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EFFECT OF EXTERNAL SULFATE ATTACK ON MECHANICAL PROPERTIES AND MODELING OF HYBRID FIBER REACTIVE POWDER CONCRETE

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ABSTRACT: - Sulfate attack is a serious factor play important role in the degradation of structural capacity of reinforced concrete structures members especially those members exposure with ground water or sea water. This paper study the effect of external sulfate attack on mechanical properties of hybrid fiber reactive powder concrete (HFRPC) containing (polypropylene fiber and steel fiber) and normal strength concrete (NSC) after specimens have been casted, directly and continuously cured, and full immersed in saline solution containing magnesium sulfate, the concentration of the sulfate ion used in this study was equal to upper limit defined in ACI318M building code (10000 ppm), other specimens have been direct and continuously cured and fully immersed in tap water, prepare 108 cylinder, 36 cube and 36 prism for this purpose. The mechanical properties such as compressive strength, splitting tensile strength (measured splitting resistance and tensile strength), modulus of rupture (measured tensile strength) and modulus of elasticity (measured flexural strength) tests were investigated for HFRPC and NSC at different exposure periods (28, 90 and 180) days. Test results showed continuous development with time in mechanical properties for HFRPC when cured in sulfate water but test results for NSC showed significant deterioration when cured in sulfate water. An analytical equations have been derived by curve fitting to derive the relationships between the mechanical properties and compressive strength for HFRPC and NSC and its validation with ACI predicted. The ACI expression for the mechanical properties may result in underestimation of HFRPC and good accuracy of NSC under tap water and sulfate water curing condition.

Keywords: hybrid fiber reactive powder concrete, normal strength concrete, mechanical properties, tap water, sulfate water, curing, mechanical properties ,cracks, flexural strength, splitting resistance, curve fitting, building code, failure mode.

1. INTRODUCTION

Concrete is the important construction material where used in many structures, the main requirements for successful concrete are high strength and durability. For this reason a large number of researcher that studied the factors affecting on strength and durability of concrete, also for several years the problem of the durability of concrete was an important topic of interest for the engineers in Iraq and Arabian Gulf (1). Durability of reinforced concrete and the problems associated with it are nowadays a matter of considerable concern. It can be defined as the ability of concrete to keep its strength and serviceability conditions without degradation when the structure subjected to different environment conditions during its design life. In general, deterioration of structures takes place due to a number of physical, chemical, or mechanical factors. Impact force is an example of the mechanical factors while saline environment represented by sulfate and chlorides action is the chemical cause of deterioration of reinforced concrete (1). In Iraq deterioration problems of reinforced concrete structures came mainly from extraneous aggressive ions attack represented by sulfates and chlorides in underground water especially in the southern regions of Iraq, and high gypsum sulfates in the soil (2). Still further, the port concrete structures located south Iraq in Basrah city is one of the world's most aggressive environments to concrete. Many researcher study effect of aggressive environment on durability of reactive powder concrete such as Al-Kadhi (2007) (3) studied the strength of RPC samples that were partially immersed in aggressive water containing high percentage of sulfate and chloride ions after 28 days of moist curing. Mahdi (2009) (2) studied the durability of self-compacted reactive powder concrete (SC-RPC) exposed to harsh environment. There were no decreases in the properties of the SC-RPC due to exposing its samples to partial immersion in saline solution containing high percentages of chloride and sulfate ions. The salts components used were ($CaCl_2.2H2O$, NaCl, and $MgSO_4.7H2O$) up to 360 days, after 28 days of initial curing. Hawi (2014)(4) studied the effect of sulfate attack with external effect on normal strength concrete (NSC) with mix ratio equal to 1: 1.5:3 and cement content 380 kg/m3, all samples initial curing in tap water for 28 days after it has been exposed to a solution of sulfate, three different sulfate solutions used in this study including sodium, magnesium, and calcium at four levels (0%, 2%, 4% and 6%)each for three exposure periods of (60, 90 and 120) days. Notwithstanding this, the mechanical properties of Hybrid Fiber Reactive Powder Concrete (HFRPC) under external attack of sulfate and chloride salts were not adequately addressed in the previous research studies. In present research paper, a mechanical properties tests on HFRPC were conducted with variations of curing time under salt attack. Based on the experimental results, mechanical properties were studied in terms of the compressive strength, splitting tensile strength (measured splitting resistance and tensile strength), modulus of rupture (measured tensile strength) and modulus of elasticity (measured flexural strength). In addition, a mathematical expressions were proposed for simulating above mechanical properties as functions of the concrete compressive strength under salt attack for HFRPC and NSC. Further, theses expressions were compared with ACI building code expressions.

2. EXPERIMENTAL WORK

2.1 Materials Used

The mechanical properties of NSC and HFRPC have been estimated experimentally by using one concrete mix proportion for NSC and other for HFRPC. The design compressive strengths were 25MPa and 100MPa for NSC and HFRPC respectively at the 28-th day.

1. Ordinary Portland cement type (I) was used in this work for HFRPC and NSC Chemical and Physical Properties of Cement Used in this Study as shown in Table(1).
2. Natural sand was used in NSC. Further, fine sand used in HFRPC with maximum particle size of (600) µm. Grading of Fine Aggregate as shown in Table (2).
3. Gravel used only in NSC with maximum particle size of (10) mm the grading of the gravel agree as shown in Table (3).
4. Silica fume used only in HFRPC. Composition and Properties of silica fume as shown in Table (4).
5. Superplasticizer (Glenium51) used only in HFRPC, Glenium 51 complies with (ASTM C494 type a) (8) .Typical Properties of Glenium 51as shown in Table (5).
6. Steel fiber and polypropylene fiber used only in HFRPC, the volume fraction used in this study according to trial mix and previous researches such as (9).Table (6) shows properties of these fibers and Figure (1) shows the sample of this fibers.
7. Tap water was used in curing and mixing of all the concrete samples as well as the control samples.

2.2 Mix Proportions

Table (7) gives mix proportions used in this study depended on the several trial mixes and same previous researches (10, 11, 12 and13). One NSC mix and one mix HFRPC mix.

