

Experimental Studies to Investigate the Properties of Polystyrene Concrete Ferrocement Plates

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Abstract

This research is concerned with a new type of ferrocement of polystyrene concrete, which has several advantages compared to ordinary reinforced concrete plates, such as lower density, abrasion resistance, compressive and flexural strength. The experimental program consisted of casting and testing of 24 ferrocement plates. The dimensions of the ferrocement plates were (600×300×40) mm in (length × width × height) respectively. The effect of various factors such as mix proportions of cement to polystyrene (C:P) ratio has been investigated, both by destructive and non-destructive methods. The experimental results of the compressive strength of mortar mix 1:1 and using (1:1, 1:3 and 1:5) the cement to polystyrene (C:P) ratio by volume were increased by (6.0, 9.9 and 12.2) % and (11.7, 18.1 and 20.6)% at (60, 90) days age respectively, while for mortar mix 1:2 were increased by (6.3, 10.2 and 10.5) % and (12.6, 16.5 and 19.0)% at (60, 90) days age respectively. On the other hand, increasing (C:P) ratio was found to decrease the stiffness constant and dynamic modulus of elasticity of polystyrene concrete plates. Also, the analysis of the experimental results showed that the dynamic properties such as, dynamic modulus of elasticity and stiffness constant increased linearly as the volume fraction of steel wire mesh or specific surface area was increased.

الخلاصة

يتناول هذا البحث نوعا جديدا من ألواح الفيروسمنت لخرسانة البولستاييرين يتميز بمزايا تجعلها مفضلة على تلك للخرسانة الاعتيادية، ومنها كثافة واطنة ومقاومة البلى وتحسين مقاومة البلى والانضغاط والانحناء. تضمن الجزء العملي تهيئة وفحص 24 لوحا من الفيروسمنت. إن أبعاد نماذج ألواح الفيروسمنت ثابتة وهي (600×300×40 ملم) (طول×عرض×ارتفاع) على التوالي. وقد اشتمل البحث على تغيير نسب خلط البولستاييرين إلى السمنت، إما الفحوصات فقد تضمنت الفحوصات الاتلافية وغير الاتلافية. وقد لوحظ من النتائج العملية زيادة مقاومة الانضغاط لخلطات مونه سمنت 1:1 ويزيادة نسبة السمنت/البولستاييرين (1:1, 3:1, 5:1) حيث كانت (6.0, 9.9, 12.2) % و (11.7, 18.1, 20.6) % بعمر 60 و 90 يوما على التوالي، بينما لخلطات مونه سمنت 1:2 كانت (6.3, 10.2, 10.5) % و (12.6, 16.5, 19.0) % بعمر 60 و 90 يوما على التوالي. ومن ناحية أخرى، فقد كان لزيادة نسبة السمنت/البولستاييرين نقصان معامل المرونة الديناميكي وثابت المرونة لتلك الألواح. أيضا فقد اظهر تحليل النتائج العملية إن الخواص الديناميكية مثل معامل المرونة الديناميكي وثابت المرونة يزدادان بزيادة النسبة الحجمية للمشبكات الحديدية أو مع زيادة مساحته النوعية.

- Introduction

The work in this investigation was planned in order to obtain further information on the flexural behavior and dynamic properties of the polystyrene concrete ferrocement plates.

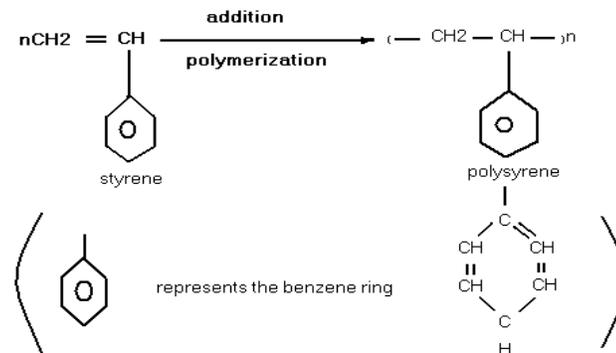
Concrete containing polymers are termed "plastic concrete". The added polymer improves the properties of the basic material, by condensing, reducing its porosity, and by increasing its durability and strength, both static and dynamic, particularly in bending and tension.

The relative weight of the polymer component added to the mineral part (termed the "polymer-cement ratio" if the mineral is cement). It is possible to prepare concrete with only polymer binder without the addition of mineral. In such cases, it is termed "polymer concrete".

A polymer is a chemical substance made up of repeating units, each unit being called a monomer.

Monomers → polymerization → polymer

The polystyrene



Polymerization, carried out using a peroxide catalyst, gives a tactic and amorphous polystyrene. This is hard and brittle and has the characteristic metallic ring when struck. To reduce brittleness, polystyrene can be toughened by mixing with another polymeric material (usually styrene-butadiene-copolymer). Typical properties of polystyrene are given in Table (1).

Table (1): Typical properties of polystyrene (Canom,1998).

| Properties | Conventional | Toughened |
|--|--------------|-----------|
| Density ($\times 10^3 \text{Kg mm}^{-3}$) | 1.04-1.11 | 0.08-1.10 |
| Thermal conductivity ($\text{wm}^{-1}\text{k}^{-1}$) | 0.09-0.21 | 0.04-0.17 |
| Thermal expansively($\times 10^{-1} \text{k}^{-1}$) | 60-80 | 34-210 |
| Tensile strength (MN m^{-2}) | 35-62 | 17-45 |
| Compressive strength (MN m^{-2}) | 80-110 | 28-62 |
| Young's modulus (MN m^{-2}) | 2410-4130 | 1720-3100 |
| Elongation at break | 1-3 % | 8-50 % |

- Research Significances

Polymer concrete (PC) is a composite material formed by combining mineral aggregate such as sand or gravel with a monomer.

The composition of PC is determined by its applications especially loading stress levels and ability to resist to corrosive environment. PC is increasingly being used as an alternative to cement concrete in many applications.

There is indeed little research about the effect of polystyrene on the properties of concrete.

