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# Study the Effect of Polystyrene on Some Mechanical Properties of Concrete

*By*

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***Abstract:***

In this study, some mechanical properties of polystyrene concrete have been investigated, by destructive and non – destructive method. The experimental results of non – destructive test were correlated with compressive strength, tensile strength, flexural strength, impact strength and crack patterns. The test result showed that the mechanical properties of concrete improved with addition of polystyrene up to 1/3 (percentage cement /Polystyrene). On the other hand, increasing polystyrene to cement ratio was found to increase flexural strength and abrasion resistance for concrete.

***Keywords:***

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## Introduction

The work in this investigation was planned in order to obtain further information about the effect of addition of polystyrene to the cement on the some mechanical properties of concrete. 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. It such cases, it is termed “polymer concrete “. A polymer is a chemical substance made up of repeating units, each unit being called a monomer. 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 ( * $10^3$Kg $mm^{-1}$) | 1.04 – 1.11 | 0.08 – 1.10 |
| Thermal conductivity ( $wm^{-1}k^{-1}$) | 0.09 – 0.21 | 0.04 – 0.17 |
| Thermal expansively(* $10^{-}$ $k^{-1}$) | 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 % |

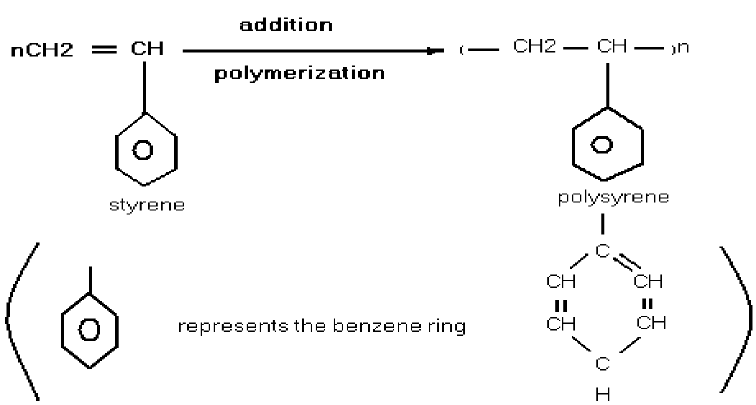



Fig (1): The polystyrene; Monomers → polymerization → polymer

## Research Significances

Polymer concrete (PC) is a composite material formed by combing 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 using 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, tensile strength, flexural strength, crack patterns and abrasion resistance of polystyrene are investigated at room temperature.

## Polystyrene Concrete

The properties of polystyrene concrete were investigated by a number of workers Sussman (1975) , Jawad (1987) and Bagon and Frondistou (1987).Generally the mechanical properties of expended poly styrene concrete such as elasticity and shear modulus are influenced by the ratio of expended polystyrene beads to cement content . Sussman (1975) reported that the compressive strength, flexural strength, and the modulus of elasticity of poly styrene concrete are directly proportional to the density. Bagon and Frondistou (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 (1987) obtained an empirical relationship for calculation of compressive strength of polystyrene concrete as follows.

$$Fc = \rho s \, ( Cs - 110 ) / ( 8.6 * 10 ) \quad \ldots\ldots\ldots\ldots (1)$$

Where Fs is the cylinder compressive strength in ( MPa ) , ρs is the saturated bulk density in (Kg / $m^3$) and Cs is the cement content in (Kg / $m^3$). The results of the tensile strength obtained by Bagon and Frondisou (1987) were ( 9.5 – 13.8 ) MPa. Jawad (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 / $m^3$).

## Non – Destructive Test

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

Ultrasonic pulse velocity was used to monitor the variations in compressive strength . The Ultrasonic pulse velocity was measured by an ultrasonic concrete tester ( CSI ), type cc – 4 as shown in plate ( 1 ). The test method is prescribed by BS. 1881 : part 203 : 1986 specifications .

