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NO-FINE LIGHTWEIGHT AGGREGATE CONCRETE MODIFIED WITH STYRENE BUTADIENE RUBBER

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Abstract:

No-fines concrete is a form of lightweight concrete obtained when fine aggregate is omitted. No-fine concrete mainly used for both load bearing and non-load bearing for external walls and partitions and in in-filling panels in framed structures. The essential objective of this work is to investigate the effect of incorporation of polymer (SBR) on the performance of no-fine concrete made from lightweight aggregate (porcelinite) and to suggest possible applications of this type of concrete. Three concrete mixes with different aggregate/cement ratios (A/C) (6:1, 8:1 and 10:1) by volume were selected. Each of these mixes included six mixes which differed in polymer/cement ratios, (0%, 5%, 10%, 15% and 20%) by weight to find the optimum polymer/cement ratio. Density, compressive strength, splitting tensile strength and drying shrinkage were conducted on all concrete mixes. The test results showed that the compressive strength of no-fine lightweight aggregate concrete increased with the increase in polymer/cement ratio up to 15%, and the compressive strength reduced at polymer /cement ratio of 20% . At polymer/cement ratio of 15%, the percentage of increase in compressive strength measured relative to reference mixes was about 50%. On the other hand, the splitting tensile strength was increased with the increase in polymer/cement ratio for all mixes. The percentage of increase in splitting tensile strength compared with reference mixes increased from about 30 to 90% with the increase of polymer/cement ratio from 5 to 20 %. Also the drying shrinkage strains of no-fine concrete decrease, with the increase in polymer/cement ratio. The percentages of decrease in drying shrinkage strain at 56 days were from 5 to 30% with the increase of polymer/cement ratio from 5 to 20%.

Keyword: **no-fine concrete, Porcelinite Aggregate, Styrene Butadiene Rubber, Compressive strength, Splitting tensile strength, Drying shrinkage**

الخرسانة الخالية من الركام الناعم المصنوعة من الركام خفيف الوزن والمطورة بالبوليمر

الخلاصة :

تعد الخرسانة الخالية من الركام الناعم احد أنواع الخرسانة خفيفة الوزن حيث يتم ا لحصول عليها بحذف الركام الناعم من الخرسانة الاعتيادية. ان الهدف الرئيسي من هذا البحث هو دراسة تأثير إضافة احد أنواع البوليمر المعروف باسم ستايرين بيوتادين على اداء الخرسانة الخالية من الركام الناعم والمصنوعة أيضا من الركام خفيف الوزن ومن ثم اقتراح التطبيقات المناسبة لهذا النوع من الخرسانة. تم استعمال ثلاث خلطات خرسانية بنسب مختلفة من الركام/ الاسمنت (6:1 , 8:1 ,10:1) وكل خلطة من هذه الخلطات تضمنت نسب مختلفة من البوليمر/ الاسمنت (٥ ، ١٠، ١٥ ، و٢٠%). بعد المعالجة الرطبة تم إجراء فحوصات الكثافة الجافة، مقاومة الانضغاط، مقاومة الشد الانشطاري، وانكماش الجفاف. أظهرت النتائج بان مقاومة الانضغاط تزداد بزيادة نسبة البوليمر/ الاسمنت ولغاية نسبة ١٥% بعد هذه النسبة تبدأ بالانخفاض إن نسبة الزيادة في مقاومة الانضغاط عند نسبة البوليمر/ الاسمنت ١٥% كانت تقريبا ٥٠%. من جانب أخر إن مقاومة الشد الانشطاري تزداد بزيادة نسبة البوليمر/ الاسمنت حيث تراوحت الزيادة من ٣٠ إلى ٩٠% عند زيادة نسبة البوليمر/ الاسمنت من ٥ إلى ٢٠% . أشارت النتائج أيضا إن قيم انكماش الجفاف تنخفض بزيادة نسبة البوليمر/ الاسمنت حيث لوحظ بان نسبة الانخفاض بعمر ٥٦ يوم تراوحت من ٥ إلى ٣٠% عند زيادة نسبة البوليمر/ الاسمنت من ٥ إلى ٢٠%.

