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Chemical evaluation of cement-based sandcrete wall deterioration

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Abstract

Cement-based structure stability could be characterized not only by their mechanical strength, soil geophysics and loading condition, but also the resistance to various physical and chemical factors that could initiate its corrosion. The contribution of water and various water-based solutions in the environment, to cement-based structure durability could be either physical as in seasonal flooding of the structure or chemical often initiated by the presence in the solution of organic or inorganic compounds or gases. Irrespective of the corrosion type, its destructive effect could be attributed to the build up of internal stress and weakening of the structure matrix. This work is aimed at investigating the role of chemical changes in the sandcrete matrix in the formation and development of macrocracks in cement-based sandcrete walls. Collected sandcrete samples were analyzed using titrimetric and granulometeric methods. Results showed that the percentage composition between the top and bottom of SiO_2 was high in all the sandcrete blocks samples analyzed ranging from 76.72% to 80.30%. This indicates high permeability of ground level structure. The acidic nature of the soil in some area varying from $pH = 5.89 - 6.11$ could seriously undermine the structures strength. The percentage compositions of CaO were generally very low ranging from 3.83% at the ground to 4.44% at the top levels. For most points there were percentage compositional differential across cracked points horizontally and vertically. This is an indication of either poor cement quality or non-compliance to standards' requirements. There is a need to develop a model equation for the migration of minerals' hydrates in sandcrete wall.

Keywords: Chemical evaluation; Composition differential; Ions diffusion; Deterioration; Crack formation

1. Introduction

Concrete structures are hardly ever built under ideal conditions, so, for variety of reasons, defect may occur as the concrete is being cast or after some time [1]. The factors that initiate corrosion of cement-based structure could be physical or chemical in nature [2,3]. Reaction occurring internally in cemented systems may have significant adverse effect on concrete structure [2–7].

The compressive strength of cement-based structures is expected to increase steadily with age. However, this statement may not be true for many structures, especially those serving in aggressive environments. In some areas, most cement-based structures were found to develop microcracks within a few years after construction despite the fact that acceptable standards were observed [3]. Various researchers have proved that long exposure of cement-based structures to aggressive medium containing acids, salt and alkalis immensely enhance their physicochemical and mechanical properties deterioration [2–8].

Reactions occurring internally, such as alkali-aggregate reaction give cause for concern, because this type of deterioration does occur in non-aggressive environment [7]. The potential for reaction is conditioned by chemical and mineralogical nature of the concrete system components; cement-aggregate–water composition, as well as prevailing environmental condition — temperature, humidity, etc.

The basic origin of the chemical energy potential involved in alkali-aggregate reaction is associated with the thermodynamically unstable nature of the reaction products involving the siliceous aggregate materials and the alkaline mineral hydrates from the cement [9]. This to a large extent defines

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the cement-based structures matrix rheology and morphology. For structures exposed to seasonal wetting or flooding by water their chemical deterioration will depend on the extent of solubility of the mineral hydrates and possible migration through the various hardened matrix. Such migration of the soluble salts or hydrates will be enhanced by contact of such structure to a wet earth base/foundation. This determines the stability of the cement-based structure and its development of microcrack or even collapse.

The research work will be presented in two parts. The first is aimed at investigating chemical composition contributions to cracks development in cement-based structures. The major objectives of study are:

- To determine the percentage content of SiO_2, MgO, Fe_2O_3, CaO, Na_2O Al_2O_3 present in sandcrete samples collected from four cracked walls indigenous cement and sand.
- To discuss the effect of these oxides as components of cement mineral hydrates on the sandcrete structure.

The second part will attempt to develop model equation for the migration of minerals' hydrates in sandcrete wall.