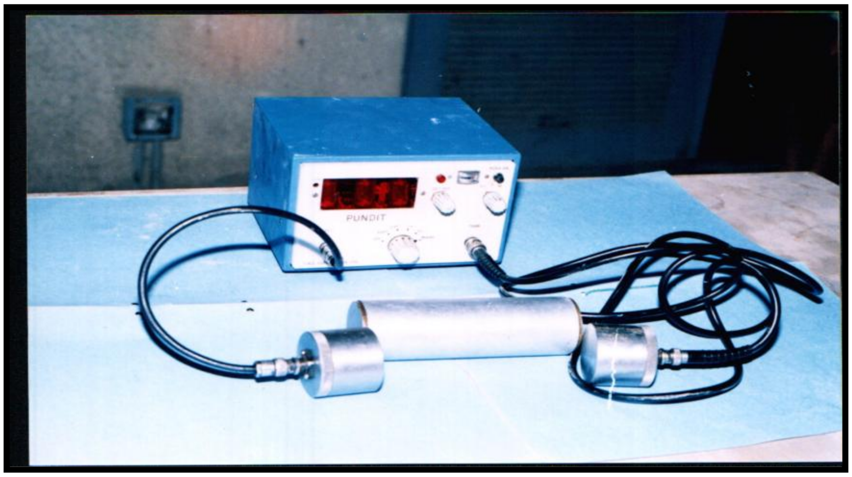



Plate (1): Ultrasonic pulse transit time test .

**Destructive Test**

*Compressive strength test*

Compressive strength was carried out and tested according to B. S 1881: part 116 : 1983. A total number of 28 standard cubes ( 150 mm ) were tested by using a digital universal testing machine of 2000 kN maximum capacity as shown in plate(2). 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.

Plate (2) : Compressive strength testing machine .

**Tensile Strength Test**

The tensile strength was determined according to the producers outlined in ASTM C – 496. A total numbers of 28 cylinders ( 100 *200 mm ) were tested. Cylinder were cast , demolded and cured in a similar way as the cubes . Each tensile strength value was the average of strength of three specimens.

**Flexural Strength**

Concrete prisms of dimensions (100 * 100 * 400 mm ) were cast according to ASTM C 78 – 84 : 1989 producer as shown in plate (3). A total numbers of prisms were tested. The were cast demolded and cured in a similar manner as the cubes. Each value of the modulus of rupture was the average of the test results of three prisms. For plates the flexural behavior of plates was studied in two-way bending action by supporting the plates on a square steel frame 560*560 mm. The plates were subjected to a uniform distributed load by using a 10cm layer of slightly compacted sand. The loading system was similar to that adopted by Matti (1985) and Jawad (1987) with the exception of using the universal testing machine with maximum capacity of 10 tons. The loading was applied at a constant rate of 2400 N/min. for all plates.

Plate (3) : Flexural strength testing machine .

**Abrasion Resistance Test**

The abrasion resistance was determined according to the German DIN 52108 (7) standard test method which was applied on 70 mm cubes. The apparatus required for this test are the Bohme disk abrader and abrasive materials. The Bohme disk abrader consists mainly of three parts as shown in Figure 1.

1 . The approximately 750 mm diameter rotating disk poisoned horizontally with the speed of (30 ± 1) revolution / min.

2 . A U frame about 40 mm thickness and 71 mm 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 specimen's thickness.

**Testing Procedure**

Prior to each test. The specimen was weighed to the nearest 0.01g and measured to the nearest 0.1 mm. 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 60 sec. abrasion period both the disk and contact face were cleaned. The test was continued for a standard 12 min. period of abrasion. The specimen was then weighed at accuracy of 0.01 g. The depth of wear was considered as the mean reduction in the specimen thickness , using the following equation :

$$\mathbf{D_W = R_m / \rho . A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where

$\mathbf{D_W}$ : depth of wear .

$\mathbf{R_m}$ : reduction in mass after 12 min. abrasion period.

$\boldsymbol{\rho}$ : density of the specimen.