2.3 Concrete Mixing, Casting and Curing Procedure

Mixing method for NSC included the following steps are first mix all of the coarse and fine aggregate and then cement is added and complete mixing after that the addition of water and mixing continued until obtaining a homogeneous concrete. While mixing method for HFRPC included mixing both fine sand with silica fume and then adding cement and complete mixing. Polypropylene fiber added to dry mix before water after which it is added Superplasticizer to water and add it to the dry mixture with continued mixing and finally added steel fiber to the mixture. The method of mixing for HFRPC have been proposed by the Wille et al. (2011) (14). After 24 hours from casting stage, all the samples (cubes, cylinders and prism) were taken out of the molds, marked and then cured. One of the principal problems of concrete durability is the external attack of sulfate and chloride salts, especially those present in ground water and soil in the southern of Iraq. Salt used to prepare the solution were pure magnesium sulfate ($MgSO_4.7H_2O$) was added up equal to the highest proportion of ACI318-14(15) equal to 10000 ppm, which is the effect in very severe potable water was used as a solvent for magnesium sulfate, added 200 gm $MgSO_4.7H_2O$ for 20L Potable water. Figure (2) show steps to prepare sulfate water and Figure (3) shows sample from sulfate used in this study. After twenty four hours from casting, all samples were demolded and curing in containers in the laboratory, Part of these specimens direct curing and fully immersion in tap water and the second part from specimen direct curing and fully immersion in sulfate water (magnesium sulfate). Similar curing procedure was applied for (NSC) and (HFRPC). Duration curing for specimen used in test material proprieties (28, 90 and 180) days. Figure (4) show basins curing for sulfate used in this study.

2.4 Material Properties Test

In order to study the material property a series of tests were conducted in two type curing ,tap water curing and sulfate water curing such as (compressive strength, splitting tensile strength, modulus of elasticity and modulus of rupture) for HFRPC and NSC at the age of 28 ,90,180 days for both curing. Total number of specimens 36 cubes, 108 cylinders and 36 prisms. Table (8) contains a summary of the material specimens used and Figure (5) shows Specimens under Test.

3. RESULT AND DISCUSSION

3.1 Effect of Curing Type with Exposure Period on Material Properties

Table (9, 10, 11 and12) shows the effect of type of curing and exposure periods in experimental results of mechanical properties for NSC. Results demonstrate specimens cured by water a showed continuous increase in compressive strength. This can be explained by ordinary continuous hydration of binding materials compounds. But the specimens cured by magnesium sulfate showed continuous reduction in compressive strength with time up to 180 days. The results of this work is in agreement with results of the Hawi (4) who noted deterioration in compressive strength for NSC when subjected to magnesium sulfate (MS), compressive strength reach to 24.44 MPa at 120 days when cured in MS a compare with referential compressive strength cured in tap water reach to 30.87MPa. This decrease in compressive strength might be due to (21); the contact of samples with a salt solution, caused the material to deteriorate by stresses resulting from the pressure of salts crystallizing in the pores. Furthermore, the increase in porosity and reduction in strength are due to leaching of lime.

Mishra (22) indicated that the average deterioration of the 40 MPa concrete samples after 365 days exposure to marine environment has been found to be between 20-30% with respect to the concrete cured in normal water for the similar period of exposure. It was explained the strength deterioration of concrete specimens to be due to the attack of sulfate ions which give rise to the formation of expansive light compounds such as ettringite, thaumasite and calcium aluminate hydrate, also due to the leaching out of salts deposited in the voids of concrete. Tables (9, 10, 11 and 12) showed the continuous increase in in experimental results of mechanical properties for HFRPC when curing in tap and sulfate water this improvement could be attributed to the effect of low permeability and ordinary continuous hydration of binding materials compounds. It is of interest to compare results with those obtained by Mahdi (2) who recorded continuous increase in compressive strength of exposure period of 360 days to the saline solution after its 28 days initial curing in tap water. Continuous increase for HFRPC, the reason may be due to the nature of silica fume to improve concrete strength as a pozzolanic material ,which acts as filler material and produces a additional bond material calcium silicate hydrate (CSH) as a result of reaction between silica fume and calcium hydroxide ,the formed CSH fills the capillary pores in cement paste which gives high strength, Many research such as Yousif (23), Hannawayya (24) and Saderkarimi (25) were noted increased silica fume content caused in increased compressive strength for concrete.

3.2Effect of Type of Concrete on Material Properties at Same Curing Condition and Exposure Period

Table (13,14,15 and 16) show effect of type of concrete in tap water curing and sulfate water curing, the results shows that the percentage of increase in experimental results of the mechanical properties between HFRPC and NSC decrease with increase time in tap water but increase with time in sulfate water, also it can be noted the percentage of increasing in sulfate water curing more than tap water curing because of the compressive strength for HFRPC increase continuously with time in sulfate water curing but compressive strength for NSC decrease with time. The continued evolution of the resistance of HFRPC due to few permeability prevents the entry of harmful substances from the surrounding to inside.

4. FAILURE MODES

Figures (6) to (7) showed crack pattern of specimens at failure stage under different test, from these figure it can be noted suddenly failure with larger crack width for specimens containing on NSC when curing in tap water and sulfate water but observed ductile failure with smaller crack width for specimens containing on HFRPC when curing in tap water and sulfate water.

5. MECHANICAL PROPERTIES-COMPRESSIVE STRENGTH RELATIONS AND ITS VALIDATION WITH ACI PREDICTED

An analytical equations have been derived by using software computer program "Kaleida Graph Program"(26) adopted curve fitting technique to derive these relations and its validation with ACI-318M(15) building code predicted as follows;

5.1 Tensile Strength-Compressive Strength Relation

The compressive strength of concrete is important parameter that used in the design different reinforced concrete members and the tensile strength factor is need to know in order to capture crack stage level in concrete members. The resistance to crack which is the most important feature when durability against aggressive environment is considered. The splitting tensile strength and modulus of rupture are used in the present paper in order to measure tensile strength of HFRPC and NSC. The relationships between compressive strength and tensile strength are presented in Figure (9) through Figure (12) for NSC and HFRPC at different curing types and exposure periods. Figures (9) and (10) show comparing experimental results with ACI limits (15)for two type curing and different exposure period for NSC, indicated these comparison experimental results in tap water curing ($F_{sp)exp,t}$ and $F_{r)exp,t}$) approaching to ACI limit but in sulfate water curing ($F_{sp)exp,s}$ and $F_{r)exp,s}$) moving away from ACI limits, or other words, experimental results in sulfate water curing lower than ACI limit. It can be noted from Figures (11) and (12) experimental results for HFRPC in tap water and sulfate water curing significant different with ACI limit usually be higher than ACI limit. From these comparisons above so it can say the equation from ACI code (15) that binds compressive strength with spitting tensile strength and modulus of rupture it can be used for

NSC in tap water curing but cannot used for NSC in sulfate and HFRPC in tap water and sulfate water curing.