2. Experiment

Samples were collected from non-industrial areas of Kaduna, capital of Kaduna State in Nigeria, specifically from the Kurmi mashi I and II and Ungwan Mu'azu I and II areas. The structures are located in abandoned market site constructed 5 and 6 years ago respectively. Samples were collected from three levels on both sides across and along the cracked line. The controlled samples were also collected from structure located in the same area. Additional experiments were conducted on local indigenous cement, ground soil and sand commonly used in production of sandcrete blocks in the area. The experimental methods used were the titrimetric, gravimetric and instrumental. All the experiments were conducted as specified in Refs. [10–12]. The analyses were carried out to determine the percentage content of SiO_2, CaO, MgO, Al_2O_3, Fe_2O_3, Na_2O, and loss on ignition.

3. Results and discussion

Experimental results presented in Tables 1–6 show the percentage compositions of the various cement-based structures. The two ground soil samples gotten from the area in Ung/Muazu Kaduna were found to be humus in nature.

The data presented show that the percentage composition of SiO_2 is relatively high in all the samples varying from 76.72% to 80.3%. In all the samples the ground levels have the highest SiO_2. This pattern of high SiO_2 concentration at the ground, compared to the upper level is an indication of relatively high permeability of soil water and fresh rainwater solutions into the structure. This pattern is the same even for the control sample.

pH tests carried out on the ground soil (Tables 3 and 4) show that the soil is humus in nature and acidic (pH 5.89 and 6.11 respectively). In the presence of moisture and long exposure of the structure to soil water, the acids could react with cement mineral hydrate especially $Ca(OH)_2$ to produce perhaps soluble calcium salt and water. The leaching of the resultant product from the hardened matrix exposes it to further attack, leaving behind a weak structure. It is also well documented that such pH considerably enhances metal reinforcement corrosion.

The data in Figs. 1–4 show that the alkaline oxides' concentrations (K_2O and Na_2O) were relatively more in the ground levels. In some cases their concentration at the top level were practically zero. This could be attributed to possible migration of free alkaline hydroxide from the top down especially during the rainy seasons. The high moisture content of exposed cement-based structure during this period enhances diffusivity and easy leaching of the alkali from the lower level to the ground water and their consequent migration of top down.

From Tables 1-4, the percentage content of calcium oxide CaO at the ground level was always the lowest while the top was the highest. It varied from 3.83% for ground level to

Table 1
Chemical composition of sandcrete samples from Zone I (%)

Compounds	Ground soil	Ground level		Middle level		Top level	
		Left side	Right side	Left side	Right side	Left side	Right side
SiO_2	51.76	78.49	78.48	77.00	77.10	76.72	76.80
CaO	1.50	4.04	4.05	5.56	5.55	5.98	5.96
MgO	0.19	0.18	0.18	0.16	0.16	N.D	N.D
Al_2O_3	21.43	3.55	3.53	3.02	3.00	2.98	2.98
Fe_2O_3	8.98	3.09	3.06	2.99	2.97	2.95	2.95
Na_2O	0.75	0.68	0.67	0.77	0.77	0.81	0.80
K_2O	1.82	0.43	0.43	0.42	0.42	0.39	0.39
SO_3	0.01	0.14	0.15	0.15	0.15	0.16	0.16
LOI	13.56	9.44	9.44	9.89	9.83	10.01	10.00
Σ	100.00	100.04	99.98	99.96	99.95	100.00	100.04

Table 2
Chemical composition of sandcrete samples from Zone II (%)

Compounds	Ground soil	Ground level		Middle level		Top level	
		Left side	Right side	Left side	Right side	Left side	Right side
SiO_2	49.41	78.50	78.63	78.63	78.70	77.52	77.52
CaO	1.42	4.10	4.09	4.00	4.01	5.49	5.49
MgO	0.20	0.16	0.16	0.15	0.15	0.00	N.D
Al_2O_3	22.91	3.36	3.31	3.08	2.99	2.86	2.85
Fe_2O_3	9.57	2.98	2.98	2.87	2.88	2.73	2.74
Na_2O	0.71	0.68	0.69	0.77	0.77	0.81	0.81
K_2O	1.71	0.42	0.42	0.41	0.41	0.39	0.393
SO_3	0.05	0.15	0.15	0.16	0.16	0.16	0.161
LOI	13.76	9.57	9.56	9.93	9.93	10.04	10.03
Σ	99.74	99.92	99.99	99.93	100.00	100.00	99.99

