Effect of Salinity in Civil Engineering Concrete Basement

L. A. Uneke, P. P. Akpan & L. L. Kormah
Department of Civil Engineering,
Rivers State Polytechnic Bori,
Nigeria
paulynciap06@yahoo.com

S. Ayagere
Department of Architecture,
Rivers State Polytechnic Bori,
Nigeria

Abstract
This study adopts a laboratory approach to investigate the effect of salinity on concrete basement with emphasis on Magnesium Sulphate as the sole attacking agent. A mix ratio of 1:2:4 was adopted in preparing 100 concrete cubes which were cured in 5 containers of various quantity-0g, 5g, 10g 15g and 20g of Magnesium Sulphate salt in solution. The cubes were tested for compressive strength for 7, 14, 21, and 28 days respectively using Non Destructive Schmidt Rebound hammer test. The results obtained shows increase in Compressive strength of the concrete cubes with respect to increase in age and a decrease in the compressive strength of concrete as the quantity of Magnesium Sulphate in solution increases. This shows that Magnesium Sulphate affect concrete in proportion present and duration of attack. This result is in agreement with findings of Akinkurolere O.O et al (2007).

Keywords: *Salinity, Concrete basement, Magnesium Sulphate, Compressive Strength, Mix ratio*

Introduction

A basement is one or more floors of a building that are either completely or partially below the ground floor (http://en.wikipedia.org). Basements are mostly constructed with concrete. When such construction is carried out in a marine environment of sea water, then the effect of salinity on such structure needs to be examined. Salinity is the saltiness or dissolved salt content of a body of water. Sea water in the world's ocean has a salinity of about 3.5%. This means that every kilogram (roughly one liter by volume) of sea water has approximately 35 grams of dissolved salts (http://en.m.wikipedia.org).

According to Osei (2000) and Water encyclopedia (2012), great bodies of water covers about 71% of the earth surface reaching in some places to depth more than ten kilometers (10km). Deterioration of concrete is rarely due to one isolated cause. In tackling deterioration of concrete in sea water, the salinity effect must never be left out as it usually comes into play most especially when water of its constituent is used or when concrete is being worked upon in region of its (salt) reach.
Marine environments are very aggressive, since sea water consists mainly of chlorides and sulphates. Chlorides affect durability by initiating corrosion of the reinforcement steel, and sulphates by deteriorating the concrete itself. (Mathias Maes, et al, 2012)

The effect of aggressive chemicals on the behavior of building materials is a topic of significant practical interest, as it affects the safety and durability of structures. Many naturally occurring soils and water sources contain Sulphates which lead to deterioration of structures (Kumar and Rao, 1994). A field engineer attention is concerned with the effect of Sulphates on structures in fresh or hardened state since the chemical deterioration of concrete subjected to seawater has been a topic of interest to concrete researchers in the last few decades, and the findings have revealed some very important facts, but still it remains to be a dynamic subject for further study and research (Kumar 2000).

Among the many properties which are of interest, compressive strength is a predominant property which gives the quality of hardened concrete (Grundy, 1981). Because of this, compressive strength is therefore the parameter tested for in this study to determine the effect of salinity on concrete strength.

Rapid urban and industrial growth demands more land for further development. In order to meet this demand land reclamation and utilization of unsuitable and environmentally affected lands have been taken up. Most of these lands are in sea water environment. This study will be of high importance to the construction team involved in the erection of building especially Builder, Civil and Structural engineer in order to increase their knowledge on how salinity affects the structural stability of a concrete basement in a saline environment.

Review of Related Literature

Studies carried out by researchers related to this area are highlighted and the gaps required to be filled by this project work our pointed out. The effect of aggressive chemicals on the behavior of building materials is a topic of significant practical interest, as it affects the safety and durability of structures. Many naturally occurring soils and water sources contains Sulphates which lead to deterioration of structures (Kumar and Rao, 1994).

The effect of sea water on concrete was first discussed in 1840 by J. Smeaton and L. J. Vicat. Their two-year examination on the research topic titled "What is the trouble with concrete in sea water" revealed that a large number of concrete structures in sea water in the United States, Canada, Cuba and Panama are exposed to chemical deterioration (Tibbetts, 1968). Concrete in marine environment suffer deterioration which may be due to the effects of chemical reaction of seawater constituents with cement hydration products, alkali-aggregate expansion which occur when reactive aggregates are present, crystallization pressure of salts within concrete when one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel in reinforced or pre-stressed members, and physical erosion due to wave action and floating objects (Mokhtar and Swamy, 2008; Gopal, 2010).

