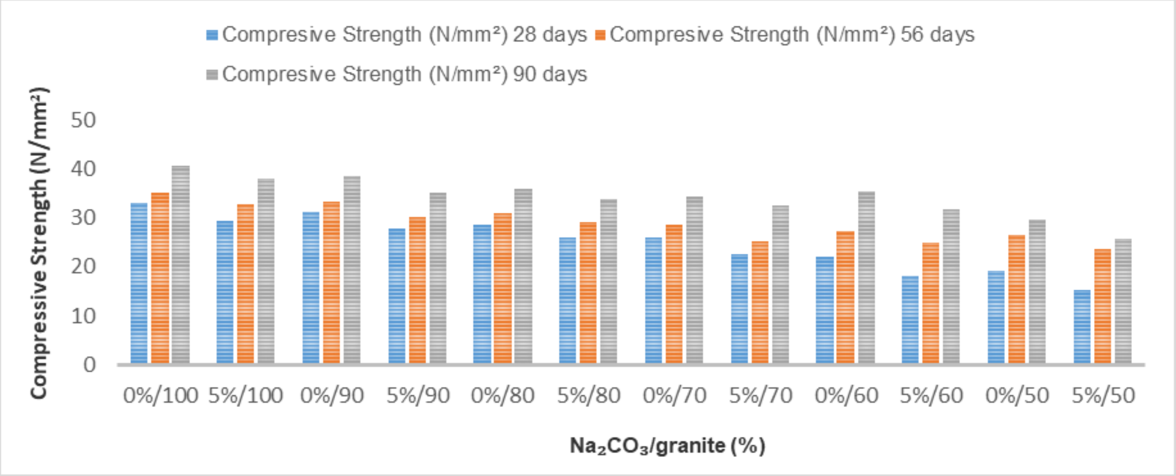

Fig. 1 - Variation in compressive strength of concrete due to Na_2CO_3

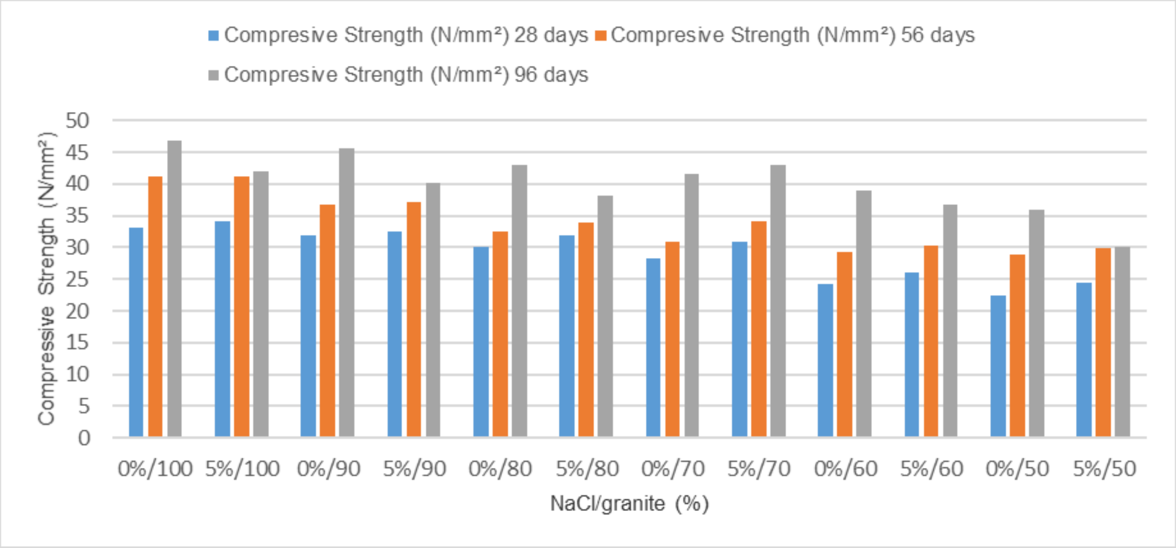

Fig. 2 - Variation in compressive strength of concrete due to NaCl

$100 \times 100 \times 100\ mm$. The tested specimens were kept under a mild exposure condition for 28, 56 and 90 days before compressive assessment of specimens. Weight and compressive strength values of the samples were determined.