Table 3
Chemical composition of sandcrete samples from Zone III (%)

Compounds	Ground soil	Ground level		Middle level		Top level	
		Left side	Right side	Left side	Right side	Left side	Right side
SiO_2	3.42	80.30	80.30	79.40	79.40	79.30	79.30
CaO	3.08	3.83	3.82	4.25	4.26	4.44	4.44
MgO	0.60	0.17	0.17	0.15	0.14	N.D	0.00
Al_2O_3	6.15	3.02	3.00	3.00	3.01	2.98	2.97
Fe_2O_3	3.99	2.98	2.98	2.94	2.95	2.89	2.88
Na_2O	0.85	0.64	0.65	0.68	068	0.70	0.71
K_2O	1.98	0.43	0.43	0.41	0.41	0.40	0.40
SO_3	1.13	0.15	0.15	0.16	0.16	0.16	0.17
LOI	9.31	8.57	8.44	8.98	8.98	9.13	9.12
Σ	00.51	100.09	99.94	99.97	99.99	100.00	99.99

Table 4
Chemical composition of sandcrete samples from Zone IV (%)

Compounds	Ground soil	Ground level		Middle level		Top level	
		Left side	Right side	Left side	Right side	Left side	Right side
SiO_2	72.89	79.67	79.65	79.67	79.64	79.29	79.30
CaO	3.18	3.92	3.92	4.10	4.11	4.35	4.36
MgO	0.62	0.18	0.18	0.16	0.16	0.00	0.00
Al_2O_3	6.24	3.32	3.33	3.23	3.23	3.33	3.31
Fe_2O_3	3.97	2.79	2.79	2.69	2.70	2.61	2.61
Na_2O	0.82	0.71	0.72	0.75	0.75	0.80	0.81
K_2O	1.82	0.35	0.35	0.34	0.34	0.34	0.34
SO_3	0.92	0.15	0.16	0.16	0.16	0.17	0.17
LOI	9.58	8.89	8.90	8.90	8.91	9.10	9.10
Σ	100.04	99.98	100.00	100.00	100.00	99.99	100.00

Table 5
Chemical composition of sandcrete from uncracked zone (%)

Compounds	Ground level	Middle level	Top level
SiO_2	80.80	80.10	80.00
CaO	4.49	4.87	5.02
MgO	0.54	0.50	0.49
Al_2O_3	4.15	4.02	3.98
Fe_2O_3	3.19	3.14	3.00
Na_2O	0.74	0.78	0.80
K_2O	0.54	0.53	0.49
SO_3	0.17	0.17	0.17
LOI	5.38	5.85	6.01
Σ	100.00	99.96	99.96

Table 6
Chemical composition of an indigenous cement brand and typical sharp sand from Kaduna used predominantly for sandcrete block production and mortar

Compounds	Sand, %	ASHAKA, %
SiO_2	81.63	26.03
CaO	1.68	62.00
MgO	0.52	0.82
Al_2O_3	4.89	3.80
Fe_2O_3	3.20	2.40
Alkalis	0.82	1.05
SO_3	0.03	1.65
LOI	7.23	2.25
Σ	100.00	100.00