Akinsola O.E. et al (2012) in their article titled "Investigation of salinity effect on compressive strength of reinforced concrete" adopted a laboratory controlled experimental approach, in order to induce the worst scenario of concrete mix and determine the consequent effect on reinforced concrete element; a mix ratio of 1:3:6 was adopted for the experiment. Reinforced concrete elements were cast using both lagoon and ocean water while fresh water was used as a control experiment. These samples were buried at a depth of 1.5m below the ocean and lagoon bed soil characteristics and observed for a period of 150 days. Both the ocean and the lagoon samples increase in compressive strength from 10.65N/mm2 and 10.57N/mm2 on 7th day to 17.05N/mm2 and 18.04N/mm2 on the 21st day respectively as against the 14.20N/mm2 on 7th day to 17.05N/mm2 and 18.04N/mm2 fresh water sample. On 14th day fresh water sample has 17.48N/mm2 as against 12.10N/mm2 and 12.55N/mm2 recorded for both ocean and lagoon water samples. The findings revealed that concrete sample cast and cured with fresh water gained appreciable compressive strength over 150 days period while sample cast and cured with ocean and lagoon water slowly increase in strength but lower when compared with fresh water reinforced concrete element. Therefore the study recommended that a rich mix other than 1:3:6 and 1:3:5 be strictly enforced on construction sites for concrete under saline attack, increase concrete cover be used for protection against corrosion, and that non destructive test be carried out on all formworks under vertical loads like slabs and beams before they are stripped.

Similarly, Akinkurolere O.O et al (2007), in their paper titled “The Influence of salt water on the compressive strength of concrete” presented the result and findings of an experimental research on the influence of salt water from Lagos Lagoon, in Nigeria on the compressive strength of concrete. In the research, 132 concrete cubes of mould size 150x150x150mm were casted with fresh water (66 cubes) and salt water (66 cubes) in the ratio of 1:2:4 by weight of concrete and water-cement ratio of 0.6. They were cured in fresh water and seawater respectively. The concrete cubes were tested for compressive strength for 7, 14, 21 and 28 days respectively. The compressive strength of concrete is shown to increased by the presence of salt or ocean salt in the mixing and curing water. The rate of strength gain is also affected when the concrete is cast with fresh water and cured with salt water.

Felah M Wegian (2010) observed that the compressive strength and consequently the other related strengths of concrete were shown to increase for specimens mixed and cured in sea water at early ages up to 14 days, while a definite decrease in the respective strengths was observed for ages more than 28 days and up to 90 days. The reduction in strength increases with an increase in exposure time, which may be due to salt crystallization formation affecting the strength gain.

M. M. Amin, et al (2007) investigated the relation between physical strength of mortars sized 150 × 150 × 150mm and the effects of different concentrations of sulfate solutions, SO_4^{2-} (1%, 3% and 5%) for 3, 14 and 28 days and found that the stronger the Sulphate concentrations, the greater the Sulphate attack.

Sunil Kumar, Rao Kameswara (1993) also presented the result of an investigation in which the effects of Sulphates on the initial and final settings of ordinary Portland cement and compressive strength of concrete were investigated. They observed that the type of Sulphate and ion concentration affect the setting time significantly. The parameters reduce the compressive strength at different ages.

Sea Water

Sea water has a total salinity of about 3.5% (78% of the dissolved solids being Nacl and 15% MgCl2 and MgSO4), and produces a slightly higher early strength but a lower long-term strength Abrams Duff (1924).

The crust and interior of the earth constitutes the main source of seas. Salinity, which is measured in terms of, dissolved materials per kilogram of sea water or equivalent parts per thousand, represents the total quantity of dissolved salt in seawater. Vicat (1812) stated that the world seawater in most cases has salinity of the range (34% -35%) though the properties of water to dissolved salts tend to vary within the ocean, the major component ions are evenly distributed in ocean water in relatively constant proportion that accounts for the defects and failures of buildings located in coastal areas. See table 1 for composition of sea water.

Table 1: Major ions Composition of Sea Water

Common name	ions	(g)
Sodium	Na^{+}	10.360
Magnesium	Mg^{++}	1.294
Calcium	Ca^{++}	0.413
Potassium	K^{+}	0.387
Strontium	Sr^{++}	0.008
Chloride	Cl^{-}	19.353
Sulphate	SO_4	2-2.712
Bromide	Br^{-}	0.008
Boron	N_3B_3	0.001
Bicarbonate	HCO^{3-}	0.142
Flouride	F^{-}	0.001

Source: Laboratory analysis (2009).

According to Vicat (1812), Prascal et al. (2006) the chemical action of seawater on concrete is mainly due to attack by magnesium sulphate ($MgSO_4$). The mode of the attack is crystallization. Potassium and Magnesium Sulphates (K_2SO_4, $MgSO_4$) present in salt water can cause sulphate attack in concrete because they can initially react with Calcium hydroxide $Ca(OH)_2$ which is present in the set cement formed by the hydration of C3S and C2S as depicted below (Bryant, M., 1964).

$$K_2SO_4.10H_20 + Ca(OH)_2 \longrightarrow CaSO_4.2H_2O + 8H_2O + 2KOH$$

$$MgSO_4.10H_20 + Ca(OH)_2 \longrightarrow CaSO_4.2H_2O + Mg(OH)_2 + 8H_2O$$

The attack by magnesium sulphate (MgS) is quite demanding as it forms sparing soluble magnesium hydroxide that forces the reaction to the right forming gypsum, MgS will equally react with the Calcium Sulphate (CSH) gel present in the set cement to form more gypsum (Swarmy, 1992).

