Effect of Plastic Fibers on Properties of Foamed Concrete

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ABSTRACT

The main objective of this work is to study the effect of adding plastic fibers on Lightweight Aggregate Foamed Concrete (LWAFC) using mix proportion of 1:2.6:0.4 by volume (cement: fine Porcelanite: coarse Porcelanite) with 2% foaming agent by weight of water, and using sand as a partial and total replacement of local Porcelanite aggregate in that mix.

The properties of lightweight aggregate foamed concrete reinforced with different percentages of plastic fiber (0.5, 0.75, and 1% by volume) were studied. Compressive strength, splitting tensile strength, flexural strength, dry density, initial surface absorption, water absorption, ultrasonic pulse velocity, acoustic impedance, and impact resistance tests were conducted on mixes at ages of 7, 28, and 60 days.

The results showed a significant increasing in impact resistance, splitting tensile strength, and water absorption 34.55%, 4.2%, 326%, and 27.3% respectively. While the results indicated that the compressive strength, ultrasonic pulse velocity, dry density and acoustic impedance of the composites were reduced when the crimped plastic fiber volume fraction increases. The percentage of reduction of these properties was 15%, 11.1%, 6.23%, and 12.55% respectively.

Keyword: Lightweight Aggregate, Porcelanite, Foamed Concrete, Plastic Fiber.

تأثير الألياف البلاستيكية على خواص الخرسانة الرغوية و الخفيفة الوزن

الخلاصة

إن الهدف الرئيسي لهذا البحث هو دراسة تأثير إضافة الالياف البلاستيكية على الخرسانة الرغوية الخفيفة الوزن باستعمال نسب خلط حجمية ١ ، ٢,٦ ، ٠,٤ (سمنت : بورسيلانايت ناعم : بورسيلانايت خشن) وباضافة ٢% من المادة الرغوية كنسبة وزنية من الماء وباحلال الرمل كبديل جزئي أو كلي من ركام البورسيلانايت المحلي في الخلطة.

تمت دراسة استعمال الالياف البلاستيكية بنسب حجمية مختلفة (٠,٥ ، ٠,٧٥ ، ١,٠%) لتسليح الخرسانة الرغوية الخفيفة الوزن. تم إجراءفحوصات مقاومة الانضغاط و مقاومة الشد و

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فحص الانثناء و مقاومة الصدم والكثافة الجافة و الامتصاص السطحي الاولي و الامتصاص الكلي وسرعة الذبذبات الفوق الصوتية والمعاوقة الصوتية للخلطات بأعمار ٦٠،٢٨،٧ يوماً.

بينت النتائج زيادة ملحوظة في مقاومة الصدم و مقاومة شد الانفلاق و امتصاص الماء و التي بلغت ٣٤,٥٥% , ٤,٢% , ٢٧,٣% على التوالي مع زيادة محتوى الالياف على الرغم من تسجيل انخفاض في مقاومة الانضغاط و الذبذبات فوق الصوتية و الكثافة الجافة و المعاوقة الصوتية مع زيادة محتوى الالياف. وقد بلغ مقدار الأنخفاض في هذه الخصائص ١٥%, ١١,١%, ٦,٢٣%, ١٢,٥٥% على التوالي.

INTRODUCTION

Lightweight concretes (LWC) can be produced with an oven-dry density range of approximately 300 to a maximum of 2000 kg/m^3, with corresponding cube strengths from approximately (1 - over 60) MPa and thermal conductivities of (0.2 - 1.0) W/m K [1]. These values can be compared with those for normalweight concrete of approximately (2100–2500) kg/m^3, 15 MPa to greater than 100 MPa and (1.6–1.9) W/m K.

The concrete is naturally a brittle material, and contains a large number of micro cracks, which are responsible for the weakness in tensile strength of concrete. Therefore the inclusion of fibers as reinforcement is generally thought of as a remedy for the poor tensile strength of cement and concrete. The role reinforcement, however, is not so much in the improvement of static strength as control of cracking. On the other hand, the ability to control on size and amount of cracks will also lead to enhanced durability [2].

RESEARCH SIGNIFICANT

The weather in Iraq is hot in summer and cold in winter. Therefore, the thermal insulation is one of the main problems facing the engineers working in building and housing sector. More recently, there has been a great interest in the production of lightweight building components, which can be used for the purpose of the thermal insulation and acoustic impedance.

The use of such components in buildings has great advantages and causes a great reduction in the energy required for heating and cooling and, consequently, results in cost reduction to a great extent. Such type of lightweight concrete is very much needed in many buildings of importance are present [3]. But due to brittleness of lightweight aggregate foamed concrete, it is suggested to reinforce this concrete with fiber, thus enhancing its properties.

EXPERIMENTAL PROGRAM

Materials

Cement

Ordinary Portland cement type I, manufactured by Al Kubaisa Cement Factory, was used in all mixes throughout this investigation. The percentage oxide composition and physical properties indicate that the adopted cement conforms to the Iraqi specification No. 5/1984 [4], as shown in Table (1)&(2).

Fine Aggregate

Natural sand brought from Al-Aubaidy region in Al-Anbar Governorate - Iraq was used in some mixes, and its gradation lies in zone (3). Results also indicated that the fine aggregate grading and sulfate content are within the requirements of the Iraqi specification No.45/1984 [5], as shown in Table (3).

Porcelanite

Porcelanite stone was used in this study as a coarse aggregate in all mixes and as a fine aggregate in some mixes. It was brought from north of Al-Rutba town in Al-Anbar Governorate – Iraq. It has a white-yellow color and is characterized by high permeability and low density. After crushing, it was used as coarse and fine aggregate with maximum size 9.5 mm and 4.75 mm, respectively.

Foaming Agent

Foaming agent type EUCO from Swiss Chemistry Factory is chloride free Table (4). It was used to produce lightweight concrete by entraining a controlled amount of air bubbles to concrete mix that was brought from Ideal Building Corner (IBC) in Iraq.

Fibers

Plastic fiber for reinforcement was used; it was brought from Sika Company. It was crimped with aspect ratio of 63. The specifications and properties of fiber used throughout the experimental work are illustrated in Table (5).

Mixing Water

Ordinary tap water was used throughout this investigation for mixing and curing for all concrete mixes.