In this study; compressive strength, dynamic properties, abrasion resistance, flexural behavior and crack patterns of polystyrene concrete ferrocement plates are investigated at room temperature.

- Literature Review

- Ferrocement

The following definition of ferrocement was adopted according to ACI committee 549 in (1982), as "A type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small wire diameter mesh. The mesh may be of metallic or other suitable materials".

- Polystyrene Concrete

The properties of polystyrene concrete were investigated by a number of workers Sussman in (1975), Jawad in (1987), and Bagon and Frondistou in (1987). Generally the mechanical properties of expanded poly styrene concrete such as elasticity and shear modulus are influenced by the ratio of expanded polystyrene beads to cement content.

Sussman in (1975) reported that the compressive strength, flexural strength, and the modulus of elasticity of polystyrene concrete are directly proportional to the density.

Bagon and Frondistou in (1987) showed that the modulus of elasticity and tensile strength of polystyrene concrete are 70% and 35% respectively greater than those of perlite concrete of same density.

Parton and Shendy in (1987) obtained an empirical relationship for calculation of compressive strength of polystyrene concrete as follows:

$$F_c = \rho_s (C_s - 110) / (8.6 \times 10) \quad \dots\dots\dots (1)$$

Where F_s is the cylinder compressive strength in (MPa), ρ_s is the saturated bulk density in (Kg/m³) and C_s is the cement content in (Kg/m³).

The results of the tensile strength obtained by Bagon and Frondistou (1987) were (9.5-13.8) MPa.

Jawad in (1987) obtained the dynamic properties of different cement to polystyrene ratios using ultrasonic pulse velocity method. The results of the dynamic modulus of elasticity, compressive strength and densities ranged from (1.2-6.8) GPa, (33-42) MPa and (509-1170) (Kg/m³).

- Dynamic Modulus of Elasticity

Many researchers (Raof in 1975 and Matti in 1985) evident that the velocity (V) depends on the density (ρ), elastic modulus of materials (E, G) and the mode of wave propagation. The relationship between elastic modulus and density can be written as follows:

$$(E, G) = K. (\rho V^2) \quad \text{Where} \quad \dots\dots\dots (2)$$

E : is the dynamic modulus of elasticity (GPa).

G : is the dynamic shear modulus.

K : is a constant whose magnitude depends on the mode of wave propagation and Poisson's ratio for concrete ranged between (0.15-0.35), ($K=0.9-0.93$).

ρ : is the density of material (kg/m^3).

V : is pulse velocity (km/sec).

Matti in (1985) used ultrasonic pulse velocity for the determination of dynamic properties of ferrocement plates. Also, it can be expressed on wave velocity of plate and surface as follows:

$$V_p^2 = E/\rho(1 - \alpha^2) \quad \dots\dots\dots (3)$$

$$V_{sur} = KV_s \quad \dots\dots\dots (4)$$

Where

V_p^2 : Wave Pulse velocity of plate

V_{sur} : Surface pulse velocity

V_s : Longitudinal pulse velocity ($V_s=0.58V_p^2$)

Al-Jalawi in (2006) used ultrasonic pulse velocity for characterization of compact lightweight ferrocement plates, she found that this method can be used for finding dynamic properties of lightweight ferrocement plates. Such properties are needed as design parameters in the design of ferrocement structures.

The relation between dynamic and static modulus of elasticity was given an equation below according to the BS 8110 as follows:

$$E_s = 1.25 E_d - 19 \quad \dots\dots\dots (5)$$

Where

E_d, E_s : Dynamic and static modulus of elasticity in (GPa)

- Flexural Behavior of Ferrocement

The load-deflection behavior of ferrocement exhibit three stages Walkus and Kowalski in (1971). The first stage is the elastic or uncracked stage, the second stage is the quasi-elastic stage where in multiple cracking occurs and the third stage is the plastic stage where the yielding of reinforcement and widening of the cracks occur.

Empirical equations for the determination of ultimate and first crack moments of ferrocement structural elements reinforced with square wire mesh in pure bending have been derived by Kumer and Sharma in (1976) as follows:

$$M_u = 3700V_f + 1700 \quad \dots\dots\dots (6)$$

$$M_{1st} = 100V_f + 1700 \quad \dots\dots\dots (7)$$

Where

M_u, M_{1st} are the ultimate moment and first crack moment in (kg.cm) respectively.

V_f is the volume fraction of reinforcement.

Balaguru, Naaman and Shah in (1977) derived a theoretical equation for the calculation of the first crack moment of ferrocement under flexural load as follows:

$$M_{cr} = \frac{1}{6}bh^2f_r[1 + (m - 1)V_f] \quad \dots\dots\dots (8)$$

Where

M_{cr} = Moment at first crack (kN.m)

b = Width in (m)

h = Height in (m)

f_r = Modulus of rupture = $0.62\sqrt{f'_c}$ in (MPa)

f'_c = Compressive strength of the mortar in (MPa)

m = Modulus ratio = E_f/E_m

V_f = Volume fraction of steel wire mesh in the direction where the first crack moment is being calculated.

- Experimental Work

- Introduction

This section describes the materials used in the production of the specimens, mix proportion and the methods of testing. Also, the experimental program in this investigation consisted of three series of tests namely series A, B and C. The experimental variables studied in test series were the cement to sand ratios of the matrix and the cement to polystyrene ratio of the plates. The details of the polystyrene concrete ferrocement plate specimens are shown in Table (2).