1.Introduction:

Lightweight concrete (LWC) can be classified broadly into three major groups by the method of production: they are aerated concrete, lightweight aggregate concrete and no-fine concrete. Aerated concrete is obtained by introducing foam bubbles inside the cement matrix or the sand cement grout. In Europe, it is also called "gas concrete". By varying the foam-sand ratio, concrete densities ranging from 300 to 1600 kg/m3 can be attained. Lightweight aggregates employed in lightweight concrete have a wide range of sources which can be natural materials, processed natural materials or synthetic substance from processed by products or environmental wastes. No-fine concrete, as its name implies, is concrete without any fine aggregate, i.e. consisting of cement, water and coarse aggregate only. No-fine concrete is thus an agglomeration of coarse aggregate particles, each surrounded by a coating of cement paste up to about 1.3 mm thick (Neville, 2000).

LWC finds a wide range of applications, from insulation to structural applications. No-fine concrete usually used for both load bearing and non-load bearing for external walls and partitions and in in-filling panels in framed structures.

The advantages of no-fine concrete are lower density, lower cost due to lower cement content, lower thermal conductivity, relatively low drying shrinkage, no segregation and capillary movement of water, better insulating characteristics than conventional concrete because of the presence of large voids.

The main objective of this study was to investigate the performance of no-fine concrete made with lightweight aggregate (porcilinite) and modify with Styrene Butadiene Rubber (SBR) and to suggest possible applications of this type of concrete.

2. Experimental Program:

2.1 Materials:

2.1.1 Cement:

Ordinary Portland cement manufactured in Lebanon (Turabt Al-Sabia) was used in all mixes throughout this study. The percentage oxide composition and physical properties of the cement indicate that the adopted cement conforms to the Iraqi specification No.5 /1984.

2.1.2 Coarse Aggregate:

Local naturally occurring lightweight aggregate of porcelinite stones was used as coarse aggregate with single size 19 mm. It was obtained from Al-Rutba region.

The aggregate for each batch was washed by water and spread inside the laboratory in order to bring the aggregate particles to saturated surface dry condition. Several physical and chemical properties were determined for coarse porcelinite aggregate. **Table 1** lists these properties and their corresponding proper specifications.

2.1.3 Styrene Butadiene Rubber (SBR)

A milky white latex based on modified styrene butadiene copolymer emulsion which is known commercially as Cempatch SBR 100 was used throughout this investigation. **Table 2** indicates the technical description of the aqueous solution of SBR used in this study which is complied with ASTM C 1059-2003.

2.2 Concrete Mixes:

Three concrete mixes with different aggregate/cement ratios (6:1, 8:1 and 10:1) by volume were selected. Each of these mixes included six mixes which differed in polymer/cement ratios (P/C), (0%, 5%, 10%, 15% and 20%) by weight to find the optimum P/C ratio.

Since workability tests can not be done due to very little cohesion between particles, experienced visual examination and trail and error method were used for deciding optimum water/cement ratio. A water/cement ratio higher than the optimum would make the cement paste flows to the bottom of the concrete and makes that portion dense, whereas, with too low a water/cement ratio, the cement paste will be so dry that aggregates do not get property smeared with paste which results in insufficient adhesion between the particles. The details of all concrete mixes used throughout this investigation are shown in **Table 3.**

2.3 Preparation and Curing of Test Specimens .

All concrete specimens were cast in steel molds in layers of approximately 50 mm depth. Each layer was compacted by simple rodding. Mechanical compaction or vibratory methods may be caused the cement paste to run off the aggregate.

The specimens were kept in their molds at room temperature with a plastic sheet cover to minimize water losses for 24 hours. After that they were demolded and immersed in water tank up to age of 28 days at laboratory temperature of about (23±2 ^{o}C).

