EFFECT OF POLYMER (S.B.R.) ON SULFATE RESISTANCE OF CONCRETE

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الخلاصة:

تعتبر مقاومة الخرسانة لهجوم الكبريتات واحده من الجوانب المهمة لديمومة الخرسانة. لقد تم في هذا البحث إجراء مقارنة بين مقاومة الخرسانة الاعتيادية للكبريتات ومقاومة خرسانة الاسمنت البورتلاندي البوليمرية لهجوم الكبريتات المشترك (هجوم داخلي وخارجي للكبريتات). الهجوم الداخلي للكبريتات تم عن طريق إضافة الجبسوم لرفع محتوى الكبريتات الى مستوى مساوٍ الى تربة مدينة الرمادي وهو (2.17%) بينما هجوم الكبريتات الخارجي تم عن طريق استخدام مواد كيميائية ($MgSO_4.7H_2O$, Na_2SO_4, $CaCl_2.2H_2O$, NaCl) لماء الحنفية لتحويله الى ماء مشابه للماء الجوفي الموجود في مدينة الرمادي.

الفحوصات المختبرية المستخدمة كانت كالآتي (فحص مقاومة الانضغاط والانثناء، معامل المرونة، الهطول، سرعة الموجات فوق الصوتية وفحص النسبة الكلية للأملاح بعد التعرض للهج وقد وجد بأن مقاومة انضغاط الخرسانة العادية لأعمار (7، 28، 90، 180) يوم على التوالي كانت كالآتي (20، 28، 11.166، 7) ميكا باسكال أما مقاومة انضغاط خرسانة الاسمنت البورتلاندي البوليمرية بنسبة (بوليمر/اسمنت) = 5% فكانت كالآتي (21.83، 32.66، 12.76، 8.73) ميكا باسكال ولنسبة (بوليمر/اسمنت) = 10% كانت كالآتي (24.166، 35.866، 15.533، 11.366) ميكا باسكال.

أما بالنسبة لمقاومة انثناء الخرسانة العادية لأعمار (7، 28، 90، 180) يوم فكانت كالآتي (3.953، 3.7، 1.68، 11.305) ميكا باسكال. أما مقاومة خرسانة الاسمنت البورتلاندي البوليمرية لنسبة (بوليمر/اسمنت) = 5% كانت كالآتي (4.05، 5.025، 2.13، 1.605) ميكا باسكال ولنسبة (بوليمر/اسمنت) = 10% فكانت كالآتي (4.43، 6.375، 2.43، 1.92) ميكا باسكال.

معامل المرونة الاستاتيكي بعمر (28) يوم للخرسانة العادية كان (37.4) كيكا باسكال ولخرسانة الاسمنت البورتلاندي البوليمرية مساوياً إلى (9.7، 13.63) ميكا باسكال ولنسبة (بوليمر/اسمنت) = (5، 10)% على التوالي. الهطول للخرسانة العادية كان (155) مم، ولخرسانة الاسمنت البورتلاندي البوليمرية مساوياً إلى (142، 75) مم لنسبة (بوليمر/اسمنت) = (5، 10)% على التوالي. سرعة الموجات فوق الصوتية للخرسانة العادية لأعمار (27، 28، 90، 180) يوم كالآتي (4.2، 4.445، 4.203، 4.56) كيلومتر/ثانية أما بالنسبة لخرسانة الاسمنت البورتلاندي البوليمرية بنسبة (بوليمر/اسمنت) = 5% فكانت كالآتي (4.36، 4.646، 4.53، 4.176) كيلومتر/ثانية ولنسبة (بوليمر/اسمنت) = 10% كالآتي (4.437، 4.837، 4.656، 4.52) كيلومتر/ثانية.

وقد أشار البحث إلى أهمية استخدام البوليمر لتطوير مقاومة الخرسانة لهجوم الكبريتات حتى إذا ارتفعت نسبة الكبريتات أكثر من (0.5)% وهو الحد الأقصى المسموح به حسب المواصفة القياسية العراقية (م. ق. ع. رقم 45 لسنة 1970).

ABSTRACT:

The resistance of concrete to sulfate attack is considered as one of the important factors for concrete durability.

The effect of SBR polymer on sulfate resistance of concrete is investigated. Both internal and external sulfate attack are considered.

Internal sulfate attack was made by adding gypsum to raise the sulfate content of sand to that of Ramadi city soil (2.17%), while the external sulfate attack was made by adding chemical materials ($MgSO_4.7H_2O$, Na_2SO_4, $CaCl_2.2H_2O$, NaCl) to tap water to convert it into water similar to groundwater of Ramadi city.

The laboratory tests were compressive and flexural strength, modulus of elasticity, slump, ultra-sound velocity and total percentage of sulfate after exposing to attack for different ages.

It was found that the compressive strength of reinforced normal concrete (RNC) for ages (7,28,90,180) days respectively were (20,28,11.166,7) MPa, the compressive strength of polymer Portland cement concrete(PPCC) with polymer/cement ratio(P/C)=5% (PPCC5) were (21.83,32.666,12.766,8.733) MPa and for PPCC with (P/C)=10% were (24.166,35.866,15.533,11.366)MPa.

While the flexural strength of RNC for different ages (7,28,90,180) respectively were (3.953,3.7,1.68,11.305) MPa, the flexural strength of PPCC5 were (4.05,5.025,2.13,1.605) MPa and for PPCC10 were (4.43,6.375,2.43,1.92) MPa.

The static modulus of elasticity at age (28) days for (RNC) was (37.4) GPa , for PPCC5 was (9.7) GPa and for PPCC10 was (13.63) GPa.

Slump for (RNC) was (155) mm, for PPCC5 was (142) mm and for PPCC10 was (75) mm.

T he ultra-sound velocity of RNC for ages (7,28,90,180) respectively were (4.2,4.445,4.203,4.53) Km/sec , for PPCC5 were (4.36,4.646,4.53,4.176) Km/sec and for PPCC10 were (4.437,4.837,4.656,4.52) Km/sec.