Table (2): Summary of plate test specimens.

| Series No. | Plate Specimen Designation | Number of Specimens | Ferrocement Layers | | | | C/P Ratio | W/C Ratio |
|------------|----------------------------|---------------------|--------------------------|---------------|-----------|----------------------------|-----------|-----------|
| | | | Mortar Mix (Cement:Sand) | No. of Layers | V_f (%) | S_r (cm^{-1}) | | |
| A | PA-0 | 3 | 1:1 | 0 | 0.00 | 0.00 | 1:3 | 0.40 |
| | PA-1 | 3 | | 1 | 0.61 | 0.244 | 1:3 | 0.40 |
| | PA-2 | 3 | | 2 | 1.04 | 0.416 | 1:3 | 0.40 |
| B | PB-0 | 3 | 1:2 | 0 | 0.00 | 0.00 | 1:3 | 0.40 |
| | PB-1 | 3 | | 1 | 0.61 | 0.244 | 1:3 | 0.40 |
| | PB-2 | 3 | | 2 | 1.04 | 0.416 | 1:3 | 0.40 |
| C | PC-1 | 3 | 1:2 | 2 | 1.04 | 0.416 | 1:1 | 0.40 |
| | PC-5 | 3 | | 2 | 1.04 | 0.416 | 1:5 | 0.40 |

V_f = Volume fraction of steel wire mesh.

S_r = Specific surface area of steel wire mesh, ($S_r = 4V_f/d$).

- Materials

- Cement

The cement used in this study was Ordinary Portland Cement (O.P.C) produced at Kufa factory. The physical and chemical properties of this cement are summarized in Table(3).

Table (3): A) Physical properties of the cement.

| Physical Properties | Test results | IQS (No.5: 1984) Limits |
|---|--------------|-------------------------|
| Fineness, Blaine, cm ² /gm | 3115 | ≥ 2300 |
| Setting time, Vicat's method | | |
| Initial hrs: min. | 1:58 | ≥ 0: 45 |
| Final hrs: min. | 4:35 | ≤ 10: 00 |
| Compressive strength of 70.7 mm cube, MPa | | |
| 3 days | 21.8 | ≥ 15 |
| 7 days | 30.2 | ≥ 23 |

B) Chemical composition of the cement.

| Oxide | Percentage (%) | IQS (No.5: 1984) Limits |
|--------------------------------|----------------|-------------------------|
| CaO | 63.5 | ----- |
| SiO ₂ | 20.97 | ----- |
| Fe ₂ O ₃ | 3.67 | ----- |
| Al ₂ O ₃ | 5.50 | ----- |
| MgO | 2.35 | ≤ 5.0 |
| SO ₃ | 2.42 | ≤ 2.8 |
| Free lime | 1.23 | |
| L.O.I. | 2.27 | ≤ 4.0 |
| I.R. | 0.95 | ≤ 1.5 |

- Fine Aggregate

A well graded natural silica sand was used.

- Mixing Water

Clean tap water was used through out this work for casting and curing all the specimens.

- Steel Wire Mesh

The steel wire meshes obtained from a local factory were used. The galvanized square woven wire mesh with wire diameter of 1.0mm and 10mm diagonal size was used in this investigation.

- Expanded Polystyrene Beads

The expanded polystyrene beads used in present work. The density of these beads was 17.5 kg/m³ and having very low water absorption (about 0.2% by weight). The sieve analysis is given in Table (4).

Table(4): Polystyrene beads sieve analysis.

| Sieve size or No. | % Passing |
|-------------------|-----------|
| 3/8" | 100 |
| 3/16" | 78 |
| 8 | 1.4 |
| 10 | 0.6 |
| 16 | 0 |

- Loading Testing Machine

In this research work the loading machine shown in Plate (1) was manufacture to test the polystyrene concrete ferrocement plate specimens. The loading machine was calibrated in Central Organization for Standardization and Quality Control before accomplishment of the experimental test. The details of the steel frame section W12×79 used in the testing machine is given in Table (5).



(A) The load cell unit with 1500kN capacity

(B) Moveable solid beam

(C) A load dial gauge unit

Plate (1): Flexural strength testing machine.

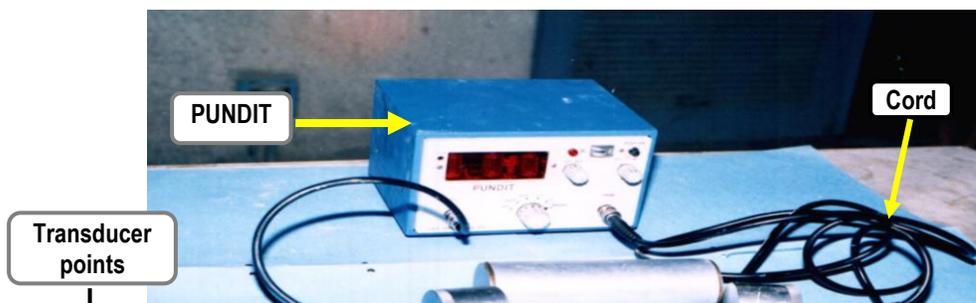
Table (5): Details of the steel frame section W12×79 used in the testing machine.

| Designation | Area A | Depth d | Flange | | Web Thickness tw | Nominal Weight Per (m) |
|-------------|---------------------------------|------------------|---------------|-----------------|------------------------|------------------------------|
| | | | Width bf | Thickness tf | | |
| W12×79 | (mm ²) (13612.8) | (mm) (311.15) | (mm) (305) | (mm) (17.02) | (mm) (10.92) | (Kg.) (107.146) |

- Non-Destructive Test

- Ultrasonic Pulse Velocity test (U.P.V)

The Ultrasonic pulse velocity was measured by an ultrasonic concrete tester (CSI), type cc-4 as shown in Plate (2). The test method is prescribed by ASTM C-215-02 specifications.