5.2 Modulus of Elasticity-Compressive Strength Relation

Figures (13) and (14) demonstrated the compressive strength relationship with modulus of elasticity for NSC and HFRPC at different curing types and exposure periods. Results indicated for NSC experimental results ($E_{c)exp,t}$) more than ACI limit when curing in tap water but lower than ACI limit when curing in sulfate water ($E_{c)exp,s}$) and for HFRPC experimental results more than ACI limit in both curing, these results due to ACI code designer for NSC when curing in tap water. From experimental results derived equations of compressive strength relationship with splitting tensile strength, modulus of elasticity and modulus of rupture. Equations derived from experimental results by using Kaleida Graph Program (26), Table (17) shows equations for NSC and HFRPC when curing in tap water and sulfate water. The mechanical properties of the HFRPC under tap water and Sulfate water curing conditions, the ACI expression results in lower mechanical properties than the experimentally based value and, therefore, lower estimates of the stresses. Further, the mechanical properties of the NSC under tap water and sulfate water curing conditions, the ACI expression results are almost equal the experimentally based value and, therefore, the ACI expressions can be applied for NSC under both curing conditions.

6. CONCLUSION

Based on the above experimental and analytical results for the mechanical properties represented by modulus of elasticity, splitting tensile strength, modulus of rupture and compressive strength presented in this research paper, the following main conclusions are drawn;

1) The mechanical properties are increased continuously with time up to 180 days for hybrid fiber reactive powder concrete (HFRPC) specimens when cured in tap and sulfate water, but increased continuously with time up to 180 days for normal strength concrete (NSC) specimens when cured in tap water and decreased continuously with time up to 180 days when cured in sulfate water.
2) Mechanical properties for HFRPC when cured in tap water were more than sulfate water at same exposure period, the maximum percentage of reduction in sulfate water relative to tap water equal to (10.66, 16.96 ,20.29 and 19.37)% for compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity respectively.
3) Mechanical properties for NSC when cured in tap water were more than sulfate water at same exposure period, the maximum percentage of reduction in sulfate water relative to tap water equal to (52.29, 55.42, 62.12 and 32.80)% for compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity respectively.
4) Significant difference in mechanical properties between NSC and HFRPC when comparison those in tap and sulfate water curing at different exposure period. The maximum percentage of increase for HFRPC relative to NSC for compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity when curing tap water equal to (243.43, 382.66, 303.33 and 97.54)% respectively and in sulfate water equal to (406.19, 621.03, 688.70and 130.51)% respectively.
5) The ACI expression for the mechanical properties may result in underestimation of HFRPC and good accuracy of NSC under tap water and sulfate water curing condition.
6) The ACI provisions for mechanical properties can be applied to NSC under tap water and sulfate water curing conditions.

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Table (1): Chemical and Physical Properties of Cement Used in this Study*

Chemical Composition of cement			
Oxide Composition	Abbreviation	Content by weight (%)	Limit of Iraqi Specification No.5/1984(5)
Lime	CaO	63.11	-
Silica	SiO_2	20.66	-
Alumina	Al_2O_3	5.13	-
Iron oxide	Fe_2O_3	3.36	-
Magnesia	MgO	2.32	5.0 (max)
Sulfate	SO_3	2.05	2.8 (max)
Loss on ignition	L.O.I.	2.39	4.0 (max)
Insoluble	I.R.	0.68	1.5 (max)
Lime saturation factor	L.S.F.	0.93	(0.66-1.02)%
Physical Properties of Cement			
Physical Properties		Test Results	Limits of Iraqi Specification No.5/ 1984 (5)
Specific surface area(Blaine method),(m^2 /kg)		330	230 (min)
Setting time (vicat's apparatus) Initial setting time, (hrs: min.) Final setting time, (hrs: min.)		1 : 50 3: 40	0:45 (min) 10:00 (max)
Compressive strength, (MPa) 3 days 7 days		27.2 37.4	15 (min) 23 (min)
Soundness (Autoclave method), (%)		0.22	0.8 (max)

*Chemical and Physical analysis is conducted by National Center for Construction Laboratories and Researches.

Table (2): Grading of Fine Aggregate*

Sieve size (mm)	Natural sand (for NSC)		Fine sand (for HFRPC)	
	Cumulative passing %	Limits of Iraqi Specification No.45/1984 (6) for Zone 2	Cumulative passing %	Limits of Iraqi Specification No.45/1984 (6) for Zone 4
10	100	100	100	100
4.75	97	90-100	100	95-100
2.36	83	75-100	100	95-100
1.18	70	55-90	100	90-100
0.600	54	35-59	95	80-100
0.300	20	8-30	53	15-50
0.150	4	0-10	10	0-15

* The test is performed in the constructural Materials Laboratory of faculty of Engineering Al- ustansiriayah University Iraq.

Table (3): Grading of Coarse Aggregate*

Sieve size (mm)	Cumulative passing%	Limit of Iraq Specification No.45/1984 (6) for size 10 mm
14	100	100
10	94	85-100
5	16	0-25
2.36	0	0-5

*The test is performed in the constructural Materials Laboratory of faculty of Engineering Al-Mustansiriayah University Iraq.