**A** : contact surface area of the specimen.

Each value of abrasion or wear depth is the average of test results of three cubes.

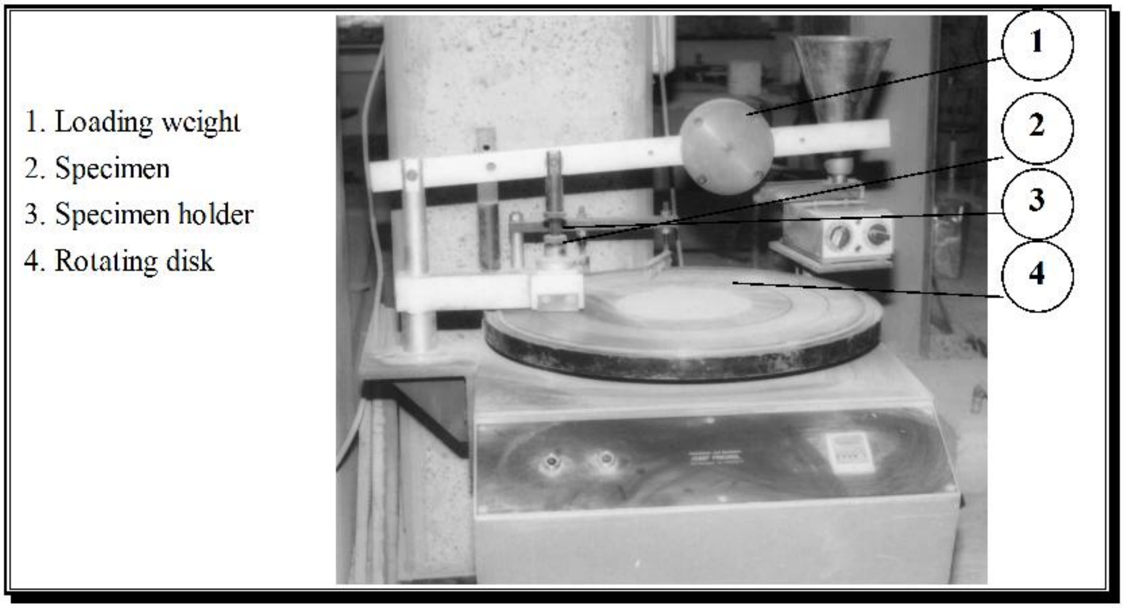



**Fig.2** Abrasion resistance testing machine

**Experimental Work**

This section describes the materials used in the production of the specimens, mix proportion and the methods of testing. The specimens were cast, moist cured for 28 days, air dried in the laboratory. They were tested at the ages 30 and 60 days.

*Material*

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 (2).

**Table 2: a) physical properties of the cement**

| Physical properties | Test results | I.Q.S.5:1984[40] limits |
|---|---|---|
| Fineness ,Blaine,cm$^2$/gm | 3300 | ≥2300 |
| Setting time ,Vicat's method<br>Initial hrs: min<br>Final hrs : min | <br>1: 50<br>3: 35 | <br>≥ 00 : 45<br>≤ 10 : 00 |
| Compressive strength of<br>70.0 mm cube , MPa<br>3 days<br>7 days | <br><br>23.5<br>33.6 | <br><br>≥ 15<br>≥23 |

**Table 2: b) Chemical Composition of Cement**

| **Oxide** | **(%)** | **I.Q.S.5:1984[40] limits** |
|---|---|---|
| CaO | 64.6 | ……… |
| $SiO_2$ | 21.97 | …….... |
| $Fe_2O_3$ | 3.67 | ……… |
| $Al_2O_3$ | 4.6 | ……… |
| MgO | 1.7 | ≤ 5.0 |
| $SO_3$ | 2.6 | ≤ 2.8 |
| Free Lime | 0.68 | - |
| L.O.I | 1.53 | ≤ 4.0 |
| L.R | - | ≤ 1.5 |
| **Compound composition** | **(%)** | **I.Q.S.5:1984 limits** |
| **$C_3S$** | 47.97 | ……….. |
| **$C_2S$** | 23.77 | ……….. |
| **$C_3A$** | 8.47 | ………. |
| **$C_4AF$** | 11.15 | ………. |
| **L.S.F** | 0.95 | 0.66-1.02 |

Fine and Coarse Aggregate
A well graded natural silica sand was used . The gravel used was 10 mm maximum size.

