Influence of Accelerated Curing on Fiber Reinforced Concrete

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Abstract

The adopted accelerated curing methods in the experimental work are 55ºC and 82ºC according to British standard methods. The concrete mix with the characteristics compressive strength of 35MPa is design according to the ACI 211.1, the mix proportion is (1:2.65:3.82) for cement, fine and coarse aggregate, respectively. The concrete reinforced with different volume fraction (0.25, 0.5 and 0.75)% of glass, carbon and polypropylene fibers.

The experimental results showed that the accelerated curing method using 82ºC gives a compressive strength higher than 55ºC method for all concrete mixes. In addition, the fiber reinforced concrete with 0.75% gives the maximum compressive strength, flexural and splitting tensile strength for all types of fibers with ages.

1. INTRODUCTION

The addition of different fibers in plain concrete will controls cracking and shrinkage and also enhances the strain capacity [17].

Abbas [2] studied different concrete mixes of (1:4), (1:5) and (1:6) as (cement, porcelinite aggregate) respectively. The cement content (300 Kg/m^3) with different W/C ratio (0.4, 0.45 and 0.5). The accelerated curing methods are according to British standard (BS1881: part: 112:1983). A good correlation was obtained for light weight concrete between accelerated compressive strength and normal compressive strength at 28-day equals to (0.245) for the water bath at 55ºC and (0.335) for the water bath at 82ºC.

Abbas and Awad [1] studied the accelerated strength tests using the British standard curing methods BS1881: Part 112 to predict the strength at later ages. Four different chemical compositions of cement were used with two target compressive strength equals to (35 and 45) MPa. The Comparison between methods refers to despite the fact that the 35 ºC method is the simplest and most convenient of the three; the correlations for a range of different concretes may be somewhat more widely dispersed than for the 55 ºC method. The third method of 82 ºC is more complex and it needs high water temperature. The percent of accelerated strength test (35 ºC, 55 ºC and 82 ºC methods) of 7-day normal curing strength approximately were 0.4, 0.6 and 0.7 respectively.

Al-Mishhadani et al (2009) [3] examined the properties of reinforced carbon fiber light weight concrete. The compressive strength in concrete mixes increases slightly about (1.15%, 0.49% and 2.2%) for different carbon volume fraction of (3%, 3.75% and 4.5%) respectively while the tensile strength increases by (173%, 242% and 296%) respectively.

The experimental work by Khalil and Abdulrazaq (2011) [14] includes, producing high performance concrete reinforced with carbon volume fractions (0%, 0.2%, 0.3%, 0.4% and 0.5%). The addition of carbon fibers causes a slight increase in compressive strength and significant increase in splitting tensile and flexural strengths with increase of fiber volume fraction. The percentage increase in splitting tensile and flexural strengths with fiber volume fraction 0.5% at 28 days is about 45% and 46% respectively.

Banthia and Soleimani (2005) [8] and Singh et al (2010) [19] found out that the reinforced with (1%) polypropylene fiber led to reduced the compressive strength at 28 days about (13%) compared to reference concrete.

On the other hand, Mtasher et al (2011) [16] studied four concrete mixes with polypropylene fiber (0.4, 0.8, 1.0 and 1.5) % as percentage weight of cement, the test results showed that the increase in compressive strength up to (11, 24.35, 46 and 56.4)% and the flexural strength increase about (24.6, 49.36, 57 and 85)% respectively.

Rehman (2012) [18] found that the percentage increase in tensile strength for polypropylene reinforced concrete up to (93, 101 and 129) % and for carbon fiber about (170, 177 and 220) % of no fine aggregate concrete containing different volume fraction (1, 3 and 5) %, respectively.

Chandramouli et al (2012) [10] found that the percentage increase in compressive strength at 28 days of different grades of concrete (M20, M30, M40 and M50) with 0.03% glass fiber by volume of concrete compared to the reference mix is about (20-25)% and for the flexural and split tensile strength (15 to 20)%.

The main aim of the investigation is to study the effect of accelerated curing on the mechanical characteristics of fiber reinforced concrete by using three types of fibers glass, carbon, and polypropylene.

2. EXPERIMENTAL WORK

2.1 Materials

- Cement

The ordinary Portland cements (OPC)-Al-Shemalyia was used conforming to the IQS 5/1984 [13]. The chemical and physical properties listed in Tables (1) and (2), respectively.

Table 1 Chemical composition of the cement

Oxide Content %	Results by weight (%)	Limits of Iraqi specification No.5 / 1984[13]
SiO_2	19.59	-
Al_2O_3	4.63	-
Fe_2O_3	3.53	-
CaO	61.58	-
SO_3	2.74	≤ 2.8
MgO	2.75	≤ 5.0
Loss of ignition	1.64	≤ 4.0
Insoluble restitute	0.78	≤ 1.5
Lime saturation value	0.95	0.66-1.02
Compound Composition (Bogue` s Equations)		
C_3S	57.78	-
C_2S	12.89	-
C_3A	6.31	-
C_4AF	10.73	-

- Chemical tests are conduct by the central organization for standardizations and quality control –ministry of planning.