Rob B. Polder and Joe A. Larbi in 1979 carried out an investigation of concrete exposed to North Sea water submersion for 16 years. One of the aims of the investigation was to ascertain the penetration of and subsequent attack of concrete by Sulphate and Magnesium. The result shows that there was an increased Sulphate content in the first 7mm of the concrete only.

Materials and Method

Commercially available Ordinary Portland Cement was used for this purpose.

Crushed granite stone aggregate of maximum size 20mm confirming to IS 383-1970 was used together with the fine aggregate

Potable drinking water suitable for concrete work according BS 3148, 1980 was used.

The Magnesium Sulphate solution of various concentrations were prepared by adding Magnesium Sulphate salt in the proportion of 5g, 10g, 15g, and 20g to a fixed volume of water in the containers for curing the concrete cubes.

A nominal mix ratio of 1:2:4 (Cement: Fine Aggregate: Coarse Aggregate) was adopted for the purpose of this work and a water-cement ratio of 0.6 was used. The batching of the concrete was carried out by weight. Batching by weight is more preferable to that of volume because it is more accurate and lead to more uniform proportioning. It was manually done.

The aim of mixing of concrete is to produce a homogenous, consistent and uniform coloured concrete. Hand mix was adopted for this purpose. A measured quantity of sand was spread on a concrete platform. A measured quantity of cement was spread on the sand and mixed until the colour of the mixture was uniform. The measured aggregate is spread on the cement and sand mixture and mixed thoroughly before water was added and turned.

Concrete moulds measuring 150mm x 150mm x 150mm was prepared. The inside of the mould was lubricated with engine oil. Then the prepared concrete was poured into the mould with trowel in three layers. After pouring each layer, compaction was made with the help of the Temping Rod with the bullet ended side stroking into the concrete for 35 Strokes. This was carried out when the remaining two layers were added. After Pouring each layer into the mould, the mould was stroked from outside on all four wall moderately with the help of mallet so that no honeycombs forms at the contact surface of the Concrete and the mould. The top of the mould was trimmed and finish it smooth with the help of trowel. One hundred cubes were moulded. After 24 hrs the cubes were demoulded and transferred into five contains of different quantity of Magnesium Sulphate salt in solution. The cubes were completely covered.

Each of the five containers contained twenty cubes. Test was carried out on the cubes on the 7th, 14th, 21st and 28th days respectively. The cubes were carried from the container and allowed to dry before taking the weight of each cube after which the Schwidt rebound hammer was used to perform the compressive strength test. The readings from the Rebound hammer were recorded as Rebound no.

Non Destructive test using Schmidt Rebound Hammer was carried out on 100 concrete cubes cured in 5 containers of varying quantity of Magnesium Sulphate in solution. Each container has 20 cubes respectively. Five cubes were tested from each container on 7, 14,21and 28 days respectively.

Data Presentation, Analysis and Discussion

The results obtained from the tests are shown in tables 2 – 5. The result displayed on the bar chart in figure 1 shows that for the control (0g of Magnesium Sulphate salt), the concrete compressive strength increases with age. 43.44 N/mm3 on the 7th day to 62.85 N/mm3 on the 28th day. The higher value of the compressive strength observed is associated with rebound hammer test. Its result is good for comparison.

The results in table 6 and figure 1 above shows a decrease in compressive strength at 7th days for concrete cured in 5g, 10g 15g and 20g of Magnesium Sulphate in solution when compared with that of 0g which served as the controlled. As the quantity of salt in solution increases so is the decrease in compressive strength.

At the 14th days, all the batches recorded an increase in compressive strength when compared to the 7th days. There is also a decrease in compressive strength of concrete cured in 5g, 10g, 15g and 20g in solution of Magnesium Sulphate salt.

The 21st and 28th day tests show the same trend as the previous testing days. There is a decrease in the strength of the concrete with respect to the testing days. The result from the 28th day test shows increase in compressive strength of all the proportion of the salt over other days of testing. Decrease in the concrete strength for the different proportion of the salt is also noticed.

Figures 2 to 5 shows the same trend of decrease in strength of concrete when the compressive strength of the concrete cubes tested on the different days is compared with the quantity of salt in solution for those days.

Conclusion

Having successfully carried out this research work, the following conclusions are made based on the non destructive Rebound hammer test employed. Salinity with respect to Magnesium Sulphate salt affects the compressive strength of concrete. Compressive strength of concrete decreases with increase in salinity of $MgSO_4$. Civil engineering concrete works should never be made in Magnesium Sulphate saline environment except with the used of Sulphate resistant cement.