It was found that (PPCC10) has higher resistance to sulfate attack than (PPCC5) and (NRC).

The thesis refers to necessity of polymer to improve the resistance of concrete to sulfate attack although if the sulfate percentage raise to more than (0.5) % which represents the maximum limit of sulfate percentage in I.O.S No. 45-1970.

1- GENERAL

Because concrete plays a critical role on building up the infrastructure system in our society, and with unexpected deterioration of existing concrete structures built in the last century, the durability of concrete structures becomes a key issue for concrete technology recently. (1)

Conventional Portland cement concrete has number of limitations, such as low flexural strength, low failure strain, susceptibility to frost damage and low resistant to chemicals.

In certain situations, these problems can be solved by using materials, which contain inorganic polymer or resin (commercial polymer) instead of or in conjuction with Portland cement.

These relatively new materials offer the advantages of higher strength, improved durability, good resistance to corrosion, reduced water permeability and greater resistance to damage from freezing and thawing cycles. (2)

2- POLYMERS

Polymers are chemical compounds formed by chemical reaction in which relatively simple chemical units called monomers are reacted together to form larger molecules that contain repeating structural units of the original molecule. (3)

SBR has been used in this in this investigation, where SBR are copolymers produced from butadiene and styrene as in figure (1).

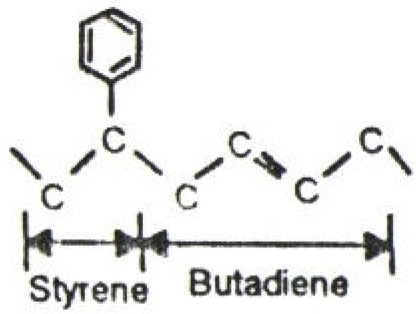

Figure 1: SBR chain (4)

SBR is cheaper than natural rubber and is widely used as a synthetic substitute for it. SBR has good low-temperature properties, good wear and weather resistance, however it has poor resistance to fuels and oils and poor fatigue resistance. (4)

3- Types of Polymer Concrete:

According to the methods of preparation and to the properties of concrete, there are three types of polymer concrete:

3-1Polymer Concrete(PC)

3-2Polymer Impregnated Concrete(PIC)

3-3Polymer Portland Cement Concrete (PPCC). (5)

In this investigation (PPCC) has been used.

3-1- Polymer Concrete (PC):

Polymer concrete is formed by polymerization of monomer mixed with aggregate at the ambient temperature using a catalyst or curing agent. (6)

3-2 Polymer Impregnated Concrete (PIC)

Polymer impregnated concrete is made by impregnation of precast hardened Portland cement concrete with low viscosity monomers (in either liquid or gaseous form) that are converted to solid polymer under the influence of physical agents (ultraviolet radiation or heat) or chemical agents (catalysts). (2)

3-3 Polymer Portland Cement Concrete (PPCC)

It is produced by incorpotrating a monomer, polymer monomer mixture, or a dispersed polymer (latex) into a cement concrete mix. To affect the polymerization of the monomer or prepolymer monomer, a catalyst is added to the mixture. (2)

4- Sulfate Attack

Sulfate attack is a common form of concrete deterioration and is commonly subdivided according to the source of the sulfate ion into: (7)

1. Internal sulfate attack
2. External sulfate attack.

It is observed when structures are exposed to sulfate solutions, or are placed in sulfate bearing soils and or groundwater. (8)

Sewage and sea water both contain dangerous amounts of sulfate.(9)

Solid salts do not attack concrete, but when present in solution they can react with hardened cement paste. (5)

The destructive action of sulfates on concrete is primarily the result of their reaction with either C_3A or the C_3A hydration products to form the high sulfoaluminat (ettringite, $C_3A.3CASO_4.32\ H_2O$). (10)

It is demonstrated that sulfate attack on concrete results from a chemical reaction between the sulfate ion and Hydrated Calcium Aluminate and/or the Calcium Hydroxide components of hardened cement paste in the presence of water. (2)

The reaction is accompanied by considerable expansion, causing gradual softening and possible disintegration, together with loss of strength of the material in which it takes place. (11)

On hydration, Portland cement with more than 5% potential C_3A will contain most of the Alumina in the form of monosulfahydrate, $C_3A.CS^{-}.H_{18}$.

If the C_3A content of the cement is more than 8%, the hydration products will also contain $C_3A.CH.H_{18}$.

In the presence of Calcium Hydroxide in Portland cement pastes, when the cement paste comes in contact with sulfate ions, both the alumina containing hydrates are converted to the high sulfate form (ettringite, $C_3A.3CS^{-}.H_{32}$)

$C_3A.CS^{-}.H_{18}+2CH+2S^{-}+12H \rightarrow C_3A.3CS^{-}.H_{32}$ .... (1-1)

$C_3A.CH.H_{18}.2CH+3S^{-}+11H \rightarrow C_3A.3CS^{-}.H_{32}$. .... (1-2) (12)

Expansion due to ettringite formation causes tensile stresses in the concrete when these stresses become greater than the concrete's tensile strength, concrete begins to crack .these cracks allow easy ingress for more sulfates into the concrete and the deterioration accelerates. (7)

5- FACTORS INFLUENCING SULFATE ATTACK:

5-1 Sulfate type:

The sulfate differs in its solubility in water, e.g. unhydrated calcium sulfate is soluble less than other types of sulfate while ammonium sulfate has the highest ability to be soluble as shown in the table below: (13)

Compound type	Ability of solubility in cold water gm/100cm^{3}water
Calcium sulfate	0.02
Sodium sulfate	4.76
Magnesium sulfate	26
Ammonium sulfate	70.6

5-2 Sulfate concentration:

