Stress-Strain Relationship for Steel-Fiber Reinforced Polymer Modified Concrete under Compression

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Abstract

The present study, concern about an experimental work to study the stress-strain relationship of steel-fiber reinforced polymer modified concrete under compression.

Four different mixes with weight proportions of (1:2:4) were used as; normal weight concrete (NC), polymer modified concrete (PMC) with (10%) of cement weight and two mixes of steel-fiber polymer modified concrete with (1%) and (2%) volume fraction of steel fiber, (SMPC).

The influences of polymer and fiber addition on peak stress, strain at peak stress and the stress-strain curve were investigated for concrete mixes used. For all selected mixes, cubes (150×150×150mm) were made for compressive strength test at (28) days while stress-strain test was caried out on cylinders (150 mm × 300 mm) at the same age.

Results showed an improvement in compressive strength of polymer modified concrete (PMC) over reference mix, the maximum increase of it was (13.2 %) at age of (28) days. There is also an increase in compressive strength with increasing of steel fibers content with comparison to normal concrete, the maximum increases of it were (19.6% and 25.2%) of mixes with 1% and 2% fiber content by volume respectively. In terms of modulus of elasticity, the addition of polymer and the presence of fibers cause a significant increase in it.

The peak of stress- strain curve for normal strength concrete (Mix No.1) was linear whereas it was more sharp for the other mixes. The behaviour of normal strength concrete (Mix No.1) was linear up to 20 % of ultimate strength, while for the mixes with the higher strength i.e. polymer modified concrete and fibers reinforced concrete (Mixes No.2, 3 and 4) the linear portion increases up to about 50 % of ultimate strength.

Key Words: Steel fiber Reinforced Concrete, Polymer Modified Concrete, Modulus of elasticity, Concrete Stress-Strain Behaviour.

علاقة الاجهاد-الانفعال للخرسانة المسلحة بالالياف الحديدية والمحورة بالبوليمر تحت الانضغاط

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الخلاصة

تتمحور هذه الدراسة حول الفحصوصات المختبرية لدراسة علاقة الاجهاد-الانفعال تحت حمل الضغط للخرسانة المسلحة بالالياف الحديدية والمطورة بالبوليمر. كما وتم استخدام اربع خلطات بنسب خلط (4:2:1) وكانت عبارة عن خرسانة اعتيادية وخرسانة مطورة بالبوليمر بنسبة وزنية قدرها (10%) وخلطتين لخرسانة مطورة بالبوليمر ومسلحة بالالياف الحديدية بنسب حجمية (1%) و (2%).

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تم في هذه البحث دراسة تاثير اضافة البوليمر (SBR) والالياف الحديدية على الاجهاد الاقصى، الانفعال عند الاجهاد الاقصى و طبيعة الاجهاد-الانفعال للخرسانة المستخدمة. تم فحص مقاومة الانضغاط بعمر (28) يوم باستخدام مكعبات بابعاد (150×150×150) ملم بينما تم دراسة منحني الاجهاد-الانفعال باستخدام اسطوانات بابعاد (150×300) ملم.

اوضحت النتائج المختبرية بان هناك تحسن في مقاومة الانضغاط بعمر (28) يوم عنها للخلطة المرجعية (خلطة رقم 1) بمقدار (13.2%) للخلطة الحاوية على البوليمر (خلطة رقم 2) وكانت هذه الزيادة بمقدار (19.6%) و (25.2%) للخلطتين الحاويتين على البوليمر والالياف الحديدية بنسب حجمية (1%) و (2%) على التوالي. كما اظهرت النتائج بان اضافة البوليمر او/ و الالياف الحديدية أدى الى زيادة ملحوظة في معامل مرونة الخرسانة المنتجة.

اثبتت النتائج بأن تصرف منحني الاجهاد-الانفعال للخلطة المرجعية (خلطة رقم 1) كان خطياً الى (20%) من الاجهاد الاقصى بينما ازداد التصرف الخطي للخلطات الاعلى مقاومة (الخرسانة المحورة بالبوليمر والمسلحة بالألياف) ليصل بحدود (50%) من الاجهاد الاقصى.

1. Introduction

Concrete has occupied an important place among construction materials and is widely used in all types of civil engineering structures ranging from small buildings, as a result the durability of concrete structure becomes a key issue for concrete technology recently(1).The behaviour of concrete is quite complex because this behaviour depends on rate of loading, materials properties and proportions, chemical and physical characteristics of materials, curing conditions, dimensions of specimens, etc[2].

Concrete is not a perfectly elastic material because of generation and propagation of micro cracks under loading and this will influence the shape of the stress–strain relation and the magnitude of the modulus of elasticity[3].

The stress–strain relation for concrete is very important for designing requirements. This relation is useful for calculating the modulus of elasticity which depends generally on maximum compressive strength(2).Normal concrete with different densities ranged between 2300-2600kg/m3 shows a stress strain relationship graph that is approximately linear up to (30-40)% of ultimate strength. Also for normal concrete, the peak of the curve of stress – strain is intermediate between sharp peak for high strength concrete and flat top for low strength concrete[4].

A number of empirical expression describing the stress-strain diagram of plain concrete have been reported by several researchers [5,6,7,8]. However, in these equations the effect of additives such as fibers has not been accounted for in the constant parameter of them.