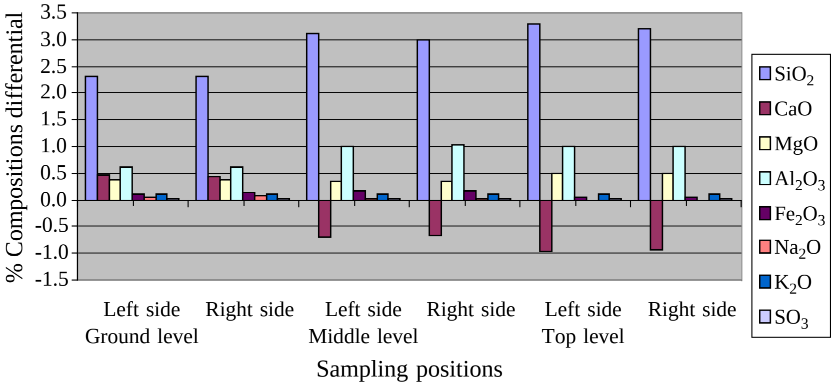

Fig. 1. Chemical composition differences between sandcrete from Zone I and from the uncracked zone.

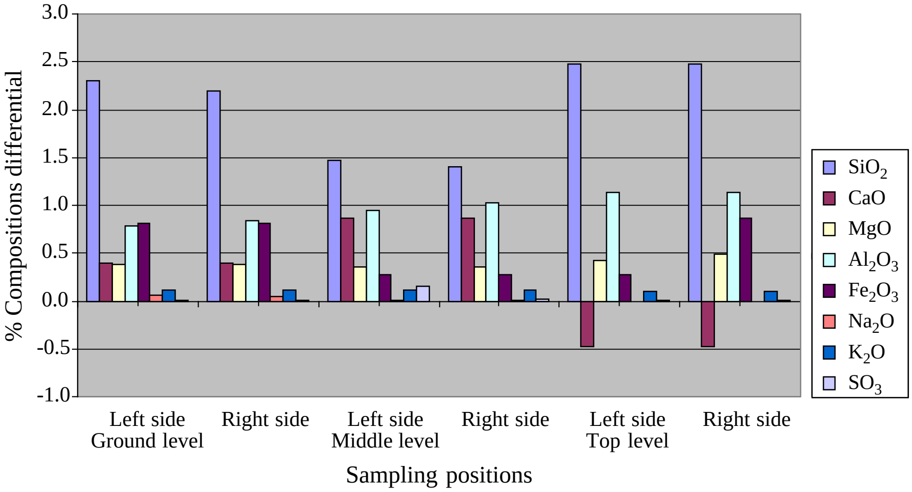

Fig. 2. Chemical composition differences between sandcrete from Zone II and from the uncracked zone.

5.96% at the top level. This discrepancy could be attributed to the gradual leaching of the mineral hydrates from the structure matrix. The leaching process leaves behind a spongy matrix and enhanced ground water diffusion into the structure [3,9]. The analysis of Figs. 1–4 shows that compared to the uncracked wall, the CaO content was relatively low. The cracking process might also therefore be enhanced by the poor sand/cement ratio used for the production. The cement content or quality could not ensure proper binding of the fine aggregates. Consequently the

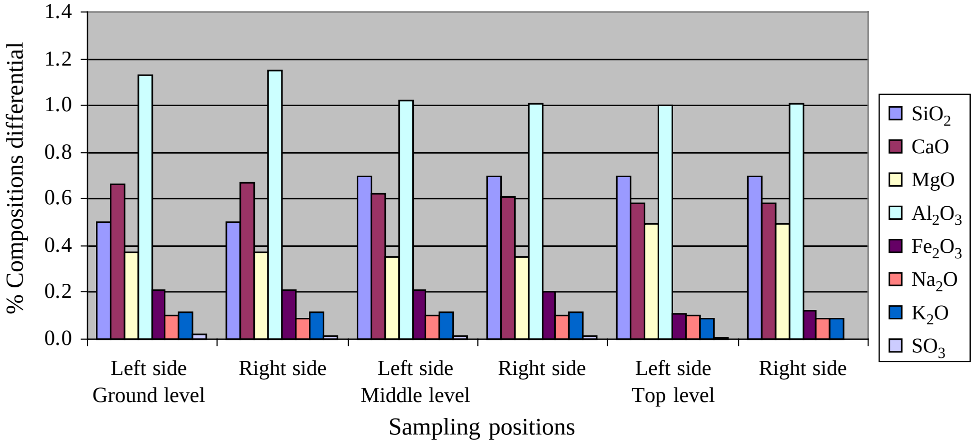

Fig. 3. Chemical composition differences between sandcrete from Zone III and from the uncracked zone.