2.4 Tests:

2.4.1 Workability

No standard method is available for workability tests of no-fine concrete, a visual check to ensure even coating of all particles is adequate, (Shetty, 2009).

2.4.2 28- Day Oven Dry Bulk Density:

The bulk density of the dried no-fine concrete can be calculated as: (Satish Chandra and Leif Berntsson, 2002).

$$\gamma_{dry} = \gamma_{Adry} + C + W_n + m_{ma} \text{ ----------------- Eq. (1)}$$

where:

γ_{dry} – the bulk density of the dried concrete in kg/m^3

γ_{Adry} – the bulk density of the dry, compacted lightweight aggregate in kg/m^3

C- the cement content in Kg/m^3

W_n – the chemically bound water after the hydration of the cement which is equal to the non-evaporable water.

The chemically bound water may be expressed as:

$$W_n = \alpha\, 0.25\, C \text{ ------------------------------- Eq. (2)}$$

Where:

α – the hydration degree which may be in the range of 0.7-0.8 after 28 days hydration in room temperature. and

m_{ma} – the amount of the other fine and dry particle addition in $k\ g/m^3$.

In this study the solid particles of the SBR polymer (57%) were considered as m_{ma}

2.4.3 Compressive Strength:

The compressive strength test was determined according to B.S. 1881 Part 116. This test was conducted on 150 mm cubes using an electrical testing machine with a capacity of 2000 KN at loading rate of 15 MPa per minute.

2.4.4 Splitting Tensile Strength:

The splitting tensile strength test was performed according to ASTM C496, (2003). (d=150 mm, h=300 mm) cylinders concrete specimens were used. The specimens were testing using an electrical testing machine with a capacity of 2000 KN.

2.4.5 Drying Shrinkage:

This test was carried out in accordance with ASTM C 490-2003 using 100x100x400 mm prism specimens to measure the change in length of the hardened concrete and by using mechanical extensometer.

All specimens were immersed in water for 7 days then two points were defined with demic points on each of two opposite sides and stored in laboratory at about (23±2 ^oC and 50±5 percent relative humidity) up to the age of 56 days.

3. Results and Discussions:

3.1 28-Day Oven Dry Bulk Density:

As expected, the 28 day oven dry density values decrease with the increase of aggregate/cement ratio. The values of air dry density ranged between (841.67-884.05) kg/m^3. This is attributed to the high aggregate content in addition to the fact that the use of single sized aggregate in no-fine concrete forms large interconnected voids distributed throughout the body of the concrete. The porous structure of this type of concrete is responsible for the lower density of no-fine concrete in comparison with the ordinary concrete. The decreased density means lower dead load of the structure. Furthermore, no-fine concrete with SBR showed slightly higher density than those without SBR with values ranging from 855.49 to 906.69 kg/m^3 , **Fig.1.**

3.2 Compressive Strength:

The compressive strength test results for all types of no-fine concrete are presented in **Table 4** and **Figs.2** and **3.** Results show that the compressive strength of unmodified concrete decreased with the increase of aggregate/cement ratio. The compressive strength for concrete 6:1, 8:1 and 10:1 was 3.14, 2.19 and 1.57 MPa respectively.

Data also show that the compressive strength of latex-modified concrete increased with the increase in polymer/cement ratio up to 15%, and the compressive strength reduced at polymer /cement ratio of 20%, **Fig. 3.** At polymer/cement ratio of 15%, the percentage of increase in compressive strength measured relative to reference mixes was about 50%. This may be attributed to the fact that, up to this ratio (15%), the polymer acts to strengthen the concrete microstructure, but a further increase in the polymer/cement ratio leads to discontinuities in the microstructure which reduce the strength. This trend was also observed by Ohama, 1995 for normal weight concrete.

The structural recommendations for load-bearing walls require a minimum compressive strength at 28 days of 2.76 MPa, Everett,1993. However, the strength of no-fine concrete (8:1), with SBR 10% is comparable to those of load bearing blocks and is sufficient for the application of no fine-concrete as walling materials.