The use of polymer modification for cement mortar and concrete is not new. In 1923 using polymers “as an admixture” which consists of polymeric compound to improve properties such as strength, modulus of elasticity, water proof, durability of cement mortar and concrete.

Among various concrete types, concrete modified by polymers is increasingly used in construction . Jo et al (2008)[9], reported that compared to cement-based concrete, polymer concrete is stronger and more durable. For this reason, polymer concrete is used in many structures such as box culverts, hazardous waste containers, trench lines, floor drains, and in the repair and overlay of damaged cement concrete surfaces such as pavement and bridges.

Polymer concrete (PC) such as polyester concretes are viscoelastic and will fail under sustained compressive loading at stress levels greater than 50% of ultimate strength. Sustained loading at a stress level of 25% did not reduce ultimate strength capacity for loading period of 1000 hr [10].

Rapid setting organic polymers are used in PC as binders; the most popular binders currently in use are epoxy, polyester, and methyl methacrylate. Studies on epoxy and polyester polymers have shown that the strength, failure strain, failure mode and stress – strain relationships are influenced by curing method and strain rate[11].

Use of steel-fiber reinforced concrete has steadily increased during the last 25 years. Considerable developments have taken place in the field of steel-fiber reinforced concrete as reported by Bentur and mindess(12,13). The current field of application of steel-fiber reinforced concrete include highway and air port field pavements, hydraulic structures, tunnel linings (12,14,15).
To design and analyze structures using steel-fiber reinforced concrete for compression, the stress-strain behaviour of material is needed. The stress-strain curve is needed to evaluate the toughness of the material for consideration of ductility (12). Balaguru and Shah (1992)(16), have reported the effect of addition of steel-fibers on compressive strength ranges from negligible to marginal and also observed considerable increase in strain at peak stress and the toughness of the material.

2- Experimental Program:

2-1 Materials

The materials used in this research are described as follows:

2-1-1 Cement

Cement type I (ordinary Portland cement) of Kubaisa Factory for cement production was used in this study. Chemical compositions and physical analysis of this type are shown in Tables (1) and (2) respectively. The results indicated that the available cement conforms to the Iraqi specifications (IQS) No.5–84[17].

2-1-2 Fine Aggregate

The fine aggregate used is natural sand having a fineness modulus of 2.65 and a water absorption of 1.3% obtained from Kubaisa region. It was clean, free of organic impurities and deleterious substances and relatively free of clay. The grading of sand is conforming to the requirements of the British Standard BS EN 882-1983 (18), zone (2), as shown in Table (3).

2-1-3 Coarse Aggregate

The coarse aggregate used in this work is a mixture of crushed and rounded gravel brought from Samarra region . All aggregates were saturated surface dry. The specific gravity and absorption were 2.72 and 0.9% respectively. Table (4) shows the grading of this aggregate; this Table gives the limits specified by the British Standard BS 882-1983 (18).

2-1-4 Water

Drinking tap water is used for mixing, and for curing the concrete.

2-1-5 Polymer

Styrene-Butadiene-Rubber (SBR) is the type of polymer which is used in this study. It is copolymers produced from butadiene and styrene. Latex is typically included in concrete in the form of a colloidal suspension polymer in water. This polymer is usually a milky-white fluid. The emulsion polymerization of latex modifies the concrete structure system through two processes, cement hydration and film formation(19). The chemical structure of styrene-butadiene (SBR) polymer is given in Table (5) (20)...SBR is used as a ratio by weight of cement of (10) % for mixes No. 2, 3 and 4.

2-1-6 Fibers

The steel fiber used in this investigation was crimped along the length (undulated) and having a tensile strength of 550 MPa. Two fiber volume fractions (1 and 2)% and were used in Mixes (3 and 4) of this study.

2-2 Mix Proportions

The concrete mix 1: 2: 4 (by weight) of ordinary Portland cement: fine aggregate of maximum size 4.75 mm: coarse aggregate of maximum size of 20 mm is chosed to study the effects of adding steel fibers .The mix proportions are given in Table (6). Four mixes namely, normal concrete (NC), polymer modified concrete (PMC) and two mixes of steel fiber polymer modified concrete (SPMC) were used. Mix No.1 (NC) was without polymer and steel fiber while Mix No.2 (PMC) has SBR polymer of 10% of cement weight. In addition, the other two mixes were with SBR and steel fiber as volumetric ratios of 1% and 2% for Mix No.3 and No.4 respectively.

2-3 Concrete Mixing

A mechanical mixer of (0.07) m3 capacity, operated by electrical power was used. The ordinary method was used in mixing normal concrete, Mix No.1. With regard to Mix No.2, first of all aggregates and cement were added before adding polymer and dry mixing are continued until the dry mix became homogeneous. Then the polymer was added until all particles are fully coated with polymer and finally water is added and mixing continues until uniform mix is obtained. This procedure is similar to the method used by Ohama(21). Mixes No.3 and 4, the dry cement and aggregates are mixed first and the mixing continued while about 80% of water was added. After that, the fibers were then fed continuously to the mixer. Finally, the remaining water along with polymer was added and the mixing was continued for a suitable time.

2-4 Preparation of Samples

The procedure of preparation of samples in this study was done conforming with ASTM – Designation: C 192/C 192/M- 2002[22].