Water
Tap water was used through out this work for both mixing and curing of concrete.

**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 (3).

**Table 3: Polystyrene beads sieve analysis.**

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

## Mix Design and Properties

The concrete mix was designed according to British mix design method B.S 5328: part 2: 1991. This mix was design to give the forget design strength of 30 MPa and a slump of (70mm).
The properties of the concrete mix are summarized in table (4)

**Table 4: Mix properties.**

| Slump mm | W/C ratio | Weight properties | Mix properties Kg/m$^3$ | | | |
|---|---|---|---|---|---|---|
| | | Cement:Sand:Gravel | Water | Cement | Sand | Gravel |
| 70 | 0.48 | 1:1.5:3.2 | 195 | 380 | 570 | 1215 |

## Moulds for Plate

The moulds used for casting of the specimens comprised of a square steel frame measuring 600*600*50 mm, which was fastened to a wooden plate faced by a steel plate as shown in plate (4).

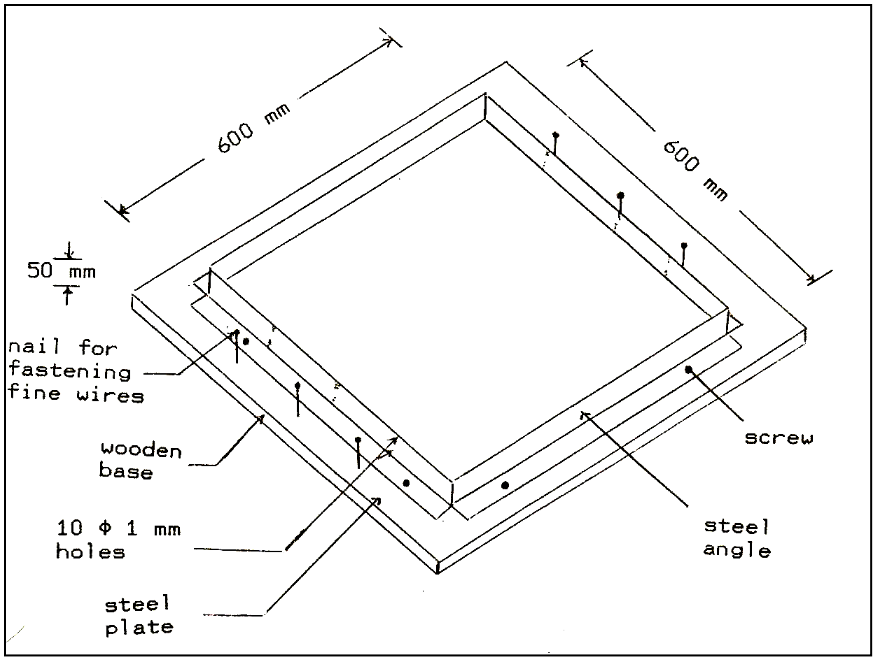



**Fig (3)**: Details of the mould use.

## Concrete Mixing and Casting

The concrete mixtures were produced in a horizontal pan - type mixer of 0.1 $m^3$ capacity. The interior surface of mixer was cleaned and moisted before it was used. Five mix proportions were used in preparation of polystyrene concrete. The cement to polystyrene (C/P) ratios were 1:1, 1:2, 1:3, 1:4 and 1:5 by volume. The water to cement (w/c) ratio by weight was 0.46 for all mixes. In this procedure, part of the 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 polystyrene beads. No additives were used, the mixing time lasted 6 minutes, and this ensures a uniform distribution of the polystyrene beads in the mix. A table vibrator was used to achieve full compaction for the molded test specimens.