Table 2: 0g of Magnesium Sulphate salt in solution for 7, 14, 21 and 28 days

S/NO	7 DAYS		14 DAYS		21 DAYS		28 DAYS	
	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO
1	7.78	15.00	8.21	16.50	8.48	28.50	8.36	27.00
2	7.95	18.50	7.99	27.00	7.98	24.50	8.12	29.00
3	8.46	18.00	8.40	18.50	8.08	23.00	8.27	27.50
4	8.22	19.00	8.02	23.50	7.94	22.50	8.35	23.55
5	8.07	20.00	8.01	20.50	8.38	21.00	7.84	22.45
Average	8.10	18.10	8.13	21.20	8.17	23.90	8.19	25.90

Table 3: 5g of Magnesium Sulphate salt in solution for 7, 14, 21 and 28 days

S/NO	7 DAYS		14 DAYS		21 DAYS		28 DAYS	
	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO
1	7.37	9.50	7.59	10.00	7.62	19.00	8.06	34.50
2	7.60	9.50	7.67	8.50	8.02	15.50	7.70	28.50
3	7.77	11.50	7.68	15.50	8.26	19.00	7.71	30.50
4	7.82	10.50	7.68	22.50	8.18	16.50	7.86	22.50
5	7.48	11.00	8.15	13.00	8.00	13.50	7.61	20.50
Average	7.61	10.40	7.75	13.90	8.02	16.70	7.79	24.30

Table 4: 10g of Magnesium Sulphate salt in solution for 7, 14, 21 and 28 days

S/NO	7 DAYS		14 DAYS		21 DAYS		28 DAYS	
	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO
1	7.92	9.50	8.31	15.00	8.15	14.50	8.08	25.00
2	7.58	10.00	8.17	5.00	7.83	10.50	8.05	21.00
3	7.95	9.50	8.02	13.50	7.71	10.20	8.12	19.50
4	7.93	8.50	7.51	10.50	8.30	10.00	8.28	25.50
5	7.93	10.00	7.82	9.00	8.20	10.30	7.66	24.50
Average	7.86	9.50	7.97	10.60	8.04	11.08	8.04	23.10

Table 5: 15g of Magnesium Sulphate salt in solution for 7, 14, 21 and 28 days

S/NO	7 DAYS		14 DAYS		21 DAYS		28 DAYS	
	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO
1	7.80	8.80	8.07	9.75	8.11	11.35	8.17	22.00
2	7.81	8.80	8.27	9.40	7.81	10.50	7.97	26.50
3	8.25	9.20	8.02	10.00	8.25	12.00	7.98	19.50
4	8.95	8.70	7.97	9.60	8.14	11.20	7.83	20.50
5	7.92	9.50	7.89	9.80	7.90	10.00	8.02	20.00
Average	8.15	9.00	8.04	9.71	8.04	11.01	7.99	21.70

Table 6: 20g of Magnesium Sulphate salt in solution for 7, 14, 21 and 28 days

S/NO	7 DAYS		14 DAYS		21 DAYS		28 DAYS	
	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO	WEIGHT (Kg)	REBOUND NO
1	7.80	15.50	7.85	9.00	7.78	10.00	7.92	15.50
2	7.85	21.00	7.79	11.00	7.78	10.15	7.87	17.00
3	7.90	13.50	7.82	10.00	7.98	10.20	7.78	16.00
4	7.77	17.50	7.77	9.00	8.10	10.10	8.00	16.00
5	7.88	12.00	7.83	11.50	7.86	10.48	8.05	16.00
Average	7.84	10.50	7.81	12.10	7.90	10.20	7.92	16.10

Concrete Compressive Strength Results

Table 6: Table showing the compressive strength for 0g, 10g, 15g, and 20g of Magnesium Sulphate salt in solution for curing days of 7, 14, 21 and 28 respectively.

Concentration of salt (g)	Curing Days	Average Weight of Cubes (Kg)	Density Kg/m3	Average Rebound No	Compressive Strength (N/mm^2)
0	7	8.10	2.40	18.10	43.44
	14	8.13	2.41	21.20	51.07
	21	8.17	2.42	23.90	57.86
	28	8.19	2.43	25.90	62.85
5	7	7.61	2.25	10.40	23.45
	14	7.75	2.30	13.90	31.92
	21	8.02	2.38	16.70	39.68
	28	8.20	2.43	24.30	59.04
10	7	7.86	2.33	9.50	22.12
	14	7.97	2.36	10.60	25.03
	21	8.00	2.37	11.90	28.21
	28	8.04	2.38	23.10	55.03
15	7	8.15	2.41	9.00	20.94
	14	8.04	2.38	9.70	23.06
	21	8.02	2.38	11.01	26.16
	28	7.99	2.37	21.70	51.37
20	7	7.80	2.31	8.25	19.07
	14	7.81	2.31	9.00	21.06
	21	7.90	2.34	10.20	23.88
	28	7.92	2.35	16.10	37.78

