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Crack Propagation in Cement Mortar Exposed to External Sulfate Attack

Abstract- This study displays experimental investigation to find out the effect of the external sulfate attack on crack propagation in cement mortar cubes exposed to two sulfate solutions. For this purpose, five mixes of mortar are designed to cast 90 cubes (18 cubes of each mix) and two sulfate solutions (magnesium sulfate $MgSO_4$ and sodium sulfate Na_2SO_4), each of 34000 p.p.m SO_4^{-2} concentration are prepared. The cubes are evenly distributed in each of the solutions and in tap water as well. The testing technique is carried out compressive strength and Ultrasonic Pulse Velocity (UPV) tests simultaneously to specify the stress/strength ratio at which cracks propagate. The tests are carried out after 56 and 150 days of exposing to sulfate solutions. The results show that crack propagation takes place in specimens exposed to sulfate solutions at stress/strength ratios higher than those which are kept in tap water. The main conclusion, according to this study results, is that sulfate particles delay the propagation of cracks in cement mortar cubes.

Keywords- Crack propagation, sulfate attack, stress/strength ratio.

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1. Introduction

Sulfate attack has many types; Ettringite formation, thomosite formation, magnesium sulfate attack and physical sulfate attack (PSA) —a subset of physical salt attack involving Sodium Sulfate [1]. The most common explanation to the deterioration caused by the sulfate attack is that sulfate attack causes expansion resulted from the formation of ettringite and gypsum. However, most, if not all reliable concrete references recognize the attack of magnesium sulfate as the most severe attack. Besides, some concrete references talk about the physical effect (not chemical).

The initiation and propagation of cracking in concrete and other cementitious materials is a governing mechanism for many physical and mechanical material properties [2].

In concrete which is not subjected to any attack, the previous experimental results showed that microcracks initiation takes place at a stress-strength ratio ranging between 0.15 and 0.44 (rather than at a specific value) [3].

Microcracks already exist in concrete at the interface between aggregate and hydrated cement paste even prior to the application of load. These cracks remain stable and do not grow under stress up to 30 percent of the ultimate strength [4].

However, when concrete exposed to sulfate solution of high concentration, its physical and mechanical properties will be changed. This change may include crack initiation and propagation. Cracks in concrete are macro and micro, the former is noticeable by naked eyes, while the latter is not.

Non- destructive test, specifically, the ultrasonic pulse velocity device is used (in this research) to specify the point at which the velocity starts to decrease continuously with loading increment till failure. This point is considered to be the initiation of crack propagation (this is the concept of this research). The UPV is changing with the load increment or in other words, with stress-strength ratio. The change in UPV gives a notion about the crack behavior.A comparison can be done between the UPV through specimens in tap water and specimens in sulfate solution(s) to find out the effect of sulfate compounds on crack behavior in hydraulic Portland cement mortar.

2. The Significance of Research

This research aims to find out the effect of the external sulfate attack on crack initiation and propagation in mortar. This aim needs answers to the following questions:

Does external sulfate attack change the stress-strength ratio at which the crack starts to propagate?

Does external sulfate attack change the behavior of crack propagation?

Is the effect of magnesium sulfate similar to that of sodium sulfate on crack initiation and propagation?

3. Experimental Work

The experimental work of this study consists of:

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1- Casting mortar cubes (50mm side size) of five mixes, total number of cubes are 90. The materials used are, Ordinary Portland Cement in one mix and Sulfate Resistant Cement in four mixes and river sand type M (the chemical analysis and properties of the materials are listed in the appendix). Mixing is done manually and compaction is done by tamping according to ASTM 109-87 [5]. Table 1 shows the cement type used in each of the five mixes, mix proportion and number of cubes. Mix 2 and 3 of the similar W/C ratio, which is 0.485, this ratio is specified in ASTM 1012 (the specification to test the external sulfate attack) [6]. Mix 1 is a 0.35 W/C ratio, which is low ratio and the mix needs more physical work than that of the standard compaction, so the mix is porous and allows to sulfate solution to penetrate easily into the cube body. Mixes 4 and 5 of W/C ratios 0.55 and 0.65 respectively, are to get different strengths.