Table 2 Physical properties of the cements

Properties	Results	Requirement of Iraqi Specification No.5/1984[13]
Specific surface (Air permeability test)- (m^2/kg)	355	230(min)
Autoclave expansion,%	0.03	-
Setting time -(vicate apparatus), 1. Initial – (hr:min) 2. Final – (hr:min)	 1:35 5:30	 00:45(min) 10:00(max)
Compressive strength –(MPa): 1. 3-days 2. 7-days	 30.5 31.5	 15.0(min) 23.0(min)

- Physical tests are conduct by the central organization for standardizations and quality control –ministry of planning.

- Fine Aggregate

The natural fine aggregate (sand) brought from Al-Ukhaider district. The grading of sand is within the Iraqi specification IQS 45/1984 [12] - zone two. The sieve analysis listed in Table (3). Table (4) shows the physical properties and the sulfate content.

Table 3 Sieve analysis of the fine aggregate

Sieve opening (mm)	Passing by weight (%)	Requirement of IQS 45/1984 -(Zone 2)
10	100	100
4.75	94	90-100
2.36	84	75-100
1.18	76	55-90
0.60	45	35-59
0.30	16	8-30
0.150	4	0-10

Table 4 Physical properties and sulfate content of fine aggregate

Properties	Results	IQS 45/1984 [12]
Fineness modulus	2.82	
Specific gravity	2.61	
Moisture content (%)	0.2	
Absorption (%)	1.4	
Passing sieve size 75μm (%)	1.6	$\leq$ 5%
Sulfate content (SO_3) (%)	0.15	$\leq$ 0.5%

- Coarse Aggregate

The natural crushed coarse aggregate with maximum size of 20mm from Al-Niba`ee district is used. The crushed gravel is within the Iraqi specification IQS 45/1984 [12]. The sieve analysis, physical properties and sulfate content are listed in Table (5) and Table (6) respectively.

Table 5 Sieve analysis of crushed coarse aggregate with 20mm maximum size

Sieve size (mm)	% passing by weight	Limits of IQS 45/1984 [12]
37.5	100	100
20	98	95-100
10	45	30-60
5	4	0-10

Table 6 Physical properties and sulfate content of crushed coarse aggregate

Properties	Results	Limits of IQS 45/1984 [12]
Dry rodded unit weight (kg/m^3)	1650	-
Specific gravity (SSD)	2.65	-
Absorption (%)	0.5	-
Passing sieve size 75µm (%)	0.85	≤ 3
Sulfate content -SO_3 (%)	0.01	≤ 0.1

- Mixing Water

Tap water used in this study for mixing and curing methods.

- Chemical Admixture

Glinume 51 (G51) - superplasticizer is used in concrete mixes. G51 is conforms to the ASTM C494-05 [4] types A and F.

- Fibers

Three types of fibers were used, polypropylene fiber, carbon fiber and glass fiber. It was brought from Sika Company the geometrical and physical characteristics of fibers are illustrated in Table (7).

Table 7 Technical data of fiber used according to Sica Company

Form	Polypropylene Fiber	Carbon Fiber	Glass Fiber
Density (gm/cm^3)	0.91	1.9	2.7
Alkali and Sulfate content	Nil	-	
Chloride content	Nil	-	
Base (%)	100% pure Polypropylene	98 wt(Carbon content)	-
Fiber thickness (microns)	18 and 30	7	
Young modulus (MPa)	5500-7000	5500-7000	8000
Tensile strength (MPa)	350	590	2500
Melting point	160 $^{\circ}$C	-	
Fiber length(mm)	12	6	20
Elongation at break (%)	-	1.4	
Specific surface area (kg/m^2)	250		
Thermal conductivity	slow		

2.2 Mix Proportion of Concrete

The ACI 211.1 concrete mix design is adopted with the characteristic compressive strength (35) MPa. Ten concrete mixes with slump rang (75-100) mm for fine aggregate-sand (653) Kg/m^3, crushed coarse aggregate- gravel (1215) Kg/m^3, cement content (318) Kg/m^3 and with (0, 0.25, 0.5 and 0.75) % by volume fraction of concrete for each fiber type (carbon, polypropylene and glass).

2.3 Mixing and curing of Concrete

The dry materials (cement, sand and gravel) were initially mixed for (1.5-2.0) minutes using rotary mixer equipment. The required water was added, and then re-mixed for further 1.5 minutes.