Mixes

First and foremost problem was the developing of a mix design method for foam concrete which is convenient to cover all the factors, it depend upon as well as flexible for wide analysis of results. Neither Indian standards nor ASTM and British Standards specify any definite way of producing foam concrete [6].

After many trials, one reference mix proportion was used in this investigation (1:2.6:0.4) by volume (cement: sand: coarse Porcelanite) and (cement: fine Porcelanite: coarse Porcelanite) except mixes that used (1 :(1+1.6):0.4) (cement: (sand+ fine Porcelanite): coarse Porcelanite) by volume, the details of the mixes used throughout this investigation are given in Table (6).

Casting, Compaction, and Curing

The process of mixing influences the quality of the concrete in the hardened state. The mix material is required to be uniformly distributed and consistent in the concrete mix in order to reduce the weak spots within the concrete specimens. Furthermore, the bond strength between particles and full coating of cement binder to the aggregate and fiber will be increased and encouraged by the proper mixing.

Mixing procedure is important to obtain the required workability and homogeneity of concrete mixes. Mixing was performed by an electric tilting mixer. The aggregate was used in a saturated surface dry (SSD) condition.

The mixing sequence was as follows: coarse aggregate and fine aggregate, added in the mixer, the mixing continued for 1minute, then the required quantity of dry cement added, and the mixing continued for 3 minutes when a good homogenous mix was produced. Then, two third of the required quantity water was added to the dry materials, and the remaining water and the required quantity of foaming agent were added to machine to make foam then added to the mix Before casting, the mould sides and the base were oiled slightly to prevent concrete sticking to the surfaces [7]. The casting was carryout into four layers. Each layer was compacted by using a vibrating table. The specimens were left under polyethylene sheets in the laboratory for one day after casting, then they were demolded, marked and stored in a small tank of water until testing time (7, 28, and 60 days).

Tests

Determination of the Workability of Concrete

The slump test was carried out in accordance with the procedure described in ASTM C143M-03 [8].

The (w/c) ratio and dosage of mixes were adjusted to get almost similar workability, (slump 75-100) mm for all mixes. Table (7) lists the optimum dosage of mixes for various types of concrete.

Dry Density Test

The dry density test was determined from the dried weight (105 ºC for 24 hrs) and the measured volume. Three (100) mm cubes were measured in each sample tested. The density was found by weighing the specimens and dividing the weight by the measured volume of the specimens.The dry density was tested at age (7, 28, and 60) days.

Compressive Strength:

This test was conducted on 100 mm using a digital compression testing machine of 2000 kN capacity at fixed load according to B.S. 1881: part 116:1989 [9]. The test was conducted at ages of 7, 28 and 60 days, and three specimens were tested at each age.

Splitting Tensile Strength

The splitting tensile strength test was performed according to ASTM C496 -04 [10]. (100×200) mm cylindrical concrete specimens were used. The specimens were tested using an electrical testing machine with a capacity of 2000 kN. This test was conducted at ages of (7, 28, 60) days. The average splitting tensile strength of three cylinders was calculated.

Flexural Strength

Flexural strength of concrete was measured on (400×200×50) mm flags specimen in conformity with the Iraqi specification No.1107/1988 (type C) [11]. The slabs were subjected to one-point loading. The loading rate was subjected at fixed load. The specimens were tested at age of (7, 28, and 60) days and the average of three specimens in each mix were taken.

Impact Resistance (ACI 544 Method)

The drop weight test was conducted following the test technique suggested by the ACI committee 544-1996 [12] on fiber reinforced concrete. The specimens used in impact resistance test 150 mm in diameter and 63.5 mm in thick. This test rests a specimen on the base plate within four positioning lugs.

The specimen bottom covered with a thin layer of a heavy grease to reduce the friction between the specimen and the base plate. Then, a 4.54 kg hammer consecutively fields from a 457 mm height on a 50.8 mm diameter steel ball standing at the center of the specimen, subjecting the specimen to repeated impact blows. The number of blows developing the first visible crack on the specimen top is the first-crack strength.

The falling operation continuous to trigger the ultimate failure is the opening-up of the specimen to touch three of the four lugs. The number of blows triggering the ultimate failure is the failure strength. The test was conducted at ages of (7, 28, and 60) days. Three specimens were tested at each age.

INITIAL SURFACE ABSORPTION

The initial surface absorption was carried out according to B.S.1881-part5 [13]. Cubes of (100) mm were used. The specimens were tested at age of (28) days and the average of three specimens in each mix were taken.

Water Absorption

The test was carried out according to ASTM C642-97[14] on 100 mm cubic specimens. The specimens were first weighted and then dried in an oven at a temperature of 100-110 ^{0}C for a period of 24 hours. After that, they were removed from the oven and allowed to cool in dry air to a temperature of 20-25 ^{0}C and reweighed. The above procedure was repeated until the difference between two successive weights did not exceed 0.5%. The final weights were considered as oven dried weights.

Then, the specimens were immersed in water at a temperature about of 21 ^{0}C for 48 hours. After that, the surface was dried with a cloth and weighed. This procedure was repeated until the difference between two successive weights of surface-dried specimens at intervals of 24 hours showed an increase in weights less than 0.5% of the heavier weights. The final weights were considered surface-dried weights after immersion.

Absorption of each specimen was calculated as the increase in weight resulting from the immersion, expressed as a percentage of the weight of the dry specimen. The test was conducted at age of 7, 28, and 60 days.

Ultrasonic Pulse Velocity (UPV)

According to the ASTM C597–02 [15], the ultrasonic pulse velocity test was done using a portable equipment called PUNDIT with transducer of variable frequency of (24, 37, 54, 82, 150 and 200) kHz. The equipment was used with direct transmission method by placing the transducer on the opposite face of the concrete cubes. The test was done to evaluate the pulse velocity, which is calculated as follows:

$$V = \frac{L}{T}$$

Where

V : Pulse velocity, km/sec.

L : Distance between the centers of transducer face, m.

T : Transit time, sec.

Acoustic Impedance (AI) for foam concrete was calculated by using the following equation sited by [16]:

$$AI = \rho V$$

ρ : Density, kg /m^3.

V: Pulse velocity, km/sec.

