SOLUBILITY OF CONCRETE IN ACID SOLUTION AS A DETERMINANT FACTOR IN THE ASSESSMENT OF CONCRETE STRENGTH

A.M. OLAJUMOKE+, I.A. OKE and M.O. OGEDEMGBE
Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

Abstract

The need exists for early assessment of strength of concrete in modern reinforced concrete construction to minimise losses. Possibility of using solubility of concrete in acid solutions to carry out its strength assessment was investigated. Standard concrete cubes were cast and cured for different days. At each curing day, a set of concrete cubes of the same water-cement ratio was tested for strength using a conventional method. Another set of the same concrete cubes was also soaked for 48 hours in HCl at different acid concentrations. Dissolved solids concentration was later determined using Standard method. The results showed that dissolved solids increased with increase in HCl concentration, likewise, compressive strength increased with increase in curing days. Relationship between compressive strength and dissolved solids concentration of concrete in HCl solutions indicated that there was perfect correlation between them with correlation coefficient of 1.0. For 3, 7 and 28 days uncrushed concrete at 0.55 water-cement ratio in 75 mg/l of HCl the dissolved solids were 29637, 27288 and 26148 mg/l respectively while compressive strength were 20.36, 22.41 and 26.20 N/mm^2 respectively. Similarly, for 3, 7 and 28 days uncrushed concrete at 0.65 water-cement ratio in 75 mg/l HCl concentration, the dissolved solids were 35062, 32286, and 33032 mg/l respectively while compressive strength were 8.40, 11.23 and 12.66 N/mm^2 respectively. It was concluded that solubility of concrete in HCl solution could be used as an alternative method in the assessment of strength of hardened concrete.

Key words: Solubility, concrete, acid solutions, concentration, dissolved solids, compressive strength, correlation coefficient, water-cement ratio.

1. Introduction

Concrete has been established as a versatile material in construction industry because when mixed in adequate proportions and properly laid in position, after hardened it can safely sustain large load in compression. When reinforced, it can sustain both large applied compression and tension loads. However, the amount and quality of constituent materials (cement, fine and coarse aggregates as well as water) influence the properties of hardened concrete. All these constituent materials are in abundance in Nigeria. This is one of the reasons why reinforced concrete structures is popular than steel structures in Nigeria coupled with availability of technical hands and ease of handling reinforced concrete construction. Cement is among the major construction materials world wide and its production and chemical composition is almost the same any type.

Production of cement has been described by various authors such as Neville and Brookes (1993), Taylor (2000) and Roger (1999). The widely used Portland cement in Nigeria is that being produced by the West African Portland Cement (WAPCO). The chemical composition of the cement as given by the Company is 45% $3CaO.SiO_2 (C_3S)$, 15% $2CaO.SiO_2 (C_2S)$, 7% $3CaO.Al_2O_3 (C_3A)$ and 9% $4CaO.Al_2O_3.Fe_2O_3 (C_4AF)$. This shows that $3CaO.SiO_2$ (also known as tri-calcium silicate) is the major constituent of the Portland cement followed by $2CaO.SiO_2$ (also known as di-calcium silicate). This conforms to the chemical composition reported for ordinary Portland cement by Neville and Brookes (1993). According to the authors, the silicates (C_3S and C_2S) are the most important compounds that are responsible for the strength of hydrated cement paste while C_3A contributes to the strength of cement only at the early ages but is beneficial in the manufacture of cement for it facilitates the combination of lime and silica.

It has been reported by many authors (Neville and Brookes, 1993; Mosley and Bungey, 1993) that properly prepared concrete attains about 75% of its ultimate strength at 28 days (time it can adequately support the design loads). However, field experience has shown that many reinforced concrete structures could not be delayed for such long time before additional floors are added due to early completion time required by the clients. Many multi-storey buildings are being completed within a few weeks and as a result of this, some structural elements of such hastily completed reinforced concrete structures

+ *corresponding author* (email: aolajumo@oauife.edu.ng)

may later be found to have strength well below the specified one from design. Hence, such structures may be incapable of sustaining anticipated ultimate loads during the service conditions. Most times, demolition of such structure is always difficult to carry out due to huge economic loss that may be involved (as many floors might have been constructed over the defected structural elements) and when the structure is put into use, failure ultimately occurs. In most cases, before collapse of reinforced concrete occurs, cracks would have been formed which may eventually lead to collapse. It should be noted that in reinforced concrete structures cracks can result from a number of factors which include, overloading of structures,.poor workmanship, serious under-reinforcement, or due to fatigue; while sudden collapse results from serious over-reinforcement. However, in properly designed and supervised construction, occurrence of these factors is reduced to the minimum.