For the normal curing, after casting (30-40) minutes, the molds are covered with wetted nylon bag. The specimens were kept in curing tank until the age of test. While the specimens for accelerated curing test transforming to accelerated curing equipment and start the accelerated curing procedure as mentioned below.

3. Accelerated curing methods

The British standard BS 1881: Part 112: 1983 [14] presented three methods using water bath (Fig.1) at 35ºC, 55ºC and 82ºC. In the present study the adopted accelerated curing methods are 55ºC and 82ºC.

A-55ºC method: cover the cubes with a plate and leave the samples at a temperature of (20±5)ºC for at least 1hr. Lower the samples into the filled curing tank for not less than (1 + 1/2)hr or more than (3 + 1/2) hr after the addition of water to other material in the concrete mix. Kept the samples in the tank more than (19hr + 50min) at a temperature (55±2)ºC. After removing the samples from the curing tank submerge the cubes in the cooling tank for a period between (1 and 2)hr then test.

B-82 º C methods: cover the cubes with a plate and leave the samples at a temperature of (20±5)ºC for at least (1)hr. Lower the samples into the empty curing tank filled with water at a temperature 20ºC. Kept the samples for a period of not less than (14hr + 15)min at a temperature of (82±2)ºC is raised during (2hr±15min). Discharge the water from the curing tank within (5)min and remove the specimens from the tank and test.

Fig.1 Water bath equipment

4. Test performed

- Unit Weight of Fresh Concrete

This test was directed according to the **ASTM C567-00**.

- Compressive Strength

The compressive strength test was directed according to British slandered, 1881: part 116[9]. The cube molds with (100x100x100)mm was casted. The electrical equipment machine was used.

- Ultrasonic Pulse Velocity (UPV)

Conferring to the ASTM C597–02 [6], the ultrasonic pulse velocity test was done using portable equipment called PUNDIT and the equipment was used with direct transmission method.

- Splitting Tensile Strength

The splitting tensile strength test was directed according to the ASTM C496 [5]. This test was done at ages (7, 28 and 90) days for cylindrical concrete specimens (150×300)mm.

- Flexural Strength

The flexural strength of concrete was prepared for (100×100×400) mm prisms according to ASTM C78 [7]- two-point loading.

5. RESULTS AND DISCUSSION

- Compressive Strength, Density and Ultrasonic Pulse Velocity

Table (8) and Fig.(2) showed that the compressive strength results for 82°C accelerated curing method is higher than 55°C curing method for all types of reinforced concrete fibers (glass, carbon, and polypropylene). This behavior attributed to raise the curing temperature which leads to speed the hydration of chemical reaction, thus, affects the early strength of concrete [11].

Similar observations were reported by Abbas and Awad [1].

The concrete mix using 0.75% glass fiber in the 82°C accelerated curing method gives a higher percentage increase in compressive strength up to 21% compared to the reference concrete mix. In another hand, the increase percentage of fiber causes an increase in compressive strength for all types of fiber with age. In general, the improvement in compressive strength with increase of fiber percentage was may be attributed to the ability of fiber to delay the undesirable development of micro-cracks that led to limit the propagation of these micro-cracks [15].

The reinforced concrete with (0.75%) of fiber gives the maximum compressive strength for all types of fibers with age. The fiber reinforced concrete with 0.75% glass fiber results specified a maximum increase in compressive strength up to (22, 12 and 13) % at 7, 28, and 90 days respectively, this behavior is in agreement with Chandramouli et al [10] and Roa et al [17]. The density of concrete mix increases with the increasing of fiber percent used as compared to reference concrete mix for both carbon and glass fiber, while polypropylene fiber showed a slight decrease in density compared to reference concrete mix.

The results of ultrasonic pulse velocity increases with the fiber percentage increase for carbon and glass fiber as compared to reference concrete mix and that is conformed with compressive strength results, while polypropylene fiber gives result closer to reference concrete mix as presented in Fig.(3).

The relationship between ultrasonic pulse velocity with the compressive strength is a linear with high coefficient of determination (R^2=0.903) which is presented in Fig. (4).

Table 8 The Accelerated strength, Compressive strength, Density and Ultrasonic Pulse for different concrete mixes

Mix No.	Density (Kg/m^3)	Accelerated strength (1-day)		Compressive strength (MPa)			Ultrasonic Pulse Velocity(Km/s)		
		55°C	82°C	7 day	28 day	90 day	7 day	28 day	90 day
MRef.	2610	13.3	17.8	23.8	35.2	43.5	4.008	4.502	4.856
MG0.25	2723	14.5	19.4	25.9	36.5	45.5	4.155	4.625	4.878
MG0.5	2815	15.5	20.6	27.5	38.1	47.2	4.268	4.736	4.902
MG0.75	2925	16.2	21.5	29.1	39.5	49.1	4.315	4.995	5.295
MC0.25	2702	14.5	18.9	25.2	36.3	45.1	4.142	4.612	4.870
MC0.5	2788	15.8	20.0	26.9	37.8	47.5	4.215	4.724	4.902
MC0.75	2865	16.1	21.1	28.1	38.9	48.6	4.298	4.888	5.215
MP0.25	2601	13.1	18.1	24.1	35.3	43.7	4.015	4.508	4.687
MP0.5	2595	13.4	18.4	24.5	35.6	44.1	4.009	4.505	4.651
MP0.75	2581	13.9	18.8	25.1	36.1	44.6	4.000	4.485	4.521