Results and Discussions

Dry Density

The effect of volume fraction of plastic fiber on the dry density is shown in Figures from (1) to (3). It can be seen that the addition of plastic fibers caused a reduction in the dry density as the percentage of fiber increased for different ages. It is noticed that the reduction in dry density when (V_f % = 0.5%) at different ages and for CPP and CSPP mixes was slight at 60days was 0.7%, 1.58%, respectively, but for CSP mix, this reduction was 7.5%. The percentage of reduction in dry density at 60days when adding 0.75% and 1%, was 5.6,and 10.8 % respectively for CPP; 2.4 and 2.9% for CSPP, respectively, and 8.42 and 10.2% for CSP, respectively. This finding was attributed to the high air content and large volume of voids present in the mixes when adding a 1% volume fraction with low aspect ratio of plastic macro fiber mixes of low unit weight and, hence, producing a concrete with a reduced compressive strength. The dry density decreases with increasing percentage of volume fraction, thus leading to a substantial reduction in the compressive strength. These results are in agreement with that reported by Al-Rubaiy [17].

Initial Surface Absorption (ISA)

The rate of water absorption by the surface zone of concrete under a fixed hydrostatic head was determined during a prescribed period between 10 minutes and two hours . The results showed that the initial surface absorption was more than 3.6 ml/m^2/sec for all specimens, and this verifies that the foamed concrete has an excessive porosity or honeycombing.

Water Absorption

Water absorption measurements were carried out according to ASTM C642-82[14]. The results are tabulated in Figures (4) to (6). The results also show that the water absorption increased with increasing fiber volume fraction. The percentage of increment in water absorption at 60 days was 16.6, 27.13, and 37.1% by addition of 0.5, 0.75, and 1% by volume of fiber respectively. Then may be attributed to the high air content and large volume of voids present in the mixes with increasing volume fraction.

Compressive Strength

The effects of volume fraction of crimped plastic fibers on compressive strength at different ages are shown in Figures. (7) to (9). The percentage of reduction in compressive strength for CPP specimens at 60 days was 8.82, 20.5, and 29.4% by adding 0.5, 0.75, and 1% by volume of fiber, respectively. For CSPP specimens the reduction was 6.7, 21.05, and 27.8% by adding 0.5, 0.75, and 1% by volume of fiber, respectively, and for CSP specimens 4.4, 13.7, and 18.34% by adding 0.5, 0.75, and 1% by volume of fiber, respectively. This result was in agreement with Jeffery et al. [18]. The reduction in compressive strength is probably due to the weak plastic fiber material.

Splitting Tensile Strength

The effect of volume fraction of plastic fiber on the splitting tensile strength of different mixes is shown in Figures (1٠) to (1٢). In general, it can be seen that the splitting tensile strength improves by the addition plastic fiber, the percentage of increment at age 60 days was 21.6, 35.2, and 55.68% for CPP specimens by addition of 0.5, 0.75, and 1% by volume of fiber, respectively. For CSPP specimens the percentage of increment was18.75, 31.25, and 49.2% by addition of 0.5, 0.75, and 1% by volume of fiber, respectively, and for specimens CSP the percentage of increment was 17.34, 29.6, and 47.9% by addition of 0.5, 0.75, and 1% by volume of fiber, respectively.

This increment in tensile strength by addition of fiber is may be due to the well bond of fiber to the matrix, the total length has been corrugated which means multiple interaction points which led more batter mechanical anchorage. The specimen without fiber failed suddenly once the concrete cracked, while the fiber reinforced concrete specimens were still intact together. This different mode of failure is due to that, when the specimen reinforced with fiber is forced to split apart in the tensile strength test, the load is transferred into the fibers as a pullout behavior when the concrete matrix began to crack where it exceeded the pre-crack state.

Ultrasonic Pulse Velocity

Figures (1٣) to (1٥) show a representation of ultrasonic pulse velocity for concrete without fibers and concrete containing different percentages of volume fraction (V_f %). Generally, these figures demonstrate that the values of velocity of ultrasonic waves for all specimens increase slightly with the increase in age up to 28 days. This is because of the progress of hydration. This decreases the voids space within the concrete mass. On the other hand, the (UPV) of all mixes decreases with the increase of volume fraction of fiber. This behavior in redaction in (UPV) is similar to that in compressive strength. These results are in agreement with previous findings by Al- Attar [19].

Flexural Strength

Figures (1٦) to (1٨) show the graphical representation for the development of flexural strength with age for concrete without fibers and concrete containing different amounts and types of fibers. The same figures also reveal the failing load of the concrete corresponding to the increase in the amount of fiber volume fractions. It was found that the flexural strength increased slightly as the fiber volume fraction was increased. The percentage of increase was 2%, 4%, and 8% by addition 0.5%, 0.75%, and 1% by volume, respectively for CPP mix, the percentage of increase was 2.3%, 4.5%, and 8.6% by addition 0.5%, 0.75%, and 1% by volume respectively for CSPP mix, and the percentage of increase was 2.93%, 4.88%, and 6.8% by addition 0.5%, 0.75%, and 1% by volume respectively for CSP mix. Generally, the results of most mixes less than type C that indicated in I.Q.S. 1107/1988 (failing load 4.4 kN), while for CSP mix Specimens failing load at 60 days age approximately similar to type C.

Furthermore, the results and all figures showed a general upward trend in the flexural strength for all specimens reinforced with fiber concrete. The specimens without fiber cracked and failed in a brittle manner when the strain in concrete reached its ultimate value. Specimens reinforced with fiber also cracked at the ultimate strain, but it is capable to carry the load well after the crack developed in the concrete. This is because of the indications that the fiber reinforced concrete has the ability to hold on the cracked concrete and preventing the concrete flag to fall apart.

Acoustic Impedance

The acoustic impedance of foamed concrete specimens reinforced with different percentages of fiber is illustrated in Figures (١٩) to (2١). These figures demonstrate the change in acoustic impedance when using different volume fractions of fibers distributed randomly in the matrix. Results indicate that there is a similar behavior for the (UPV) and acoustic impedance with the volume fraction of fibers. However, the increase in concrete compressive strength and (UPV) was due to the reduction in the void ratio which affects negatively the concrete density and acoustic impedance. The results showed also improvement in acoustic impedance when fiber content increase.

Impact Resistance

Figures (2٢) to (2٤) show the mode of failure of plastic macro fiber reinforced concrete specimen under the drop-weight test (The test technique suggested by ACI committee 544 on fiber reinforced concrete) [12]. The specimens without fiber shows a complete separation of the failed parts, and most failure occurred by breaking into four pieces.