In order to make quality assessment easier and to reduce the ugly incidence of collapse of reinforced concrete structures resulting from poor quality concrete, there is need to develop alternative means of strength assessment of the concrete especially at the early ages. One of such alternative methods is considered in this study as a follow-up of a previous study by the authors (Olajumoke *et al.*, 2006). This study aims at using solubility of concrete in acid solution to assess the compressive strength of concrete.

2. Materials and Methods

Fresh concrete of 1:2:4 prescribed mix by weight were prepared and cast using water-cement ratios of 0.55, 0.60 and 0.65 respectively. Steel moulds of 100 mm x 100 mm x 100mm were used to cast the concrete. Each concrete cube was properly compacted in two layers and each layer was subjected to 25 blows which were evenly distributed over the surface of the concrete. Then, the surface was rendered smooth with hand trowel. A total of 162 cubes were cast for this study. After about 24 hours, the steel moulds were removed and the cubes were cured by total immersion in water for the different curing ages of 3-day, 7-day and 28-day. Two different concentrations (75mg/l and 150mg/l) of hydrochloric acid (HCl) were prepared from 35% concentration of HCl and distilled water was used for the control solution. The choice of HCl for this study is based on the fact that it is staple acid on the shelf of many science laboratories and also it is one of the strong acids that can easily attack concrete. According to Neville and Brooks (1993), no Portland cement is resistant to the attack of acids and the degree of attack increases as acidity increases (attack occurs at values of pH below about 6.5).

At 3-day, 7-day, and 28-day curing, the compressive strengths of the cubes were determined by the conventional method (force applied from machine to determine the crushing loads). Avery Denison compressive machine was used to determine the maximum crushing loads for the cubes and the loads were later converted to strength. Both crushed and uncrushed concrete cubes were soaked in the acid and water solutions for 48 hours after curing them in water. The dissolved solids concentrations were determined for both crushed and uncrushed concrete using standard methods of APHA (1998). The dissolved solids concentrations were determined by evaporating to dryness 25 ml of the thoroughly-mixed concrete solutions. The results of average of three specimens were recorded for each curing day. It should be noted that the total dissolved solids were determined based on the assumptions that there were no supplementary cementing materials; the amount of soluble calcium oxide and silica of the cement was fixed as given by the WAPCO unless from another source, and soluble silica and calcium in aggregates were assumed to be siliceous and were generally insoluble in acid.

3. Results and Discussion

The set of concrete cubes prepared using the three water-cement ratios of 0.55, 0.60, and 0.65 were used in the determination of the compressive strength of the cubes. Table shows the compressive strength and dissolved solids concentration at the different curing days and acid concentrations. Generally, it can be observed that as the curing day increases, the compressive strength of the concrete is increasing for the entire three water-cement ratios. This is shown in Fig. 1. However, as the water-cement ratio was increasing the magnitude of compressive strength was decreasing. For example, at 3-day curing for 0.55 water-cement ratio concrete cubes, the compressive strength was 20.36 N/mm^2 while it was 12.66 N/mm^2 for 0.65 water-cement ratio concrete cubes. Also, at 28-day curing for 0.55 water-cement ratio concrete cubes, the compressive strength was 26.20 N/mm^2 while it was 12.66 N/mm^2 for 0.65 water-cement ratio concrete cubes. These show that the relationship between compressive strength development and water-cement ratio is non-linear rather it is polynomial (Fig. 2 and 3) with correlation coefficient (R^2) of 1.0. This is an indication that there is a perfect correlation between the compressive strength and dissolved solids.

Effect of Curing Age and Water-cement Ratio on the Dissolved Solids Concentration

It can be observed from the Table that as the curing age increased, the amount of dissolved solids was decreasing for each water-cement ratio. This shows that as the curing age increased, the concrete was

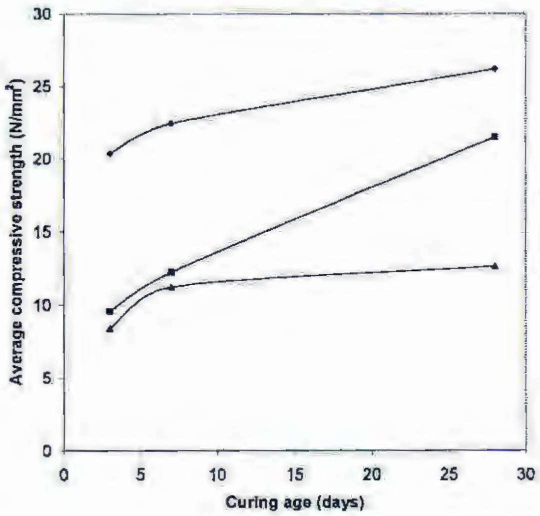


Fig. 1: Average compressive strength versus curing days at different water-cement ratios