According to (Neville), the rate of sulfate attack increases with an increase in the strength of the solution, but beyond concentration of about 0.5 percent of $MgSO_4$ or 1 percent of Na_2SO_4 the rate of increase in the intensity of the attack becomes smaller. (5)

5-3 Cement type:

Generally, a high resistance to sulfate attack is obtained when the tricalcium aluminate (C_3A) content of the cement is kept low; Portland cement complying with B.S12 (14) usually contain significant proportion of tricalcium aluminate (C_3A) but in sulfate resisting Portland cement complying with B.S4027 (15) the amount is limited to 3.5% by weight. (16)

5-4 Cement content in mixture:

There is a very effective way of increasing resistance to sulfate by increasing the cement content of the mix. (9)

5-5 Curing method:

According to Neville(5), high-pressure steam curing improves the resistance of concrete to sulfate attack. This applies to concrete made both with sulfate-resisting and ordinary Portland cements, since the improvement is due to the change of C_3AH_6 into a less reactive phase and also the removal of $CA(OH)_2$ by the reaction with silica.

5-6 Wetting and drying cycles:

Alternating saturation and drying lead to rapid deterioration. (5)

5-7 Solution properties:

Neville shows that the addition of calcium chloride to concrete mixture reduces from its resistance to sulfate regardless of cement type.(5)

5-8 Water movement:

It can be seen that when the concrete is subjected to the pressure of sulfate bearing water on one side the rate of attack is highest. (17)

5-9 External loads applied on concrete:

The speed of chemical reaction increases with the increasing of applied stresses reacted materials. (18)

5-10 The level of water table and its seasonal variation:

Salt concentrations may vary seasonally with amount of rainfall and fluctuations in water table, the concentration increases in dry periods and this leads to severe sulfate attack. (8)

5-11 The form of construction:

Massive forms of construction will deteriorate less quickly than thin sections. (19)

5-12 Permeability:

In general, highly impermeable products will only suffer surface attack and then usually by sulfates from external sources. With highly permeable products attack may proceed simultaneously throughout the mass of the product and by sulfates either present in the material or from external sources or both. (9)

6- Experimental Program

The experimental program was planned to study the effect of external and internal sulphate attack on some properties of RNC, PPCC5 and PPCC10, and to overcome this problem of attack, S.B.R was used as an admixture to concrete mixes. Table (1) below shows the details related to samples, tests examine the efficiency of polymer in the improvement of concrete durability and ages. The mix proportions and quantities of concrete mixtures are shown in tables (2) and (3).

Table (1) Details of experimental program:

Test type	Ages of curing (days)	Number and types of samples
1. Compressive strength	7, 28, 90, 180	Four cubes with size (10×10×10)cm for every age.
2. Flexural strength	7, 28, 90, 180	Four prisms with size (10×10×50)cm for every age.
3. Modulus of elasticity	28	Four cylinders with size (15×30)cm
4. Ultra-sound velocity	7, 28, 90, 180	Four cubes with size (10×10×10)cm for every age.

Table (2) Mix proportions of concrete mixtures

Concrete type	Mix proportion	Water/ Cement ratio	Polymer/ Cement ratio	Internal sulfate %	External sulfate %	Total sulfate %
Reference concrete	1:1.5:3	0.54	0%	4.481	0.275	4.756
Polymer concrete	1:1.5:3	0.45	5%	4.481	0.275	4.756
Polymer concrete	1:1.5:3	0.45	10%	4.481	0.275	4.756

Table (3) Quantities of concrete mixtures

Concrete type	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Water kg/m^3	Polymer kg/m^3
Reference concrete	393	590	1179	212	0
Polymer concrete with polymer/cement ratio=5%	400	600	1200	180	20
Polymer concrete with polymer/cement ratio=10%	392	588	1176	176	39.2

7- MATERIALS

7-1 Cement:

Sulphate resisting Portland cement manufactured by Al-Qa'im Cement Factory was used in this investigation. The characteristics of cement are as shown in table (4)

The test results conform to the Iraqi specification No.5/1984.

Table (4) physical properties of sulphate resisting cement (with fineness 365 m^2/kg):

Physical properties	Test result	Limits of Iraqi specification No.5/1984
Fieness (m^2/kg) Setting time: Initial (minutes) Final (hours)	365 129 3:47	 ≥ 45 ≤10
Compressive strength(N/mm^2) 3day 7day	 17.4 25.2	 ≥15 ≥23

7-2 Aggregates:

7-2-1 Fine aggregates:

The fine aggregate used was brought from Al-Nebai region, and tested before use to determine grading and other physical properties, as shown in table (5) test results are conformed to the Iraqi specification No. 45/1980.

Table (5) physical specification of fine aggregate.

Sieve size (mm)	Percentage passing	Limits of Iraqi specification No.45./1980
4.75	100	100
2.36	100	95-100
1.18	95	90-100
0.6	84	80-100
0.3	43	15-50
0.15	10	0-15

Water absorption: 2.13%

Specific gravity: 2.6

Sulphate content (SO_3): 0.192≤ 0.5%

7-2-2 Coarse aggregate:

The coarse aggregate used in this investigation was brought from Al-Nebai region and it was continuously graded, irregular shape, natural river gravel.

A 20mm maximum size of coarse aggregate was used in this investigation and the physical properties of it is shown in table (6).

Table (6) Physical specification of coarse aggregate:

Sieve size (mm)	Percentage passing	Limits of Iraqi specification No.45/1980
20	100	90-100
10	54	30-60
5	4	0-10

Water absorption: 0.93
Specific gravity: 2.64
SO_3 content: 0.1%(equal to maximum limit of Iraqi specification)

7-3 Styrene-Butadiene Rubber (S.B.R.):

The main typical properties of S.B.R. were as follows:

Colour: white

Specific gravity: 1.01

pH: 5.5

By adding the cement and aggregate to the mixer and premix for approximately 1 minute, then add SBR polymer and mix for further two minutes slowly after that water will be added slowly until the desired consistency is reached. (5)

7-4 Gypsum

Natural gypsum ($CaSO_4.2H_2O$) rocks used to produce gypsum material was obtained from Heet region. These rocks were crushed and grinded by machine and sieved on the same sieves of sand grading test. Then some of residual particles weights on every sieve were taken in order to use in preparation of mixtures. The chemical composition is shown in table (7).