3.3 Splitting Tensile Strength:

The test results of the tensile splitting strength of various types of no-fine concrete mixes are given in **Table 4** and shown graphically in **Figs. 4** and **5.** It is found that the highest splitting tensile strength was at aggregate/cement ratio 6:1 and decreased with the increase of aggregate/cement ratio.

Data also show that the splitting tensile strength was increased with the increase in polymer/cement ratio for all mixes containing different aggregate/cement ratio, **Fig.5.** The percentage of increase in splitting tensile strength compared with reference mixes (without SBR) increased from about 30 to 90% with the increase of polymer/cement ratio from 5 to 20 %. This can be interpreted in terms of the contribution of high tensile strength by the polymer itself and an overall improvement in cement-aggregate bond.

3.4 Drying Shrinkage:

The test results of drying shrinkage strains up to 56 days for various types of no-fine concrete are presented in **Table 5** and **Fig. 6 .** Generally, the test results showed high drying shrinkage at early age due to rapid loss of moisture from the surface of the specimen.

The test results also indicated that the drying shrinkage strains of latex-modified concrete decrease, with the increase in polymer/cement ratio. For example, the percentages of decrease in drying shrinkage strain at 56 days were from 5 to 30% with the increase of polymer/cement ratio from 5 to 20%. This reduction is due to improvements in water retention and water reduction effects.

4-Conclusions:

Within the limitations of materials and testing program employed in this study, some important conclusions can be described in the following sections.

1. The compressive strength of latex-modified no-fine lightweight concrete increased with the increase in polymer/cement ratio up to 15%, and the compressive strength reduced at polymer

/cement ratio of 20%. At polymer/cement ratio of 15%, the percentage of increase in compressive strength measured relative to reference mixes was about 50%.

2. The splitting tensile strength was increased with the increase in polymer/cement ratio for all mixes containing different aggregate/cement ratio. The percentage of increase in splitting tensile strength compared with reference mixes increased from about 30 to 90% with the increase of polymer/cement ratio from 5 to 20 %.

3. The drying shrinkage strains of latex-modified concrete decrease, with the increase in polymer/cement ratio. The percentages of decrease in drying shrinkage strain at 56 days were from 5 to 30% with the increase of polymer/cement ratio from 5 to 20%.

4. The strength of no-fine concrete (8:1), with SBR 10% is comparable to those of load bearing blocks and is sufficient for the application of no fine-concrete as walling materials.

5- References:

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Table 1. Chemical and physical properties of porcelinite lightweight aggregate

property	Specification	Test result
Specific gravity	ASTM C127-2003	1.62
Absorption, %	ASTM C127-2003	32
Dry loose unit weight, kg/m^3	ASTM C29-2003	710*
Dry rodded unit weight, kg/m^3	ASTM C29-2003	750
Aggregate crushing value, %	BS 812-Part 110-1990	16
Sulfate content (as SO_3), %	BS 3797-Part 2-1981	0.32**
Staining Materials		
Stain intensity Stain index	ASTM C641-2003	No stain 0

* Within the limit of ASTM C330 (880 kg/m^3)and BS 3797-Part 2 (960 kg/m^3).
** Within the limit BS 3979- Part 2 (1.0%)

Table 2. Technical description of SBR

Appearance	Milky white liquid
pH	10.5
Specific gravity	1.01
Mean particle size	0.17 micron
Solid particles content	57 %

Table 3. Details of the mixes used throughout this study

Type of mix	Aggregate/cement ratio by volume	Polymer/cement ratio by weight (%)	w/c ratio by weight of cement
MI 0	6:1	0	0.38
MI 5	6:1	5	0.35
MI 10	6:1	10	0.33
MI 15	6:1	15	0.31
MI 20	6:1	20	0.30
MII 0	8:1	0	0.43
MII 5	8:1	5	0.41
MII 10	8:1	10	0.38
MII 15	8:1	15	0.36
MII 20	8:1	20	0.34
MIII 0	10:1	0	0.45
MIII 5	10:1	5	0.43
MIII 10	10:1	10	0.41
MIII 15	10:1	15	0.38
MIII 20	10:1	20	0.36