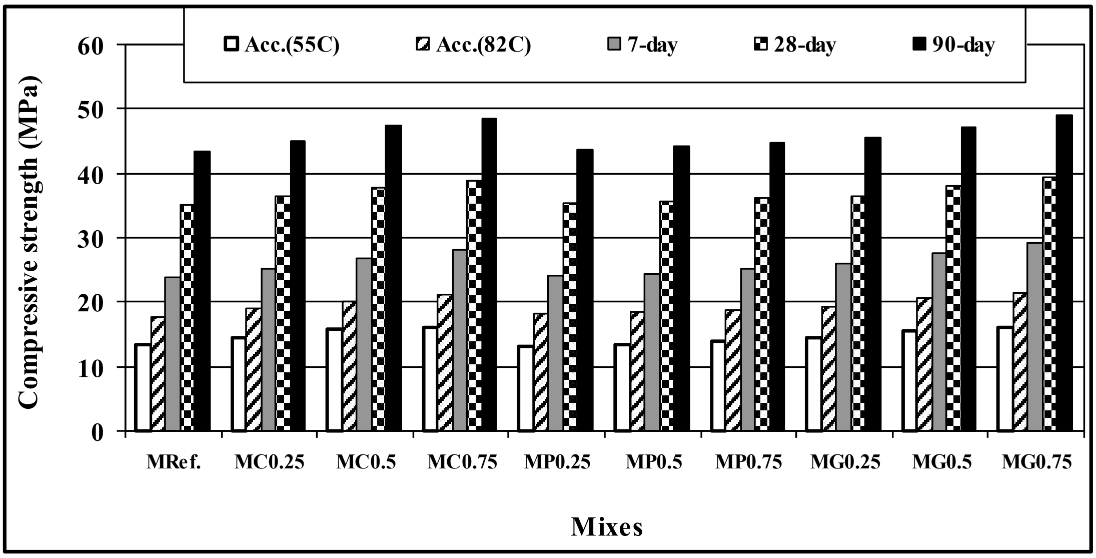


Fig.2 Compressive strength for different mixes with normal and accelerated curing ages