The average percentage of weight loss and compressive strength were measured for sodium chloride and sodium carbonate as shown in Tables 2 and 3, while Figures 1 and 2 give the compressive strength values of various concrete specimens after immersion in Na_2CO_3 and NaCl. The results in Figure 1 for washed gravel show that curing in 5% sodium carbonate solution, the weight reduction was significant with increase in percentage of gravel content compared with the control. Compressive strength rises with days but declines with increase in gravel content. The compressive strength results indicate that there is major decrease in all concrete cubes at 28, 56 and 90 days and is as a result of Na_2CO_3 concentration compared with the control. However, caution is required in the use of water containing these substances. The results obtained show that the presence of 5% sodium carbonate in water decreased the compressive strength of concrete specimen significantly at 28 and 90 days. Also, Both Na_2CO_3 and NaCl reacted chemically with some cement hydrates and formed new products in the pore or cracks. Cement which is one of concrete materials is a combination of complex compounds. The reaction of water with cement leads to setting and hardening of cement [4]. The tricalcium silicate (C_3S), tricalcium aluminate (C_3A) and tetracalcium alumina ferrite (C_4AF) phases react very fast with measuring water and become soaked with calcium hydroxide ($Ca(OH)_2$). The initial setting is credited to hydration reactions. It should be noted that the development of sodium silicate and gyrolite as a result of setting of cement leads to decrease in concrete compressive strength. The mode of attack on concrete involves the breakdown of structure of the silica sand by hydroxyl ions which is followed by adsorption of the alkali-metal ions on the freshly formed surface of the reaction product. When gyrolite gel and water reacted together, it swells by absorbing large quantity of water. The cement paste cracking surrounding the aggregates was as a result of hydraulic pressure which leads to decrease in concrete compressive strength. From chemical point of view, it is possible for chloride to be bound to hydration products by physical adsorption on Calcium-silicate-hydrate (C-S-H).

3.2 Sodium Chloride attack

One of the important factors contributing to concrete deterioration is chloride. It may be either in a bond or free condition, while free chloride levels promote corrosion of the reinforcement in structural concrete. Structural concrete with chlorine levels promote corrosion of reinforcement. Five percent (5%) solution of NaCl concentration was used to investigate the durability of concrete and its suitability in saline environment with varying granite and gravel as coarse aggregate in SCC. The compressive test results were used to determine the optimum granite/gravel replacement in concrete for 0% and 5% concentration as shown in Table 2. The results as show in Figure 2 revealed that an increase in percentage of gravel content causes a progressive decrease strength compared with the control. However, concrete with higher percentage of gravel are more workable compared with 100% granite. The concrete cured in 5% NaCl concentration has compressive strength increases at 28 and 56 days, while a sharp decline in strength was observed at 90 days compared with the control cured in control (0% of NaCl). It was also observed that NaCl caused early compressive strength increase that cannot be maintained for long term. From Figure 2, 70-100% of granite concrete performed better in NaCl solution at 90 days.

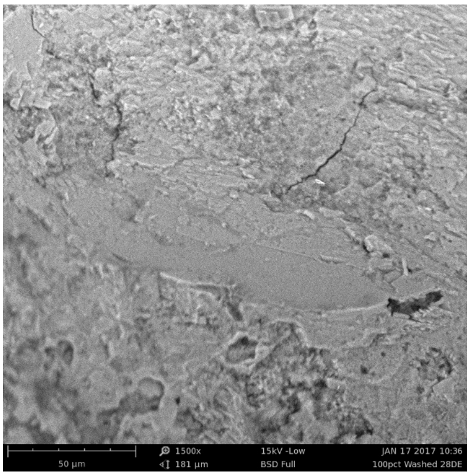

Fig. 3 -100% granite (control) SEM cured in water

3.3 Microstructural analysis

3.3.1 SEM and EDX Analysis

The homogeneity of Figure 3 was as a result of good SCC mixed design which leads to resistance to segregation, and also shows that the bond between gravel/granite aggregates and cement paste was good. Also, as a result of this, good strength, durability and longer service life of concrete structure is assured.

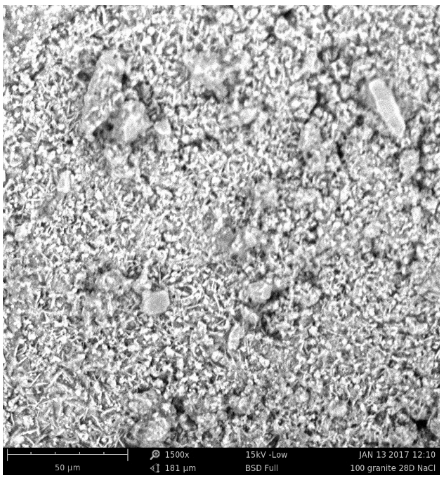

Fig. 4 - 100% granite (control) SEM cured in 5% NaCl solution.