In order to control on gypsum proportion, the gypsum quantity was added to sand according to the following equation: (18)

$W=(R-SO_3\ sand)\ S/N$…(1-3)

Where:

W: weight of gypsum added to sand (kg)

R: Required SO_3 percentage (SO_3 of Ramadi soil=2.17%)

S: weight of cement in mixture (kg)

N: SO_3 percentage in gypsum=41.5%

Gypsum must be mixed perfectly with sand to provide homogenous mixture and the quantity of sand must be reduced with magnitude equal to added gypsum weight.

Table (7) Chemical composition of gypsum used.*

Compound	Percentage
CaO	26
SO_3	41.5
Soluble salt $SiO_2+Fe_2O_3$	3.7
($MgO+Na_2O$)	0.08
Loss of ignition	29

*This test was made by Glass Factory.Ramdi

7-5 Water:

Mixing water is tap water but curing water is different. Curing water contains salts (NaCl, $MgSO_4.7H_2O$, Na_2SO_4, $CaCl_2.2H_2O$).

The concentrations of these salts in water represent its concentrations in groundwater of Ramadi City.Chemical composition of tap and ground water of Ramadi city and salts required to convert tap water to ground water are shown in tables (8) and (9).

Table (8) Chemical composition of Ramadi City ground water and tap water.**

Properties	Tap water	Ground water
pH	7.30	8.34
Conductivity EC(Ds. m^{-1})	0.52	4.98
Na^{+}%	0.003	0.048
K^{+}%	0.0002	0.003
Ca^{+2}%	0.010	0.037
Mg^{+2}%	0.008	0.045
Cl^{-}%	0.008	0.059
Bicarbonate%	0.001	0.010
SO_3%	0.031	0.301

**This test was made by College of Agriculture \ Department of Soil. Anbar university.

Table (9) Salt quality and concentrations used in preparation of curing water, which represent the ground water of Ramadi City (for one basin).*

Salt used	**Soluble quantity in tap water (gm/L)**
Calcium chloride $CaCl_2 . 2H_2O$	1
Sodium chloride NaCl	1.14
Magnesium sulphate $MgSO_4 . 7H_2O$	3.8
Sodium sulphate Na_2SO_4	1.87

*This test was made by College of Agriculture \ Department of Soil. Anbar university.

7-6 Basins:

Basins used in this investigation should withstand the corrosive effect of salts; therefore fiber glass basins are used for this purpose, where the samples immersed partially in curing water existing in these basins.

7-7 Testing

7-7-1 Slump test:

The slump test was done according toBS1881Part2,1970 to measure the workability of polymer–modified concrete and plain concrete and the results were:-

Table (10) Experimental results of slump test

Concrete type	Slump (mm)
1. Reference concrete (polymer/cement ratio = 0%)	155
2. Polymer concrete (polymer/cement ratio = 5%)	142
3. Polymer concrete (polymer/cement ratio = 10%)	75

The relation between slump and (polymer/cement) ratio is linear. The results show that the slump of polymer concrete with (polymer/cement) ratio=10% is less than that of (polymer/cement) ratio =5% while the slump of reference concrete is higher than that of polymer concrete, as shown in figure. (2)

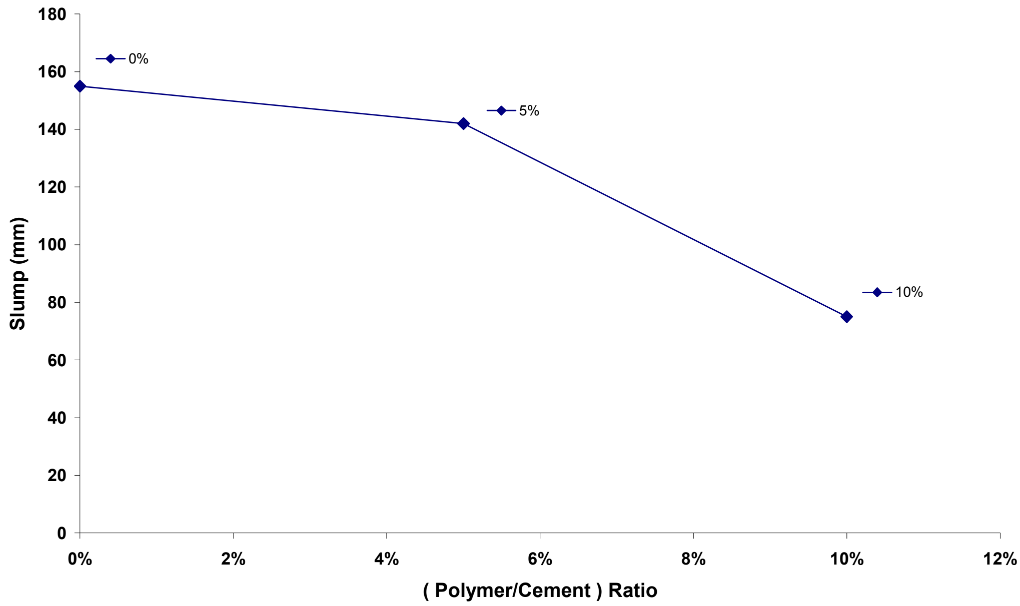

Figure 2: The relationship between slump and (polymer/cement) ratio

This can be attributed to that the polymer which disperses and deflocculates the matrix particles within a concrete mix, and the polymer behave as a lubrication agent which will reduce the friction, this can be utilized to improve workability without the addition of extra water. But the drop of workability beyond (polymer/cement) ratio=5% is attributed to the high viscosity of the mixing water which contains 10% of

SBR. This high viscosity reduces the dispersing effect of particles which leads to lower workability. (13)

7-7-2 Compressive strength:

The compressive strength test was done according to BS1881 part 4 ,1970, using 100mm cubes . 2000kN capacity hydraulic universal testing machine (ELE-Digital Elect 2000) was used for compressive strength test.