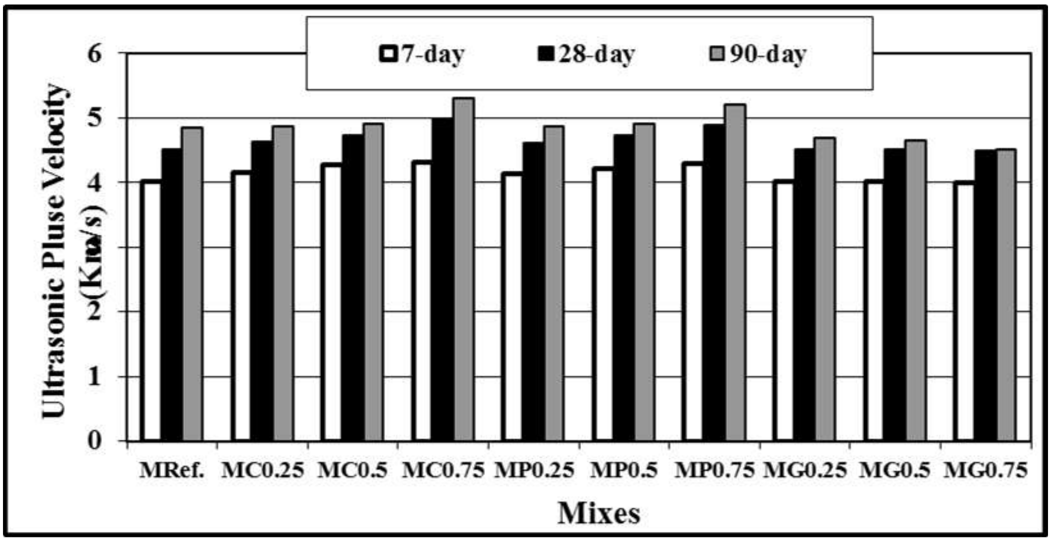


Fig. 3 ultrasonic pulse velocity (Km/s) for different mixes with ages

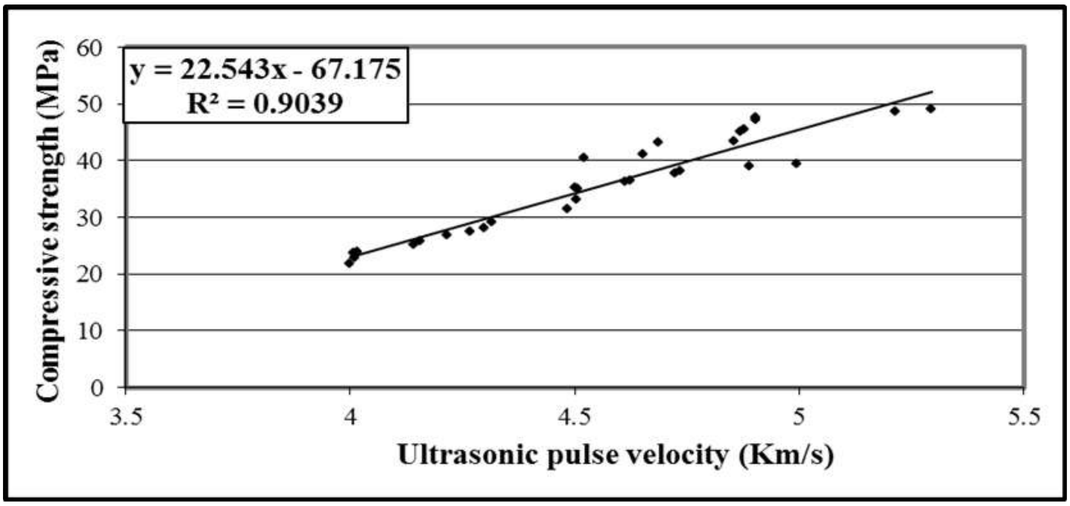


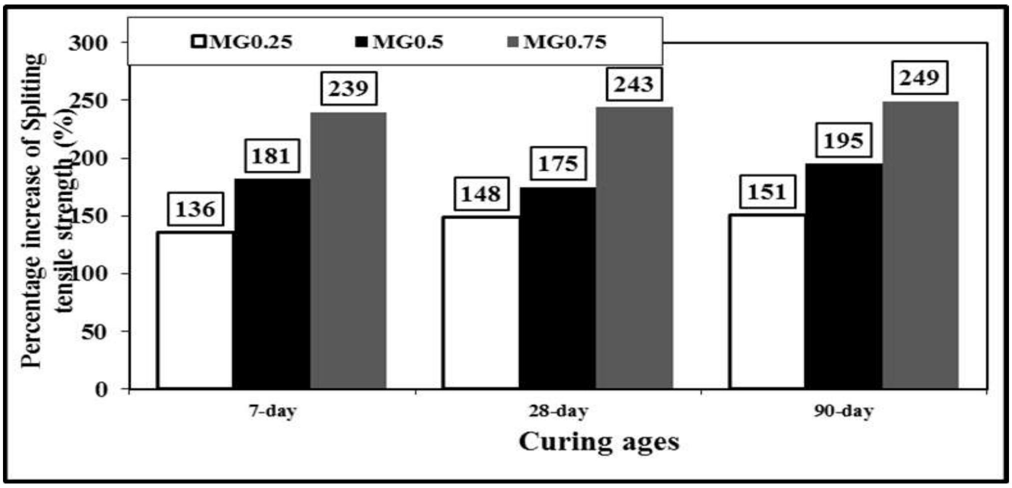
Fig.4 Compressive strength verses ultrasonic pulse velocity