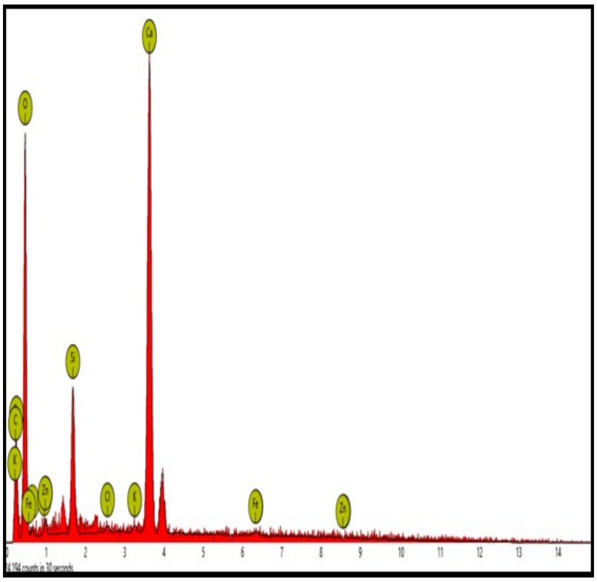

Fig. 5 - EDX of 100% granite (control) cured in water

Figure 5 show the EDX and elemental composition of the sample. Also, Figure 4 shows the microstructure of SCC made with 100% percentage of granite and cured in NaCl. It was observed that at the exposure of concrete to NaCl, dissolution of silicate-rich-type 1 calcium – silicate – hydrate (C-S-H) and the releasing of calcium sulfate ($CaSO_4$) from AFm and AFt phases were noticeable. Figures 4 and 6 present SEM and EDX analysis of 100% granite cured in 5% NaCl solution with honeycombed structure

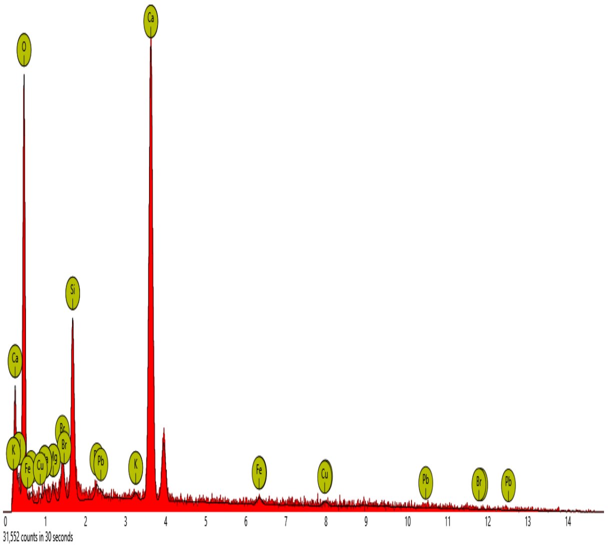

Fig. 6 - EDX of 100% granite (control) cured in 5% NaCl.