Table (4): Composition and Properties of Silica Fume*

Oxide Composition	Abbreviation	Oxide Content (%)	Limit of Specification Requirement (ASTM C 1240) (7)
Silica	SiO_2	98.87	85.0 (min)
Alumina	Al_2O_3	0.01	-
Iron oxide	Fe_2O_3	0.09	-
Lime	CaO	0.23	-
Magnesia	MgO	0.02	-
Sulfate	SO_3	0.25	-
Potassium oxide	K_2O	0.48	-
Loss on ignition	L.O.I.	3	6.0(max)
Moisture content	-	0.48	3.0(max)

* Supplied by the manufacturer

Table (5): Typical Properties of Glenium 51*

Form	Viscous liquid
Colour	Light brown
density	1.1 gm/cm^3 at 20 ^oC
pH	6.6
Viscosity	128 cps at 20 ^oC
Labeling	No hazard label required
Chloride content	None

* Supplied by the manufacturer

Table (6): Physical Properties of Polypropylene Fiber (PPF) and Steel Fiber (STF)*

Property	Type of Fiber	
	Hooked steel	Polypropylene
Length (mm)	30	12
Diameter (mm)	0.375	0.12
Aspect Ratio (L/d)	80	100
Density (kg/m^3)	7800	910
Tensile strength (GPa)	1.8	0.45
Elastic modulus (GPa)	200	5
Failure strain (%)	3.5	18

*Supplied by the manufacturer

Table (7): Mix Proportions of NSC and HFRPC

Concrete Type	NSC	HFRPC
Cement (C) (kg/m^3)	400	1000
Sand (S) (kg/m^3)	600	1000
Gravel (G) (kg/m^3)	1200	-
Silica Fume (SF%)*(kg/m^3)	-	150 (15)
Super-plasticizer(SP)** Glenium51%	-	6
Water (W) (kg/m^3)	180	200
Water/ cement ratio W/C	0.45	0.2
Steel fiber*** (STF%)	-	1
Polypropylene fiber*** (PPF%)	-	0.15
Total fiber volume*** %	-	1.15
Mix proportion by weight	1:1.5:3 Cement : Sand : Gravel	1:1: 0.15 Cement : Sand : Silica fume

***** Percent of cement weight,****** Percent of binder (cement and silica fume) weight,*** Percent of mix volume.

Table (8): Specimen and Type of Testing

Type of Specimen	Size of Specimen	Number of specimen for each Test*				Test	Standards of Test
		NSC		HFRPC			
		Tap water	Sulfate water	Tap water	Sulfate water		
Cube	(100*100)mm	3	3	3	3	Compression Strength	B.S:1881:part16[(16)]
Cylinder	(100*200)mm	3	3	3	3	Compression Strength	ASTM C39-01 (17)
Cylinder	(100*200)mm	3	3	3	3	Splitting Tensile Strength	ASTM C496-04 (18)
Cylinder	(150*300)mm	3	3	3	3	Modulus of Elasticity	ASTMC469-02(19)
Prism	(100*100*500)mm	3	3	3	3	Modulus of Rupture	ASTM C78- 02(20)

*Three specimen for each period curing (28, 90,180 days) for NSC and HFRPC at both curing conditions, total number of specimen for each test =36 specimens.

Table (9): Effect of Type of Curing with Exposure Period on Compressive Strength

Normal Strength Concrete (NSC)								
Exposure Period (days)	Type of curing						Percentage of reduction (%)	
	Tap water (MPa)			Sulfate water (MPa)				
	f'_c	f_{cu}	f'_c/f_{cu}	f'_c	f_{cu}	f'_c/f_{cu}	f'_c	f_{cu}
28	33.5	37.64	0.89	29	33	0.85	13.43	12.33
90	43.54	47.94	0.9	27	30.01	0.89	37.98	37.40
180	47.35	48.31	0.98	22.59	26.52	0.85	52.29	45.10
Hybrid Fiber Reactive Powder Concrete (HFRPC)								
Exposure Period (days)	Type of curing						Percentage of reduction (%)	
	Tap water (MPa)			Sulfate water (MPa)				
	f'_c	f_{cu}	f'_c/f_{cu}	f'_c	f_{cu}	f'_c/f_{cu}	f'_c	f_{cu}
28	115.05	117.88	0.98	111.42	114.69	0.97	3.16	2.71
90	125.33	129.59	0.97	113.78	119.24	0.95	9.22	7.99
180	128	130.05	0.98	114.35	120.89	0.95	10.66	7.04

Table (10): Effect of Type of Curing with Exposure Period on Splitting Tensile Strength

Normal Strength Concrete (NSC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (MPa)	Sulfate water(MPa)	
28	3.47	2.99	13.83
90	3.69	2.25	39.02
180	4.8	2.14	55.42
Hybrid Fiber Reactive Powder Concrete (HFRPC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (MPa)	Sulfate water(MPa)	
28	15.44	14.64	5.18
90	17.81	14.79	16.96
180	18.27	15.43	15.54

Table (11): Effect of Type of Curing with Exposure Period on Modulus of Rupture

Normal Strength Concrete (NSC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (MPa)	Sulfate water(MPa)	
28	4.5	3.42	24.00
90	5.52	3	45.65
180	6.31	2.39	62.12
Hybrid Fiber Reactive Powder Concrete (HFRPC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (MPa)	Sulfate water(MPa)	
28	18.15	17.8	1.93
90	22.05	18.02	18.28
180	23.65	18.85	20.29

Table (12): Effect of Type of Curing with Exposure Period on Modulus of Elastictiy

Normal Strength Concrete (NSC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (GPa)	Sulfate water(GPa)	
28	27.65	24.82	10.24
90	32	23.29	27.22
180	32.87	22.09	32.80
Hybrid Fiber Reactive Powder Concrete (HFRPC)			
Exposure Period (days)	Type of curing		Percentage of reduction (%)
	Tap water (GPa)	Sulfate water(GPa)	
28	54.62	50.23	8.04
90	61.81	50.55	18.22
180	63.15	50.92	19.37

Table (13): Effect of Type of Concrete on Compressive Strength

Compressive Strength in Tap water Curing			
Results for Cylinder			
Exposure Period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	115.05	33.5	243.43
90	125.33	43.54	187.85
180	128	47.35	170.33
Results for Cube			
Exposure Period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	117.88	37.64	213.18
90	129.59	47.94	170.32
180	130.05	48.31	169.19
Compressive Strength in Sulfate water Curing			
Results for Cylinder			
Exposure Period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	111.42	29	284.21
90	113.78	27	321.41
180	114.35	22.59	406.19
Results for Cube			
Exposure period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	114.69	33	247.55
90	119.24	30.01	297.33
180	120.89	26.52	355.84