Table (11) Experimental results of compressive strength test

Concrete type	(Polymer/Cement) ratio (%)	Compressive strength (MP_a)			
		7 day	28 day	90 day	180 day
Reference concrete	0	20	28	11.1	7
Polymer concrete	5 10	21.8 24.1	32.6 35.8	12.7 15.5	8.7 11.3

Table (12) Increasing percentages in compressive strength of polymer concrete with respect to reference concrete

Age(days)	P/C ratio (%)	Increasing percentages in compressive strength with respect to RNC (%)
7	5 10	9.1 20.8
28	5 10	16.6 28.1
90	5 10	14.3 39.1
180	5 10	24.7 62.3

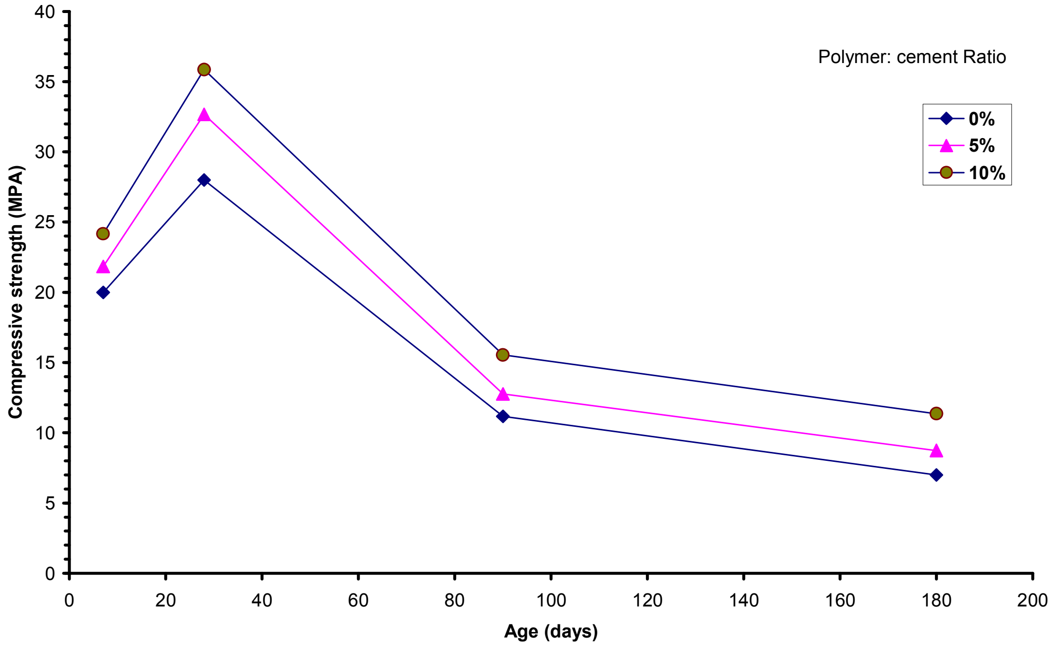

Figure 3: Relationship between age and compressive strength

Table (13) Decreasing percentages in compressive strength with respect to compressive strength of 28 days:

Concrete type	Late ages (days)	Decreasing percentages in compressive strength (%)
Reference concrete	90 180	60.1 75
Polymer concrete with p/c=5%	90 180	60.9 73.2
Polymer concrete with p/c=10%	90 180	56.7 68.3

Table (14) Decreasing percentages in compressive strength of NRC with respect to PPCC type:

PPCC type	Age (days)	Decreasing percentages in compressive strength of NRC with respect to PPCC type %
PPCC5	7	8.3
	28	14.2
	90	12.5
	180	19.8
PPCC10	7	17.2
	28	22
	90	28.1
	180	38.4

The initial increase in strength is probably due to completion of (80-85) % of hydration process at 28 days and the hydration products and gel particles fill the voids gradually; therefore the compressive strength increases.

On the other hand, the loss of strength in the late ages is due to degradation of calcium-silicate-hydrate (C-S-H), and volumetric expansion due to formation of gypsum or ettringite that leads to cracking (20). This expansion will be imped and the resulting internal stresses destroy the concrete. (5)

7-7-3 Flexural strength:

This test was done according to BS1881part118,1983, by applying two concentrated loads at the two third of a prism specimen (100*100*500)mm with an effective span of 300mm.the modulus of rupture was obtained from the following equation:

$Fb = PL/bd^2$ N/mm^2 …(1-4)

Where:

P: applied load (N)

L: effective length (mm)

b: width of prism (mm)

d: depth of prism (mm)

Figure (4) and tables (15) and (16) show that the flexural strength or modulus of rupture increases at early age (28) days but at late ages (90,180) days, it will decrease.

Increasing of flexural strength at early age is due to increasing in solid materials volume by filling the pores of concrete by hydration process, but at late ages, the sulphates of sodium and magnesium react chemically with hydrated calcium aluminate in the cement paste to form calcium sulfo-aluminate. These reactions result in the expansion and disruption of concrete.

On the other hand, the presence of chloride ions increases the permeability of concrete and reacts with C_3A to form a complex compound ($3CaO.Al_2O_3.CaCl_2.12H_2O$).