2- Preparing $MgSO_4$ solution and Na_2SO_4 solution, each of high SO_4^{-2} concentration (34000 ppm). The salt compounds used are $MgSO_4.7H_2O$, its molecular weight is a 246gm / mole and Na_2SO_4, its molecular weight is 142gm/mole.

A- The quantity of $MgSO_4$. $7H_2O$ dissolved in distilled water to produce a solution of (34000 ppm SO_4^{-2}) is: 87.125gm/litter (the mass number of the radical SO_4^{-2} is 96, so it represents 0.39 of $MgSO_4.7H_2O$ mass number, so 0.39*87.125 gm=34 gm, which gives a solution of 34000 ppm when dissolved in one liter of distilled water).

B. The quantity of Na_2SO_4 dissolved in distilled water to produce a solution of (34000 ppm SO_4^{-2}) is: 50.291 gm/liter.

The volume of each solution is 3.5 times the total volume of the specimens (according to ASTM 1012, Note 2) [6]. {5 mixes*6 cubes of each mix* cube volume $(5cm)^3$}*3.5= 13125cm^3= 13.125 litter.

Note that the concentration of SO_4^{-2} is very severe according to ACI 318-11 classification [7], that it is much greater than 10000 p, p, m (10000 ppm is considered very severe) [ditto].

3. Curing all the cubes for 28 days in tap water.

4. 6 cubes of each mix are put in $MgSO_4$ solution, the same is in Na_2SO_4solution and the rest is kept in tap water for another 150 days.

4. Test Method

Testing cubes compressive strength by using an electrical machine of 200KN capacity. Measurements are taken to reach the failure with no less than 20 and no more than 80 seconds, according to ASTM C 109. A PUNDIT of sensitivity 0.01 microsecond is used with transducers of frequency 200KH to suit the specimen dimension (50 mm) according to BS 4408: Part 5:1974 [8].

The two tests are carried out on each sample (cube) simultaneously; compressive test and ultrasonic pulse velocity test (as it is shown in the picture below). The ultrasonic pulse velocity test is one of the indirect methods that have been used to detect and observe microcracking in concrete [9]. This is done by recording the UPV with each increment of 1.2 MPa in compression loading. Then, when the ultrasonic velocity starts to decrease continuously with compression, that very point is considered (in this research) as the inflection point, which represents (according to this research) the initiation of crack propagation.

5. Results and Discussion

Generally, the initiation of crack propagation of all mixes in tap water after 74 days locates in the range (0.166-0.52) stress-strength ratio and in the range (0.16-0.52) stress/strength ratio after 150 days.

The crack propagation of all the mixes in $MgSO_4$solution after 56 days locates in the range (0.33-0.7) stress-strength ratio and (0.28-0.75) stress-strength ratio after 150 days.

Table 1: the mixes, cement types and proportion of each mix, besides the number of cubes

Mix Name	Cement Type	W/C Ratio	C/S Ratio	No. of cubes	No. of cubes in $MgSO_4$ solution	No. of cubes in Na_2SO_4 solution	No. of cubes in tap water
1	S.R.P.C	0.35	1:2	18	6	6	6
2	S.R.P.C	0.485	1:3	18	6	6	6
3	O.P.C	0.485	1:3	18	6	6	6
4	S.R.P.C	0.55	1:4	18	6	6	6
5	S.R.P.C	0.65	1:6	18	6	6	6

The crack propagation of all the mixes in $MgSO_4$solution after 56 days locates in the range (0.33-0.7) strees-strength ratio and (0.28-0.75) stress-strength ratio after 150 days.

The crack propagation of all the mixes inNa_2SO_4 solution after 56 days locates in the range (0.16-0.75) stress-strength ratio and (0.14-0.74) stress-strength ratio after 150 days. Table 2 shows the strength of each mix in each of the two sulfate solutions and in tap water, as well as it shows the stress- strength ratio at which the crack propagates.