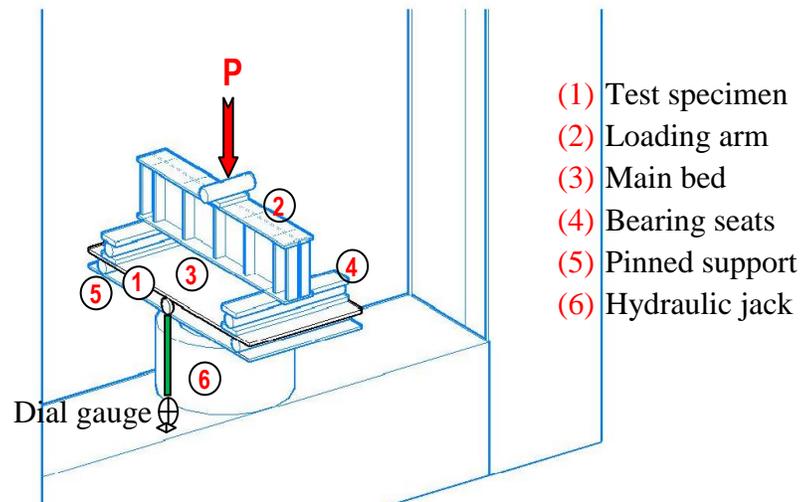
- Destructive Test

- Compressive strength test

For the hardened concrete, the compressive strength test was carried out according to (BS. 1881: part 116:1989), using a digital testing machine with a capacity of (2000 kN). Each cube was weighted at a test and after test by ultrasonic pulse velocity. Each compressive strength value was the average of strength of three cubes.

- Flexural Test

The flexural behavior test of plates was carried out according to (ASTM C-78-02). After 60 days from casting, all the plates were transported to the hydraulic testing machine of 1500kN capacity. Each plates was loaded directly at the top face with two equal concentrated loads. Each plates was supported and loaded by rollers. Forces were distributed through steel bearing plate 300mm in length to cover the entire plate width. Figure (1) shows a schematic diagram for loading arrangement of flexure test. Before loading, initial reading of deflection dial gauge was obtained. Deflection was measured at mid span by a dial gauge as shown in Figure (1).



- Abrasion Resistance Test

The abrasion resistance was determined according to the German DIN 52108 standard test method which was applied on 70mm cubes. The apparatus required for this test are the Bohme disk abrader and abrasive materials.

The Bohme disk abrader consist mainly of three parts as shown in Plate (3).

- 1 . The approximately 750mm diameter rotating disk poisoned horizontally with the speed of (30 ± 1) revolution/min.
- 2 . A U frame about 40mm thickness and 71mm length of each side to hold the test specimen.
- 3 . A loading device.

The artificial silica sand was used as the abrasive materials. During the abrasion event the sand was allowed to be in contact between the specimens and the rotating disk in order to produce appreciable loss of the specimens thickness.

- Testing Procedure

Prior to each test. The specimen was weighted to the nearest 0.01g and measured to the nearest 0.1mm. It was then placed in the holder and subjected to a standard abrasive load of 294 N. The disk was then rotated and the sand was dropped on the disk taking care that the sand remained evenly distributed over the area which is defined by a width of the specimen. At the end of each 60sec abrasion period both the disk and contact face were cleaned. The test was continued for a standard 12min period of abrasion. then the specimen was weighted at accuracy of 0.01g. Each value of abrasion or wear depth is the average of test results of three cubes.

The depth of wear was considered as the mean reduction in the specimen thickness, using the following equation:

$$D_w = R_m / \rho \cdot A \quad \dots\dots\dots (9)$$

Where

D_w : Depth of wear.

R_m : Reduction in mass after 12min abrasion period.

ρ : Density of the specimen.

A : Contact surface area of the specimen.

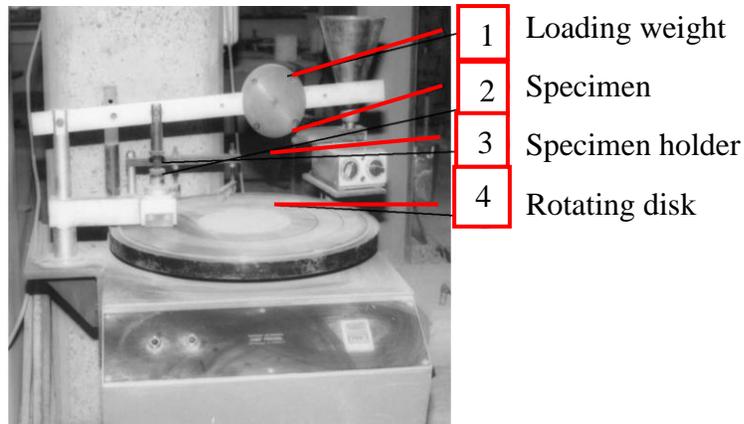
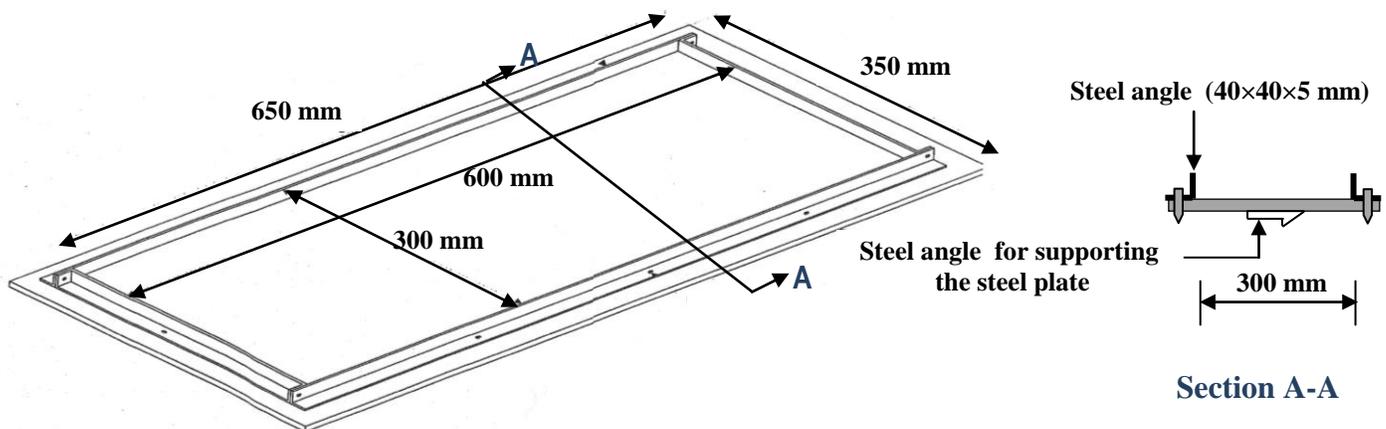


Plate (3): Abrasion resistance testing machine.