In molding the specimens, concrete mixes are placed in layers and used the manual vibrate with each layer. After filling the molds, the surfaces of the specimens were planed by using a trowel. All specimens were removed from moulds within 24 hours after molding. It should be noted that the specimens shall not be removed from molds until danger of damage to the specimens is past. After the test specimens were removed from the molds they have been stored in water for 28 days.

3- Tests

3-1 Density Test

This test was carried out according to ASTM C642-97 [23] .

3-2 Compressive Strength Test

Compressive strength was determined at age of 28 days using (150×150×150) mm cubes according to B.S.1881 part 116 (24) . ELE machine with a capacity of (1000) kN was used for that test. For all mixes, the average compressive strength of three cubes was recorded.

3-3 Stress-Strain Test

The modulus of elasticity test was done according to ASTM – Designation : C 469 – 2002 (25) . This test was carried out on cylindrical specimens with diameter equal to 150 mm and height equal to 300 mm , at an age of 28 days .Mechanical strain gauge (Extensometer) of effective length equal to (200mm), type ELE and designated for 150mm×300 mm cylindrical specimens only, was used for the determination of strain in this test . An extensometer was fixed on concrete specimen before testing so that the horizontal arms of it should be equal in distance from top and bottom of the concrete specimen, (see Fig. (1)). After fixing the strain gauge, the specimen was ready for testing where it was subjected to a constant stress rate according to ASTM- Designation: C469 – 2002 [(26).]

Strain values were obtained by dividing each dial gauge reading by the effective length of the strain gauge. Stress values were obtained by dividing each testing machine load by the cross sectional area of the concrete specimen. For all mixes, three test specimens were used for stress – strain test. From stress and strain readings which were obtained in this test, stress – strain curves have been drawn.

Table (1) Chemical composition of cement used*

Oxide chemical composition	*Content %*	*Limits of I.S. No5/1984*
SiO_2	21.5 ± 0.5	-
Al_2O_3	5.70 ± 0.3	-
Fe_2O_3	3.25 ± 0.1	-
CaO	62.5 ± 1.0	-
MgO	2.70 ± 0.3	≤ 5%
SO_3	2.50 ± 0.2	≤2.8%
Insoluble Residue	0.5	≤ 1.5
Free Lime	1.5	066 – 1.02
Loss on Ignition	0.78	≤ 4%

Table (2) Physical analysis of cement used *

Test Name	*Result*
Specific surface area,Blain Method, m^2/kg	3300 cm^2 / g
Density of cement	3.15 g/cm^3
Soundness by Autoclave Method	0.22%
Setting Time	
Initial	70 min.
Final	290 min.
Compressive Strength	
3 days	25 MPa
7 days	33 MPa

* The values were obtained from Kubaisa Cement Plant.

Table (3) Grading of Fine Aggregate

No	Sieve Size (mm)	Percent Passing	
		Fine aggregate	Limits of British Standard BS 882-1983 (18) Zone 2
1	9.50	100	100
2	5.00	97	90-100
3	2.36	90	75-100
4	1.18	81	55-90
5	0.6	57	59-35
6	0.3	29	12-40
7	0.15	8	8-30
8	0.075	4	0-10

Table (4) Grading of Coarse Aggregate

No	Sieve Size (mm)	Percent Passing	
		Coarse aggregate	Limits of British Standard BS 882-1983 (18)
1	37.5	100	100
2	20	97.3	95-100
3	10	42.4	30-60
4	5	5.1	5-10
5	2.36	-----	-----

Table (5): Specifications of styrene-butadiene rubber (SBR) polymer. used

Specifications	Given by the Company	Test Results
Appearance	White emulsion	-
Specific Gravity	1.02 ± 0.2 @ 250 c	1.01
PH value	7 - 10.5	9.83

Table (6) Mix proportions of Mixes

Mixes Proportion	No.1 (NC)	No.2 (PMC)	No.3 (SPMC)	No.4 (SPMC)
W/C ratio	0.55	0.55	0.55	0.55
Polymer/Cement ratio (%)	0	10	10	10
Fiber volumitric ratio (%)	0	0	1	2
Cement content (kg/m^3)	319	329	329	329
Water content (kg/m^3)	175	148	148	148
Fine agg. Content (kg/m^3)	638	659	659	659
Coarse agg. content (kg/m^3)	1277	1319	1319	1319
Polymer SBR content (kg/m^3)	0	33	33	33
Steel fiber content (kg/m^3)	0	0	80	158

Fig. (1) Extensometer fixed to a cylindrical specimen during test for stress strain relationship

4- Results and Discussion:

The main parameters that characterise the compressive behavior of concrete are the compressive strength, the slope of the ascending branch (modulus of elasticity), the strain at peak stress and the area under σ-ε curve (toughness).

This section deals with discussion of compressive behaviour including stress-strain relatioship for steel-fiber reinforced polymer modified concrete under compression.

4-1 Density

The results of density of all selected mixes at age of (28) days are calculated as described in section 3-1 . Table (7) shows the results of the average density of three specimens for each mix.