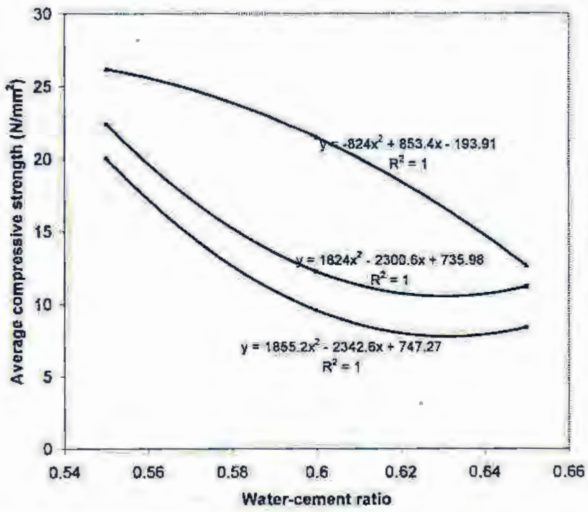
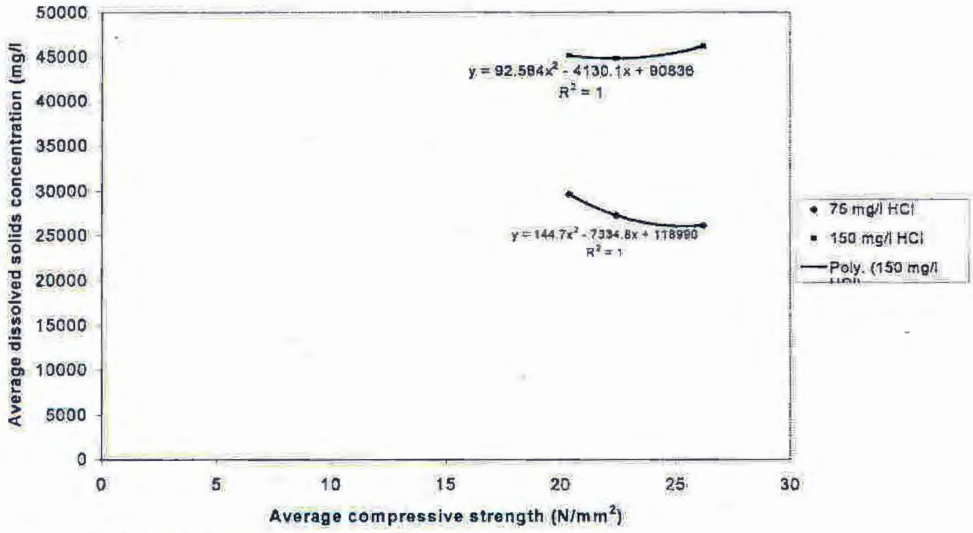


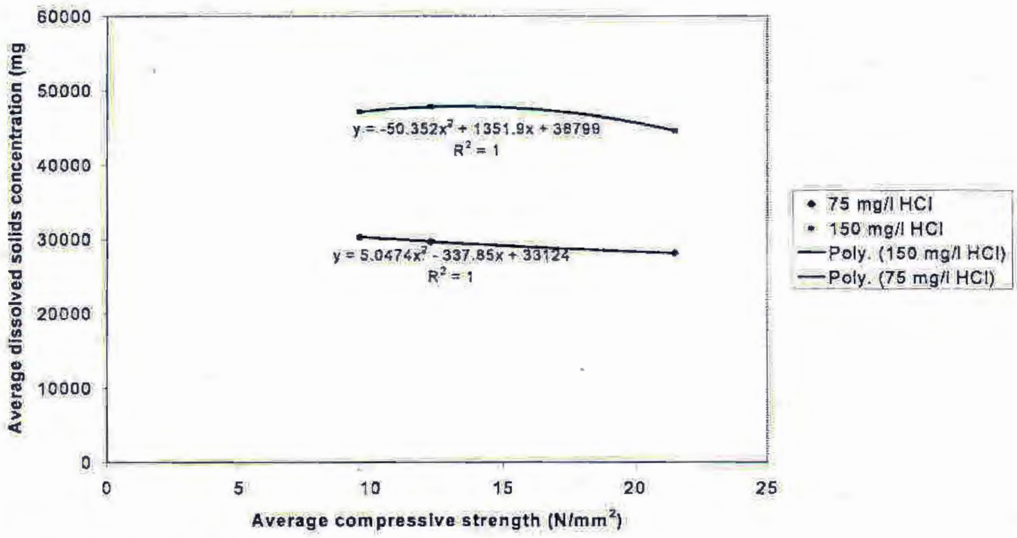
Fig. 2: Average compressive strength versus water-cement ratio for 1:2:4 concrete mix at different curing days