- Moulds for Plate

The plate specimens were cast in steel moulds to give a plate specimens with clear dimensions of (600 × 300 × 40mm) as shown in Figure (2). Each one of these steel moulds consisted of a steel plate of (650 × 350 × 5mm) enclosed by four steel angles section of (40 × 40 × 5mm). Every angle was fixed with the steel plate by three bolts as shown in Figure (2). These moulds were cleaned and their internal surfaces were greased after hardening.

All dimensions are in mm



- Mixing procedure, Casting and Curing

Figure (2): Dimensions and details of the steel mould of plate specimens. Three mix proportions were used in preparation the ferrocement layers. Cement to sand (C/S) ratios were 1:1 and 1:2 by weight. While for polystyrene concrete core, three mix proportions were used. The cement to polystyrene (C/P) ratios were 1:1, 1:3 and 1:5 by volume. The water to cement (W/C) ratio was 0.40 for all mixes as in previous work Jawad in (1987).

The mixing was done in a drum rotating laboratory mixer with a capacity of 0.08 m³. The interior surface of the mixer was cleaned and moistened before placing the materials. In all the mixes, first part of beads and a portion of the required water were mixed together until the beads were coated by a film of water. Then, the cement was gradually added

followed by the rest of water and polystyrene beads. The total mixing time was about (5-7) minutes, this ensure a uniform distribution of polystyrene beads in the mix. After mixing, the concrete was poured into lightly oiled moulds and well compacted by using 1m×1.5m table vibrator system. It was found that vibration for 40 seconds gives adequate compaction.

After compaction, the specimens were leveled by hand trawling, and covered with polyethylene sheets were used to cover the plates and control specimens in the laboratory for about 24 hours to prevent evaporation of moisture from the fresh concrete. Then, burlap sacks were placed over the plate specimens and water was sprayed on them continuously for 28 days. After that they were kept in the laboratory for one month to be normally dried until testing. Mixing and curing were performed according to the ASTM C192-02.

- Testing Procedures

The cubes, cylinders and plates were tested first using non-destructive methods namely ultrasonic pulse velocity test. After completion of non-destructive test, the specimens were tested in machines until failure.

- Results and Discussion

- Compressive Strength

In order to obtain a better understanding of the behavior of polystyrene concrete plates, it is important to study the mechanical properties of polystyrene concrete firstly.

The compressive strength results with the (C/P) ratios are summarized in Table (6), while Figures (3) and (4) show the relationships between the compressive strength with age for mortar mixes 1:1 and 1:2 with and without polystyrene. It is obvious from the results that compressive strength decrease with addition of polystyrene. These results confirmed that of Zeya (1999).

Table (6): Test values of the compressive strength of polystyrene concrete specimens.

| Age (days) | Compressive Strength (MPa) | | | | | Percentage Increment in Compressive Strength (%) | | |
|------------|----------------------------|----------------------------------|------|------|------|--|-----|-----|
| | Mortar Mix Cement/Sand | (Cement/Polystyrene) (C/P) Ratio | | | | (C/P) Ratio | | |
| | | Without (P) | 1:1 | 1:3 | 1:5 | 1:1 | 1:3 | 1:5 |
| 28 | 1:1 | 33.2 | 21.8 | 15.4 | 10.8 | --- | --- | --- |

| | | | | | | | | |
|----|-----|------|------|------|------|------|------|------|
| 60 | 1:1 | 36.7 | 23.2 | 17.1 | 12.3 | 6.0 | 9.9 | 12.2 |
| 90 | 1:1 | 39.8 | 24.7 | 18.8 | 13.6 | 11.7 | 18.1 | 20.6 |
| 28 | 1:2 | 29.6 | 19.5 | 13.2 | 9.4 | --- | --- | --- |
| 60 | 1:2 | 33.1 | 20.8 | 14.7 | 10.5 | 6.3 | 10.2 | 10.5 |
| 90 | 1:2 | 35.9 | 22.3 | 15.8 | 11.6 | 12.6 | 16.5 | 19.0 |

P : Polystyrene
C : Cement

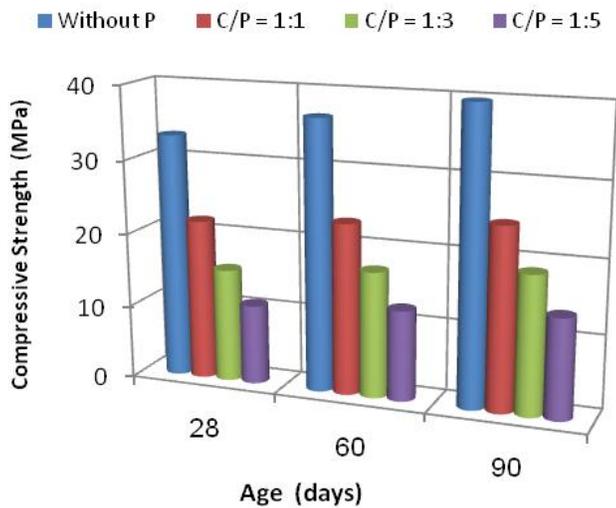


Figure (3): The effect of polystyrene on the compressive strength of mortar mix 1:1 for different ages.