The specimens reinforced with fiber displayed different modes of failure. The modes of failure of specimens reinforced with crimped plastic fiber of 0.5%, 0.75%, and 1% by volume respectively. It is noticed that specimens do not show completely separated failed parts but they have remained attached, also it can be seen the specimen in values multiple cracking, and spalling pieces in specimens contain 1% fiber is less than that specimens contain 0.75% and 0.5% by volume.

CONCLUSIONS

This investigation covers several factors affecting the properties of foamed concrete, and studies the effect of plastic fiber on properties of foamed concrete. From the test results and discussion, the following some conclusions are demonstrated:

1. The use of 0.5% crimped plastic fiber by volume decreased the compressive strength, ultrasonic pulse velocity, and acoustic impedance. The percentage of reduction ranged between (4.4-8.8) % , (2.2-5.4)% , and (5.9-9.5)%, respectively, but the increase in splitting tensile strength, flexural strength, impact resistance, and water absorption ranged between (17.3-21.6)%, (2.4-2.5)%, (131-358)%, and (2.6-27.14)%, respectively.
2. The addition of crimped plastic fiber (V_f = 0.75%) decreases the compressive strength, dry density, ultrasonic pulse velocity, and acoustic impedance. The percentage of reduction ranged between (13.7-15.54)% , (5.6-8.4)%, (13.7-20.6) % , and (7.7-8.6)% respectively, but the increase in splitting tensile strength, flexural strength, impact resistance, and water absorption ranged between (29.6-35.2)%, about 4.3%, (200-468)%, and (5.7-50.3)%, respectively.
3. The use of 1% crimped plastic fiber by volume decreased the compressive strength, dry density, ultrasonic pulse velocity, and acoustic impedance. The percentage of reduction ranged between (18.3-29.4) %, about (10)%, (9.9-15)%, and (19.5-24.1)%, respectively, but the increase in splitting tensile strength, flexural strength, impact resistance, and water absorption ranged between (47.9-55.7)%, (5-5.8)%, (255-545)%, and (15.57-62.3)%, respectively.

REFERENCES

[1].Newman, J., and Seng, B., "Advanced Concrete Technology", first edition, UK. , 2003, pp. 2/1-2/5.

[2].Nelson, P. K., L.i, C.V., and Kamada, T., " Fracture Toughness of Micro Fiber Reinforced Cement Composites", Journal of Materials in Civil Engineering, Vol. 14, No. 5, October, 2002, pp.384-391.

[3].Abdul Kader, N.," The Dynamic & Thermal Properties of Lightweight Concrete Produced Using Rice Husks and Reed Aggregates", M.Sc., Thesis, Building and Construction Engineering Department, University of Technology, Baghdad, 2005, pp. 117.

[4]. المواصفة القياسية العراقية رقم ٥ لسنة١٩٨٤، "الاسمنت البورتلاندي"، الجهاز المركزي للتقييس المواصفة القياسية العراقية والسيطرة النوعية، بغداد ، ٨ صفحات.

1. المواصفة القياسية العراقية رقم ٤٥ لسنة١٩٨٤، " ركام المصادر الطبيعية المستعمل في الخرسانة والبناء" الجهاز المركزي للتقييس والسيطرة النوعية، بغداد، ٤ صفحات.

2. ASTM C496/C496M–04, "Standard Test Methods for Splitting Tensile Strength of Cylindrical", ASTM Standards, Vol. 04.02, 2004.

[7]. Al-Safar, D., M., "Some Properties of Fiber Reinforced Foamed Concrete" M.Sc. Thesis, University of Technology, June 2012, 110.

[8]. المواصفة القياسية العراقية رقم١١٠٧ لسنة١٩٨٨، "البلاطات الخرسانية السابقة الصب"، الجهاز المركزي للتقييس والسيطرة النوعية، بغداد، ١٠ صفحات.

[9]. ACI–Committee 544–1R, "State of the Art Report on Fiber Reinforced Concrete", ACI Manual of Concrete Practice, 1996.

[10]. B.S. 1881:part 5:1970, "Test for Determining the Initial Surface Absorption of Concrete ",1970,35 pp.

[١1]. ASTM C642-97, “Standard Test Method of Specific Gravity, Absorption and Voids in Hardened Concrete”, ASTM Standards, Vol. 04-02, 1997.

[12]. ASTM C597–02, "Standard Test Methods for Pulse Velocity through Concrete", ASTM Standards, Vol. 04.02, 2002, pp. 310–313.

[13]. Al-Marsomy, M. H., "Insulating Lightweight Aggregate Concrete", M.Sc. Thesis, University of Baghdad, March 2009.

[14]. ASTM C796–97, "Standard Test Methods for Foaming Agents for Use in Produce Cellular Concrete Using Performed Foam", ASTM Standards, Vol. 04.02.

[15]. Daneil, P.J., "Lightweight Concrete", American Concrete Institute, 1971, pp.624-627.

[16]. ACI committee 523, "Guide of Cellular Concretes and for Aggregate Concretes Above 50 pcf with Compressive Strength Less Than 2500 psi", ACI Manual of Concrete Practice Part 5, 1990.

[17]. Al-Rubaiy, N. H., "Properties of Polypropylene Fibers Reinforced Concrete with a view of its Resistance to Impact Loads", M.Sc. Thesis, University of Technology, March 2002, 154.

[18]. ASTM C642-97, “Standard Test Method of Specific Gravity, Absorption and Voids in Hardened Concrete”, ASTM Standards, Vol. 04-02, 1997.

[19]. Al-Attar, A.A., "Microstructure and Mechanical Properties of Lightweight Aggregate Concrete Containing Fibers", Ph.D. Thesis, Building and Construction Engineering Department, University of Technology, 2006, pp.202.

Table (1) Physical properties of cement *.