Table (14): Effect of Type of Concrete on Splitting Tensile Strength

Splitting Tensile Strength in Tap water Curing			
Exposure Period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	15.44	3.47	344.96
90	17.81	3.69	382.66
180	18.27	4.8	280.63
Splitting Tensile Strength in Sulfate water Curing			
Exposure Period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	14.64	2.99	389.63
90	14.79	2.25	557.33
180	15.43	2.14	621.03

Table (15): Effect of Type of Concrete on Modulus of Rupture

Modulus of Rupture in Tap water Curing			
Exposure period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	18.15	4.5	303.33
90	22.05	5.52	299.46
180	23.65	6.31	274.80
Modulus of Rupture in Sulfate water Curing			
Exposure period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (MPa)	NSC (MPa)	
28	17.8	3.42	420.47
90	18.02	3	500.67
180	18.85	2.39	688.70

Table (16): Effect of Type of Concrete on Modulus of Elasticity

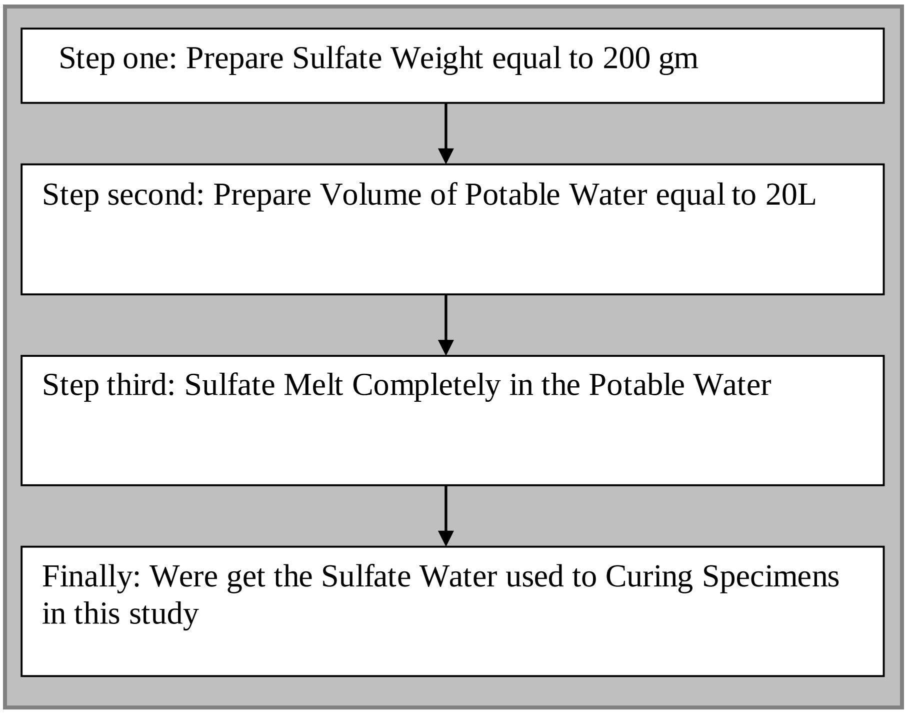
Modulus of Elasticity in Tap water Curing			
Exposure period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (GPa)	NSC (GPa)	
28	54.62	27.65	97.54
90	61.81	32	93.16
180	63.15	32.87	92.12
Modulus of Elasticity in Sulfate water Curing			
Exposure period (days)	Type of concrete		Percentage of increase (%)
	HFRPC (GPa)	NSC (GPa)	
28	50.23	24.82	102.38
90	50.55	23.29	117.05
180	50.92	22.09	130.51

Table (17): Mechanical Properties-Compressive Strength Relations*

When Curing in Tap Water		
ACI Equation (15) (MPa)	Experimental Equation (MPa)	
	NSC	HFRPC
$f_{sp} = 0.56\sqrt{f_c^{`}}$	$f_{sp} = 0.62\sqrt{f_c^{`}}$	$f_{sp} = 1.56\sqrt{f_c^{`}}$
$f_r = 0.62\sqrt{f_c^{`}}$	$f_r = 0.85\sqrt{f_c^{`}}$	$f_r = 1.92\sqrt{f_c^{`}}$
$E_c = 4700\sqrt{f_c^{`}}$	$E_c = 4802.4\sqrt{f_c^{`}}$	$E_c = 5408.2\sqrt{f_c^{`}}$
When Curing in Sulfate Water		
ACI Equation (15) (MPa)	Experimental Equation (MPa)	
	NSC	HFRPC
$f_{sp} = 0.56\sqrt{f_c^{`}}$	$f_{sp} = 0.48\sqrt{f_c^{`}}$	$f_{sp} = 1.41\sqrt{f_c^{`}}$
$f_r = 0.62\sqrt{f_c^{`}}$	$f_r = 0.58\sqrt{f_c^{`}}$	$f_r = 1.71\sqrt{f_c^{`}}$
$E_c = 4700\sqrt{f_c^{`}}$	$E_c = 4576.5\sqrt{f_c^{`}}$	$E_c = 4753.1\sqrt{f_c^{`}}$

* Equations derived from experimental results by using Kaleida Graph Program (26)

Fig. (1): Photograph of (A) Steel Fiber & (B) Polypropylene Fiber Used In Test



Step one: Prepare Sulfate Weight equal to 200 gm

Step second: Prepare Volume of Potable Water equal to 20L

Step third: Sulfate Melt Completely in the Potable Water

Finally: Were get the Sulfate Water used to Curing Specimens in this study

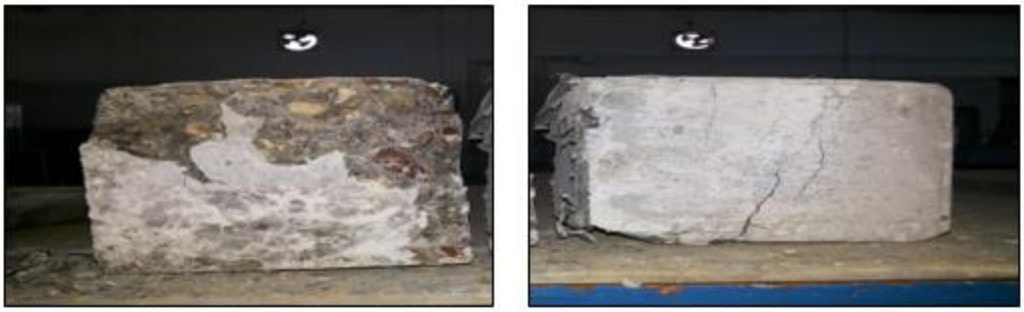
Fig. (2): Flow Chart Showing the Steps to Prepare Sulfate Water