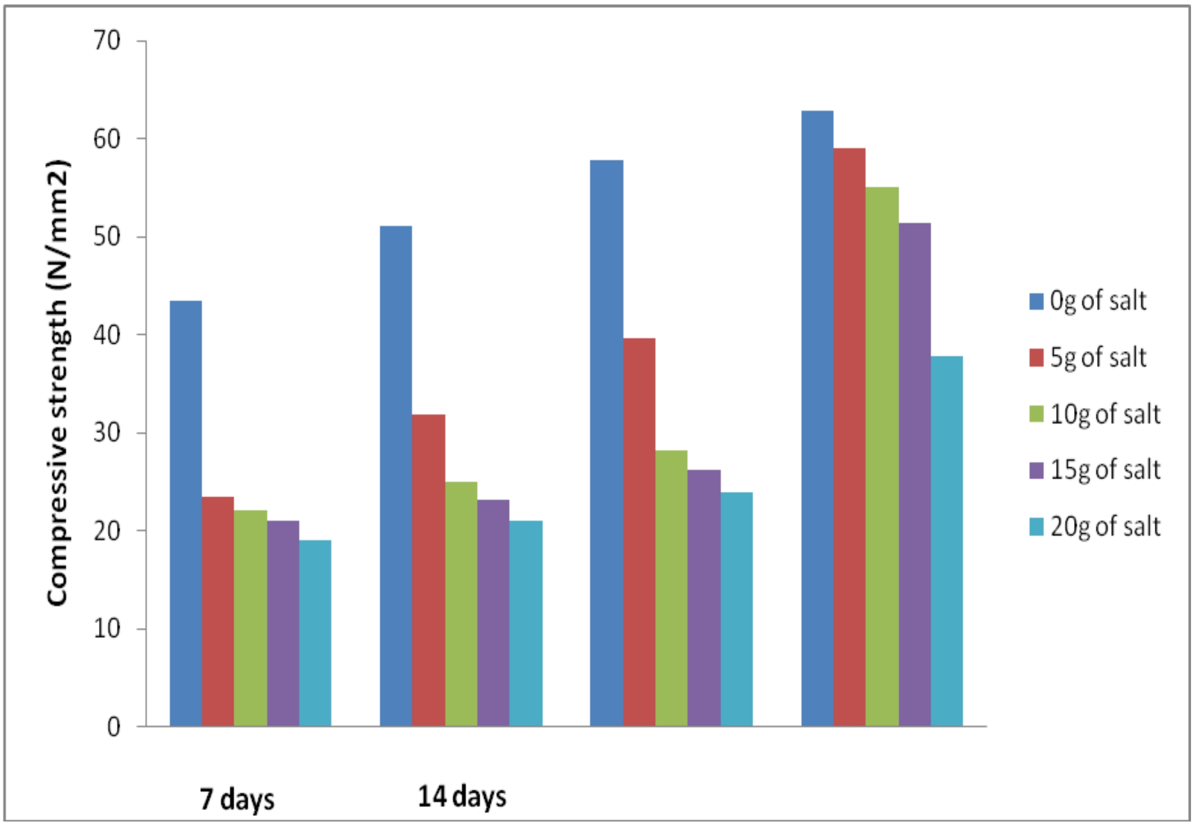

Figure 1: Graph of Compressive strength VS Age

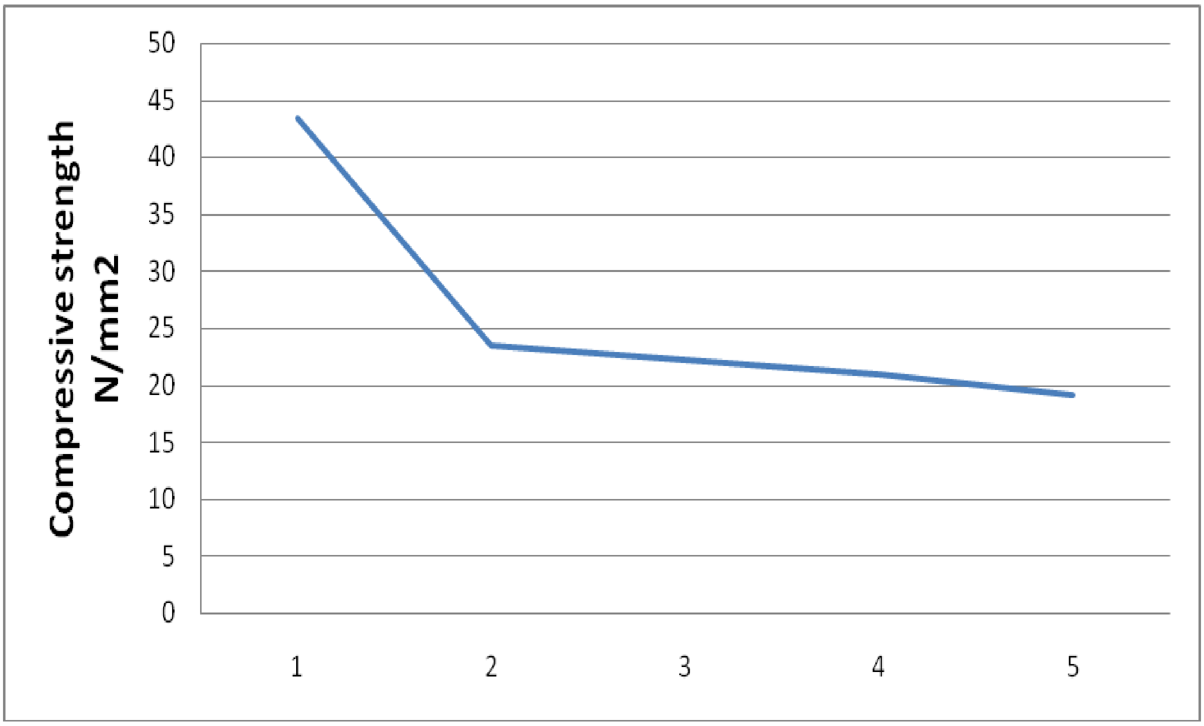

Figure 2: Graph of Compressive Strength of concrete cubes cured in 0g, 5g, 10g, 15g and 20g