Plate 1: Some of the moulded concrete cubes in the first 24 hours old

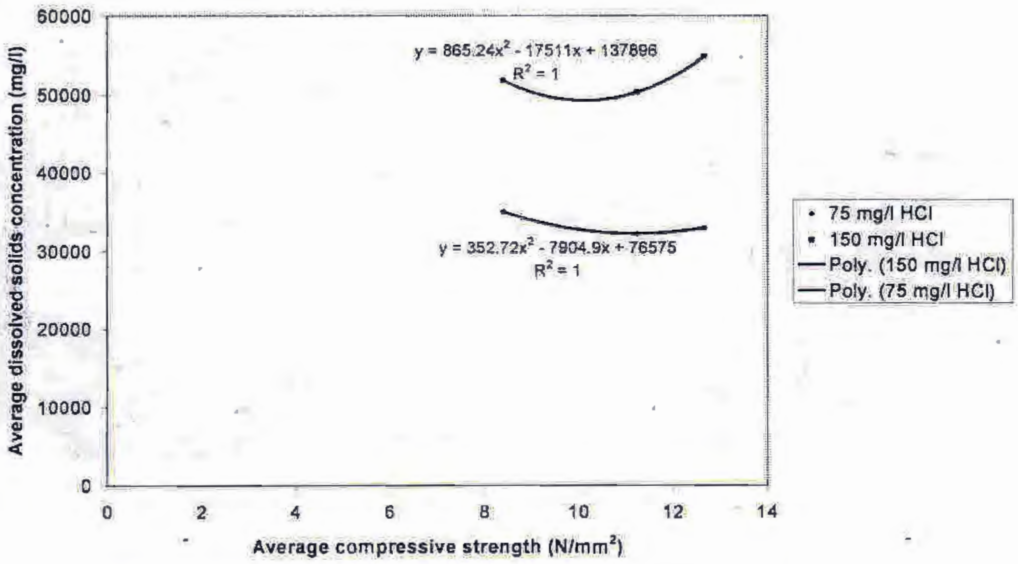
Plate 2: Soaking of concrete cubes in acid solutions using plastic bowls



(a) Concrete mix of 0.55 water-cement ratio



(b) Concrete mix of 0.60 water-cement ratio



(c) Concrete mix of 0.65 water-cement ratio

Fig. 3: Relationship between the compressive strength and the dissolved solids concentrations of 1:2:4 concrete mixes cured for 28-day

developing resistance to the attack of acid solutions. On the other hand, as the water-cement ratio increases, the quantity of dissolved solids increases. This shows that as the water-cement ratio was increased beyond optimum value, the strength of the concrete was reducing accordingly; this is evident from erodability of the concrete with highest water-cement ratio.

Furthermore, TABLE shows that for concrete of water-cement ratios of 0.55, 0.60 and 0.65, the rate of dissolution was higher for crushed concrete than for uncrushed ones. This can be attributed to an increased surface area (due to cracks through which acid solutions would have penetrated the concrete) in the crushed ones as compared to the uncrushed concrete that is solid. Similarly, the rate of dissolution was higher between curing days at early stages (3 and 7 days) for the concrete with water-cement ratio of 0.55 than for concrete of 0.60 and 0.65 water-cement ratio; but it was higher at later stage (28 days) for concrete with water-cement ratio of 0.60 and 0.65 than for concrete with water-cement ratio of 0.55. This shows that water-cement ratio of 0.55 is about the optimum water required for the 1:2:4 concrete mix for minimum void. However, for most construction works the workability (the ease with which concrete mix can be handled from mix to fully compacted shape) of concrete at that water-cement ratio will be low and would require much energy to be properly mixed, placed and compacted. Use of concrete mixer is the best at this water-cement ratio which can only be economical for large volume of concrete.