Physical Properties	Test Results	Limit of Iraqi specification No. 5/1984
Specific surface area (Blaine method), (m^2/kg)	304	230 m^2/kg lower limit
Setting time (vicate apparatus) Initial setting, hrs : min Final setting, hrs : min	 2:05 3:60	 Not less than 45 min Not more than 10 hrs
Compressive strength (MPa)		

Oxides composition	Content %	Limit of Iraqi specification No. 5/1984	Main compounds (Bogue's equation)	
Lime, CaO	62.5 %	-	C_3S	50.88 %
Silica, SiO_2	21 %	-	C_2S	21.9 %
Alumina, Al_2O_3	4.9 %	-	C_3A	7.77 %
Iron oxide, Fe_2O_3	3.08 %	-	C_4AF	9.36 %

Table (2) Chemical composition and main compound of the cement *.

Magnesia, MgO	1.5 %	5 % Max.
Sulfate, SO_3	2.3 %	2.8 % Max.
Lime Saturation	0.81	(0.66-1.02)

Sieve size (mm)	**Cumulative passing %**	**Cumulative passing % Iraqi specification No. 45/1984 Zone (3)**
9.5	100	100
4.75	100	90-100
2.36	97.37	85-100
1.18	75.83	75-100
0.60	69.57	60-79
0.30	36.73	12-40
0.15	4.33	0-10
Fineness modulus = 2.16		
SO_3 (%) = 0.08		

***Tests were conducted by National Center for Construction Laboratories and Researches**

Table (3) Grading of sand.

Table (4) Technical description of foaming agent.

Appearance	Liquid
Color	Transparent
Specific Gravity	1.01
Chloride Content	Nil
Compatibility with Cement	All Types of Portland Cement
Shelf Life	Up to 2 Year
Surface Tension	41.9N/cm^2

The data are from manufacture production report

Mix	W/C	Slump (mm)	Materials Content (kg /m^3)					
			Cement	Sand	Fine Porcelanite	Coarse Porcelanite	water	Foaming Agent
CPPN	0.7	90	360	-	493	61	252	-
CPP	0.55	100	360	-	493	61	198	3.96
CSP	0.45	96	360	992	-	61	162	3.24
CSPP	0.5	90	360	382	301	61	180	3.6

Table (5): Technical properties of crimped plastic fiber

Technical Properties	
Length of Fiber	50mm
Tensile Strength	250-350 MPa
Elastic Modulus	2500-3000 MPa
Specific Gravity	1.14
Aspect Ratio	63
Elongation	(15-20)%
Softening Point	160℃

The data are from the manufacturer production report

Table (6): Details of the mixes used

Table (7): Details of the concrete mixes used

Mix	% of fiber by volume	W/C	Slump (mm)
CPPN (Ref.)	-	0.7	90
CPP	0	0.5	100
	0.5	0.53	100
	0.75	0.55	90
	1.0	0.6	98
CSP	0	0.4	100
	0.5	0.42	95
	0.75	0.45	95
	1.0	0.52	100
CSPP	0	0.43	90
	0.5	0.45	88
	0.75	0.45	90
	1.0	0.55	100

Figure (1):Effect of fiber content on the dry density for CPP mix.

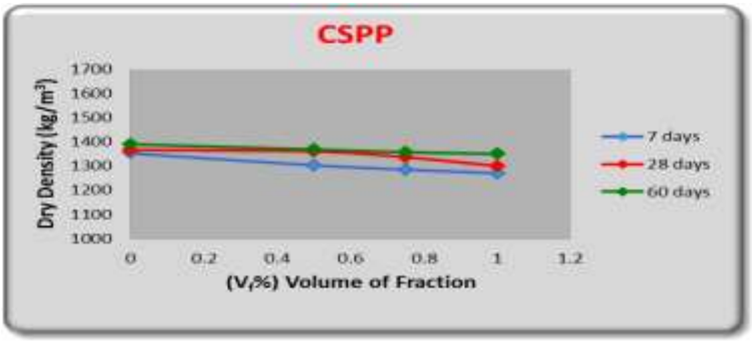


Figure (2): Effect of fiber content on the dry density for CSPP mix.

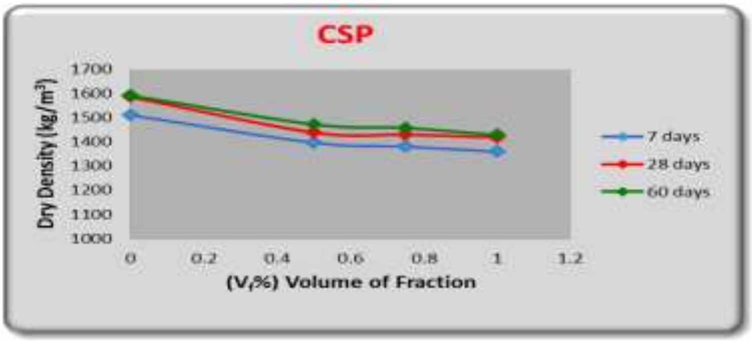


Figure (3): Effect of fiber content on the dry density at for CSP mix.

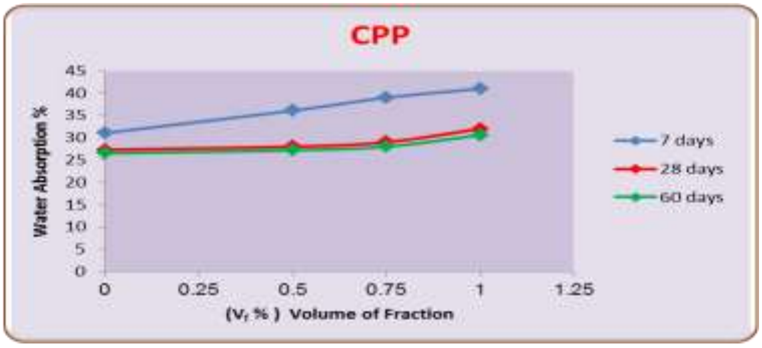


Figure (4): Effect of fiber content on the water absorption for CPP mix.

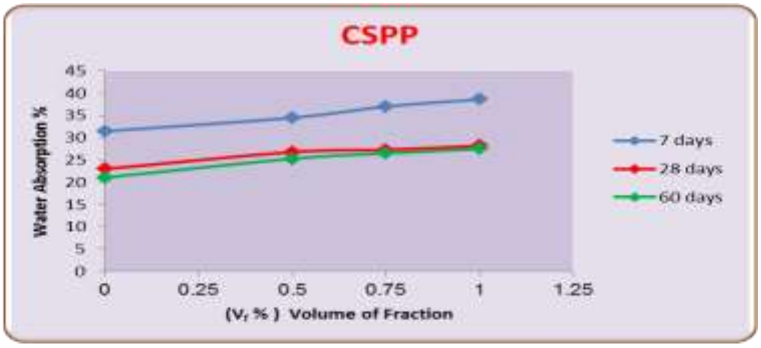


Figure (5): Effect fiber content on the water absorption for CSPP mix.