Mix1: the UPV through the specimens in tap water for (84) days has two stages, in the 1st one, it is constant with loading, while in the 2nd, it decreases with load increment. In sulfate solutions for (56) days, the UPV has three stages as it is shown in Table 3. The UPV through the specimens in tap water for (178) days as well as in sulfate solutions for (150)days, has two recognized stages, in the 1st one, it is constant with loading, while in the 2nd, it decreases with load increment, as it is shown in Table 4. Mix 2: the UPV through the specimens in tap water for both ages (84 and 178) days has two stages, in the 1st one, it is constant with loading, while in the 2nd, it decreases with load increment. In sulfate solutions for both (56 and 150) days, the UPV has three stages as it is shown in Table 5 and 6.

Mix 3: the UPV through the specimens in tap water for both (84 and 178) days,as well as in sulfate solutions for both (56 and 150) days, has two stages, in the 1st one, it is constant with loading, while in the 2nd, it decreases with load increment, as it is shown in Table 7 and 8. Mix 4:the UPV through the specimens in tap water for both (84 and 178) days has two stages, in the 1st one, it is steady with loading, while in the 2nd, it decreases with load increment, in sulfate solutions for (56 and 150) days as well, as it is shown in Table 9) and 10.

Mix 5: the UPV through the specimens in tap water for both (84 and 178) days has two stages, in the 1st one, it is constant with loading, while in the 2nd, it decreases with load increment, in sulfate solutions for both (56 and 150) days as well, as it is shown in Table 11) and 12.

The results clearly show that sulfate solutions affect the strength, the density (that the UPV is a function of the density) and the stress/strength ratio where the crack starts to propagate in all the specimens. The effect of sulfate solutions on crack propagation (the scope of this research) is that they (sulfate solutions) delay the initiation of crack propagation and change the behavior of cracking. The sulfate compounds ions and/or the compounds resulted from the reaction(s) between sulfate compounds ions and the other compounds or ions in the media (the body of the mortar) prevent the initiation of crack propagation. This is due to the additional surface area of the sulfate compounds or their products which leads to the need to an additional energy to cause crack propagation [10].

With regard to the behavior of cracking, the results show that the specimens in tap water have two phases; constant UPV with loading then the UPV starts and keeps decreasing till failure. Most of the results of the specimens in sulfate solutions show three phases; the 1st phase is that the UPV decreases with the start of loading. This might be due to the internal stresses resulted from the sulfate attack. The values of these stresses are added to the mechanical stress. The 2nd phase is that the UPV stays as it is with loading. The 3rd and last phase is that the UPV decreases continuously with loading till failure.

Table 2: The strength and density of each mix in each of the two sulfate solutions and in tap water and the stress-strength ratio at which the crack propagates

Solutions And T.W	Mix	Strength (MPa),56 (day)	Density Kg/m3 56(day)	(st./strength) ratio	Strength (MPa),150 (day)	Density Kg/m3 150(day)	(st./strength) ratio
$MgSO_4$	1	15.6	2.17	0.53	13.2	2.17	0.27
	2	25.2	2.22	0.62	28.8	2.25	0.75
	3	12	2.2	0.7	25.2	2.22	0.66
	4	12	2.17	0.3	16.8	2.2	0.28
	5	7.2		0.33	7.2	2.18	0.33
Na_2SO_4	1	13.2	2.16	0.75	14.4	2.19	0.25
	2	26.4	2.2	0.68	32.4	2.27	0.74
	3	28.8	2.23	0.75	31.2	2.24	0.5
	4	12	2.22	0.3	16.8	2.22	0.5
	5	7.2		0.166	8.4	2.19	0.14
T.W	1	12	2.04	0.4	13.2	2.2	0.35
	2	27.6	2.21	0.52	27.6	2.24	0.52
	3	28.8	2.24	0.41	28.8	2.24	0.41
	4	8.4	2.06	0.42	14.4	2.2	0.41
	5	7.2	2.1	0.166	7.2	2.19	0.16

Table 3: UPV and compression tests' readings for mix 1 after 56 days in sulfate solutions and 84 days in tap water