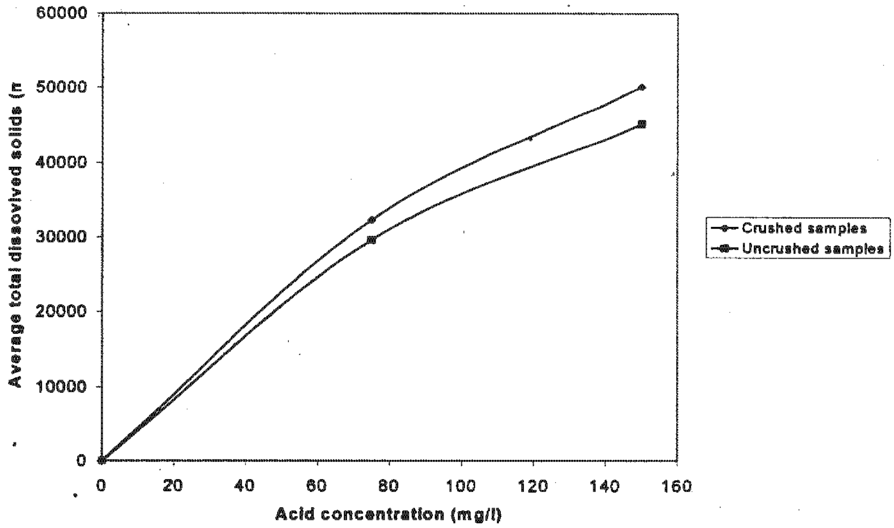
Effect of Acid Concentration on the Dissolved Solids

As stated earlier, concrete cubes prepared using the three water-cement ratios of 0.55, 0.60, and 0.65 were used in the determination of the dissolved solids. Some cast concrete cubes in steel moulds are shown in Plate 1 and soaking of some of the concrete cubes in acid and water solutions is shown in Plate 2. All the containers were covered to prevent evaporation of the liquid. TABLE shows the amount of dissolved solids at the different curing days, water-cement ratio and for the two acid concentrations (75mg/l and 150mg/l). The graph of the total dissolved solids for both crushed and uncrushed concretes are shown on Figures 4, 5 and 6 for the three different water-cement ratios.

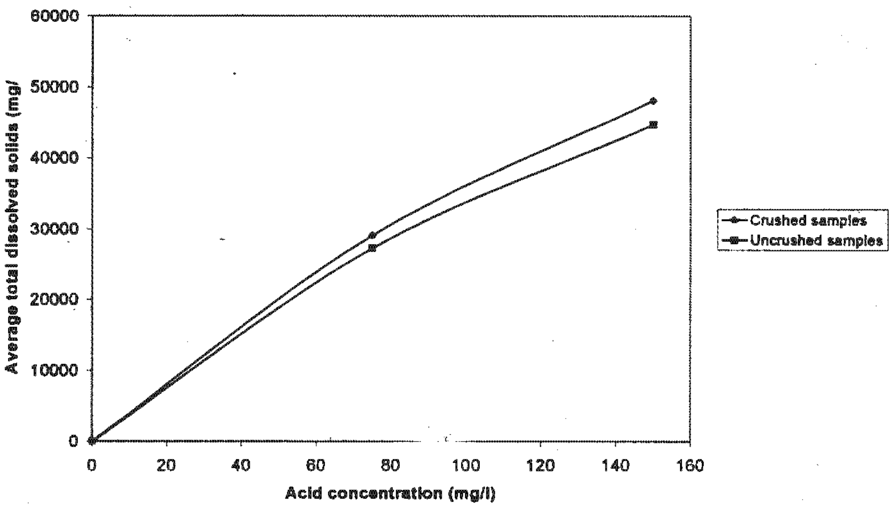
It can be observed that as the HCl concentration increases, the dissolved solids increases. Dissolved solids were highest at the lowest curing day. TABLE also shows that dissolved solids concentrations for crushed and uncrushed concrete at 0.55 water-cement ratio and cured for 3 days but soaked in 75 mg/l of HCl concentration for 48 hours were 32335 mg/l and 29637 mg/l respectively. Similar concrete at 0.65 water-cement ratio and subjected to the same conditions had their dissolved solids concentrations to be 38408 mg/l and 35062 mg/l respectively. These

Table: Average compressive strength and average total dissolved solids concentration of 1:2:4 concrete mixes at 0.55. 0.60 and 0.65 water-cement ratios for different acid concentrations