of Magnesium Sulphate in solution for 7 days

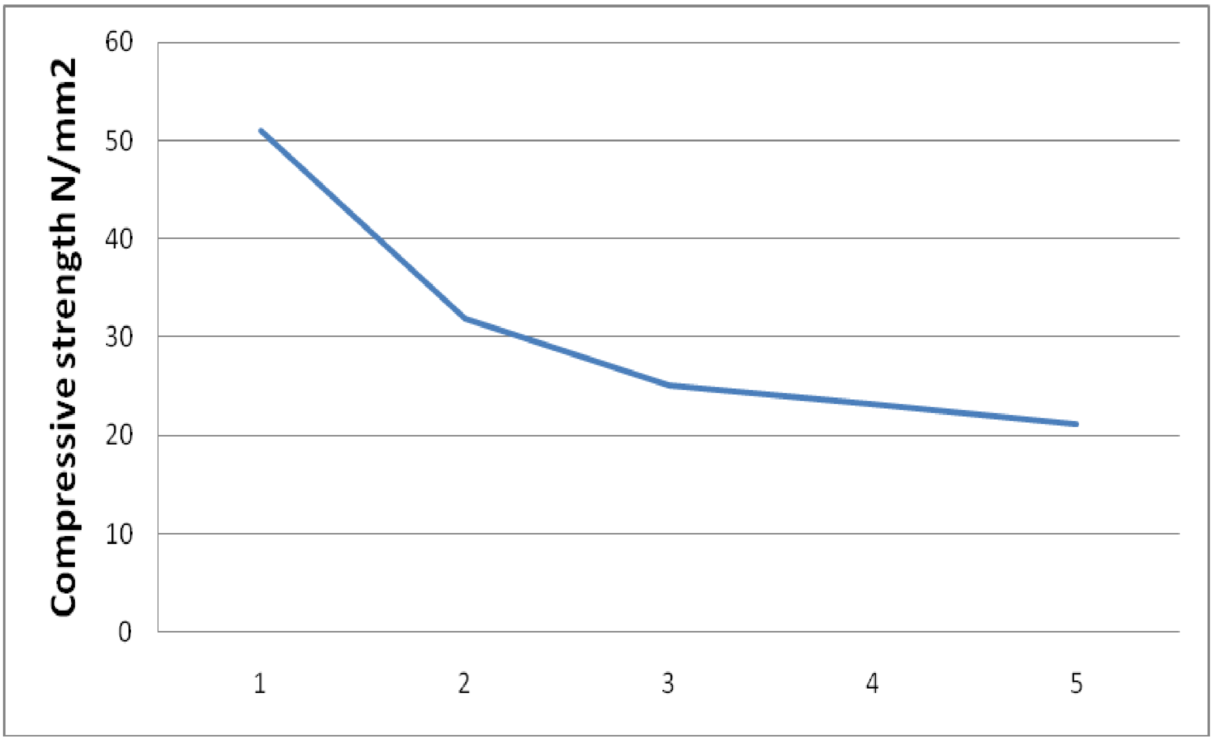

Figure 3: Graph of Compressive Strength of concrete cubes cured in 0g, 5g, 10g, 15g and 20g of Magnesium Sulphate in solution for 14 days