Fig. (3): Magnesuim Sulfate Used in Test

Fig. (4): Show Basins Curing for Sulfate

Fig. (5): Specimens under Test where
(A) Compressive Strength Test (Cube), (B)Compressive Strength Test (Cylinder), (C) Splitting Tensile Strength Test, (D) Flexural Strength Test

Fig. (6): Crack Pattern of Concrete Specimen under Flexural Test in Sulfate Water Curing; (A) NSC and (B) HFRPC

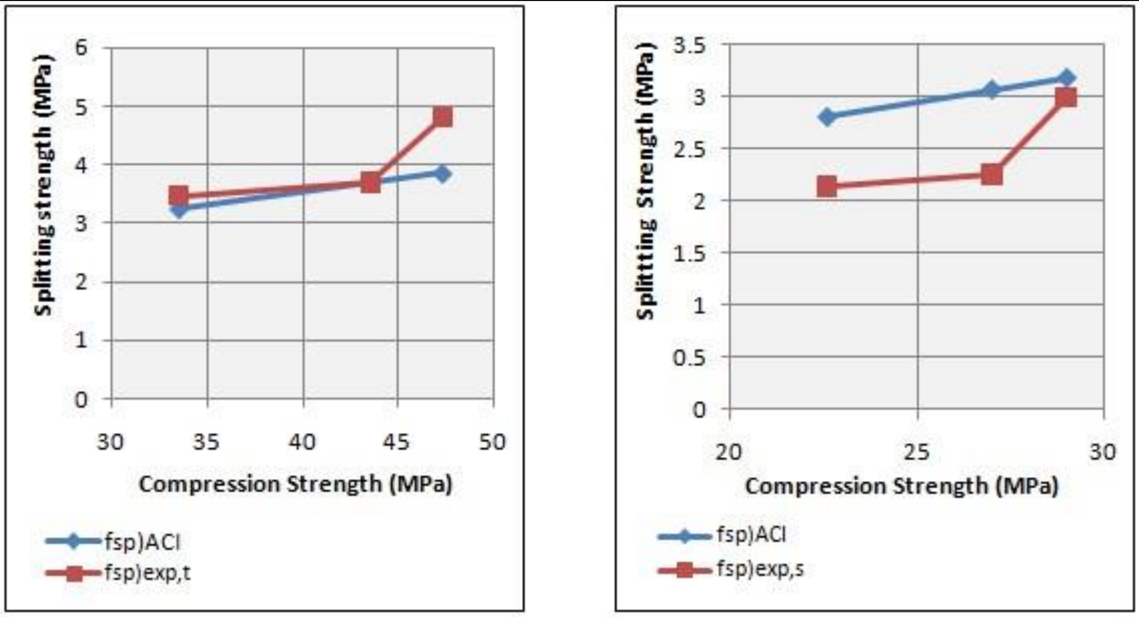


(A) (B)

Fig. (7): Crack Pattern of Concrete Specimen under Compression Test in Sulfate Water Curing; (A) NSC and (B) HFRPC

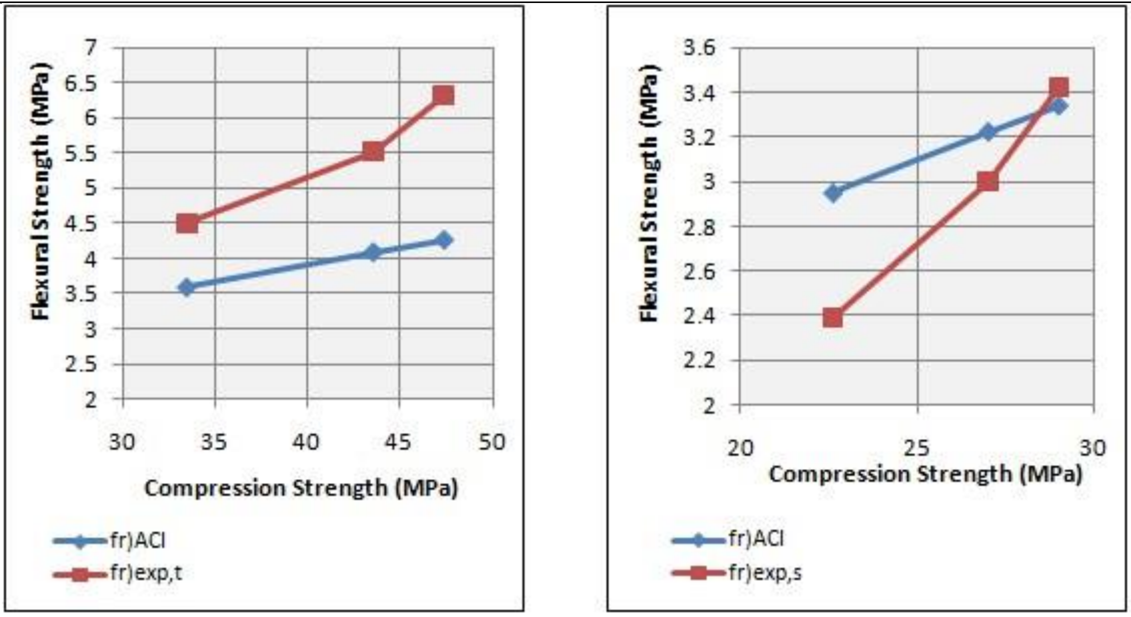
(A) (B)

Fig.(8): Crack Pattern Of Concrete Specimen Under Splitting Tensile Test in Sulfate Water Curing ; (A) NSC And (B) HFRPC