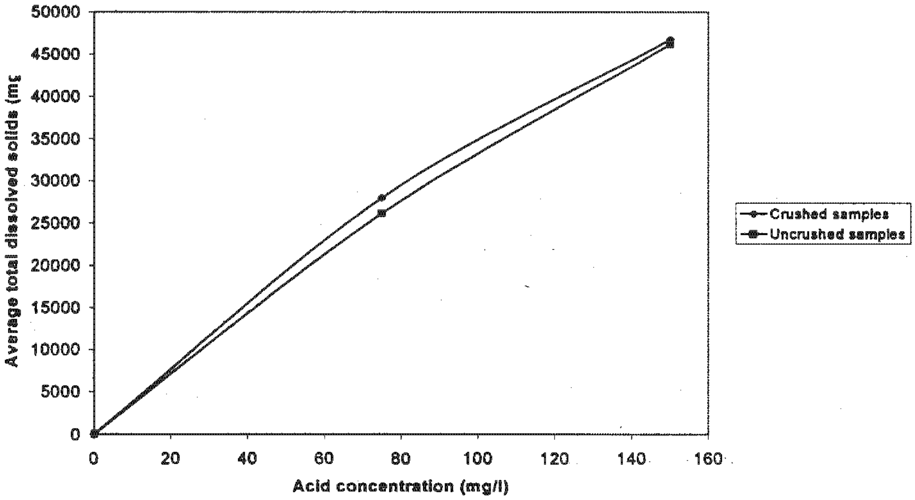
Water-cement ratio	Curing age (days)	Average Acid Compressive strength (N/mm^2)	Concentration (mg/l)	Average total dissolved solids	
				Crushed	Uncrushed
0.55	3	20.36	75	32335	29637
			150	50077	45127
	7	22.41	75	29122	27288
			150	48157	44778
	28	26.20	75	27996	26148
			150	46761	46182
0.60	3	9.58	75	33781	30351
			150	51108	47129
	7	12.26	75	32293	29741
			150	50610	47805
	28	21.49	75	29389	28195
			150	49522	44598
0.65	3	8.40	75	38408	35062
			150	61092	51853
	7	11.23	75	36553	32286
			150	55674	50363
	28	12.66	75	29759	33032
			150	55141	54881