Table (15) Experimental results of flexural strength test (MPa)

Concrete type	(Polymer/cement) ratio	Age(days)	Flexural strength(MP_a)
Reference concrete	0%	7 28 90 180	3.253 3.7 1.68 1.305
Polymer concrete	5%	7 28 90 180	4.05 5.025 2.13 1.605
Polymer concrete	10%	7 28 90 180	4.436 6.375 2.43 1.92

Table (16) Decreasing percentages of flexural strength with respect to flexural strength of 28 days

Concrete type	Late age (days)	Decreasing percentages of flexural strength with respect to flexural strength of 28days (%)
Reference concrete	90 180	54.6 64.73
Polymer concrete (p/c=5%)	90 180	57.61 68.06
Polymer concrete (p/c=10%)	90 180	61.882 69.88

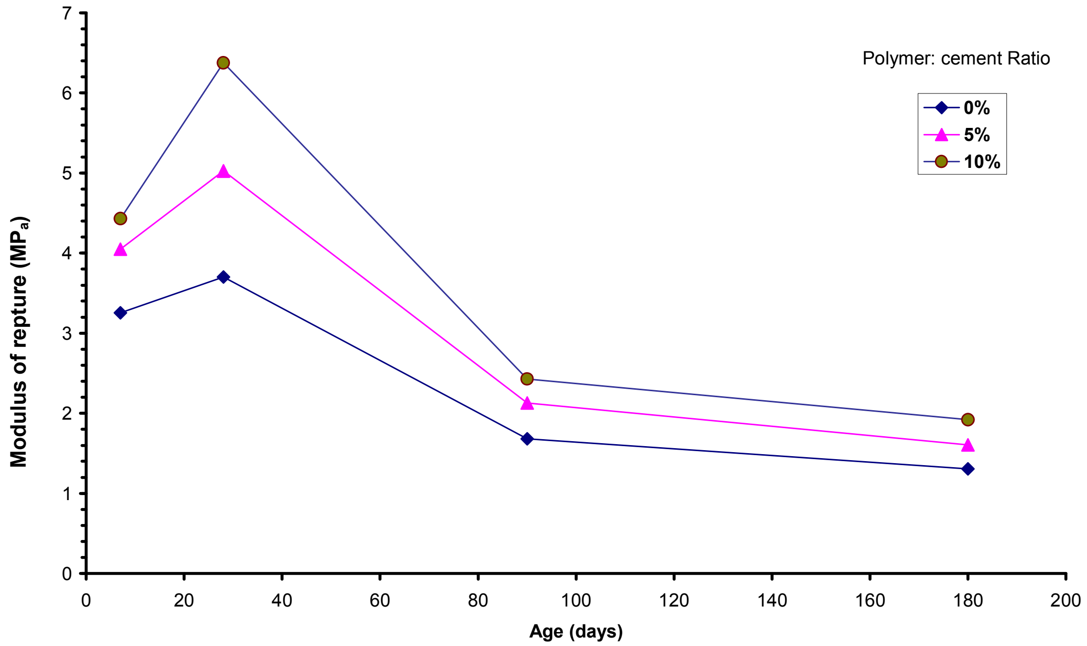

Figure 4: The relationship between age and modulus of rupture

7-7-4 Static modulus of elasticity in compression:

This test was carried out according to BS1881part121,1983. The chord modulus of elasticity was determined by using (38) specifications. The equation, which was used, is:

$Ec = (S_2-S_1)/(\in_2-0.00005)$ …… (1-5)

Where:

Ec: chord modulus of elasticity.

S_2: stress corresponding to (40%) of ultimate load.

S_1: stress corresponding to longitudinal strain ($\in 1$), which equals to 0.00005.

$\in_2$: longitudinal strain produced by stress (S_2).

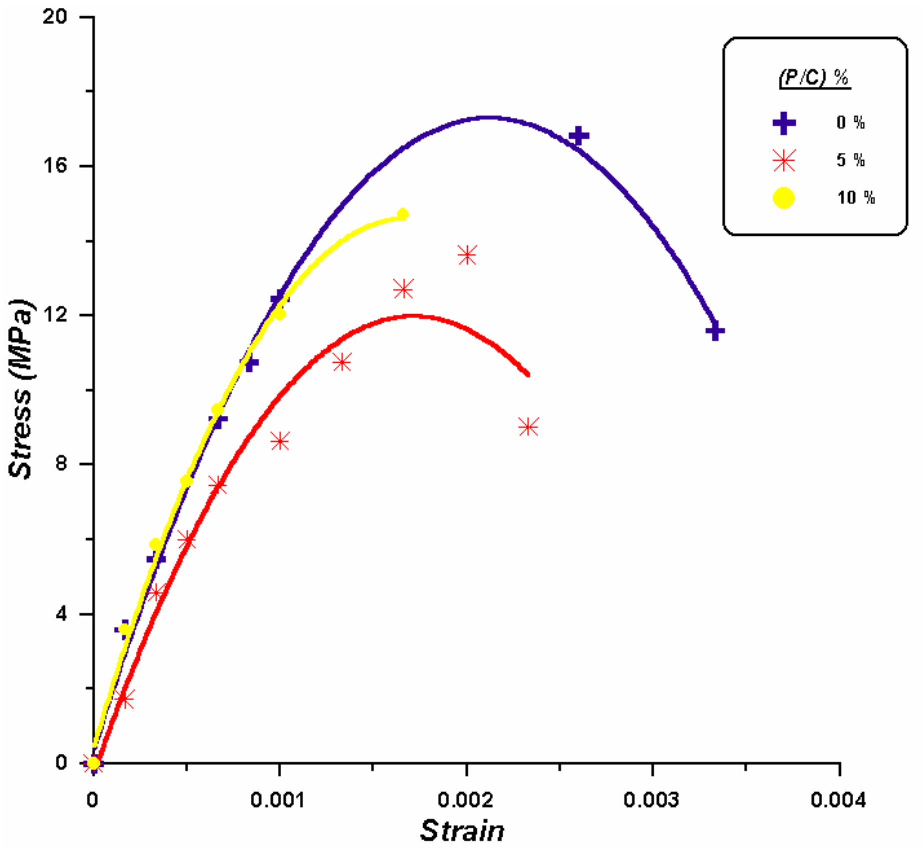

Figure 5: Stress-strain relationship

PPCC5 and PPCC10 undergoes a rapid brittle repture at the maximum loading point of compressive testing, while RNC exhibits a ductile behavior under compressive load.