(A) Tap Water Curing (B) Sulfate Water Curing

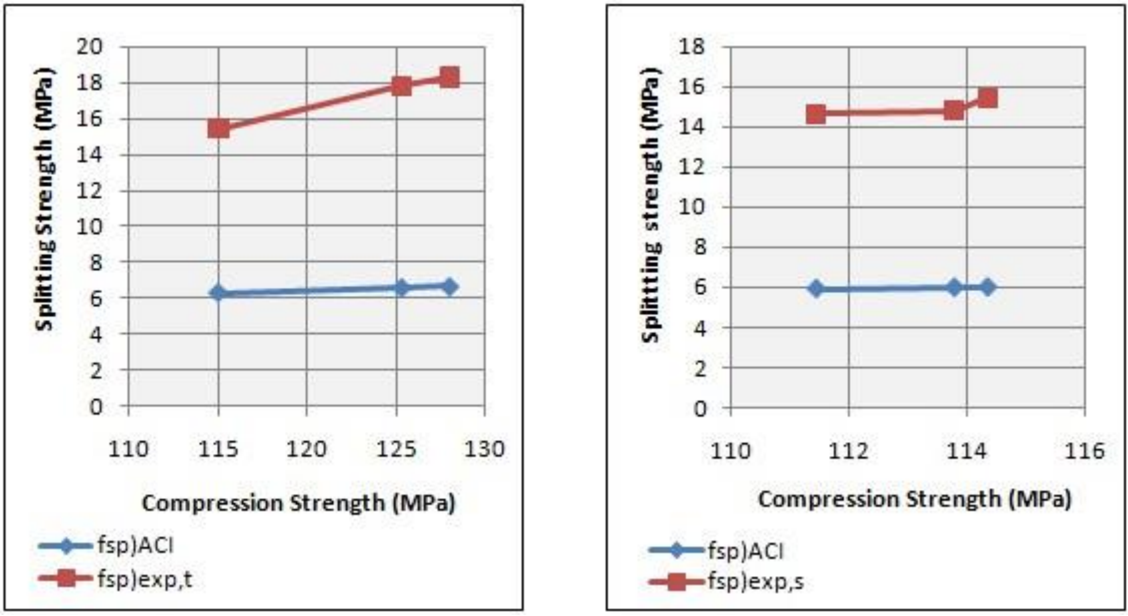
Fig. (9): Comparison between Experimental Splitting Strength with Limits of ACI for NSC



(A) Tap Water Curing

(B) Sulfate Water Curing

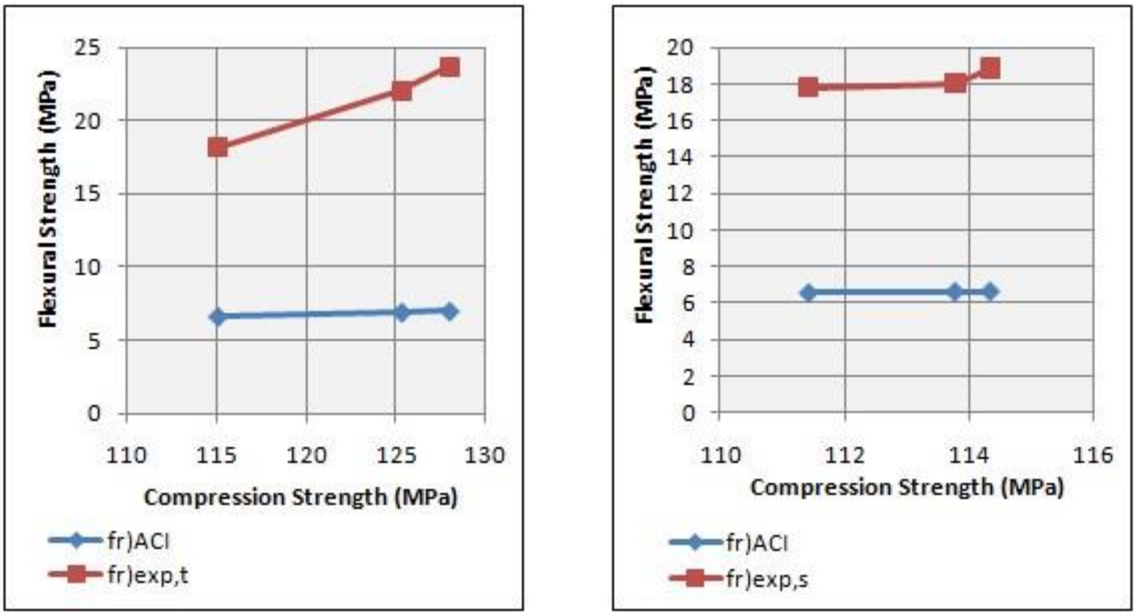
Fig. (10): Comparison between Experimental Flexural Strength with Limits of ACI for NSC



(A) Tap Water Curing

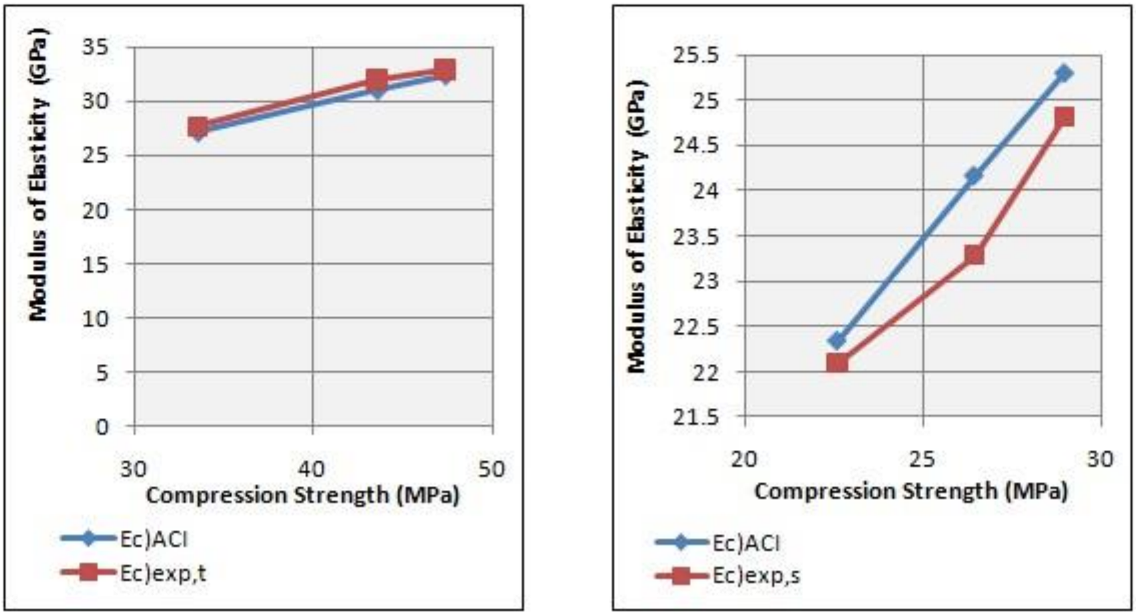
(B) Sulfate Water Curing

Fig. (11): Comparison between Experimental Splitting Strength with Limits of ACI for HFRPC