From Table (7), it would appear that the density of Mix No.2, with polymer, is higher than it for Mix No.1. This increase in density might be due to the reduction in W/C ratio and the increase in compaction, where the polymer latex addition into fresh concrete causes the effect almost typical to that of admixtures like superplasrisizer which leads to better workability results that are known as ball-bearing influence of surface active substance in polymer latex(26). While the increase in density for Mixes No.3 and No.4 is because the precense of steel-fibers in addition of polymer.

4-2 Compressive Strength

The results of compressive strength test of all selected mixes at age of (28) days are obtained from the average of three cubes and presented in Table (7), these results showed an improvement in compressive strength of polymer modified concrete (PMC) comparison to reference mix (NC), the maximum increases of it were (13.2%). An improvement in the compressive strength is found to be due to a reduction in W/C ratio with polymer modification. For PMC with (P/C=10%) , it appears that the pore size distribution of the paste and the strength of polymer films formed in them markedly affect the compressive strength. A ductile mode of failure, as compared to reference concrete’s brittle failure, is observed in testing for compressive strength. The change of mode of failure from a brittle type to a ductile type is an important contribution due to the addition of polymers.

It seems in comparison with reference mix (NC), there is also an increase in compressive strength with increasing of steel fibers content, the maximum increases of it were (19.6% and 25.2%) of mixes with 1% and 2% fiber respectively. The reason is may be the reinforement provided by steel fibers can work at both a micro and macro level. Fibers arrest the development of microcracks, leading to higher compressive strength, whereas at a macro level fibers control crack opening, increasing the energy absorption capacity of the composite[(27)].

It should be pointed out that the density increases with addition of polymer and fiber which is leading to increase of compressive strength. Fig.(2) illustrates that the compressive strength increases with increasing in density.

4-3 Modulus of Elasticity Test

The chord modulus of elasticity of each mix is determined by using (ASTM-C-469) (25), as follows:

$$Ec = \frac{S_2 - S_1}{\varepsilon_2 - \varepsilon_1} \qquad (1)$$

Where:

Ec= chord modulus of elasticity (MPa) ,

S2 = stress corresponding to 40 % of ultimate load (F´c)(MPa),

S1 = stress corresponding to a longitudinal strain, ε1 (MPa) ,

ε2 = longitudinal strain produced by stress, S2 , ε1 = 0.00005.

The test results are shown in Table (8). Figure (3) illustrates the relation between compressive strength and modulus of elasticity, and also shows the presence of fibers causes an increase in modulus of elasticity. However, opposite behaviour has been reported by other authors(28,29). The reason of this increase in modulus of elasticity is the ability of the fibers to control microcracking growth during loading which is leading to decrease the strains with increase the stresses, see figure (4).

With comparison to normal concrete, concrete developed by polymers gives higher strength and higher modulus of elasticity.

4-4 Stress-Strain Test

The strains at peak for all mixes used in this investigation are presented in Table (8) also Figure (5) illustrates the stress-strain curves for these mixes.

Although cement paste and aggregates individually have linear stress-strain relationships, the behavior for concrete is non-linear. The reasone for that is presonce of microcracking created at the interfiatial transation zone between cement paste and aggegates. Therefore, the nature of the stress-strain curve is related to internal microcrack development. A typical strees-strain curve for normal weight concrete is illustrated in Figure (6)30. It is obvious that after an initial linear portion, the curve becomes non-linear since the coalesence of microcracks at the paste-aggregate interface and then the ultimate stress is reached when a large crack network is formed by bridging between bond and matrix cracks.

Researchers have suggested that different kinds of defects called microcracks exist in the interior system of concrete before loading, these will play great role in failure mechanism of concrete and then in stress-strain behaviour.

Although the strain corresponding to ultimate stress is usually around 0.003 for normal concrete, it was 0.00475 in this investigation. The reason is may be because there is no enough vibration (manual vibrate) during production process which leads to leave air voids inside concrete as well as microcracks in interfacial transition zone. In addition, all specimens were not covered with thick nylon to prevent the evaporation which may be led to generate more defects. This effect is reflected to the compressive behaviour of the rest mixes which gave strains at peak (0.0040, 0.0035 and 0.003) for Mixes No.2, 3 and 4 respectively.

It would appear that both ascending (pre-peak response) and descending (post-peak response) portion of the stress-strain curve is affected by the addition of polymer and steel fibers. In this investigation, only the ascending part up to the peak point was investigate, while the descending part is not shown because of the lack of the appropriate testing facilities. With increasing strength of concrete, the brittleness also increase and this is proved by reduction of strain at ultimate stress because the presence of both steel fiber and polymer together. From Figure (7), it would seem that SPMC (Mix No. 4) is a typical brittle material because a higher fraction of steel-fiber (2%) with polymer would lead to increase the ultimate stress and decrease the strain at peak. In addition, It is obvious that the stress- strain relationship for Mix (1), (NC), is of flat top, while for the other mixes (with higher strength) peaks become sharper. Moreover, the departure for the ascending portion of NC stress- strain curve (Mix No.1) is linear up to (20 %) of ultimate strength, while for higher strengths (Mixes No.2, 3 and 4) the linear portion increases up to about (50 %) of ultimate strength. This is because of the presence of each polymer and steel fiber may lead to arrest both of bond cracks at micro level and matrix cracks at macro level resulting in reduce propogation and interaction of them with elastic behaviour for concrete.