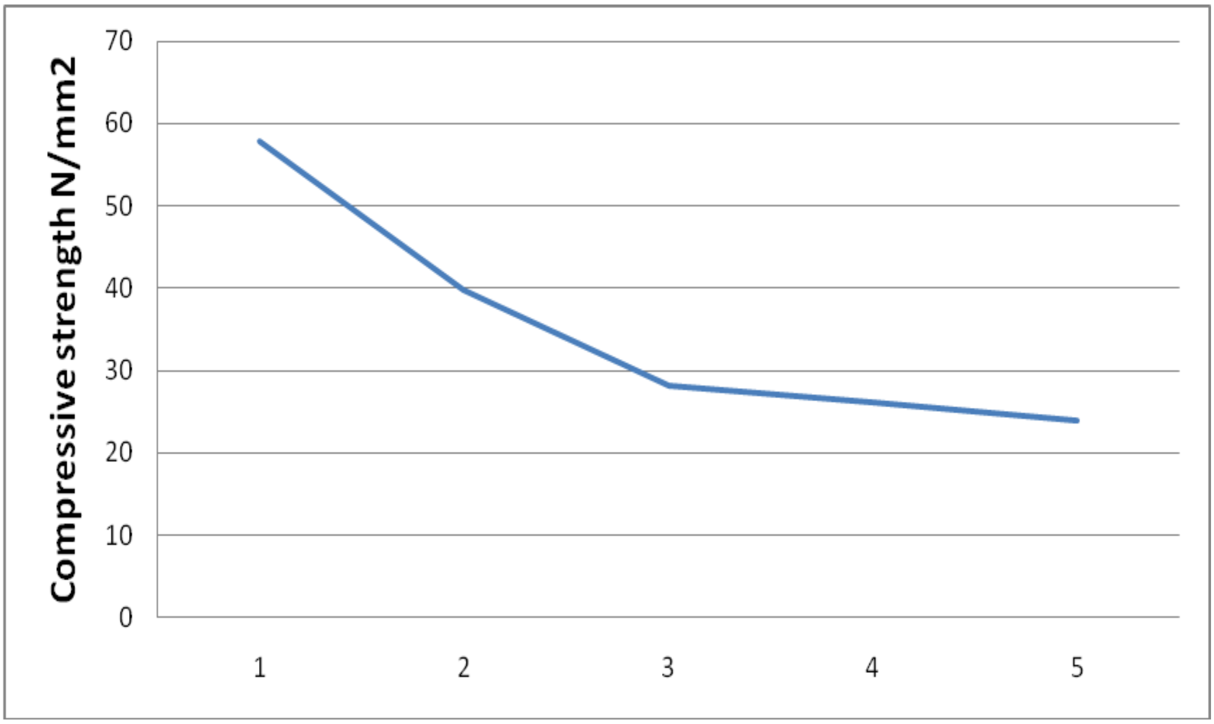

Figure 4: Graph of Compressive Strength of concrete cubes cured in 0g, 5g, 10g, 15g and 20g of Magnesium Sulphate in solution for 21 days