Table (17) Experimental results of chord modulus of elasticity at age 28 days:

Concrete type	Chord modulus of elasticity (GP_a)
Reference concrete	37.7
Polymer concrete (p/c=5%)	9.7
Polymer concrete(p/c=10%)	13.63

7-7-5 Ultra-sound test:

PUNDIT was used in measuring of UPV. The frequency of PUNDIT used is 54kHz and it's sentisity at passing time measuring is 0.10 micro second.

Frequency of 54kHz was used according to ASTM-C-469 specifications which recommended to use frequency of 50kHz or more than 50kHz in case of frequency pass is short to give more accurate readings of time. Velocity of ultra-sound was calculated from this equation:

V=L/T…(1-6)

Where:

V: pluse velocity (km/second)
L: path length (mm)
[Distance between two surfaces of sample perpendicular on cast direction].
T: time of frequency penetration (microsecond) measured by PUNDIT.

Figure (6) shows the relationship between compressive strength and pulse velocity, where pulse velocity increases with the increment of compressive strength.

This relation is related with density, where the increasing in density means reducing of pores in concrete and this leads to reduce the time required to frequencies passing through concrete as shown in figure (7).

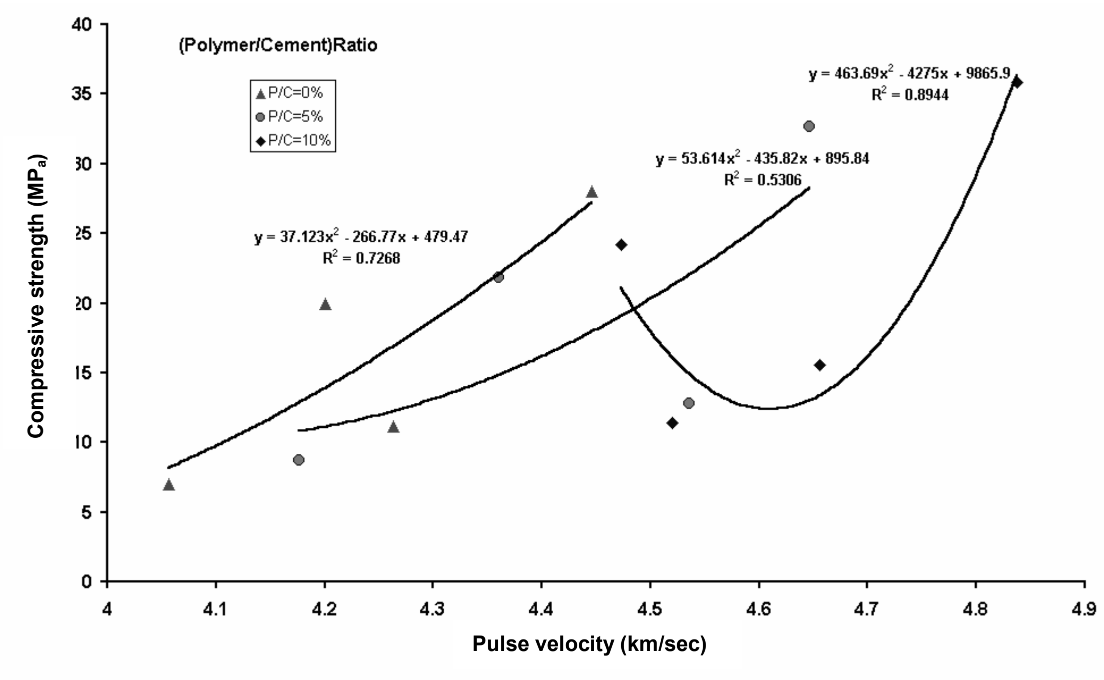

Figure 6: The relationship between pulse velocity and compressive strength

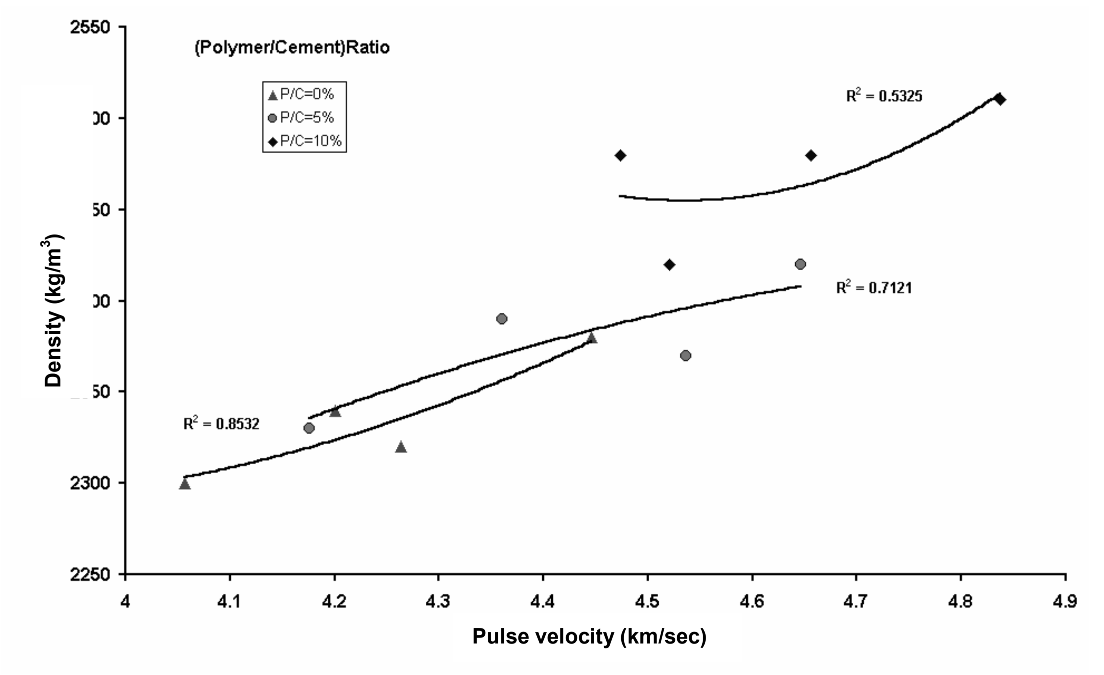

Figure 7: The relationship between pulse velocity and density

7-7-6 : Calculation of the total salt of the mix:-

This calculation can be made according to Iraqi specification (40) for different ages by depending on mix proportion of mixture, as shown in table (18).

Table (18) Total sulfate percentages of concrete types for different ages (%)

Concrete type	Mix proportion	Water/cement ratio	Polymer/cement ratio	Total sulfate percentage after exposing to chemical solutions %			
				7 days	28 days	90 days	180 days
Reference concrete	1:1.5:3	0.54	0%	4.65	4.78	4.92	5.1