5- Conclusions

1. According to the results obtained from the experimental work, the following conclusions can be give:
2. The addition of SBR and Steel fiber slightly increases the unit weight of concrete .
3. Comparison with reference mix, an increase in compressive strength at age of 28-day was (13.2%) for Mix No.2 (PMC) and (19.6% and 25.2%) for mixes with 1% and 2% volume fraction of steel fiber, (Mix No.3 and No.4), respectively.
4. There is a significant improvement in modulus of elasticity with adding polymer and steel fiber to concrete.
5. The existence of steel fiber leads to arrest the development of microcracks and control macrocracks, therefore the compressive strength and modulus of elasticity increase.
6. The stress-strain relationship of concrete is found much influenced by adding steel fiber and/or polymer to it by giving both higher compressive strength and less strain values.
7. The stress- strain relationship for normal strength concrete is of flat top, while for the other mixes (with higher strength) peaks become sharper.
8. The departure for the ascending portion of stress- strain curve of normal strength concrete is linear up to (20 %) of ultimate strength, while for higher strengths (Mixes No.2, 3 and 4) the linear portion increases up to about (50 %) of ultimate strength.

Table (7) Results of density and compressive strength of mixes

Mixes	Density (Average) (kg/m^3)	Compressive Strength (MPa)
No.1 (NC)	2315	26.5
No.2 (PMC)	2360	30
No.3 (SPMC)	2410	31.7
No.4 (SPMC)	2475	33.2

Table (8) Results of strain at peak and secant modulus of elasticity

Mixes	Strain at peak ($*10^{-4}$)	Ec (MPa) ($*10^3$)
No.1 (NC)	47.5	8.3
No.2 (PMC)	40	9.16
No.3 (SPMC)	35	11.7
No.4 (SPMC)	30	12.9

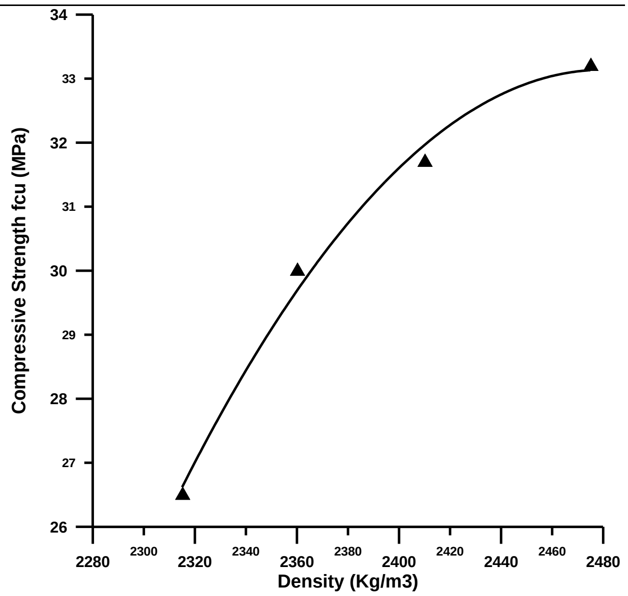

Fig.(2) The relationship between density and compressive strength of mixes used

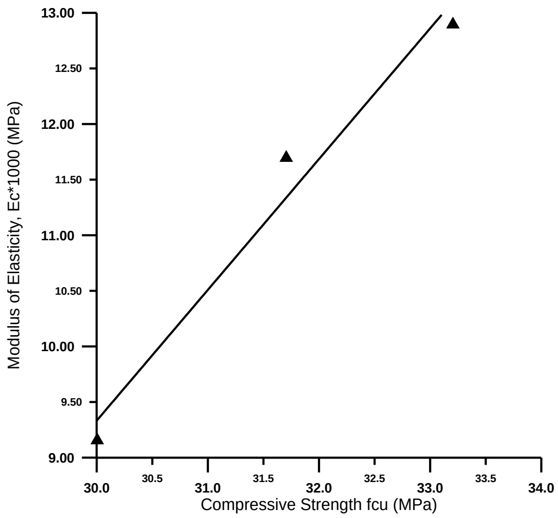

Fig.(3) The relationship between compressive strength and modulus of elasticity of mixes no. 2, 3 and 4.