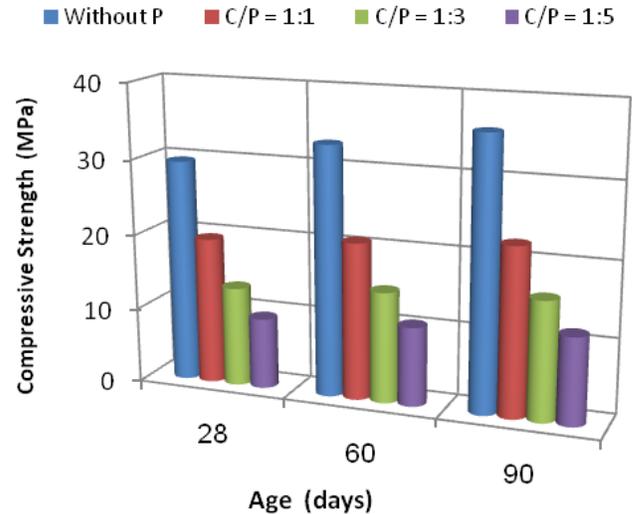


Figure (4): The effect of polystyrene on the compressive strength of mortar mix 1:2 for different ages.

- Load Versus Mid-Span Deflection Results

Experimental investigation on the behavior of load versus mid-span deflection curves for the flexural tests of series A, B and C are presented in the Figures (5) to (7) respectively.

From the load deflection curves of tested plate specimens it can be observed that the load versus mid-span deflection response can be divided into three stages of behavior. In the first stage, is the elastic or uncracked stage. In the second stage, is quazi-elastic or multiple cracking stage. Finally in the third stage, is the plastic stage which represents the yielding of reinforcement and widening of cracks.

From Figures (5) and (6), it can be seen that the increase in the volume fraction of reinforcement has a significant effect on mid-span deflection of plate specimens for series A and B. In addition, it can be noted that the increase in the volume fraction (V_f) increases the load carrying capacity and decreases mid-span deflection in plate specimens. This can be attributed to the fact that the increase in (V_f) causes a decrease in plate stiffness, which is essentially due to the increase in the modulus of elasticity of composite material and the increase in the load carrying capacity of ferrocement plate specimens.

From Figure (7), it can be observed that the increase in cement to polystyrene (C/P) ratio of plate specimens leads to increase the mid-span deflection and decreasing the load carrying capacity of plate.

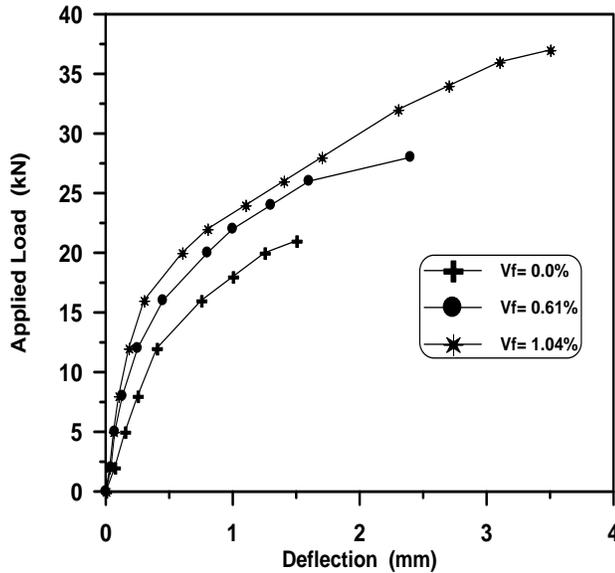


Figure (5): Load versus mid-span deflection curve of series A.

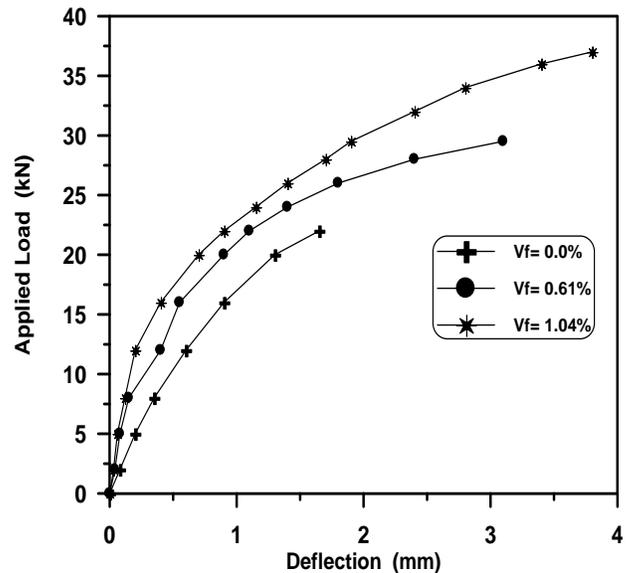


Figure (6): Load versus mid-span deflection curve of series B.

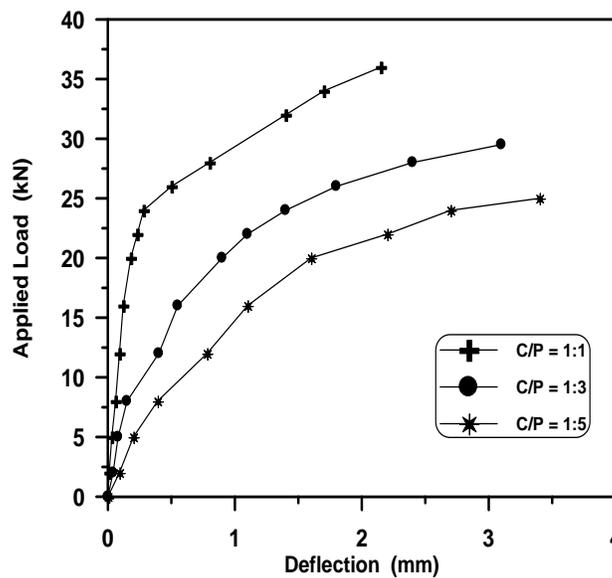


Figure (7): Load versus mid-span deflection curve of series C.

- Abrasion Resistance

The abrasion resistance test results for three series are summarized in Table (7). Figures (8) and (9) illustrate the relationship between the volume fraction (V_f) of reinforcement and depth of wear at failure for series A and B respectively. These Figures reveal that the increase in (V_f) decrease the depth of wear of the specimens.