Stress (Mpa) Mix1	Sodium sulfate		Magnesium sulfate		T.W (84)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.82	0	3.82	0	3.65	0
1.2	3.82	0.083	3.82	0.077	3.65	0.1
2.4	3.7	0.16	3.82	0.154	3.65	0.2
3.6	3.7	0.25	3.82	0.23	3.65	0.3
4.8	3.7	0.33	3.82	0.3	3.63	0.4
6	3.7	0.416	3.79	0.38	3.6	0.5
7.2	3.7	0.5	3.79	0.46	3.57	0.6
8.4	3.7	0.58	3.79	0.53	3.55	0.7
9.6	3.7	0.66	3.76	0.61	3.5	0.8
10.8	3.7	0.75	3.74	0.69	3.5	0.9
12	3.58	0.83	3.71	0.77	3.12	1
13.2	3.46	0.93	3.56	0.84		
14.4	2.08	1	3.06	0.92		
15.6			2.7	1		

Table 4: UPV and compression tests' readings for mix 1 after 150 days in sulfate solutions and 178 days in tap water

Stress (MPa) Mix 1	Sodium sulfate		Magnesium sulfate		T.W (178)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.49	0	3	0	3.65	0
1.2	3.49	0.083	2.7	0.09	3.65	0.09
2.4	3.49	0.16	2.7	0.18	3.65	0.18
3.6	3.49	0.25	2.7	0.27	3.65	0.27
4.8	3.47	0.33	2.65	0.35	3.63	0.35
6	3.44	0.41	2.67	0.45	3.62	0.45
7.2	3.42	0.5	2.6	0.54	3.57	0.54
8.4	3.35	0.58	2.55	0.63	3.53	0.63
9.6	3.18	0.66	2.5	0.72	3.5	0.72

10.8	2.97	0.75	2.1	0.81	3.4	0.81
12	2.74	0.83	1.9	0.91	3.2	0.91
13.2	1.9	0.91	1.7	1	3	1
14.4	1.5	1				

Table 5: UPV and compression test readings for mix 2 after 56 days in sulfate solutions and 84 days in tap water

Stress (MPa) mix 2	Sodium sulfate		Magnesium sulfate		T.W (84)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	4.16	0	4.3	0	4.09	0
1.2	4.16	0.045	4.33	0.047	4.09	0.043
2.4	4.16	0.09	4.33	0.095	4.09	0.086
3.6	4.16	0.136	4.26	0.14	4.06	0.13
4.8	4.16	0.18	4.26	0.19	4	0.174
6	4.16	0.227	4.26	0.23	4.09	0.21
7.2	4.12	0.27	4.26	0.28	4.09	0.26
8.4	4.12	0.318	4.26	0.33	4.09	0.3
9.6	4.12	0.363	4.26	0.38	4.09	0.35
10.8	4.09	0.41	4.26	0.43	4.09	0.39
12	4.09	0.45	4.26	0.47	4.09	0.43
13.2	4.09	0.5	4.26	0.52	4.06	0.48
14.4	4.09	0.545	4.26	0.57	4.06	0.52
15.6	4.09	0.59	4.26	0.62	4.03	0.56
16.8	4.06	0.636	4.19	0.66	4	0.6
18	4.06	0.68	4.12	0.71	3.97	0.65
19.2	4.03	0.727	4	0.76	3.87	0.69
20.4	4	0.77	3.88	0.81	3.84	0.74
21.6	3.79	0.818	3.61	0.85	3.47	0.78
22.8	3.77	0.86	3.25	0.9	3.1	0.82
24	3.5	0.9	2.73	0.95	2.9	0.87
25.2	2.94	0.95	1.44	1	2.7	0.91
26.4	2.3	1			2.4	0.95
27.6					2	1

Table 6: UPV and compression test readings for mix 2 after 150 days in sulfate solutions and 84 days in tap water