## Testing Procedures

The cubes, cylinders, prisms 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

*Ultrasonic pulse Velocity Results (U.P.V)*

The ultrasonic pulse velocity test results are presented in Table (4)

**Table 5: Test values of the ultrasonic pulse velocity of polystyrene concrete specimens.**

| Age (days) | Compressive Strength (MPa) | | | | | |
|---|---|---|---|---|---|---|
| | (cement / polystyrene) (C/P) Ratio | | | | | |
| | Without P | 1:1 | 1:2 | 1:3 | 1:4 | 1:5 |
| 30 | 30 | 29.6 | 29.9 | 33.0 | 31.8 | 29.2 |
| 60 | 36.7 | 38.2 | 40.0 | 40.6 | 40.0 | 39.4 |
| 90 | 39.6 | 41.4 | 43.3 | 45.7 | 44.3 | 42.0 |

Figure (4) shows the relationship between the compressive strength with age for concrete without and with polystyrene. It can be seen from figure that the compressive strength increasing with addition of polystyrene and the optimum mix is (1:3). These results confirmed that of Zeya (1999).

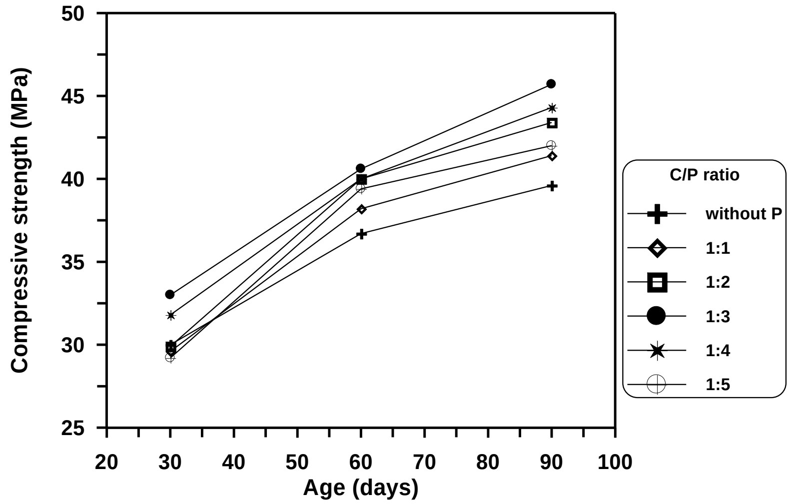



Fig (4): The effect of polystyrene on the compressive strength of concrete for different ages.

**Tensile Strength**

Figure (5) shows the tensile for polystyrene concrete with age. Similar to the compressive strength, the tensile strength showed significant increase with the increase in polystyrene. These results are summarized in table (6). These results agreed with that obtained by other investigations , Zeya (1988), Jawad (1987) and Parton and Sheady (1982) .

**Table 6: Test value of tensile strength of polystyrene concrete specimens .**

| Age (days) | Tensile Strength (MPa) | | | | | |
|---|---|---|---|---|---|---|
| | (Cement / Polystyrene) (C/P) Ratio | | | | | |
| | Without P | 1:1 | 1:2 | 1:3 | 1:4 | 1:5 |
| 30 | 4.71 | 7.80 | 8.24 | 9.30 | 10.72 | 12.12 |
| 60 | 4.99 | 8.23 | 9.21 | 10.65 | 11.44 | 12.80 |
| 90 | 5.35 | 9.62 | 10.40 | 11.38 | 12.06 | 13.00 |