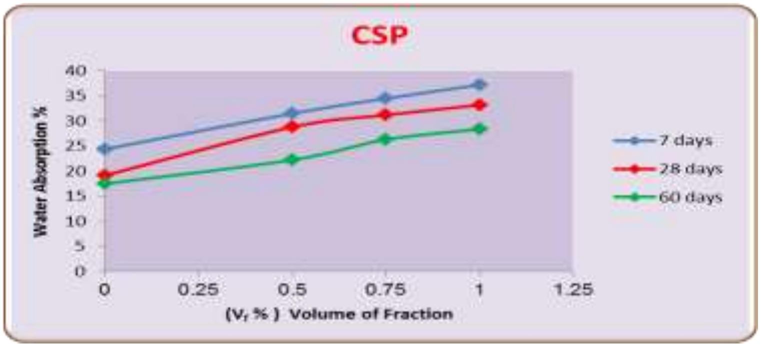


Figure (6): Effect of fiber content on the water absorption at for CSP mix.

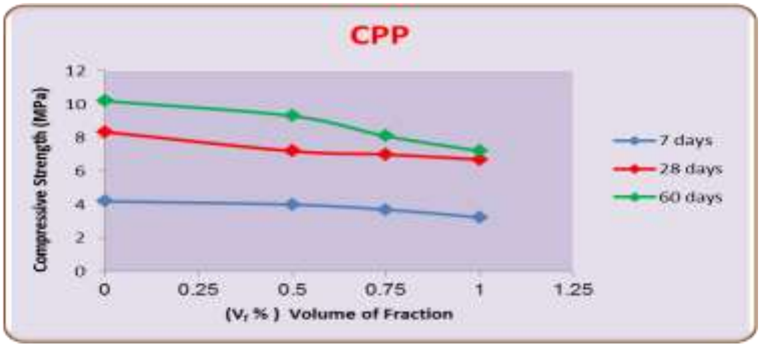


Figure (7): Effect of fiber content on the compressive strength at for CPP mix.

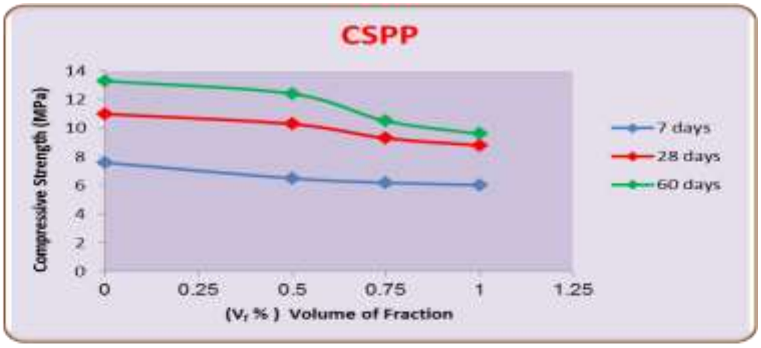


Figure (8): Effect of fiber content on the compressive strength for CSPP mix.

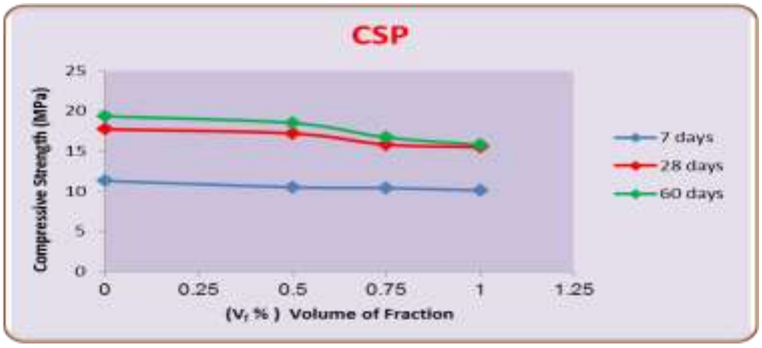


Figure (9): Effect of fiber content on the compressive strength for CSP mix.

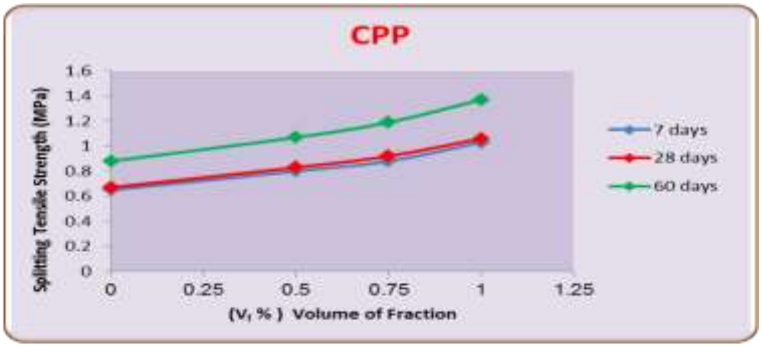


Figure (10):Effect of fiber content on the splitting tensile strength for CPP mix.

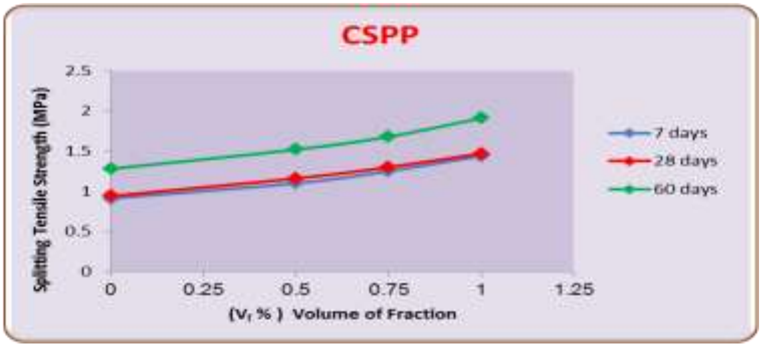


Figure (11):Effect of fiber content on the splitting tensile strength at for CSPP mix.