(a) At 3-day curing

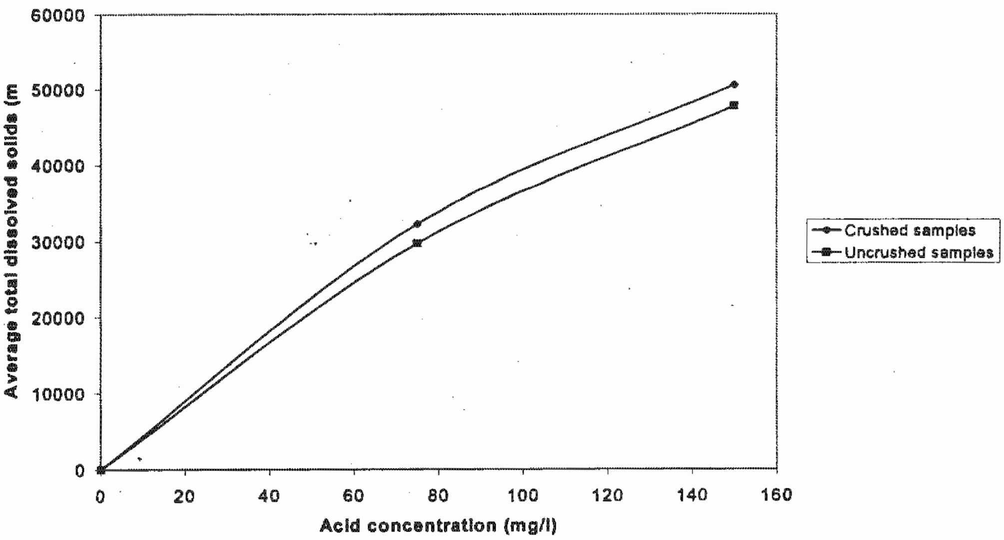


(b) At 7-day curing

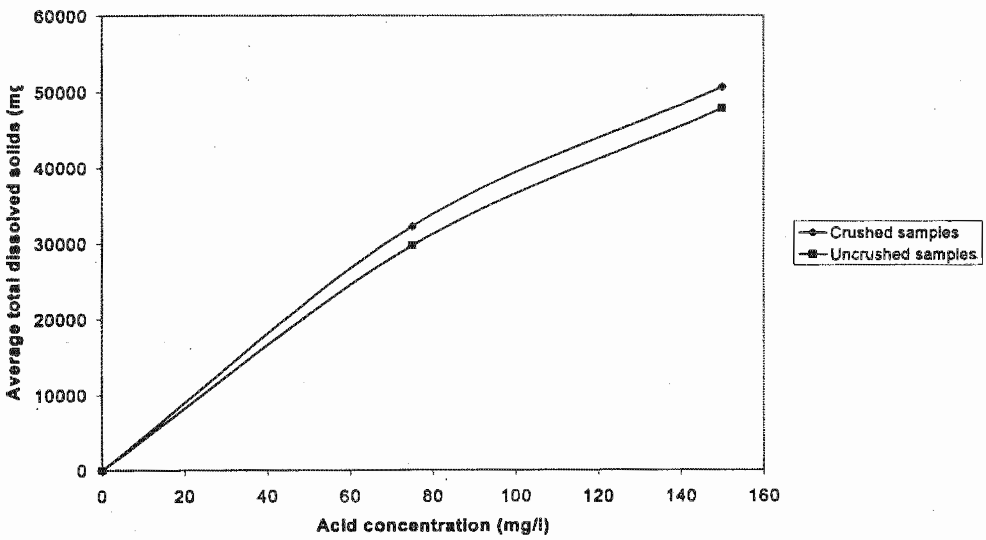


(c) At 28-day curing

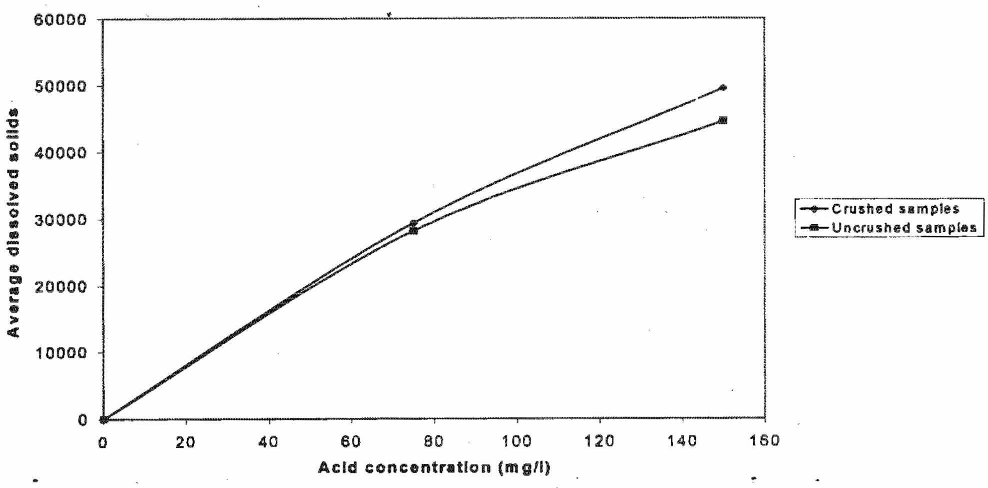
Fig. 4: Dissolved solids concentrations versus acid concentrations at different curing days for 0.55 water-ce[illegible] ratio.