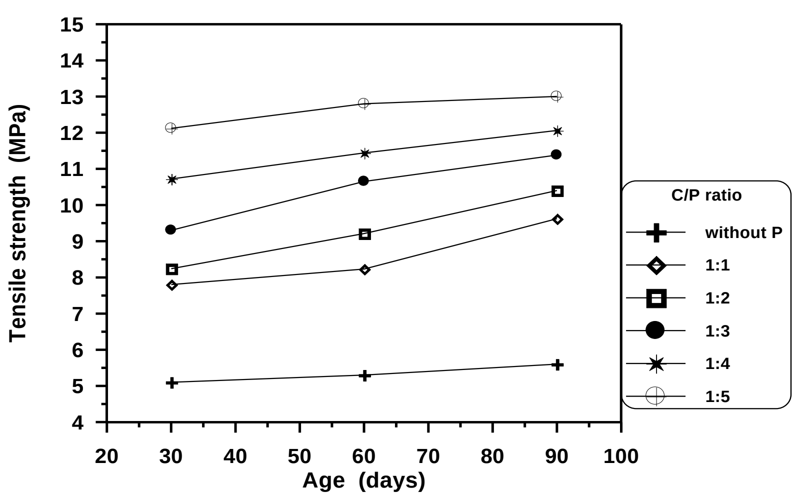


Figure (5): The effect of polystyrene on the tensile strength of concrete for different ages.

**Flexural Strength**

Table (7) show the effect of addition of polystyrene to the concrete while figure (6) shows the relationship between flexural strength and age for all mixes. It can be seen from these table and figure that the flexural strength increases with increasing of polystyrene. Similar behavior was found by Reis (2006).

**Table 7: Test values of flexural strength of polystyrene concrete specimens.**

| Age (days) | Flexural Strength (MPa) | | | | | |
|---|---|---|---|---|---|---|
| | (Cement / Polystyrene) (C/P) Ratio | | | | | |
| | Without P | 1:1 | 1:2 | 1:3 | 1:4 | 1:5 |
| 30 | 7.22 | 9.73 | 10.65 | 11.10 | 11.87 | 12.92 |
| 60 | 7.40 | 9.89 | 11.73 | 11.82 | 12.41 | 13.34 |
| 90 | 7.74 | 10.55 | 12.51 | 12.20 | 12.73 | 13.85 |

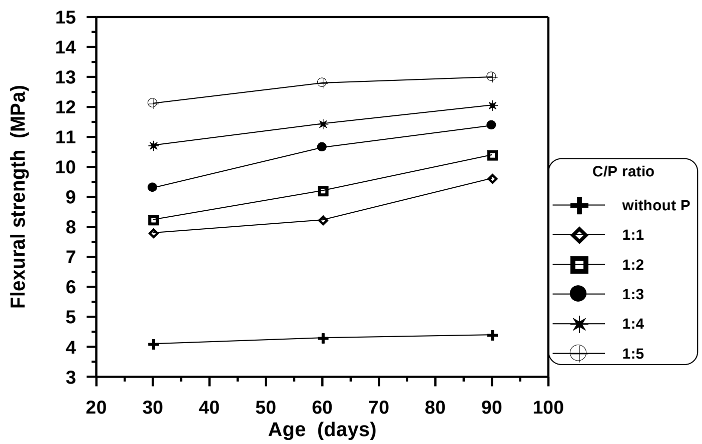



Figure (6): The effect of polystyrene on the flexural strength of concrete for different ages.

**Abrasion Resistance**

The abrasion resistance test results of the 6 mixes of plain concrete and polystyrene concrete are summarized in Table (7). The percentage of improvement in abrasion resistance when comparing the polystyrene concrete to the plain concrete mixes is also given in this table.