Stress (Mpa) mix 2	Sodium sulfate		MA		T.W (178)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	4.38	0	4.06	0	4.09	0
1.2	4.5	0.03	4.2	0.04	4.09	0.043
2.4	4.54	0.07	4.2	0.08	4.09	0.086
3.6	4.54	0.11	4.16	0.12	4.06	0.13
4.8	4.54	0.14	4.2	0.16	4	0.174
6	4.54	0.18	4.2	0.2	4.09	0.21
7.2	4.54	0.22	4.2	0.25	4.09	0.26
8.4	4.5	0.26	4.2	0.29	4.09	0.3
9.6	4.5	0.29	4.2	0.33	4.09	0.35
10.8	4.5	0.33	4.16	0.37	4.09	0.39
12	4.5	0.37	4.16	0.41	4.09	0.43
13.2	4.5	0.4	4.16	0.46	4.06	0.48
14.4	4.5	0.44	4.16	0.5	4.06	0.52
15.6	4.5	0.48	4.16	0.54	4.03	0.56
16.8	4.5	0.51	4.13	0.58	4	0.6
18	4.5	0.55	4.13	0.62	3.97	0.65
19.2	4.46	0.59	4.13	0.66	3.87	0.69
20.4	4.46	0.63	4.09	0.7	3.84	0.74
21.6	4.46	0.66	4.09	0.75	3.47	0.78
22.8	4.42	0.7	4.06	0.79	3.1	0.82
24	4.42	0.74	4	0.83	2.9	0.87
25.2	4.38	0.77	3.9	0.87	2.7	0.91
26.4	4.27	0.81	3.84	0.91	2.4	0.95
27.6	4	0.85	3.2	0.96	2	1
28.8	3.93	0.88	2.2	1		
30	3.62	0.92				
31.2	3.2	0.96				
32.4	2	1				

Table 7: UPV and compression test readings for mix 3 after 56 days in sulfate solutions and 84 days in tap water

Stress (Mpa) mix 3	Sodium sulfate		MA		T.W (84)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	4.4	0	4.2	0	4	0
1.2	4.4	0.04	4.2	0.1	4	0.04
2.4	4.4	0.08	4.22	0.2	4	0.08
3.6	4.4	0.12	4.22	0.3	4	0.12
4.8	4.4	0.16	4.22	0.4	4	0.16
6	4.4	0.2	4.22	0.5	4	0.2
7.2	4.4	0.25	4.22	0.6	3.9	0.25
8.4	4.4	0.29	4.22	0.7	3.9	0.29
9.6	4.4	0.33	4.16	0.8	3.9	0.33
10.8	4.4	0.37	3.85	0.9	3.9	0.37
12	4.4	0.41	2.08	1	3.9	0.41
13.4	4.4	0.46			3.8	0.46
14.4	4.4	0.5			3.7	0.5
15.6	4.4	0.54			3.5	0.54
16.8	4.4	0.58			3.4	0.58
18	4.4	0.62			3.3	0.62
19.2	4.4	0.66			3.2	0.66
20.4	4.4	0.7			3.05	0.7
21.6	4.4	0.75			2.8	0.75
22.8	4.3	0.79			2.6	0.79
24	4.16	0.83			2.3	0.83
25.2	4.03	0.87			2	0.87
26.4	3.66	0.91			1.6	0.91
27.6	3.64	0.96			1.5	0.96
28.8	3.2	1			1.2	1

Table 8: UPV and compression test readings for mix 3 after 150 days in sulfate solutions and 84 days in tap water