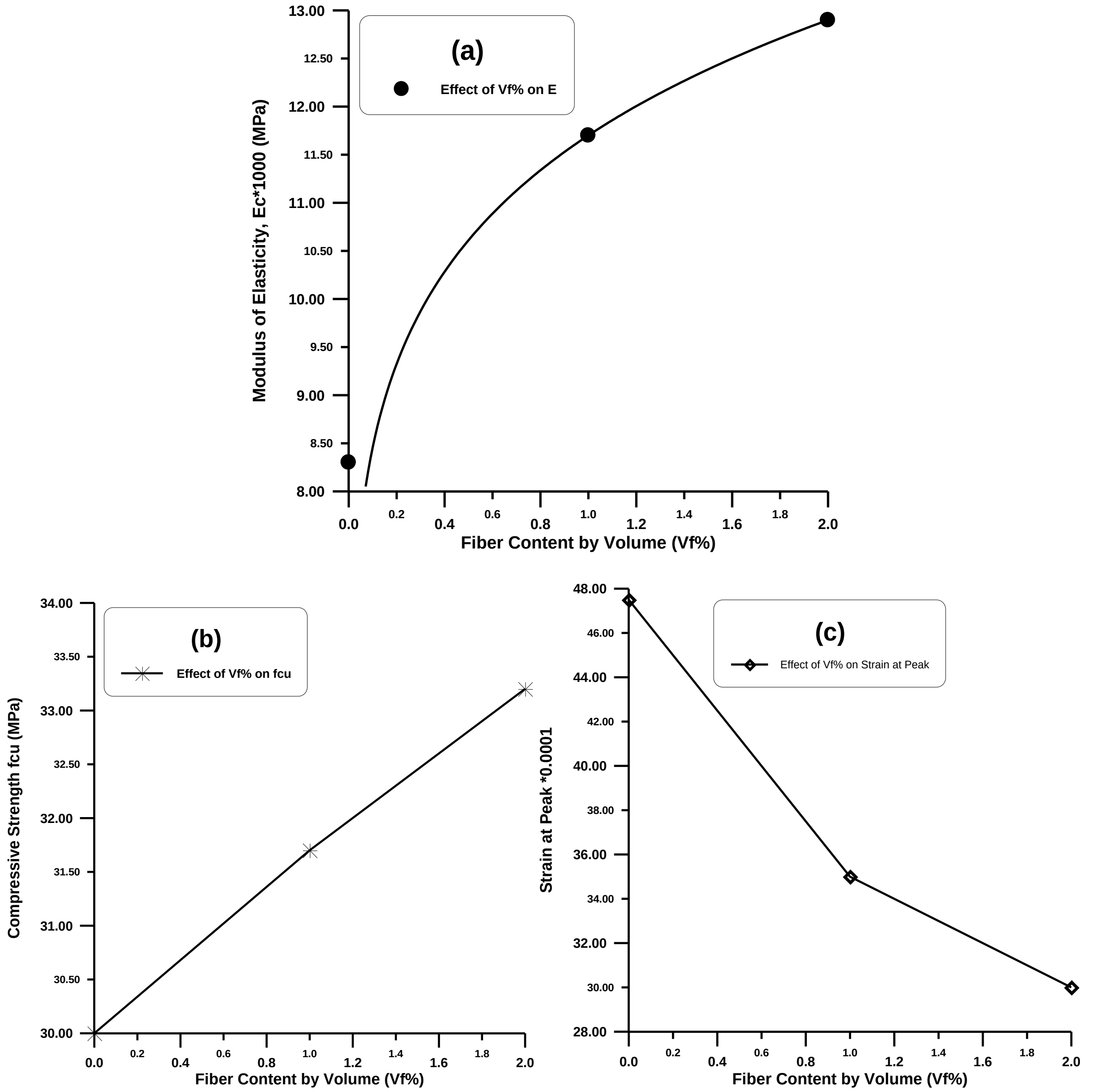

Fig.(4) The effect of fiber content on a) modulus of elasticity, b) compressive strength and c) strain at peak of mixes No. 2,3 and 4