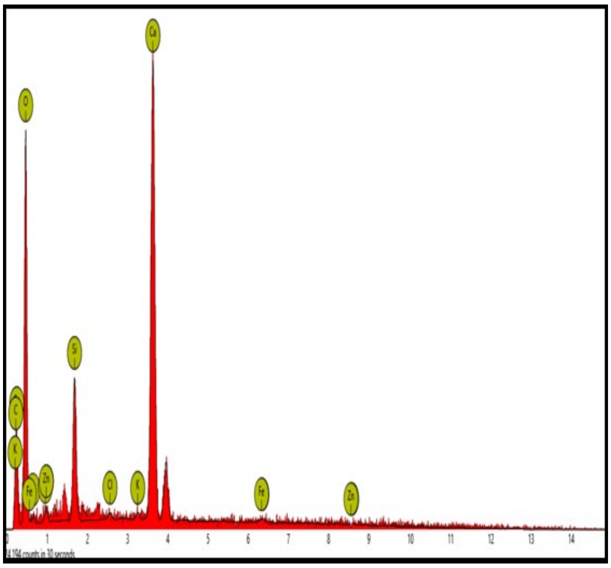

Fig. 7 - EDS result of 20% Washed gravel

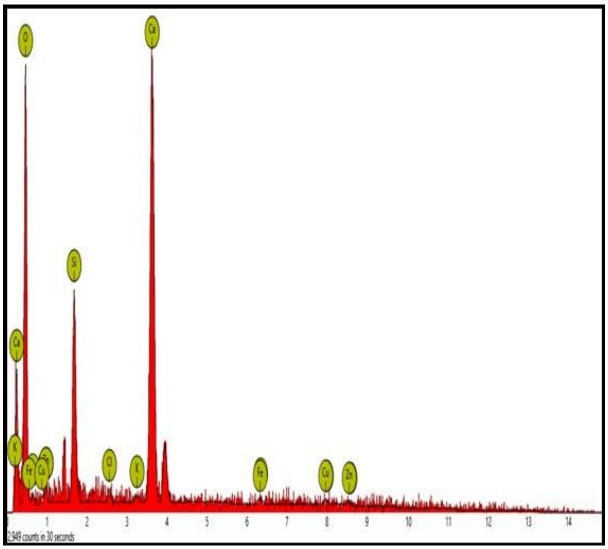

Fig. 8 - EDS result of 50% Washed gravel

(scraped particles were generated) characteristic of type II C-S-H phases, together with fibrous crystal formation with SEM image and proof by EDX data which reflect the presence of Cl concentrations with high Ca and O concentration. It was hypothesized that fibrous crystal was calcium sulfate chloride hydrate (C-S-C-H) formed by the partial substitution of Ca^{2+} for Al^{3+} in cement hydrate. From this study it was discovered that concrete specimens exposed to NaCl or chlorides leaching of calcium hydroxide accompanied by some chemical alterations.

The EDS graphs of concrete made with 0% (cured in water and NaCl), 20% and 50% gravel substitutions can be seen in Figures 5, 6, 7 and 8 respectively. A close look at the graphs shows elements with different peaks. In all the graphs, it can be seen that Calcium, Oxygen and Silicon had the highest concentrations while Chlorine was a trace element. From the results, the concentration of chlorine was below 3% for all increases in the percentage of washed gravel. Therefore, as the percentage of washed gravel increased, there was no increase in the concentration of Chlorine.

3.3.2 X-ray diffraction (XRD) analysis

From Table 4 the phases acknowledged in the sample were smectite, palygorskite, kaolinite, calcite, quartz, dolomite and micalite. Smectite and palygorskite are clay minerals, calcite and dolomite are carbonate minerals while quartz is a quartz mineral. All of these were expected to be found in the concrete sample.

Mamlouk and Zaniewski [29] reported that argillaceous and calcareous materials are the two major raw materials to start with in the Portland cement production. Materials such as chalk, limestone, oyster shells are calcium oxide which is a calcareous material while on the other hand the product of silica and alumina combination which can be obtained from blast furnace slag, clay and shale produced argillaceous materials. With the aid of this knowledge it became clear that the clay and quartz minerals have their origins from the argillaceous component used in making cement and from the aggregate in the concrete while the carbonate minerals come from the calcareous component used in making the cement.

Based on the results drawn from the Table 4, there were no foreign minerals present in the sample. Increasing the percentage of washed gravel as a coarse aggregate only increased the concentration of quartz and fairly affected the other minerals. Therefore, increasing the percentage of washed gravel in the SCC relative to granite had no adverse effect on the mineralogy of the SCC.

Table 4

XRD analysis for varying percentages of granite/gravel (washed) as coarse aggregate in SCC cured in 5% NaCl

Granite/gravel Samples (%)	Smectite	Palygorskite	Kaolinite	Quartz	Calcite	Dolomite	Micallite
100/0	0	11.6	2.75	75.86	8.17	1.12	0.55
90/10	0	9.83	0.34	81.47	7.68	0	1.13
80/20	0.2	7.32	0.2	85.07	7.22	0.09	1.42
70/30	0.25	0.53	0	87.64	6.41	0.17	0
60/40	0.2	0.12	0.2	86.23	6.17	0.56	1.52
50/50	0.2	6.42	1.4	81.49	7.77	0.87	0.23

4.Conclusions

1. From the study 70-100% of granite concrete performed better in NaCl solution at 90 days and is recommended for aggregates selection for use in saline environments.
2. The effects of sodium chloride (NaCl) decalcification, the development of porous calcium silicate hydrate (CHS) and the leaching of CaOH, all take their toll on concrete strength.
3. NaCl solutions had early age accelerating compressive strength properties that could not be sustained for long-term. Also, the strength pattern suggested that saline solutions cause long term deterioration of concrete strength while 5% Na_2CO_3 solutions reduced significantly the compressive strength of concrete, thus caution is required in the use of water containing this substance.
4. Both NaCl and Na_2CO_3 react chemically with the cement hydrates and developed new product in the pores and crack
5. Curing of SCC concrete in NaCl produced heterogeneous morphology on the surface of the concrete.
6. The EDS graph and XRD showed no presence of deleterious elements or minerals in the concrete as the percentage of washed gravel increased.

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