Stress (Mpa) mix 3	Sodium sulfate		MA		T.W (178)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	4.27	0	3.87	0	4	0
1.2	4.03	0.03	3.84	0.04	4	0.04
2.4	4.03	0.06	3.87	0.08	4	0.08
3.6	4.03	0.11	3.87	0.14	4	0.12
4.8	4.03	0.15	3.87	0.19	4	0.16
6	4.03	0.19	3.87	0.24	4	0.2
7.2	4.03	0.23	3.9	0.28	3.9	0.25
8.4	4.27	0.27	3.93	0.33	3.9	0.29
9.6	4.02	0.3	3.93	0.38	3.9	0.33
10.8	4.16	0.34	3.96	0.42	3.9	0.37
12	4.16	0.38	3.96	0.47	3.9	0.41
13.4	4.16	0.42	3.96	0.52	3.8	0.46
14.4	4.16	0.46	3.93	0.57	3.7	0.5
15.6	4.16	0.5	3.93	0.62	3.5	0.54
16.8	4	0.53	4	0.66	3.4	0.58
18	4	0.57	3.9	0.71	3.3	0.62
19.2	3.8	0.61	3.7	0.76	3.2	0.66
20.4	3.7	0.65	3.35	0.8	3.05	0.7
21.6	3.6	0.69	3.12	0.85	2.8	0.75
22.8	3.5	0.73	2.85	0.9	2.6	0.79
24	3.3	0.77	2.28	0.95	2.3	0.83
25.2	3	0.8	1.78	1	2	0.87
26.4	2.6	0.84			1.6	0.91
27.6	2.1	0.88			1.5	0.96
28.8	1.7	0.92			1.2	1
30	1.3	0.96				
31.2	0.93	1				

Table 9: UPV and compression tests readings for mix 4 after 56 days in sulfate solutions and 84 days in tap water

Stress	Sodium sulfate	Magnesium sulfate	T.W (84)

(Mpa) mix 4	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.56	0	3.79	0	3.05	0
1.2	3.56	0.1	3.74	0.1	3.05	0.14
2.4	3.56	0.2	3.74	0.2	3	0.28
3.6	3.56	0.3	3.74	0.3	3	0.42
4.8	3.51	0.4	3.71	0.4	2.7	0.57
6	3.49	0.5	3.56	0.5	2.6	0.71
7.2	3.4	0.6	3.35	0.6	2.4	0.85
8.4	3.35	0.7	3.07	0.7	2.1	1
9.6	3.27	0.8	2.88	0.8		
10.8	3.7	0.9	2.16	0.9		
12	1.92	1	1.9	1		

Table 10: UPV and compression tests readings for mix 4 after 150 days in sulfate solutions and 84 days in tap water

Stress (Mpa) mix 4	Sodium sulfate		MA		T.W (150)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.96	0	3.5	0	3.6	0
1.2	4	0.07	3.52	0.07	3.6	0.08
2.4	4	0.14	3.52	0.14	3.6	0.16
3.6	3.96	0.21	3.52	0.21	3.55	0.25
4.8	3.93	0.28	3.52	0.28	3.55	0.33
6	3.93	0.35	3.5	0.35	3.55	0.41
7.2	3.93	0.42	3.48	0.42	3.5	0.5
8.4	3.93	0.5	3.45	0.5	3.3	0.58
9.6	3.9	0.57	3.42	0.57	3	0.66
10.8	3.84	0.64	3.33	0.64	2.7	0.75
12	3.81	0.71	3.2	0.71	2.4	0.83
13.2	3.73	0.78	2.97	0.78	2.3	0.92
14.4	3.54	0.85	2.53	0.85	1.9	1
15.6	3.14	0.93	1.7	0.93		
16.8	2	1	1.4	1		

Table 11: UPV and compression test readings for mix 5 after 56 days in sulfate solutions and 84 days in tap water

Stress (Mpa) mix 5	Sodium sulfate		MA		T.W (84)	
	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.46	0	3.15	0	2.92	0
1.2	3.46	0.166	3.15	0.166	2.92	0.166
2.4	3.1	0.33	3.15	0.33	2.68	0.33
3.6	2.88	0.5	3.05	0.5	2.5	0.5
4.8	1.62	0.66	2.73	0.66	2.3	0.66
6	1.3	0.83	2.47	0.83	1.7	0.83
7.2	0.92	1	1.67	1	1	1

Table 12: UPV and compression test readings for mix 5 after 150 days in sulfate solutions and 178 days in tap water

Stress	Sodium sulfate	MA	T.W (178)

