TJES
**ISSN: 1813-162X**
**Tikrit Journal of Engineering Sciences**
**available online at: http://www.tj-es.com**

# Mechanical Properties of Reactive Powder Concrete (RPC) Exposed to Acidic Solutions

**Ali Hussain Ali, Ahmed Khaleel Ibrahim**
Technical College/Mosul, *Nenawa Province, Republic of Iraq*

## ABSTRACT

This research work includes an experimental investigation to study the mechanical properties of reactive powder concrete (RPC) exposed to acidic solutions. A comparative study was conducted on concrete mixes, control mix without exposure and mixes exposed to acidic solutions. RPC was exposed to two acids (Sulfuric acid and Nitric acid) with concentration of (1.0)% for each acid. The acidic solutions were used to study acidic rain effect and durability of RPC. Compressive strength test was used to study the effect of acid rain on RPC after exposure to the acid in a duration (48) hours. This exposure was done: after demolding and after (3 and 7) days curing. The maximum loss in compressive strength for Sulfuric acid and Nitric acid was (11.7 and 19.7)% respectively for after demolding exposure as compared with the control mix.

For durability of RPC the specimens exposed to acidic solutions tested in duration (40, 50, and 60) days, to determine the compressive strength, splitting tensile strength, flexural tensile strength, and weight loss. Test results showed that RPC resistance to Sulfuric acid more than Nitric acid. The maximum loss in compressive strength, and loss in weight were (6.20 and 2.69)% in Sulfuric acid and (22.60 and 1.32)% in Nitric acid environment respectively at (60) days as compared with the control mix. The loss in splitting tensile strength and flexural tensile strength were (17.1 and 13.3)% for Sulfuric acid and (25.7 and 25.0)% for Nitric acid exposure respectively at (40) days as compared with the control mix.

**Keywords:** Reactive Powder Concrete (RPC); Acidic solutions; Durability; Acidic rain; Loss in weight.

**الخواص الميكانيكية لخرسانة المساحيق الفعالة المعرضة لمحاليل حامضية**

**الخلاصة**

يتضمن البحث أعمال مختبريه لدراسة الخواص الميكانيكية لخرسانة المساحيق الفعالة (RPC) ألمعرضة لمحاليل حامضية. تم إجراء مقارنة بين عدة خلطات خرسانية، خلطة رئيسية بدون تعريض، و خلطات عرضت لمحاليل حامضية. خرسانة المساحيق الفعالة تم تعريضها إلى حامضين (حامض الكبريتيك و حامض النتريك) بتركيز (1.0)% لكل حامض. استخدمت المحاليل الحامضية لدراسة تأثير الأمطار الحامضية و متانة (ديمومة) خرسانة المساحيق الفعالة. استخدم فحص مقاومة الانضغاط لدراسة تأثير الأمطار الحامضية على خرسانة المساحيق الفعالة بعد تعريضها للحامض لمدة (48) ساعة. و قد تم تعريض الخرسانة للحامض: بعد فتح القالب وبعد (3 و 7) أيام معالجة. الخسارة العظمى في مقاومة الانضغاط لحامض الكبريتيك و حامض النتريك كانت (11.7 و 19.7)% على التوالي عند التعرض بعد الصب بالمقارنة مع الخلطة المرجعية.

بالنسبة لمتانة (ديمومة) خرسانة المساحيق الفعالة فان النماذج عرضت لمحاليل حامضية لمدة (40 ، 50 ، 60) يوما، و الفحوصات المستخدمة هي مقاومة الانضغاط، مقاومة الشد الانشطاري، مقاومة شد الانحناء و النقص بالوزن. بيّنت نتائج الفحص بان خرسانة المساحيق

الفعالة ذات مقاومة لحامض الكبريتيك أكثر من حامض النتريك. أن الخسارة العظمى لمقاومة الانضغاط والنقص بالوزن هي (6.20 و 2.69)% عند التعرض لحامض الكبريتيك و (22.60 و 1.32)% عند التعرض لحامض النتريك على التوالي في (60) يوم بالمقارنة مع الخلطة المرجعية. اما الخسارة في مقاومة الشد الانشطاري و مقاومة شد الانحناء فكانت (17.1 و 13.3)% عند التعرض لحامض الكبريتيك و (25.7 و 25.0)% عند التعرض لحامض النتريك على التوالي في (40) يوم بالمقارنة مع الخلطة المرجعية.