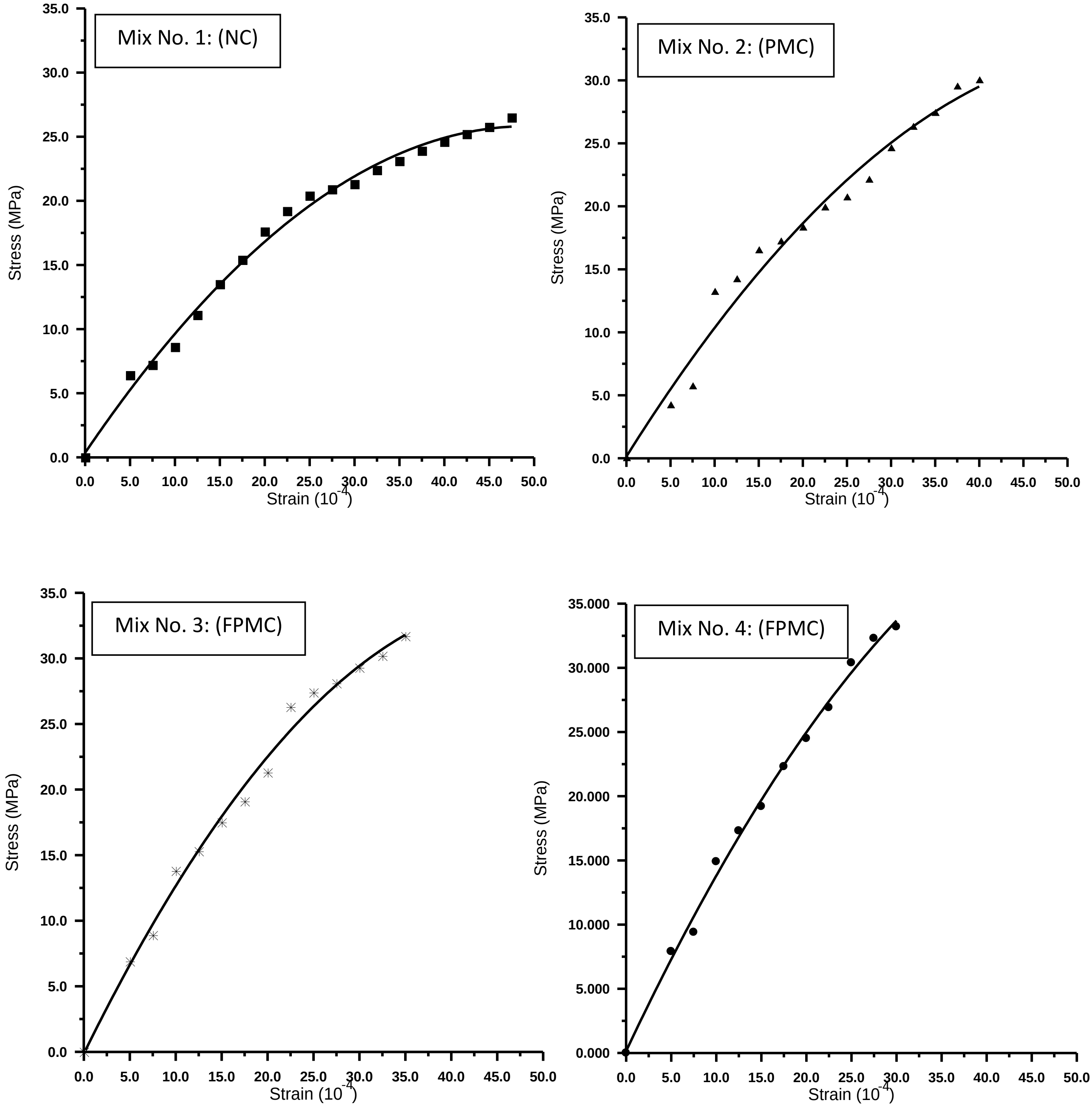

Fig.(5) Stress-strain curves for mixes No. 1, 2, 3 and 4

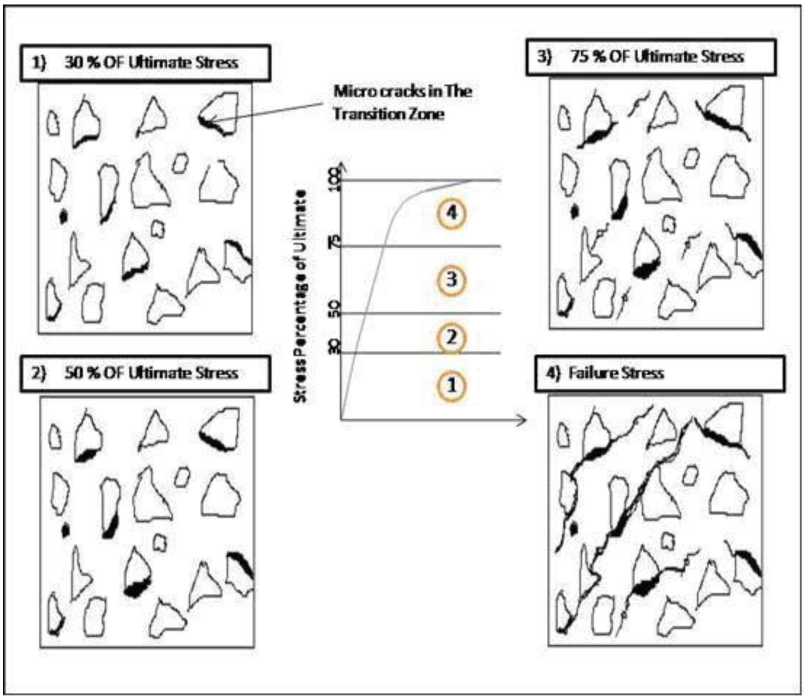

Fig.(6) Stress-strain relationship for ordinary concrete30

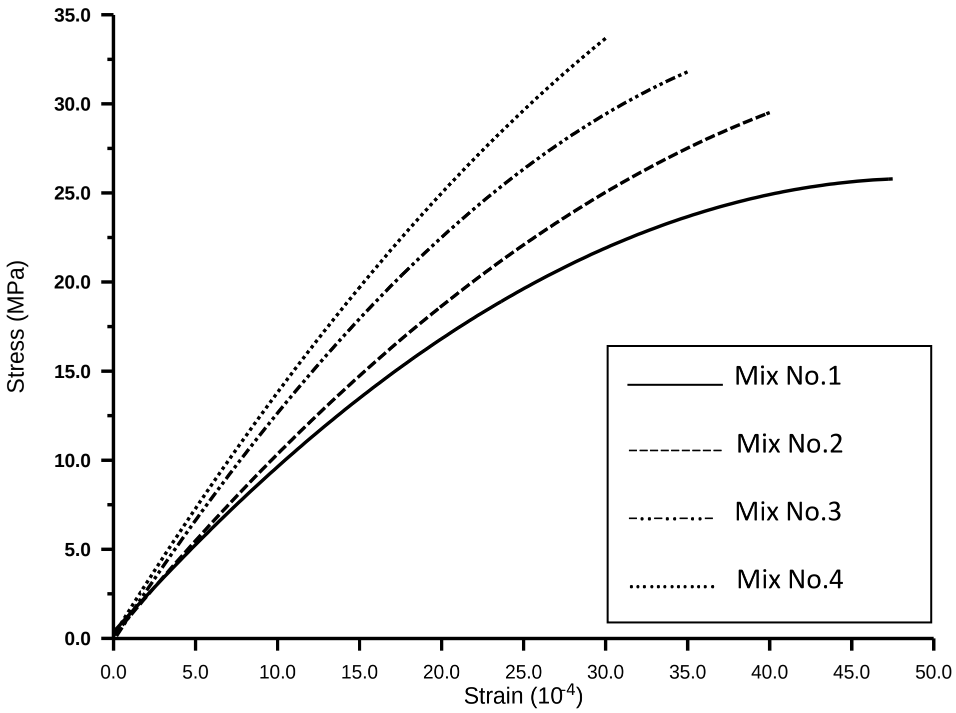

Fig.(7) Stress-strain curves for all mixes used

References

1- Al-Kubaisy , S. J. " Durability of polymer modified concrete in acidic conditions . " M . Sc. Thesis , Dep . of Civil Eng ., Univ . of Al – Anbar , 2006 .