Figure (10) exhibit the depth of wear at failure for the different cement/polystyrene (C/P) ratio. This Figure reveal that the increase in (C/P) ratio decreased the depth of wear of the specimens.

Table (7): Abrasion resistance test results.

| Mortar Mix | V _f (%) | C/P Ratio | Depth of Wear (mm) | | | Increase in Abrasion Resistance (%) | | |
|------------|--------------------|-----------|--------------------|---------|---------|-------------------------------------|---------|---------|
| | | | 28 days | 60 days | 90 days | 28 days | 60 days | 90 days |
| 1:1 | 0.00 | 0.00 | 2.82 | 2.41 | 1.95 | -- | -- | -- |
| | 0.00 | 1:3 | 1.78 | 1.54 | 1.41 | 36.9 | 36.1 | 27.7 |
| | 0.61 | 1:3 | 1.16 | 1.01 | 0.92 | 58.9 | 58.1 | 52.8 |
| | 1.04 | 1:3 | 0.82 | 0.72 | 0.61 | 70.9 | 70.1 | 68.7 |
| 1:2 | 0.00 | 0.00 | 3.02 | 2.81 | 2.57 | -- | -- | -- |
| | 0.00 | 1:3 | 1.96 | 1.59 | 1.48 | 35.1 | 43.4 | 42.4 |
| | 0.61 | 1:3 | 1.34 | 1.04 | 0.91 | 55.6 | 63.0 | 64.6 |
| | 1.04 | 1:3 | 0.92 | 0.77 | 0.64 | 69.5 | 72.6 | 75.1 |
| 1:2 | 1.04 | 1:1 | 1.13 | 0.92 | 0.79 | -- | -- | -- |
| | 1.04 | 1:5 | 0.51 | 0.40 | 0.30 | 54.9 | 56.5 | 62.0 |

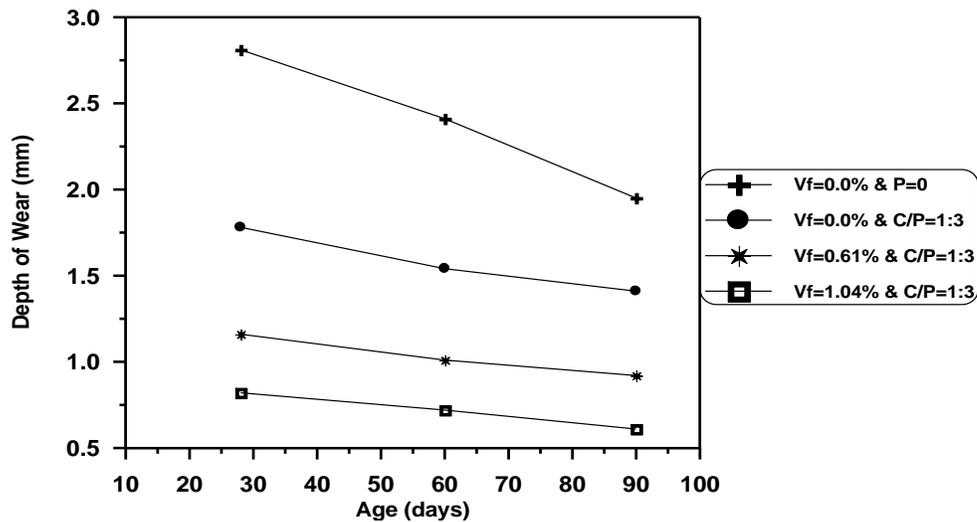
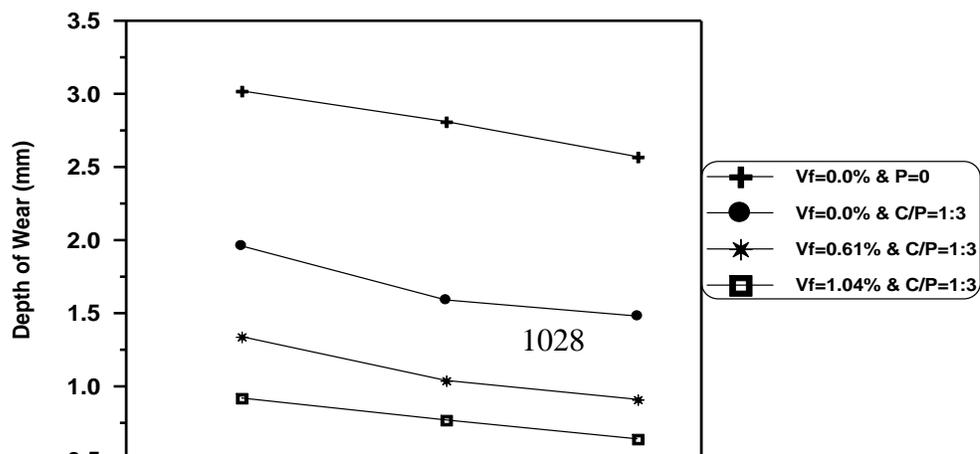


Figure (8): The effect of volume fraction of reinforcement on the depth of wear of mortar mix (C:S=1:1) for different ages.



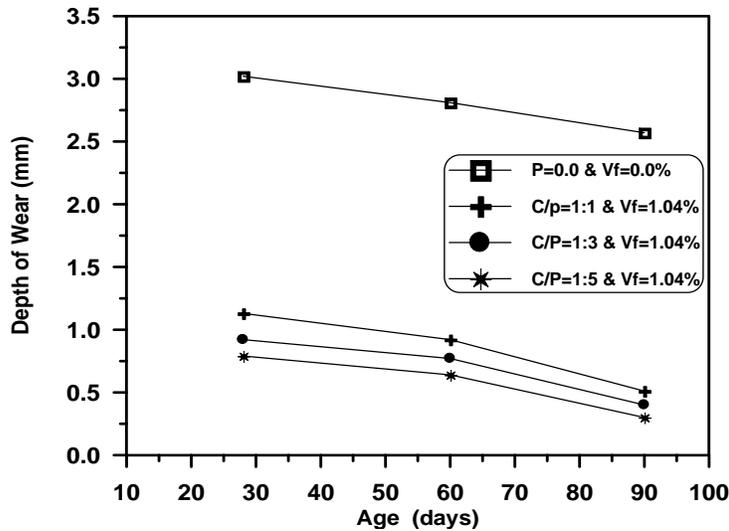


Figure (10): The effect of polystyrene content on the depth of wear of mortar mix (C:S=1:2) for different ages.