(a) At 3-day curing

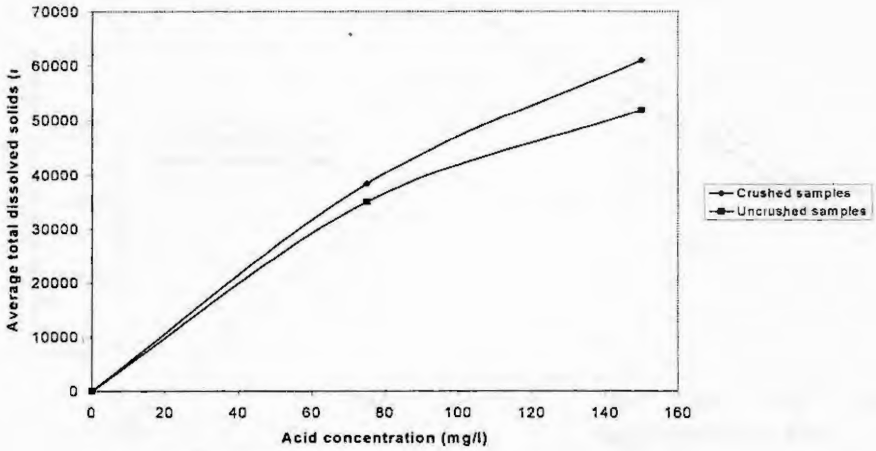


(b) 7-day curing

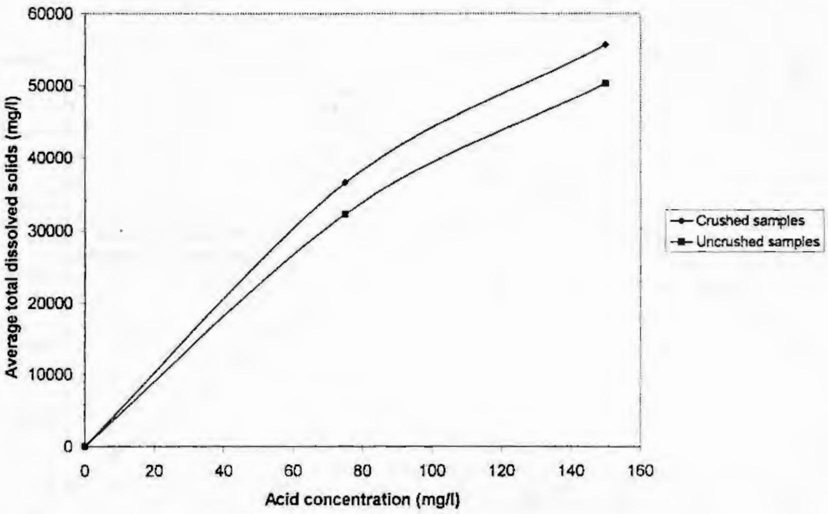


(c) At 28-day curing

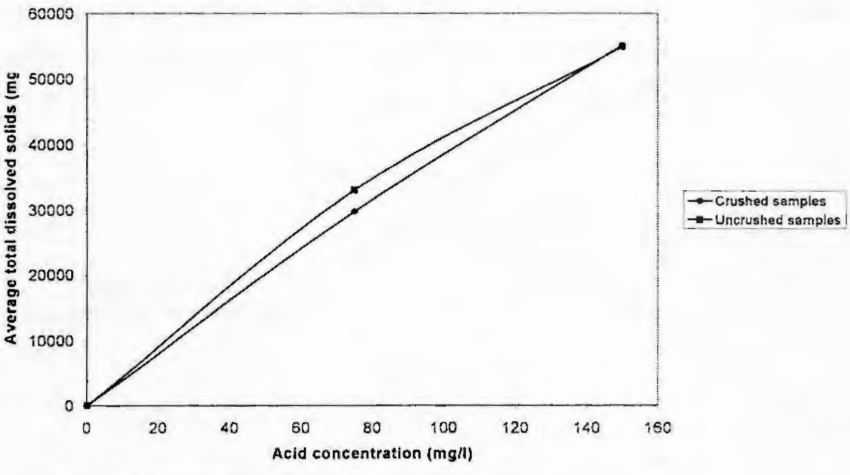
Fig. 5: Dissolved solids concentrations versus acid concentrations at different curing days for 0.60 water-cement ratio.



(a) At 3-day curing



(b) At 7-day curing



(c) At 28-day curing

Fig. 6: Dissolved solids concentrations versus acid concentrations at different curing days for 0.65 water-cement ratio.

trends were the same for 7-day and 28-day curing days. These show that as compressive strengths were reducing, the dissolved solids concentrations were increasing. Generally, there were no dissolved solids for the concrete soaked in distilled water.

It should be noted that when reinforced concrete collapses the civil/structural engineers and other interest groups would want to know the cause(s) of the failure and the first thing that come to mind is whether the concrete used was of adequate strength or not. In order to ascertain this, tests have to be carried out on the major construction materials such as concrete and reinforcing bars. However, at this time the structure would have become rubbles which makes conventional method of determining compressive strength of concrete in particular difficult, as flat surface is required to apply loads for the determination of compressive strength. Therefore, in such difficult situation and when it is difficult to have access to non-destructive conventional machine to determine the strength of hardened concrete, the results of dissolved solids concentration could be extrapolated to assess the quality in terms of strength of the hardened concrete.

4. Conclusion

It can be concluded from this study that the results of dissolved solids concentration of concrete in acid solutions can be used:

For preliminary assessment of quality of cast concrete.

(i) As an emergency means of assessment of hardened concrete strength.

(ii) As an alternative method to the conventional method of determining strength of hardened concrete.

The results of this work will be useful especially in remote areas where there is no access to conventional compressive strength testing machine, whereas the solubility method used in this study can easily be carried out in the laboratory of any secondary school. This will make assessment of concrete strength easier, thus assisting in preventing collapse of concrete structures; this would greatly contribute to the national development in providing safe and functional concrete structures.

Acknowledgement

The authors acknowledge the contributions of Messrs L.A. Osuya and A.I. Adekunle in carrying out the laboratory works.

REFERENCES

APHA (1998) "Standard Methods for the Examination of Water and Wastewater". American Public Health Association Inc. New York.

Mosley, W.H. and Bungey, J.H., 1993. Reinforced concrete design, 4th ed. ELBS with Macmillan, Hong Kong.

Neville, A.M. and Brooks, J.J., 1993. Concrete technology. ELBS with Longman, Singapore.

Olajumoke, A. M., Oke, I. A., Fajobi, A. B. and Ogedengbe, M. O. 2006. Technical assessment and remediation of a failed building in Osun state of Nigeria". Journal of Applied Science Research, Pakistan, 2(8), 462– 465.

Roger, G., 1999. Construction technology". 3rd edition. Longman, London.

Taylor, G.D., 2000. Material in Construction", 3rd edition. Longman Group London.