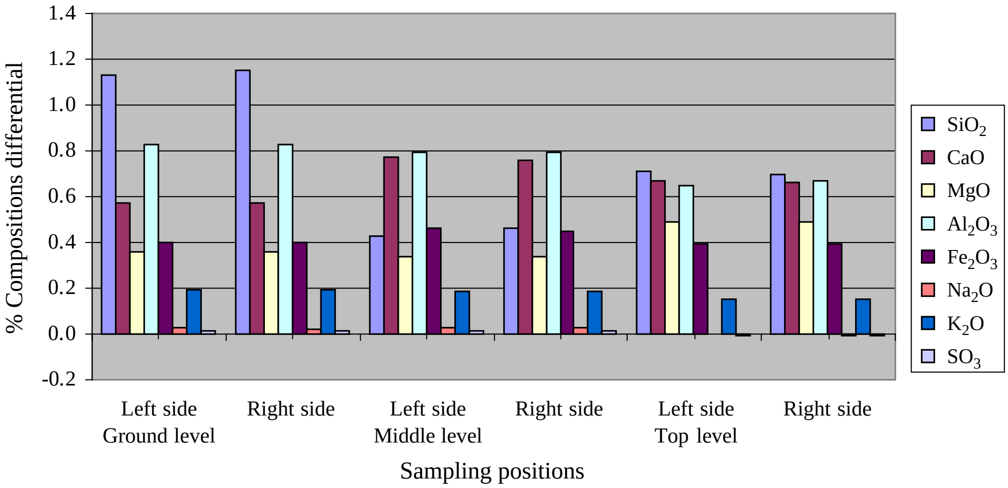

Fig. 4. Chemical composition differences between sandcrete from Zone IV and from the uncracked zone.

physico-mechanical properties of the sandcretes produced were very poor.

The percentage composition of Al_2O_3 and Fe_2O_3 generally followed a decreasing order from ground to top level, in almost all the tables. The ground soil of the sample in Table 1 had an alumina content of 21.43% and ferrous oxide 8.98%. In Table 2 alumina was 22.91% and ferrous oxide 9.5%. In Table 3 the alumina content was 6.15% while ferrous 3.97%. The ground soils for Tables 1 and 2 are clayish in nature while that of Tables 3 and 4 were humic. Comparative analyses as presented in Figs. 2–4 show that the alumina and ferrous contents differ from the standard sample value for the ground, middle, and top levels.

From all the Tables 1–4, magnesia (MgO) was found to be about 0.19% with majority of this coming with the sand. Table 6 shows that the percentage composition of the cement merges well with type IV and probably I of ASTM and NIS Portland cement [12,13]. The sand percentage composition SiO_2 was 81.63%, (calcium oxide 1.68%, Al_2O_3 and Fe_2O_3 4.89% and 3.20% respectively while the percentage loss on ignition (LOI) was 7.23%) was within acceptable limit for sandcrete blocks production and therefore may not undermine its physico-mechanical properties [14].

4. Conclusion

From the analyses the following deductions could be made from the experiments:

- The percentage composition differential between the top and bottom of SiO_2 was high in all the sandcrete blocks samples analyzed ranged from 0.4% to 3.20%. This indicates high permeability of ground level structure.
- The acidic nature of the soil in some area varying from pH = 5.89 – 6.11 could seriously undermine the structures' strength. The percentage compositions of CaO were generally very low ranging from 3.83% at the ground to 4.44% at the top levels. For most points there were percentage compositional differential across cracked points horizontally and vertically. This is an indication of either poor cement quality or non-compliance to standards' requirements.

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