**الكلمات الدالة:** خرسانة المساحيق الفعالة; المحاليل الحامضية; الديمومة; الإمطار الحامضية; الخسارة بالوزن.

## INTRODUCTION

Reactive powder concrete (RPC) is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits and build structures that are strong, durable and sensitive to environment. The use of supplementary cementitious material and additives designed to enhance the properties of concrete has grown significantly and it is no longer possible to refer to all concrete as merely "concrete" under generic term, there exist a number of more specific description, normal strength concrete (20 to 40) MPa, high strength concrete (40 to 80) MPa and ultra-high strength concrete or reactive powder concrete (RPC) above (100) MPa[1].

When unprotected concrete surfaces of sewer pipes, waste water treatment plants, cooling towers and other industrial constructions are attacked by acidic solutions degradation of the concrete microstructure occurs which seriously limits the service life of the construction components[2].

The effect of sulfuric acid on concrete is more detrimental than that of sulfate attack; in addition to attack by sulfate ions, there is a dissolution effect caused by hydrogen ions corrosion of concrete due to sulfuric acid can generally be character-ized by the following reactions[3]:

$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4.2H_2O$…(1)

$CaSiO_2.2H_2O + H_2SO_4 \rightarrow CaSO_4 + Si(OH)_4 + H_2O$…………………….... (2)

$3CaO.Al_2O_3.12H_2O + 3(CaSO_4.2H_2O) + 14H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O$ ….(3)

Acidic rain is also one of the factors which causes deterioration of concrete structures, but it is considered that it is relatively small[4].

In 2007, M.T. Bassuoni and M.L. Nehdi[3] studied the resistance of self-consolidating concrete to Sulfuric acid attack with consecutive pH reduction, it was shown that there is no direct correlation between the rate of attack expressed by mass loss and the compressive strength loss after exposure to Sulfuric acid.

In 2011, Zhou J. et. al.[5] investigated durability and service life prediction of glass fiber reinforcing polymers (GFRP) bars embedded in concrete under acid environment. This paper presents an experimental investigation into comparison of the durability of the bond between (GFRP) and steel bars to concrete under acid environment. Experimental results showed that, For GFRP bars, at the end of (75) days of conditioning duration, maximum bond strength loss of (11.0, 22.0, 17.2, and14.0)% were observed in tap water, pH = 2, pH = 3, and pH = 4 environment respectively. For steel bars, at the end of (75) days of conditioning duration, maximum bond strength loss of (19.6 and 12.3)% were observed in pH = 2 and pH = 3 environment respectively.

The aim of this research is to study the mechanical properties of reactive powder concrete (RPC) when exposed to acidic rain as well as studying the durability of (RPC) after its exposure to acidic solutions.

## EXPERIMENTAL WORK

### *Materials*

The following constituents materials were used in preparing all concrete specimens:

***Cement***

Sulfate – Resisting cement was used in this research, it was obtained from the "Hamam Al-Alil" factory. Physical and chemical properties tests of the cement used were done in accordance to the Iraqi specifications[6], and test results were tabulated in Tables (1) and (2).

***Silica fume***

In this investigation the silica fume (Silica fume-HR), which was used, has the following technical data:

**Table1. Physical results of the used cement**

| Physical properties | Test results of Sulfate-resisting cement | Iraqi Specification No. 5 / 1984 |
|---|---|---|
| Specific surface area by Blain method, m²/kg | 292.6 | ≥ 230 |
| Initial setting time (hrs : min) | 1 : 30 | 45 minute ≥ |
| Final setting time: (hrs: min) | 3 : 18 | ≤ 10 hours |
| Compressive strength, MPa<br>3 days<br>7 days | 21<br>29 | ≥15<br>≥ 23 |