**Table 8: Abrasion resistance test results .**

| **(Cement/ Polystyrene)** | **Depth of wear (mm)** | | | **Increase in abrasion resistance (%)** | | |
|---|---|---|---|---|---|---|
| **(C/P)** | **30 days** | **60 days** | **90 days** | **30 days** | **60 days** | **90 days** |
| **Without P** | **0.78** | **0.70** | **0.65** | **-** | **-** | **-** |
| **1:1** | **0.76** | **0.67** | **0.62** | **2.60** | **4.3** | **4.6** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **1:2** | **0.62** | **0.56** | **0.51** | **20.5** | **20.0** | **21.5** |
| **0.78** | **0.60** | **0.52** | **0.45** | **23.0** | **25.7** | **30.8** |
| **1:4** | **0.54** | **0.50** | **0.46** | **30.8** | **28.6** | **29.3** |
| **1:5** | **0.42** | **0.37** | **0.34** | **46.0** | **47.1** | **47.7** |

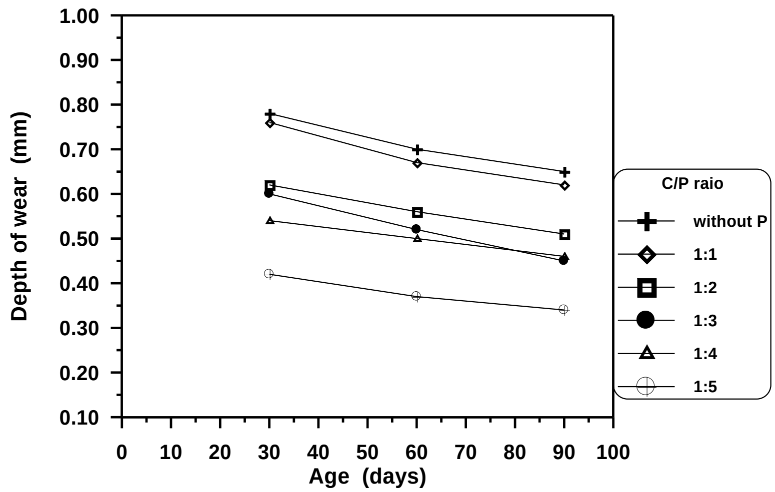



Figure (7): The effect of polystyrene on the depth of wear of concrete for different ages.

**The cracking patterns**

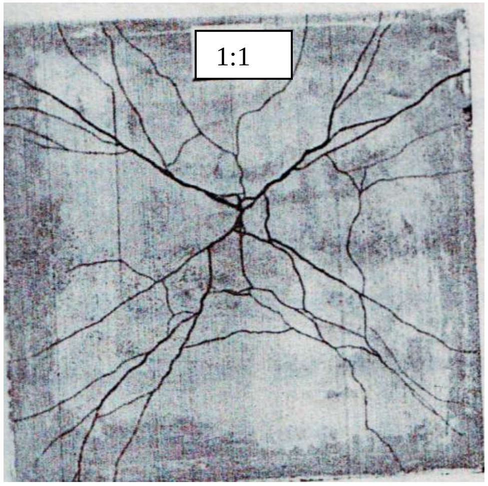
Typical cracking patterns of plates for all mixes are shown in photo (1) for all plates, the first crack appeared in the central region and then extended diagonally to wards the corners rapidly. As loading increased, more cracks started from this region and extended to wards the corners.

At can be seen from the above plates that the major factor in characterizing the cracking patterns is the polystyrene /cement ratio effect on the cracking patterns. Increasing polystyrene to cement ratio of core material leads to increase the cracks and decrease there spacing at failure due to the reduction of elastic modular of plates, the test results are shown in Table (8). This value is very closed to that obtained by Hermiz (1988).

**Table 9:Results of flexural test of plates.**

| (Cement / Polystyrene) (C/P) Ratio | No. of specimens | First crak load $W_{cr}$ (kN) | Ultimate load $W_u$ (kN) |
|---|---|---|---|
| 1:1 | 3 | 32 | 83.56 |
| 1:2 | 3 | 29 | 81.95 |
| 1:3 | 3 | 26 | 78.24 |
| 1:4 | 3 | 23 | 75.73 |
| 1:5 | 3 | 19 | 71.00 |