Polymer concrete	1:1.5:3	0.45	5%	4.42	4.53	4.75	4.83
Polymer concrete	1:1.5:3	0.45	10%	4.31	4.41	4.53	4.76

This proportion (P/C ratio=10%) causes strong monolithic network of polymer film, which prevents entrance of sulfate to concrete, as shown in figure (8).

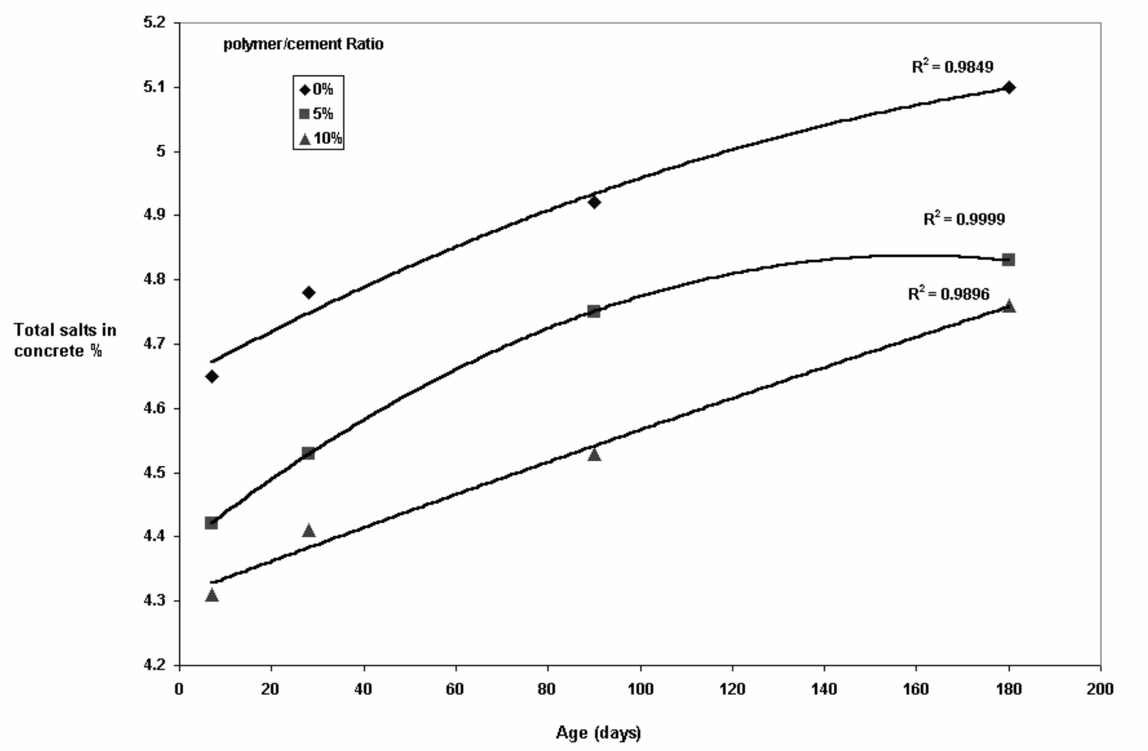

Figure 8: Relationship between the age and salts resistance

8- CONCLUSIONS

Based on the experimental results of this research, the following conclusions can be made:

1. The compressive strength of PPCC10 is higher than that of PPCC5 and RNC.
2. The flexural strengths of PPCC10 is higher than that of PPCC5 and RNC.
3. Based on No.1, the polymer concrete has higher resistance to sulfate attack than reference concrete and this resistance increases with increase of (P/C) ratio.
4. The compressive strength of RNC, PPCC5 and PPCC10 increase at early age (28) days, but at late ages (90,180) days decrease for the three types of concrete.
5. The modulus of elasticity decreases from (37.7-9.7) GP_a when (P/C) ratio increases from (0-5)% and when the (P/C) ratio increases to 10% the modulus of elasticity increases to 13.63 GP_a.
6. The decreasing percentages in flexural strength of RNC with respect to flexural strength of 28 days were (54.6, 64.73)% for ages (90, 180) days, respectively, while the decreasing percentages of PPCC5 with respect to flexural strength of 28 days were (57.61, 68.06)% for ages (90, 180) days, respectively, and the decreasing percentages of PPCC10 with respect to flexural strength of 28 days were (61.882, 69.88)% for ages (90, 180) days, respectively.
7. The relation of pulse velocity with (P/C) ratio behaves as the behavior of relation between compressive strength and (P/C) ratio.
8. The time required for frequencies passing through concrete is short at early age (28) days, but at late ages (90,180) days the time increases and this leads to decreasing of pulse velocity at late ages.

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