- Dynamic Modulus of Elasticity Plate Specimens (E_d)

The dynamic (E_d) and static modulus (E_s) of elasticity test results with the (C/S) and (C/P) ratios are summarized in Table (8) for three series. The dynamic modulus of elasticity of plate specimens increases as the surface area (S_r) or volume fraction of reinforcement (V_f) increases as shown in Figure (11). In addition, it can be seen from this Figure that the increase amount of sand effect of cement to sand ratio on the dynamic modulus of elasticity for plate.

Figure (12) reveals the effect of polystyrene to cement (C/P) ratio on the dynamic modulus of elasticity of plates. From this Figure, it can be concluded that the higher polystyrene content leads to decrease the dynamic modulus of plate specimens. This is due to the fact the elastic modulus of cement paste is much higher than that for polystyrene.

Table (8): Test results of dynamic properties of plate specimens.

| Series No. | Plate Specimen designation | Density (ρ) (kg/m^3) | Pulse Velocity (V) (km/sec) | E_s ($\rho \times V^2$) (GPa) | E_d (GPa) |
|------------|----------------------------|--|-----------------------------|-----------------------------------|-------------|
| A | PA-0 | 1080 | 2.38 | 6.12 | 5.69 |

| | | | | | |
|---|-------|------|------|-------|-------|
| | PA-1 | 1145 | 2.74 | 8.60 | 8.00 |
| | PA-2 | 1216 | 2.93 | 10.44 | 9.71 |
| B | PB-0 | 1270 | 2.62 | 8.72 | 8.11 |
| | PB-1 | 1278 | 2.93 | 10.97 | 10.20 |
| | PB -2 | 1383 | 2.98 | 12.28 | 11.42 |
| C | PC-1 | 1510 | 3.20 | 15.46 | 14.38 |
| | PC-5 | 1168 | 2.34 | 6.40 | 5.95 |

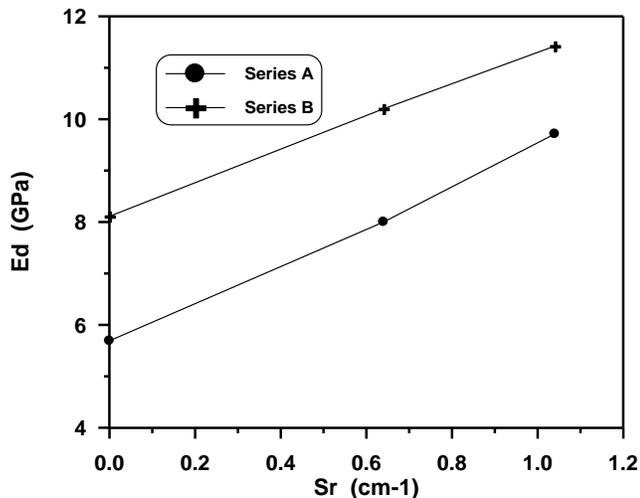


Figure (11): The effect of specific surface of steel wire mesh on the dynamic modulus of elasticity.

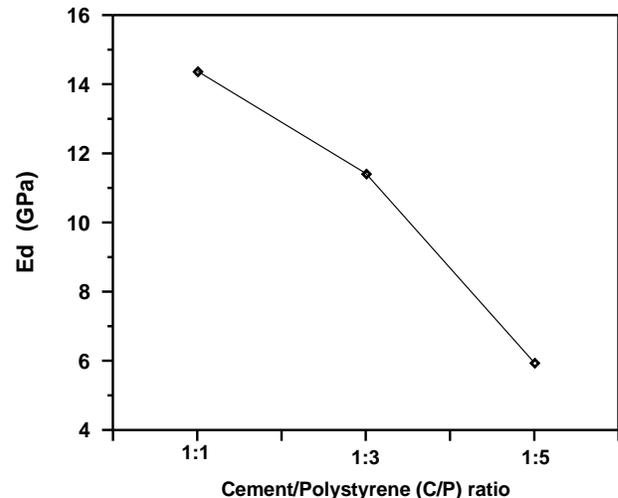


Figure (12): The effect of cement to polystyrene ratio on the dynamic modulus of elasticity.

- Conclusions

Based on the experimented results of present work , the following conclusions can be drawn :

- 1- In this study, it is observed that the value of compressive strength decrease with addition of polystyrene.
- 2- The experimental results of the compressive strength of mortar mix 1:1 and using (1:1, 1:3 and 1:5) the cement to polystyrene (C:P) ratio by volume were increased by (6.0, 9.9 and 12.2)% and (11.7, 18.1 and 20.6)% at (60, 90) days age respectively, while for mortar mix 1:2 were increased by (6.3, 10.2 and 10.5)% and (12.6, 16.5 and 19.0)% at (60, 90) days age respectively.
- 3- It is found that the increase in the volume fraction (v_f) increases the load carrying capacity and decreases mid-span deflection in plate specimens.
- 4- In this study, it is noticed that the increase in cement to polystyrene (C/P) ratio of plate specimens leads to increase the mid-span deflection and decreasing the load carrying capacity of plate.

- 5- The experimental results clearly indicate that the higher polystyrene content leads to decrease the dynamic modulus of plate specimens. This is due to the fact the elastic modulus of cement paste is much higher than that for polystyrene.
- 6- It is found that the dynamic modulus of elasticity of plate specimens increases as the surface area (S_r) or volume fraction of reinforcement (V_f) increases.
- 7- The results from testing show that the increase in (C/P) ratio decreased the depth of wear of the specimens.

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