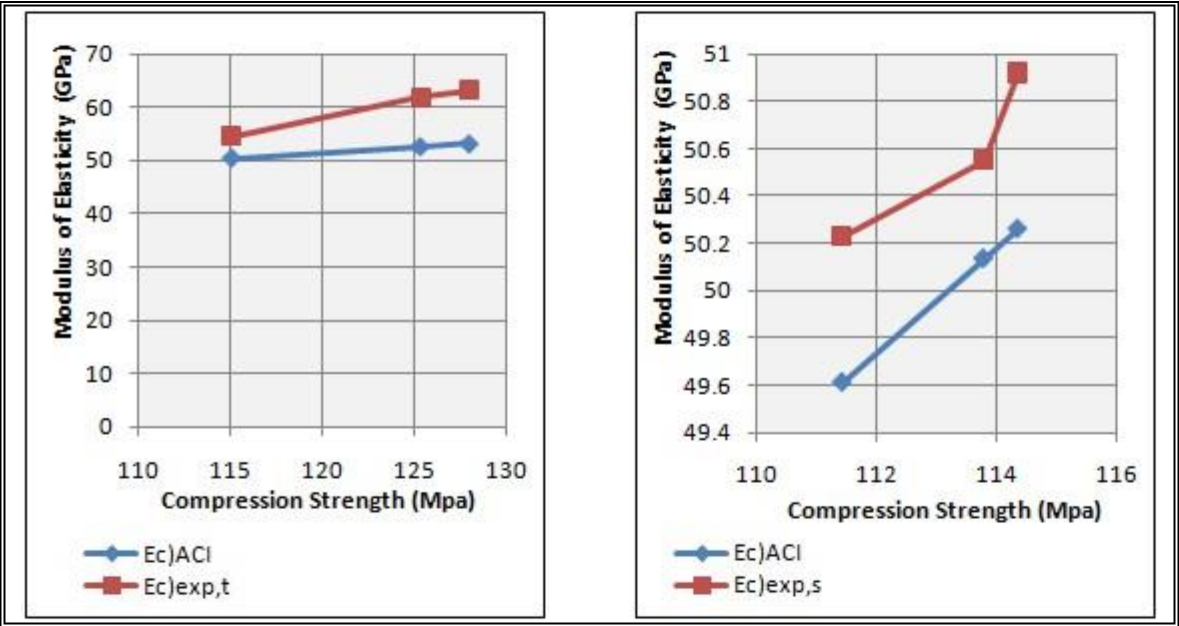
(A) Tap Water Curing (B) Sulfate Water Curing

Fig. (12): Comparison between Experimental Flexural Strength with Limits of ACI for HFRPC



(A) Tap Water Curing (B) Sulfate Water Curing

Fig. (13): Comparison between Experimental Modulus of Elasticity with Limits of ACI for NSC



(A) Tap Water Curing

(B) Sulfate Water Curing

Fig. (14): Comparison Between Experimental with Modulus of Elasticity Limits of ACI for HFRPC

تأثير الأملاح الخارجية على مقاومة خرسانة المساحيق الفعالة الحاوية على ألياف هجينة

الخلاصة

تعد مهاجمة الاملاح الكبريتية مشكلة رئيسية تؤثر بشكل سلبي على الخرسانة والمواد الانشائية المختلفة. تناول البحث تأثير الاملاح الكبريتية الخارجية على مقاومة خرسانة المساحيق الفعالة المحتوية على الياف هجينة (الياف البولي بروبلين والياف الحديد) والخرسانة العادية بعد غمر النماذج كليا وبشكل مباشر ومستمر بعد الصب في محلول ملحي احتوى على كبريتات المغنسيوم المضافة بتركيز مساوي لاعلى تركيز محدد بالكود الامريكي,وكان هنالك نماذج اخرى مغمورة بشكل كلي ومباشر في المياه الاعتيادية الخالية من الكبريتات, وقد تم تهيئة 108 اسطوانة و36 مكعب و36 موشور لهذا الغرض. أجريت فحوصات مقاومة الانضغاط و الشد بالانشطار الغير المباشر ومعامل الانحناء ومعامل المرونة لكل من خرسانة المساحيق الفعالة والخرسانة العادية خلال فترات مختلفة من المعالجة بالمياه الاعتيادية ومياه الكبريتات وتشمل فترات المعالجة(28 و90 و 180) يوم وقد اجريت هذه الفحوص لكل النماذج المعالجة بالمياه الاعتيادية والمعالجة بالكبريتات. أظهرت نتائج الفحوصات الخاصة بخرسانة المساحيق الفعالة تطور مستمر أثناء معالجتها بمياه ألاملاح الكبريتية(محلول كبريتات المغنسيوم),بينما حصل تدهور واضح في النتائج المستحصلة من الخرسانة العادية عند نفس ظروف المعالجة. تم اشتقاق معادلات خاصة بعلاقة الخواص الميكانيكية مع قوة الانضغاط للخرسانة العادية والهجينة باستخدام منحني المناسيب وتم مقارنتها مع معادلات الكود الامريكي. تبين من الدراسة ان معادلات الكود الامريكي تعطي قيم اقل للخرسانة الهجينة وقيم جيدة للخرسانة العادية تحت تأثير المعالجة بالمياه الاعتيادية والمعالجة بالكبريتات.

الكلمات مفتاحية: خرسانة المساحيق الفعالة المحتوية على الياف هجينة ، الخرسانة العادية ، الخواص الميكانيكية ، مياه عادية ، مياه الكبريتات ، مقاومة الانضغاط، معامل المرونة، معامل الانحناء ، الشد بالانشطار الغير المباشر ، منحني المناسيب.