Table 4. The 28-day density, compressive strength and splitting tensile strength test results for all no-fine concrete Mixes

Type of mix	Aggregate/ cement ratio by volume	Polymer/ cement ratio by weight (%)	Compressive strength MPa	Splitting tensile strength MPa	28-day oven dry density (kg/m^3)
MI 0	6:1	0	3.14	0.47	884.05
MI 5	6:1	5	3.76	0.62	889.84
MI 10	6:1	10	4.08	0.66	894.90
MI 15	6:1	15	4.71	0.81	900.33
MI 20	6:1	20	4.40	0.90	906.69
MII 0	8:1	0	2.19	0.33	858.31
MII 5	8:1	5	2.65	0.43	862.53
MII 10	8:1	10	2.93	0.47	866.75
MII 15	8:1	15	3.32	0.56	870.98
MII 20	8:1	20	3.08	0.63	875.05
MIII 0	10:1	0	1.57	0.24	841.67
MIII 5	10:1	5	1.89	0.32	845.13
MIII 10	10:1	10	2.11	0.34	848.58
MIII 15	10:1	15	2.38	0.41	852.04
MIII 20	10:1	20	2.10	0.46	855.49

Table 5. Drying shrinkage strains results for all no-fine concrete

Type of mix	**Drying shrinkage strain, (10^{-6})***				
	7-day	**14-day**	**21-day**	**28-day**	**56-day**
MI 0	81	164	180	205	220
MI 5	75	156	169	193	209
MI 10	71	147	161	180	198
MI 15	63	130	143	163	176
MI 20	55	115	125	142	152
MII 0	72	150	195	200	209
MII 5	69	141	183	191	199
MII 10	64	134	175	179	188
MII 15	57	120	155	159	168
MII 20	50	104	135	138	148
MIII 0	67	134	181	190	200
MIII 5	64	131	173	181	189
MIII 10	60	123	162	172	179
MIII 15	53	110	143	151	161
MIII 20	45	94	125	132	139

***After 7-day moist curing**

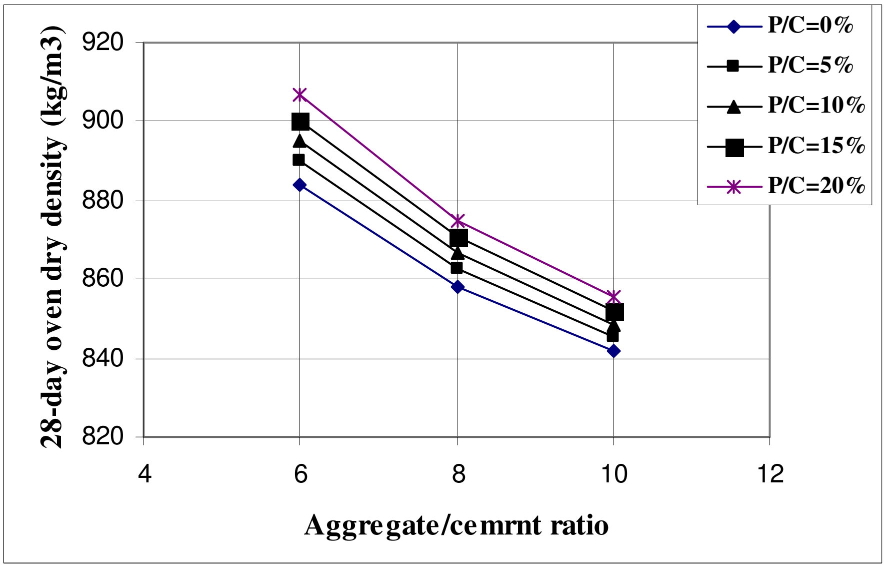

Fig.1, Relationship of oven dry density, P/C and aggregate/cement ratio for no-fine concrete