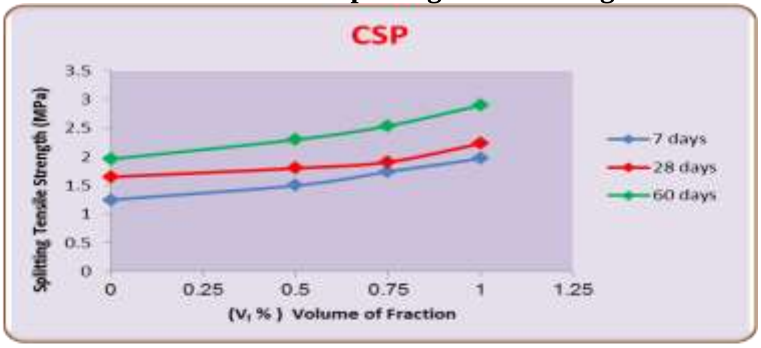


Figure (12):Effect of fiber content on the splitting tensile strength for CSP mix.

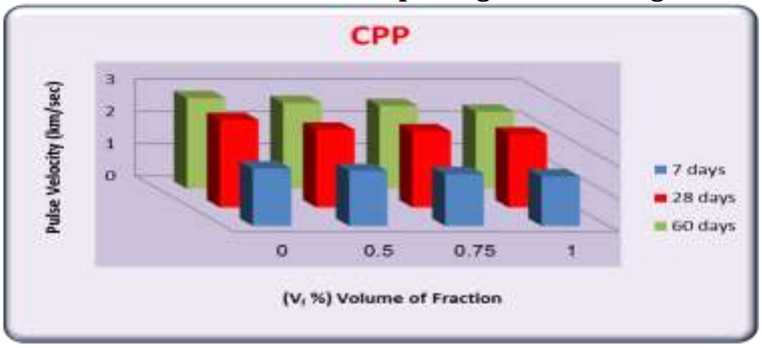
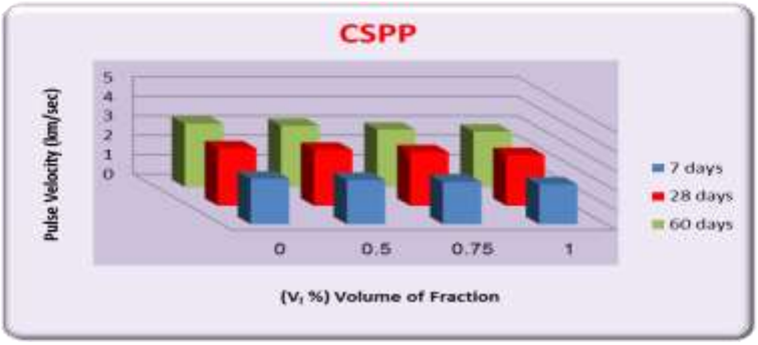


Figure (13): Effect of fiber content on the ultrasonic pulse velocity of CPP mix.



Figure(14):Effect of fiber content on the ultrasonic pulse velocity of CSPP mix.

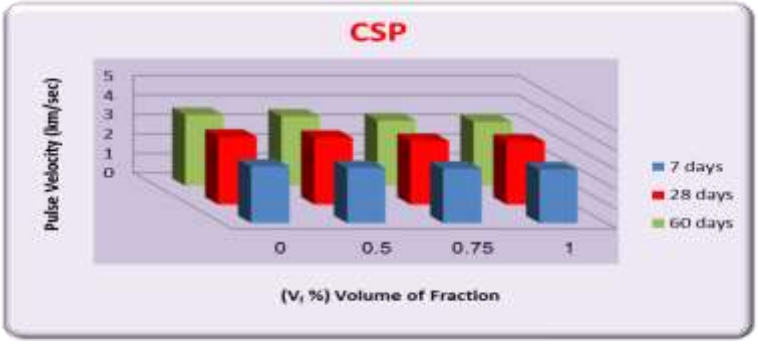


Figure (15): Effect of fiber content on the ultrasonic pulse velocity of CSP mix.

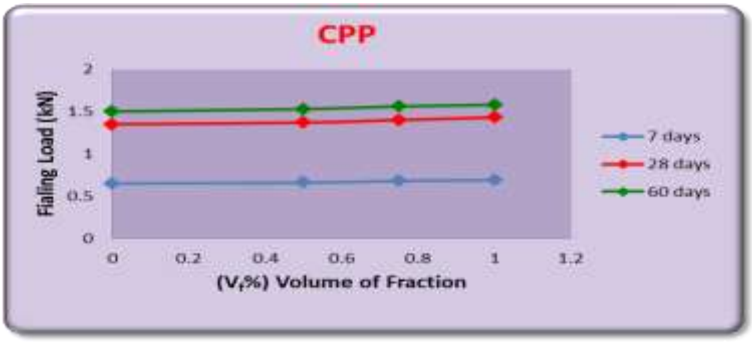


Figure (16): Effect of fiber content on the flexural strength for CPP mix.

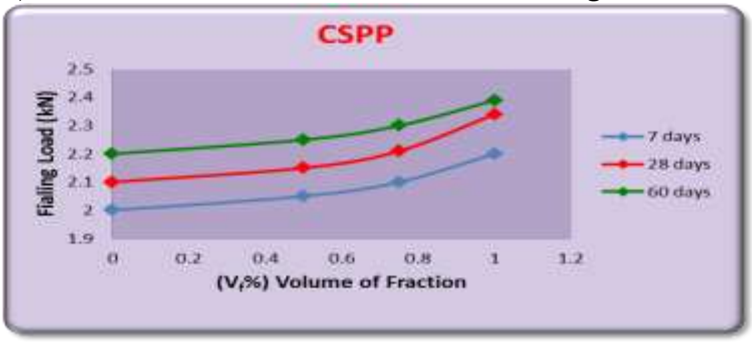


Figure (17): Effect of fiber content on the flexural strength at for CSPP mix.