1. Physical properties:
Specific gravity (2.2), Specific surface (21,000 $m^2/kg$)

**Table 2. Chemical results of the used cement**

| Basic components | Constitution (%by weight) | Iraqi Specifications No.5/1984 (%by weight) |
|---|---|---|
| MgO | 2.41 | ≤ 5.0 |
| $SO_3$ | 2.06 | 2.5≤ |
| CaO | 60.64 | - |
| $SiO_2$ | 22.66 | - |
| $Al_2O_3$ | 4.30 | - |
| $Fe_2O_3$ | 5.01 | - |
| L.O.I.* | 2.23 | 4.0≤ |

| Sieve size (mm) | Percentage retained on each sieve (%) | Cumulative percentage retained on each sieve (%) | Percentage passing on each sieve (%) | Fine sand (BS:882:1992) |
|---|---|---|---|---|
| 4.75 | 0 | 0 | 100 | 100 |
| 2.36 | 0 | 0 | 100 | 80-100 |
| 1.18 | 0 | 0 | 100 | 70-100 |

2. Chemical properties:
The chemical properties was shown in Table (3).

***Fine sand***

Fine sand, obtained from "Kanhash" village, was used. This sand was prepared in accordance with (BS: 882:1992)[7, 8], its sieve analysis was shown in Table (4).

**Table 3. Chemical properties of silica fume**

| Chemical composition | Percentages (% by weight) |
|---|---|
| MgO | 1.47 |
| $K_2O$ | 0.9 |
| CaO | 0.5 |
| $SiO_2$ | 90.7 |
| $Al_2O_3$ | 0.68 |
| $Fe_2O_3$ | 2.2 |
| $Na_2O$ | 0.86 |
| L.O.I.* | 2.5 |

***Quartz flour***

Quartz flour of particle size (10-15) µm was used in this investigation.

**Table 4. Grading requirement of Kanhash fine sand**

| Fine sand (BS:882:1992) | Percentage passing on each sieve (%) | Cumulative percentage retained on each sieve (%) | Percentage retained on each sieve (%) | Sieve size (mm) |
|---|---|---|---|---|
| 100 | 100 | 0 | 0 | 4.75 |
| 80-100 | 100 | 0 | 0 | 2.36 |
| 70-100 | 100 | 0 | 0 | 1.18 |
| 55-100 | 90 | 10 | 10 | 0.6 |
| 5-70 | 10 | 90 | 80 | 0.3 |
| -- | -- | 100 | 10 | 0.15 |

***Steel fibers***

High tensile steel fibers, crimped type, with volume fraction ($V_f$ = 1.5%), was used. Its properties was shown in Table (5).

**Table 5. Properties of steel fibers**

| Property | Specifications |
|---|---|
| Density | 7860 kg/m³ |
| Ultimate strength | 1500 MPa |
| Modulus of elasticity | 2 *$10^5$ MPa |
| Poisson's ratio | 0.28 |
| Length (l) | 25.0 mm |
| Diameter (d) | 1.0 mm |
| Aspect ratio (l/d) | 25.0 |

***Superplasticizers***

High-range water-reducing (HRWR) admixtures, superplasticizers type Sika ViscoCrete® – SF18 (Accelerator), were used. Properties of this type of super-plasticizers was shown in Table (6).

**Table (6): Properties of superplasticizer type Sika ViscoCrete® – SF18**

| Property | Constitution |
|---|---|
| Chemical base | Modified polycarboxylates based polymer |
| Density | 1.10 ± 0.02 g/cm³ |
| pH Value | 3 – 7 |
| Color | Light brownish liquid |

***Water***

Ordinary tap water was used for preparing all concrete mixtures.

***Mix proportions***

Trial mixes were used for the design of the concrete mixture. Concrete mixtures inclu- ded one control mixture and other concrete mixtures were exposed to acidic solutions (**Sulfuric acid** pH ≈ 1.3 and **Nitric acid** pH ≈ 1.1) with concentration (1.0) % for each acid. Mix proportions are **(1 : 0.25 : 0.3 : 1.2) ; w/c = 0.28,** and quantities of materials were listed in Table (7).

**Table (7): Mix proportions**

| Constituents materials | Amount (kg/m$^3$) |
|---|---|
| Sulfate-Resisting cement (Type V) | 800 |
| Silica fume | 200 |
| Quartz flour | 240 |
| Fine sand | 960 |
| Steel fibers | 110.25 |
| Superplasticizers | 20 |
| Water | 224 |

***Mixing procedure***

A mechanical mixer of (0.1) m$^3$ capacity was used to mix concrete to obtain the required workability and homogeneity. The interior surface of the mixer was cleaned and moistened before placing the constituents materials. The dry constituents are weighed and placed in the mixer and mixed for about (2) minutes to attain uniform mix and the superplasticizers was mixed with water and added to the mixture and the whole constituents were mixed for extra (3) minutes. After the concrete became homogenous the steel fibers were added to the mixture. ASTM C192[9] Specifications was used in batching all mixes.