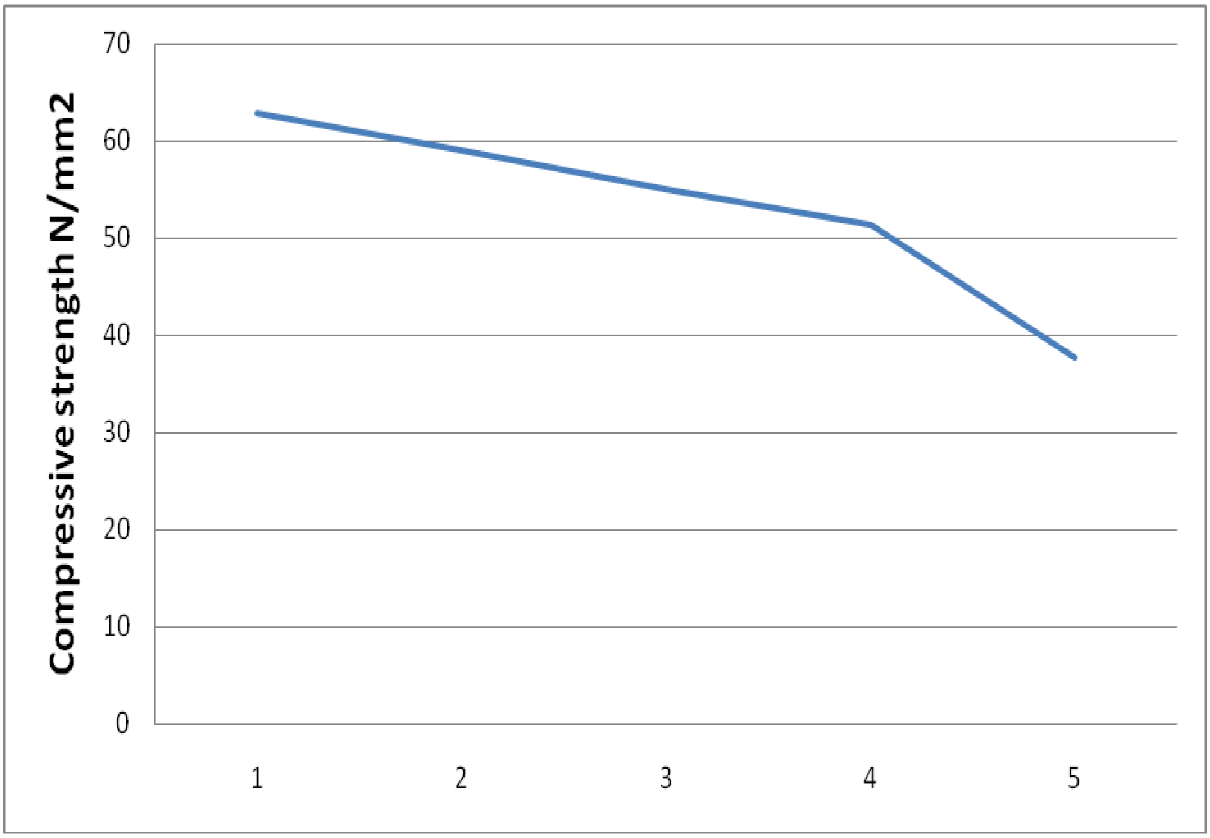

Figure 5: Graph of Compressive Strength of concrete cubes cured in 0g, 5g, 10g, 15g and 20g of Magnesium Sulphate in solution for 28 days

Reference

Abrams, D., Test for impure water for mixing concrete. American Concrete Institute, 20, pp.422. (1924)

Akinkurolere, O. O., Jiang, C and Shobola O. M. “The Influence of Salt Water on the Compressive Strength of Concrete”, Journal of Engineering and Applied Sciences, 2 (2) pp. 412 - 415. (2007)

Akinsola ,O.E., Fatokun, A.E and Ogunsanmi, O.E. “Investigation of salinity effect on compressive strength of reinforced concrete”, *Journal of Sustainable Development*; Canadian Center of Science and Education *5(6)* (2012)

Bryant, M. *Effects of Seawater on Concrete*. Miscellaneous paper no 6-690, U.S. Army Engineers, Waterways experiment station, Corps of Engineers, Vicks berg, Mississippi. (1964)

Falah, M. W., “Effects of sea water for mixing and curing on structural concrete Studies”, *The IES Journal Part A: Civil & Structural Engineering,3,* , pp. 235 – 243. (2010)

Gollop R.S. and Taylor H.F.W. Microstructural and microanalytical studies of sulphate attack. I. Ordinary Portland cement paste. Cement & Concrete Research, 22 (6), 1027-1038. (1992)

Gopal, M. “Concrete in Seawater”, Retrieved November 8, 2010, from http://www. *theconstructor.org/concrete/concrete-in-seawater/843/*. (2010)

Grundy, J. T. Construction Technology, Edward Arnold, Mill Road, Donton Green, 3ed (1981)

http://en.wikipedia.org/wiki/Basement

http://en.wikipedia.org/wiki/Salinity

http://en.wikipedia.org/wiki/Sulfate_attack_in_concrete_and_mortar

Hoff, G., Durability of offshore and marine concrete structures. In: 2nd international conference (ACI SP-127), Montreal, Canada. Farmington Hills, MI: American Concrete Institute, 33–64. (1991)

Kumar, S. and Kameswara Rao C.V.S. "Effect of sulphates on the setting time of cement and strength of concrete". Cement and Concrete Research, 26(4) pp 641–643 (1996)

Lafe, O. Elements of Reinforced Concrete Design. Macmillan Publishers: London, UK. (1986)

Leshchinsky, A., Non-destructive methods Instead of specimens and cores, quality control of concrete structures, in: L. aerwe, H. Lambotte (Eds.), Proceedings of the International Symposium held by RILEM, Belgium, E&FN SPON, U.K., pp. 377-386. (1991)

Mokhtar, M. A. and Swarmy, R.N. "Influence of Salt Weathering on the Properities of Concrete", Arabian Journal for Science and Engineering, 33(1B) pp. 501. (2008)

Neville, A.M. and Brooks, J.J., Concrete technology. England: Longman Scientific and Technical. (1994)

Osei, Y. A. Neutralization, New School Chemistry" African First Publisher Onitsha Nigeria. (2000)

Prascal, J., Jain, D. K., & Ahuja, A. K. Factors Influencing the Sulphate Resistance of Cement, Concrete and Mortar. *Asian Journal of Civil Engineering (Building and Housing)*, *7*(3), 259-268. (2006)

Tibbetts, D. C. "Performance of Concrete in Seawater", Canadian Building Series, No.2, pp. 159 – 180. (1968)

Water Encyclopaedia. Earth: The water Planet, (Ed). Earth Sylvia. Retrieved from www.watercyclopedia.com/ Da-En/ Earth- The water-planet.html # b. (2012).

Yilmaz, I . A new testing method for indirect determination of the unconfined compressive strength of rocks. Inter. J. Rock Mech. Mining Sci., 46(8): 1349-1357. (2009)

Yüksel, I., Determination of concrete strength using combined non destructive tests and application on a reinforced concrete structure. MSc. Thesis, Yildiz Technic University, Science of Technology Institute, Istanbul. (1995)