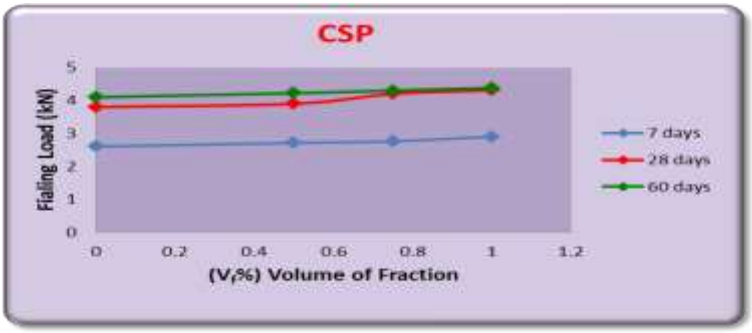


Figure (18): Effect of fiber content on the flexural strength at for CSP mix.

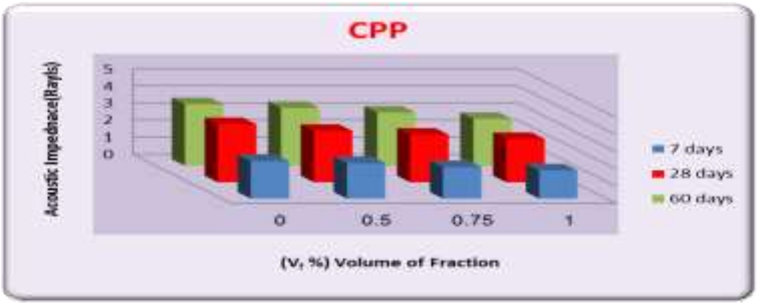


Figure (19): Effect of fiber content on the acoustic impedance of CPP mix.

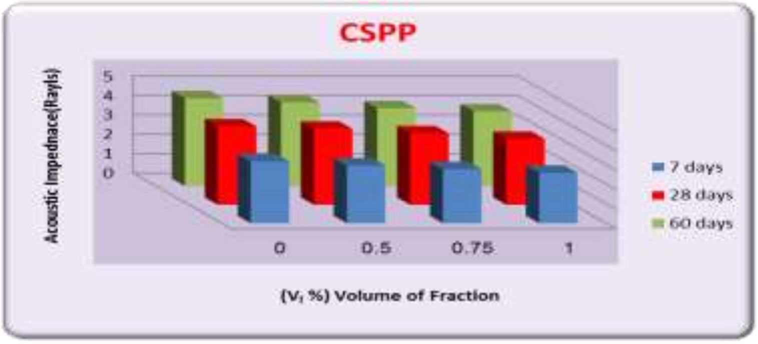


Figure (20): Effect of fiber content on the acoustic impedance of CSPP mix.

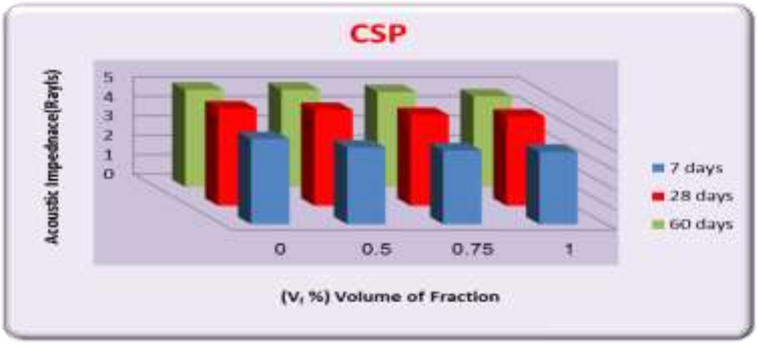


Figure (21): Effect of fiber content on the acoustic impedance of CSP mix.

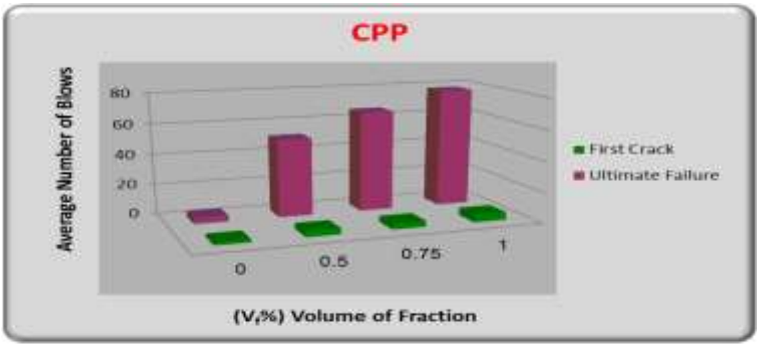


Figure (22): Effect of fiber content on impact resistance for CPP mix.

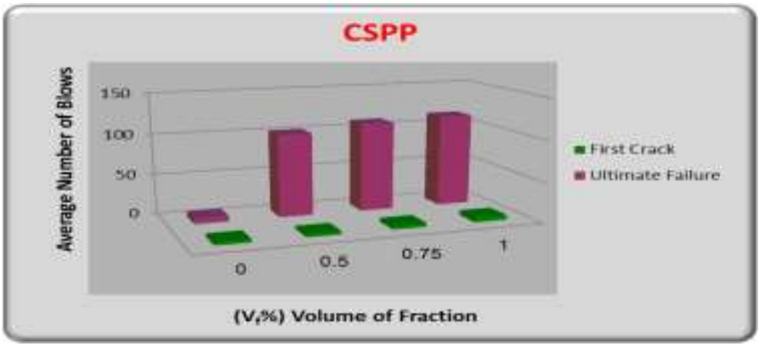


Figure (23): Effect of fiber content on impact resistance for CSPP mix.

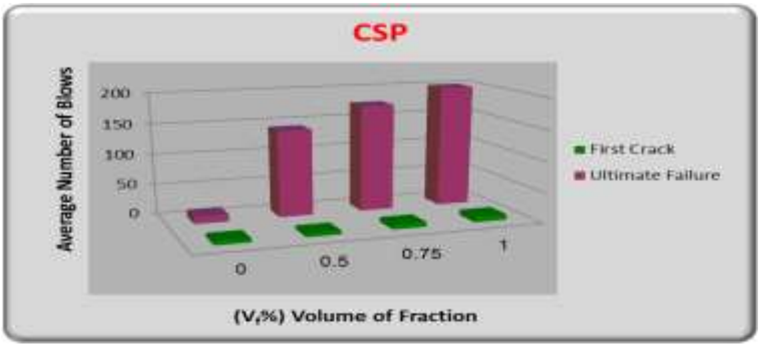


Figure (24): Effect of fiber content on impact resistance for CSP mix.