***Casting the specimens***

The fresh concrete was placed in the cast iron molds immediately after completion of mixing. The molds were coated with oil in order to remove specimens easily after cast. Concrete was casted in layers of (50) mm, each layer was compacted by using a vibrating table for (15-30) second until no air bubbles emerged from the surface of the concrete, and the concrete was leveled off smoothly to the top of the molds. Then the specimens were kept covered with polyethylene sheet in the laboratory for about (24) hours. After that the samples were removed from molds and kept in the curing tank. During these processes the flow table test[10] was done in order to obtain the fluid consistency (Flow = 190 mm).

**Table 8. Compressive strength results using acidic rain**

| Specimens Conditions | Compressive strength for Control mix (MPa) | Compressive strength for (1.0%) Sulfuric acid (MPa) | Compressive strength for (1.0%) Nitric acid (MPa) | Reduction in strength for (1.0%) Sulfuric acid (%) | Reduction in strength for (1.0%) Nitric acid (%) |
|---|---|---|---|---|---|
| Without exposure | 93.4 | - | - | - | - |
| After demolding | - | 82.4 | 75 | 11.7 | 19.7 |
| After (3) days curing | - | 85.3 | 79.3 | 8.6 | 15 |
| After (7) days curing | - | 88.8 | 84.2 | 4.9 | 9.8 |

***Testing types***

The following tests were conducted on the concrete specimens:

***Compressive strength***

Compressive strength tests were perf-ormed on cube specimens (100* 100*100) mm. at (28) days immersed in acidic rain solution and after (40, 50, and 60) days exposure to the same acidic solutions for durability, using a hydraulic press machine with a loading rate of (0.5) MPa/sec, according to BS : 1881 : Part 116 : 1983[12]. Three identical specimens from each mixture were tested at each age and the average value was reported. The percentage of reduction in compressive strength can be calculated using equation (4), as follows:

Reduction in compressive strength (%) is:

$$= \left[\frac{f'c1 - f'c2}{f'c1}\right] x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

$f'c1$: without acid attack

$f'c2$: with acid attack

***Splitting tensile strength***

Splitting tensile strength test was performed on cylindrical specimens (100*200) mm. according to ASTM C496[13]. The average value of three test specimens was taken.

***Flexural tensile strength***

Flexural strength test was performed on prisms (400*100*100) mm. according to ASTM C78[14]. The average value of three test specimens was taken.

***Weight loss***

At the end of the 28-day curing period for concrete specimens used in the sulfuric acid test program, the specimens were oven dried at (105˚C) until constant weight, cooled at room temperature, weighed using an electronic scale (accuracy of ± 0.1 g) and then immersed into the sulfuric acid and nitric acid bath with concentration of (1.0) % for each acid. Measurements were performed after (40, 50 and 60) days of sulfuric acid and nitric acid immersion; at each age the specimens were removed from the acid solution carefully and oven dried at (105˚C) until constant weight. The specimens were cooled at room temp-erature and weighed. The percentage of weight loss at each age was calculated using equation (5), as follows[15]:

Weight loss (%) = $[\frac{M1-M2}{M1}]\ x\ 100$................(5)

Where:

M1 is the specimen's weight before immersion, and

M2 is the specimen's weight after immersion.

***Curing regimes***

The curing of the concrete specimens was divided into two categories:

***Acidic rain***

The cube specimens, which were used to study the effect of acidic rain on (RPC), were exposed to acidic solutions for (48) hours after (24) hours from demolding, after (3 and 7) days curing in hot water at (60˚C)[11]. The specimens were then kept in normal curing at (23˚C and relative humidity 100% ) until testing at (28) days. Therefore, number of tested specimens = 24.