2- Jabal , Q. A. " Complete Stress- Strain Relationship for No- fines Polymer Concrete in Compression . " M . Sc. Thesis , Department of Civil Engineering, University of Anbar , 2002 .

3- Shetty, M. S., "Concrete Technology Theory and Practice." S. Chand and Company, India. 3rd. Ed., 1988.

4- Park, R. and Paulay, "Reinforced Concrete Structures." John Wiley and Sons, 1975, 769p.

5- Wang P.T., Shah S.P., Naaman A.E." Stress-strain curves of normal and lightweight concrete in compression." ACI Journal;75(11), 1978:603-11.

6- Carreira D.J., Chu K.H. "stress-strain relationship for plain concrete in compression." ACI Journal;82(6), 1985:797-804.

7- Wee T.H., Chin M.S., Mansur M. A."Stress-strain relationship of high-strength concrete in compression." ASCE Journal of Materials in Civil engineering;(2), 1996:70-6.

8- Ohama, Y., "Recent Progress in Concrete Polymer Composites." Advn Cem Bas Mat, New York, 1997: 31-40.

9- Byung J, Seung P, Jong P " Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates." Construction and Building materials 22 (2008) 2281-2291.

10- Mindess, S. and Young, J. F., "Concrete" Prentice-Hall, INC., New Jersey, 1981.

11- Vipulanandan, C. and Paul, E., "Mechanical Properties of Epoxy and Polyester Polymers and Polymer Concrete Systems." Report No. UHCE 88-13, University of Houston, 1988.

12- Nataraja M.C., Dhang N., Gupta A.P. "Stress-strain curves for steel-fiber reinforced concrete under compression." Cement and Concrete Composites 21 (1999) 383-390.

13- Bentur A, Mindess S "Fiber reinforced cementitious composites." UK:Elsevier, 1990.

14- ACI Committee 544. "State of the art report on fiber reinforced concrete." ACI 544.1R-1996 (Reapproved 2002). Manual of Concrete Practice.

15- ACI Committee 544. "Measurement of properties of fiber reinforced concrete." ACI 544.2R-1989 (Reapproved 1996). Manual of Concrete Practice.

16- Balaguru N, Shah S "Fiber reinforced cement composites." New York: McGraw-Hill 1992:179-214.

17- المواصفة العراقية الخاصة بالسمنت(5)

18- British Standard, B.S. 882-1983 "Standard Specification for Concrete Aggregates".

19- Ohama, Y., "Polymer-Based Admixtures." Cement and Concrete Composites J., 20,1998: 189-212.

20- Sujjavanich, S., and Lundy, J.R. "Development of Strength and Fracture Properties of Styrene-Butadiene Copolymer Latex-Modified Concrete" ACI Materials Journal, Vol.95, No.2, March-April 1998,pp.131-143.

21- Ohama, Y., and Sugahara, T., "Impact Resistance of Steel Fiber Reinforced Polymer Concrete ", the Twenty Fourth Japan Congress on Materials Research. The Society of Material Science, Japan, 1981, pp.254-257.

22- ASTM Committee , C 192/C 192/M. " Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. " 2002.

23- ASTM C642-97," Standard Test Method for Density, Absorption and Void in Hardened Concrete ", Annual Book of ASTM Standard, Vol. 04.02, 2003.

24- British Standard Institute BSI, B. S. 1881: Part 116:1983, "Method for Determination of Compressive Strength of Concrete Cubes".

25- ASTM Committee , C 469. " Standard Test Method for Static Method of Elasticity and Poisson's Ratio of Concrete in Compression." 2002.

26- Membarkia, S. And Vipulanandan, C.,"Michanical Properties and Water Diffusio in Polyster Polymer Concrete", Journal of Engineering Mechanics- ASCE. 121(12), Dec., 1995, pp. 1359-1365.

27- Neves, R. And Gonμalves, A. "Steel fiber reinforced concrete-ductility related properties." LNEC, Lisbon, 2000.

28- Rossi, P. and Harrouche, N.," Mix design and mechanical behaviour of some steel libre-reinlorced concretes used in reinforced concrete structures. Materials and Structures 23, No. 136, , 1990: 256-266.

29- Mansur, M, Chin, M. and Wee, T. stress-strain relationship of high-strength fiber concrete in compression. Journal of Materials in Civil Engineering Vol 11, No. 1, 1999:21-29.

30- The Internet, " Stress-strain behaviour of concrete." < WWW. Theconcreteportal.com/cons_rel.html.> [accessed April 2011].