- Flexural Strength

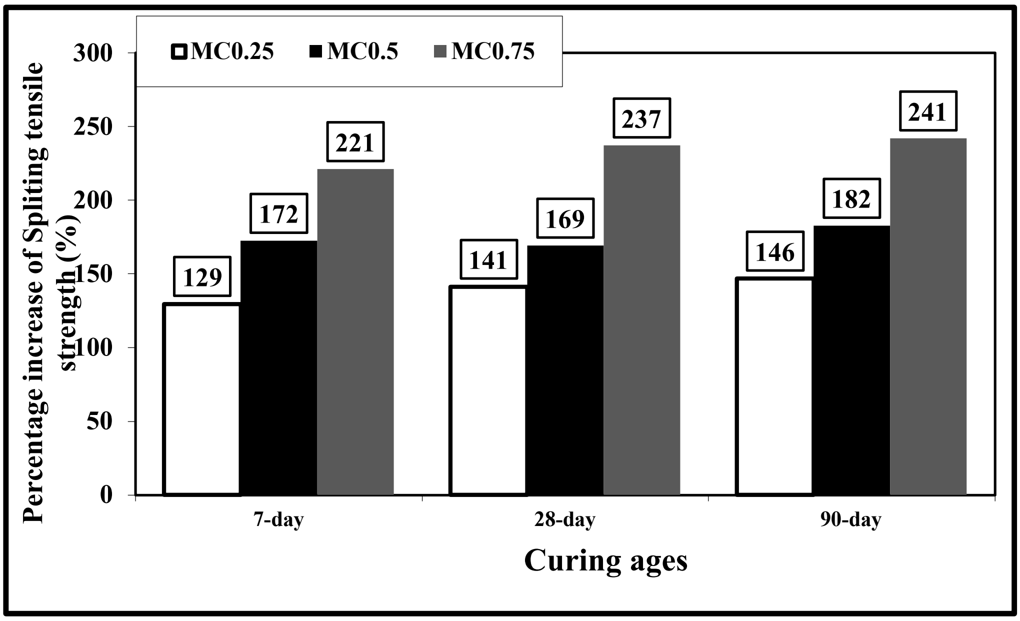
The flexural strength results for all types of fiber with different volume fraction were presented in Table (9) and Fig.(5). From the results it can be observed that the fiber reinforced concrete showed higher flexural strength for all fiber percentage at all curing ages, this may be due to the fact that the addition fibers will control the micro cracks in concrete mass [15]. The reinforced with 0.75% of fiber gives the highest flexural strength for all types of fibers with age. The percentage 0.75% of (glass and carbon fiber) addition achieved increase in flexural strength reach to (129, 116 and 140) % for glass fiber and (114, 112 and 135) % for carbon fiber at (7, 28 and 90) days, respectively as compared to reference concrete mix. This behavior is in agreement with Khalil and Abdulrazaq [14] and Mtasher et al [16].

Table 9 Flexural strength for reference and fiber reinforced concrete mixes

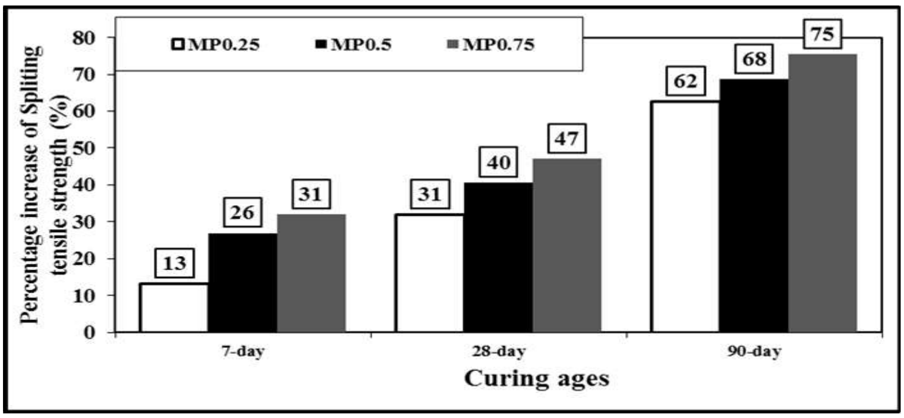
Mix No.	Flexural Strength (MPa)		
	7 day	28 day	90 day
MRef.	3.68	4.92	5.61
MG0.25	9.41	13.26	15.34
MG0.5	13.1	16.83	18.07
MG0.75	14.72	19.51	20.15
MC0.25	8.69	12.25	14.09
MC0.5	10.37	13.53	16.58
MC0.75	12.51	16.92	17.91
MP0.25	3.87	5.42	5.77
MP0.5	4.04	5.53	6.09
MP0.75	4.18	5.73	6.11



(a) Glass



(b) Carbon



(c) Polypropylene

Fig.5 Percentage increase in flexural strength for different types of fiber with curing ages

- **Splitting Tensile Strength**

From the presented results in Table (10) and Fig.(6) it can be observed that the reinforced concrete with 0.75% addition of fiber gives higher splitting tensile strength than (0.25 and 0.5) % addition for all types of fibers. The reinforced concrete with 0.75% of fiber causes an increase in the splitting tensile strength for glass fiber up to (240, 244 and 249) % and (221, 237 and 242) % for carbon fiber at (7, 28 and 90) days respectively, as compared to the reference concrete mix. This result is in agreement with Al-Mishhadani et al [3] and Rehman [18]. The relationship of the splitting tensile strength and flexural strength with high coefficient of determination (R^2=0.937) that can be observed in Fig.(7).