***Durability***

The specimens used to study the durability properties of (RPC) were treated in hot water at (60˚C)[11] for (7) days, then specimens were kept in normal curing at (23˚C and relative humidity 100% ) for (28) days, then they were immersed in acidic solutions for (40, 50, and 60) days, then they were tested. Therefore, number of tested specimens = 42, and the total numbers of the tested specimens in this investigation are =66.

## RESULTS and DISCUSSION

Results of the existing investigation were tabulated in Tables (8 to 12).

**Table 9.Compressive strength results for studying durability**

| Age | Compressive strength for Control mix (MPa) | Compressive strength for (1.0%) Sulfuric acid (MPa) | Compressive strength for (1.0%) Nitric acid (MPa) | Reduction in strength for (1.0%) Sulfuric acid (%) | Reduction in strength for (1.0%) Nitric acid (%) |
|---|---|---|---|---|---|
| 40 | 100.3 | 95.1 | 78.9 | 5.1 | 21.3 |
| 50 | 103.2 | 97.5 | 80.5 | 5.5 | 21.9 |
| 60 | 108.0 | 101.2 | 83.5 | 6.2 | 22.6 |

The following parameters may be discussed:

***Effect of acidic rain on the compressive strength of RPC***

The compressive strength development at (28) days and percentage of reduction in compressive strength, which was calc-ulated by equation (4), were listed in Table (8), discuss the comparison between control mix and (1.0)% of Sulfuric and Nitric acids respectively. Results demon-strated that concrete specimens which are exposed to acidic solutions after (24) hours from demolding exhibited a decrease in compressive strength ***more than*** those specimens exposed to acidic solutions after (3) and (7) days curing. This is because of the hydration of cement doesn't completed and the concrete does not have enough strength to stand acidic rain. On the other hand, it can be seen that the decrease in compressive strength for specimen immersed in Nitric acid was ***greater than*** specimen immersed in Sulfuric acid. This is due to Nitric acid affect the specimens more than Sulfuric acid.

**Table10. Splitting tensile strength results**

| Mix | Splitting tensile strength (MPa) |
|---|---|
| Control mix | 7.0 |
| (1.0)% Sulfuric acid | 5.8 |
| (1.0)% Nitric acid | 5.2 |
| Mix | Splitting tensile strength (MPa) |

***Effect of acidic solutions on the durability of RPC***

Effects of acidic solution on concrete durability may be discussed as follows:

***Compressive strength***

The compressive strength after (40, 50, 60) days exposure to acidic solutions and percentage of reduction of compressive strength which calculated by equation (4) are presented in Table (9). Results demonstrates that concrete specimens which are exposed to Nitric acid exhibits a reduction in compressive strength ***more than*** specimens exposed to Sulfuric acid in comparison with control mix. This is due to that Nitric acid affect the specimens more than Sulfuric acid.

***Splitting tensile strength***

The splitting tensile strength was determined after (40) days exposure to acidic solutions. The test results of the splitting tensile strength are reported in Table (10). The results indicates that concrete specimens which are exposed to nitric acid exhibits a reduction in flexural strength ***more than*** specimens exposed to sulfuric acid comparing with control mix. It is clear that the loss in splitting tensile strength for (1.0)% sulfuric acid and (1.0)% nitric acid was (17.1 and 25.7) % respectively. This is because of the influence of Nitric acid on specimens is more than Sulfuric acid.

***Flexural tensile strength***

The flexural strength was determined at (40) days age, and the test results are presented in Table (11). Test results indicated that concrete specimens which are exposed to nitric acid exhibits a reduction in flexural strength ***more than*** specimens exposed to sulfuric acid in comparison with control mix. It is clear that, the loss in flexural strength for (1.0)% of sulfuric and nitric acids was (13.3 and 25.0 %) respectively. This is due to that Nitric acid affect the on specimens more than sulfuric acid.

**Table 11. Flexural strength results**

| Mix | Flexural strength (MPa) |
|---|---|
| Control mix | 12.0 |
| (1.0)% Sulfuric | 10.4 |
| (1.0)%Nitric acid | 9.0 |

## Weight loss

Results of weight loss were fixed in Table (12). These results demonstrates that concrete specimens which are exposed to Nitric acid exhibits loss in weight ***less than*** specimens exposed to Sulfuric acid which calculated by equation (5), and the loss increases with the increasing in time of exposure to acidic solutions. This is because of Sulfuric acid causes corrosion in surface of specimens more than Nitric acid which leads to a reduction in weight of specimens.