(Mpa) mix 5	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength	UPV (km/s)	Stress/ Strength
0	3.42	0	3.31	0	3.2	0
1.2	3.42	0.14	3.35	0.16	3.2	0.16
2.4	3.4	0.28	3.31	0.33	3.1	0.33
3.6	3.35	0.43	3	0.5	3	0.5
4.8	3.26	0.57	2.2	0.66	2.3	0.66
6	3.08	0.71	1.7	0.83	1.7	0.83
7.2	2.8	0.85	1.1	1	1	1
8.4	2.17	1				

Conclusions

1- The initiation of crack propagation in cement mortar specimens exposed to sulfate solutions takes place at a stress-strength ratio higher than that of specimens in tap water.
2- Most results show that sulfate solution changes the behavior of cracking, i.e. three phases (stages) till failure not two phases as it is the case of specimens in tap water.
2- It is complex to a certain extent discriminating between sodium and magnesium sulfate's effects on crack propagation. In other words, with regard to the initiation and crack propagation, no clear difference between the two mentioned sulfate's effects is observed according to this research results.

References

[1] R.D. Hooton, "Physical Salt Attack on Concrete, Part 2," ACI Spring, Convention March 18–21, Dallas, TX, 2012.

[2] B. Pereira, G. Fischer, and J.A.O. Barros, "Image-Based Detection and Analysis of Crack Propagation in Cementitious Composites," 2007.

[3] Y. H. Loo, Propagation of Microcracks in Concrete under Uniaxial Compression, Magazine of Concrete Research, Vol. 47, No. 170, 83-91, 1995.

[4] A.M. Neville, "Concrete Technology," 2nd edition, pp 112-113, 2010.

[5] American Society for Testing and Materials ASTM C109-87 "Standard Test Method for Compressive Strength of Hydraulic Cement Mortar," Vol. 04. 02, pp. 58-60,

[6] American Society for Testing and Materials ASTM C1012-87 "Standard Test Method for Length change of Hydraulic Cement Mortars Exposed to Sulfate Solution," Vol. 04.02, pp. 464-467.

[7] ACI 318-11, "Building Code Requirements for Structural Concrete and Commentary," Chapter 4, Article 4.5Alternative cementitious materials for sulfate exposure, 2011.

[8] BS4408: Part 5 "Measurement of the Velocity of Ultrasonic Pulses in Concrete," British Standards Institution, 2 Park Street, London W1A2BS, pp. 1-19, 1974.

[9] Y.H. LOO. "A New Method for Microcrack Evaluation in Concrete under Compression, Materials and Structures," Vol. 25, pp 573-578, 1992.

[10] S. Mindess and J.F. Young, "Concrete," 1st edition, pp 356, 1981.

Appendix

Chemical analysis and physical properties of (O.P.C) used in this study

No.	Chemical components	%	Chemical compound	%
1	SiO_2	21.5	C_3S	49.91
2	Fe_2O_3	3.31	C_2S	24.25
3	Al_2O_3	4.85	C_3A	7.26
4	CaO	63.76	C_4AF	10.06
5	MgO	2.37	Fineness test (cm^2/gm)	2670
6	SO_3	1.87	Compressive strength (N/mm^2)	
7	Free CaO	0.86	At 3 days	17.4
8	I.R	0.27	At 7 days	28.4
9	L.O.I	1.45		

Chemical analysis and physical properties of (S.R.P.C) used in this study

No.	Chemical components	%	Chemical compound	%
1	SiO_2	21.73	C_3S	39.75
2	Fe_2O_3	5.12	C_2S	32.57
3	Al_2O_3	4.45	C_3A	3.17
4	CaO	62.48	C_4AF	15.56
5	MgO	1.93	Fineness test (cm^2/gm)	2670
6	SO_3	1.86	Compressive strength (N/mm^2)	
7	Free CaO	1.68	At 3 days	17
8	I.R	0.37	At 7 days	25

9	L.O.I	1.75

The properties of the sand used in this study

Sieve size	Percent passing	
	Sand grading	IQS 45
10.0	100	100
4.75	91	90-100
2.36	70	60-95
1.18	44	30-70
0.6	26	15-34
0.3	12	5-20
0.15	4	0-10
0.075	2.3	Max. 5
	Sulfate content SO_3 %	
	0.35	Max. 0.5