Table 10 Splitting tensile strength for different concrete mixes

Mix No.	Splitting tensile Strength (MPa)		
	7 day	28 day	90 day
MRef.	2.41	2.95	3.32
MG0.25	4.83	5.96	7.08
MG0.5	5.02	6.1	7.45
MG0.75	5.51	6.36	7.98
MC0.25	4.69	5.84	6.95
MC0.5	4.77	5.93	7.25
MC0.75	5.15	6.25	7.81
MP0.25	2.73	3.89	5.74
MP0.5	3.06	4.15	5.93
MP0.75	3.18	4.34	6.31

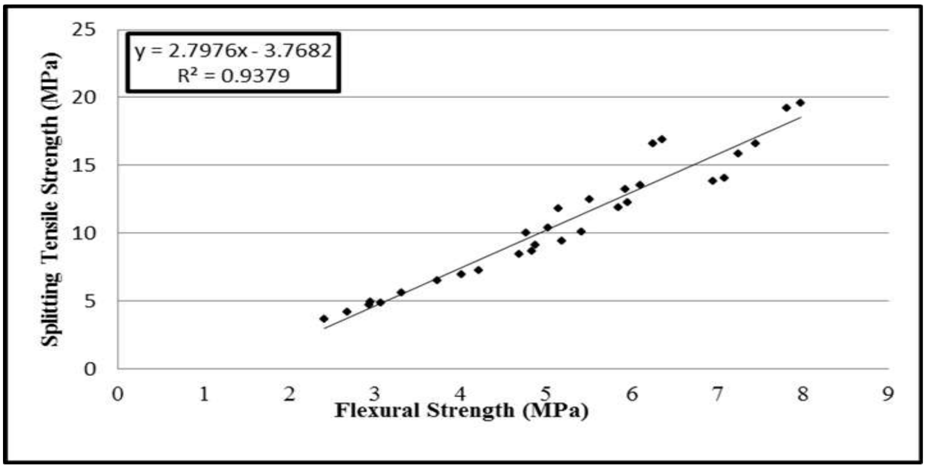
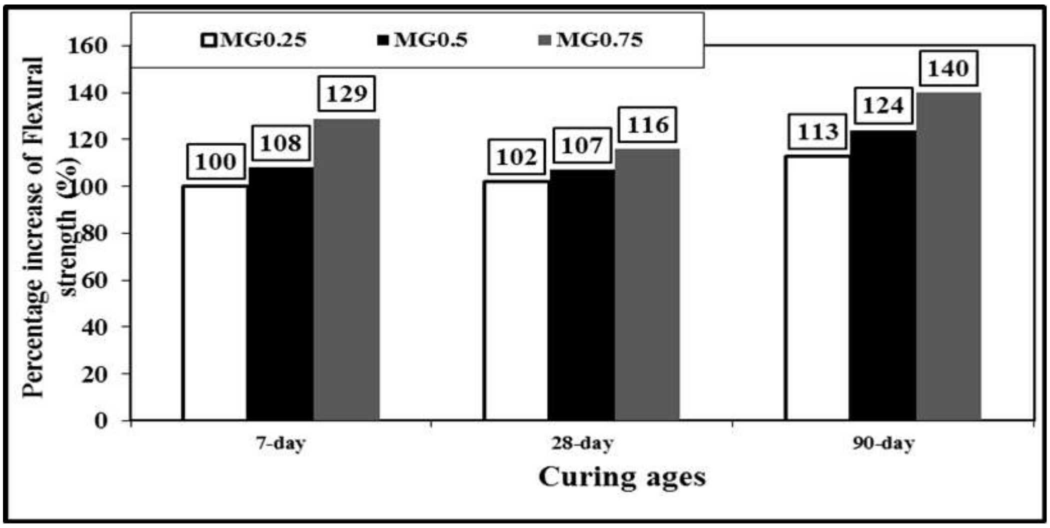
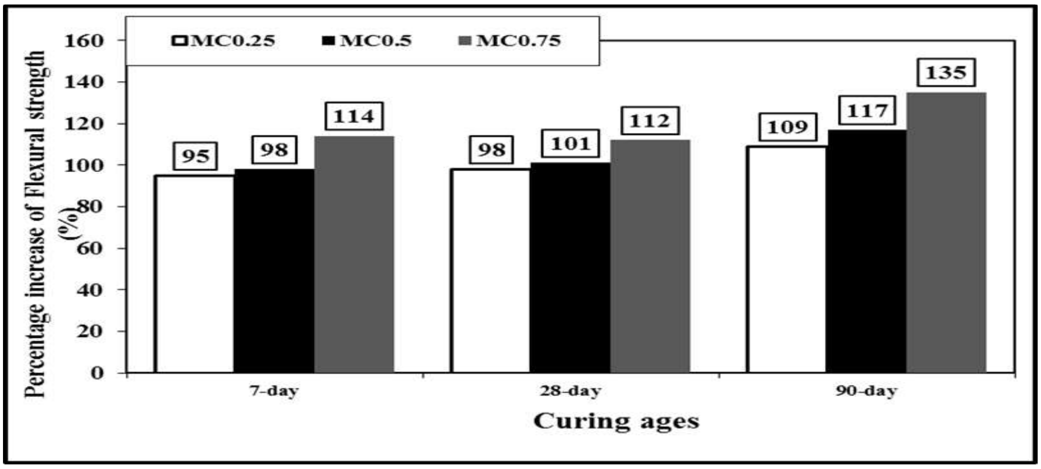