**Table12. Results of loss in weight**

| Age (Days) | Loss in weight of(1.0%) Sulfuric acid (%) | Loss in weight of (1.0%) Nitric acid (%) |
|---|---|---|
| 40 | 1.94 | 0.43 |
| 50 | 2.59 | 0.87 |
| 60 | 2.69 | 1.32 |

## CONCLUSIONS

Depending on the results of this investigation, the following conclusions can be drawn:

1. Resistance of reactive powder concrete to Sulfuric acid was more than its resistance to Nitric acid.
2. Concrete specimens which are exposed to acidic solutions after (24) hours from cast exhibits a decrease in compressive strength ***more than*** those specimens exposed to acidic solutions after (3) and (7) days exposure. On the other hand, the decrease in compressive strength for specimen immersed in Nitric acid was ***greater than*** specimen immersed in Sulfuric acid in comparison with control mix.
3. Concrete specimens which are exposed to Nitric acid exhibits a reduction in compressive strength ***more than*** specimens exposed to Sulfuric acid in comparison with control mix.
4. Concrete specimens which are exposed to Nitric acid exhibits a reduction in flexural strength ***more than*** specimens exposed to Sulfuric acid in comparing with control mix.
5. Concrete specimens which are exposed to Nitric acid exhibits a reduction in flexural strength ***more than*** specimens exposed to Sulfuric acid in comparison with control mix.
6. Concrete specimens which are exposed to Nitric acid exhibits loss in weight ***less than*** specimens exposed to Sulfuric acid, and the weight loss increases with the increasing in **the exposure time of the acidic solutions.**

## REFERENCES

1. K. Maroliya and D. Modhera, "A Comparative Study of Reactive Powder Concrete Containing Steel Fibers And Recron 3S Fibers", National Institute of Technology, Gujarat, India, pp. 83-89, 2010.

2. E. Beddoe, "Modeling acid attack on concrete: Part I. The essential mechanisms", Cement and Concrete Research 35, pp.2333-2339, 2005.

3. M.T. Bassuoni and M.L. Nehdi, "Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction", Cement and Concrete Research 37, pp.1070-1084, 2007.

4. Tsutomu Kanazu, Takuro Matsumura, Tatsuo Nishiuchi, and Takeshi Yamamoto, "Effect of Simulated Acid Rain Deterioration of Concrete", Abiko city, Japan, pp. 1481-1486, 2001.

5. J. Zhou, X. Chenand Sh. Chen, "Durability and service life prediction of GFRP bars embedded in concrete under acid

environment", Nuclear Engineering and Design 241, pp.4095-4102, 2011.

6. Iraqi standard specification "Portland cement", No.5,1984.

7.British Standard Institution" Aggre-gates" from Natural Source for Concrete ", BS: 882:1992.

8. ASTM C 117,"Standard Test for Materials Finer than No. 200 (0.075 mm.) Sieve in mineral Aggregates by washing", American Society for Testing and Materials, Philadelphia, United States, 1995.

9. ASTM C192,"Standard Test Method for Making and Curing Concrete Test Specimens for Strength in the Laboratory", American Society for Testing and Materials, Philadelphia, United States, 2002.

10. ASTM C 1437,"Standard Test Method for Flow of Hydraulic Cement Mortar", American Society for Testing and Materials, Philadelphia, United States, 2001.

11. Mohameed Seffo, Nadia Salim Ismaeel, Ali hussain Ali, “Influence of curing regimes on the compressive strength of RPC used in rigid pavements”, AL-Taqani Journal, Vol. 25, No. 3, pp.56-68, 2012.

12. British Standard Institution "Method of Testing Hardened Concrete for Other Strength", B.S. : 1881: Part 116: 1983.

13. ASTM C496,"Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens", Philadelphia, United States, 1990.

14. ASTM C78,"Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Third-Point Loading)", American Society for Testing and Materials, Philadelphia, United States, 1994.

15. E. Hewayde, M. L. Nehdi, E. Allouche, and G. Nakhla, "Using concrete admixtures for sulfuric acid resistance", Construction Materials, issue CM1, p. 28, 2007.