Photo (1): The cracking patterns.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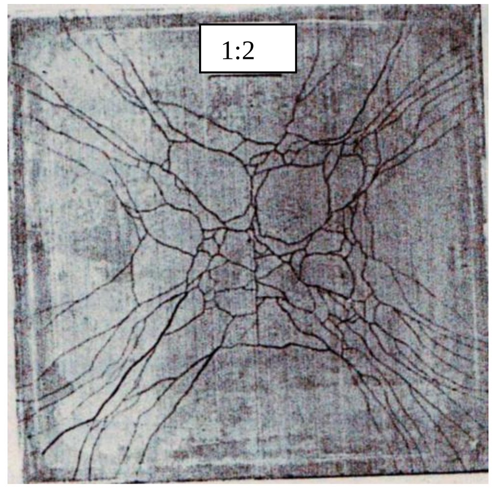
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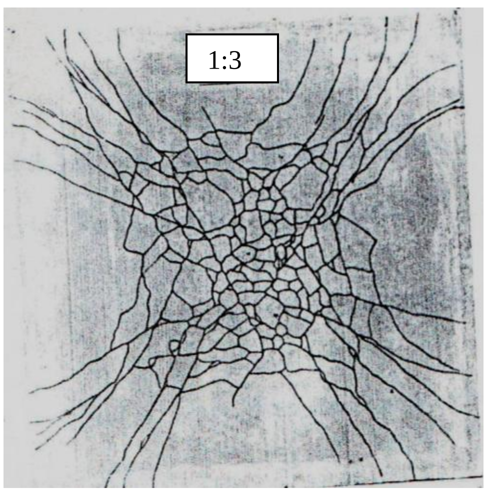
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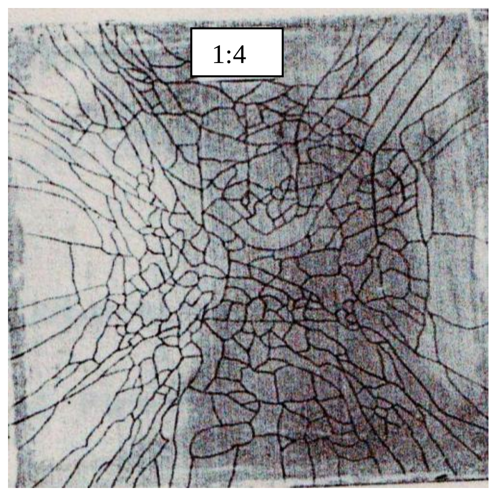
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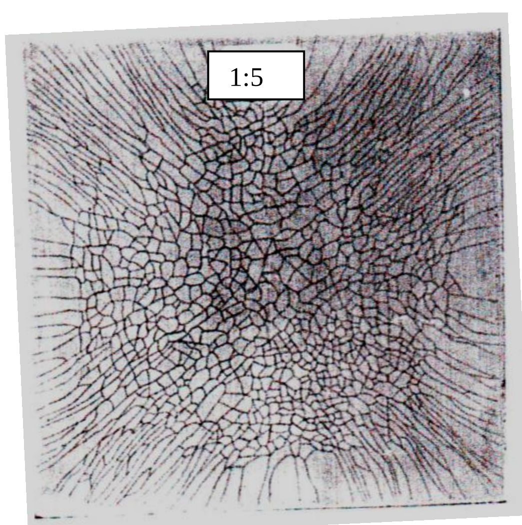
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## Conclusions

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

1. The inclusion of polystyrene improves the compressive strength of concrete. Nevertheless, the maximum improvement is achieved at mix 1:3 of C/P ratio. This improvement is about 11.4 % at 30 days, 14.9 % at 60 days and 14.0 % at 90 days.
2. The percentage of increase in tensile strength and flexural strength is directly proportional to the increase in C/P ratio.
3. The abrasion resistance of concrete was found to be increased with the increase in the percentage of polystyrene. Increasing the cement /polystyrene ratio to increase the abrasion resistance by (2.6 - 46.5)% at 30 days, (4.3 - 47.1)% at 60 days and (4.6 - 47.7) % at 90 days.

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