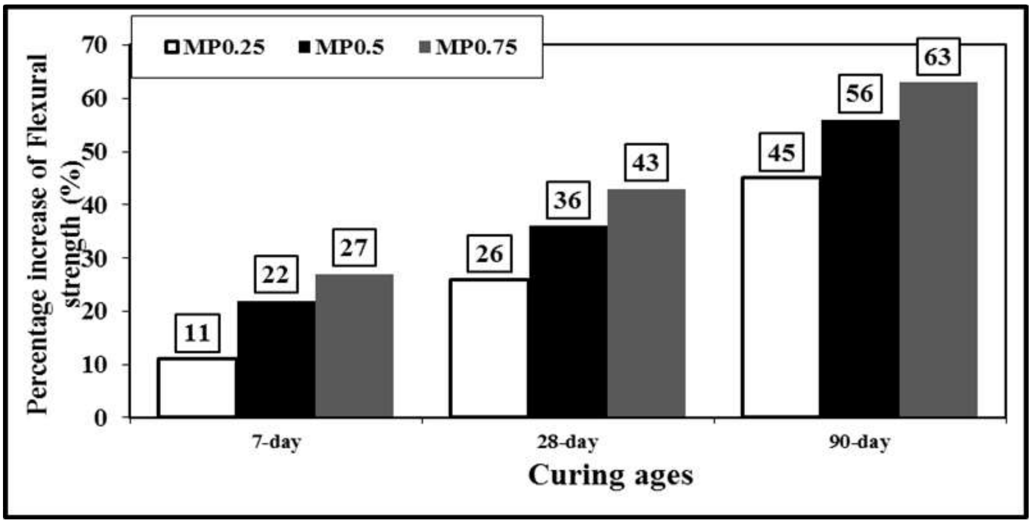
Fig.7 Flexural strength verses splitting tensile strength



(a) Glass



(b) Carbon



(c) Polypropylene

Fig.6 Percentage increase in splitting tensile strength for different types of fiber with curing ages

6. CONCLOSIONS

The main f conclusions are drawn:

1. The accelerated strength results with 82°C curing method for reinforced concrete mix with glass, carbon and polypropylene fiber is higher than 55°C curing method.
2. The maximum percentage increase of reinforced concrete with (glass, carbon and polypropylene) at 0.75% fiber addition of compressive strength up to (22, 12 and 13) %, (19, 11 and 12)% and (3, 1 and 1.5)% at (7, 28 and 90) days, respectively as compared to the reference concrete mix.
3. The density for all mixes increases when the carbon and glass fiber percentage increase, while for polypropylene fiber, the density decreases when its percentage increase.
4. The flexural strength for reinforced concrete with (glass, carbon and polypropylene) fiber reached to maximum percentage increase at 0.75% addition up to (129, 116 and 140) % , (114, 112 and 135) % and (27, 43 and 63) % at (7, 28 and 90) days, respectively as compared to the reference concrete.
5. The splitting tensile strength of 0.75% fiber addition (glass, carbon and polypropylene) achieved the maximum percentage increase up to (240, 244 and 249) % , (221, 237 and 242) % and (32, 47 and 75) % at (7, 28 and 90) days, respectively as compared to the reference concrete.

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تأثير الانضاج المعجل على الخرسانة المسلحة بالالياف

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الخلاصة

تبنى هذا البحث دراسة مختبرية لطريقة الانضاج المعجل بدرجة حرارة 55 و 82 درجة سيليزية وفقا للطريقة البريطانية. كما صممت الخلطة وفق الطريقة الامريكية (ACI) ولمقاومة انضغاط 35 ميكاباسكال وبنسبة خلط (1:2,65:3,82) لكل من الاسمنت, الركام الناعم والركام الخشن على التوالي وبنسبة تسليح حجمية للالياف (0,25, 0,5 و 0,75)% لكل من الزجاج, الكاربون والبولي بروبيلين.

من النتائج المختبرية تبين ان طريقة الانضاج المعجل بدرجة حرارة 82 درجة سيليزية تعطي مقاومة انضغاط اعلى من درجة الحرارة 55 درجة سيليزية ولكل الخلطات. اضافة الى ان تسليح الخرسانة بنسبة 0,75% من الالياف تعطي مقاومة انضغاط ومقاومة انثناء ومقاومة انشطار اعلى من بقية النسب المستخدمة لكل انواع الالياف ولمختلف الاعمار المدروسة.