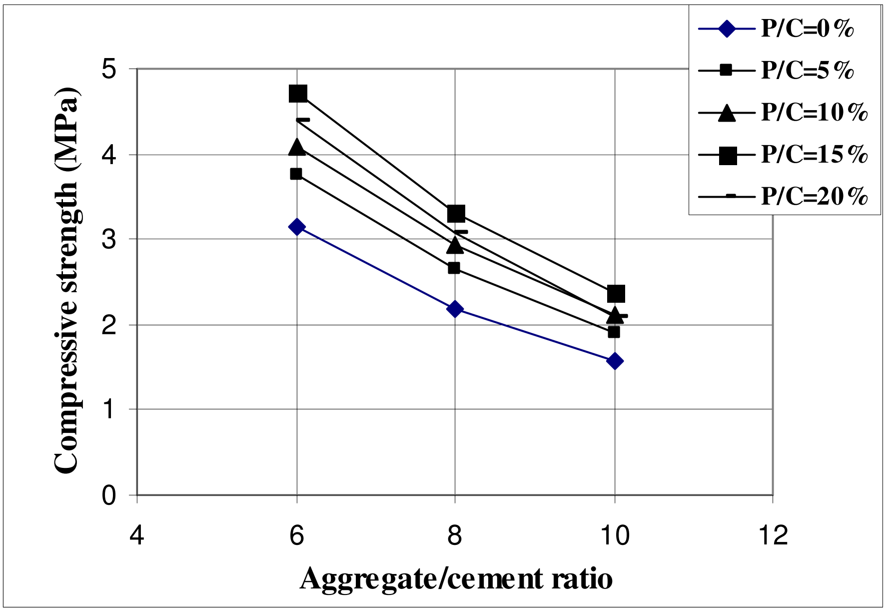

Fig.2. Relationship of compressive strength, P/C and aggregate/cement ratio for no-fine concrete

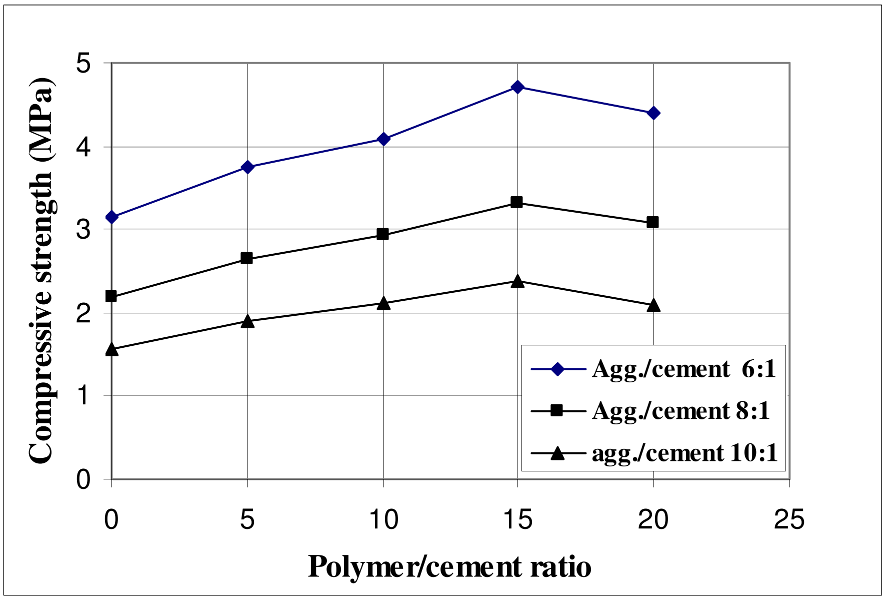

Fig.3. Effect of polymer/cement ratio on the compressive strength of no-fine concrete

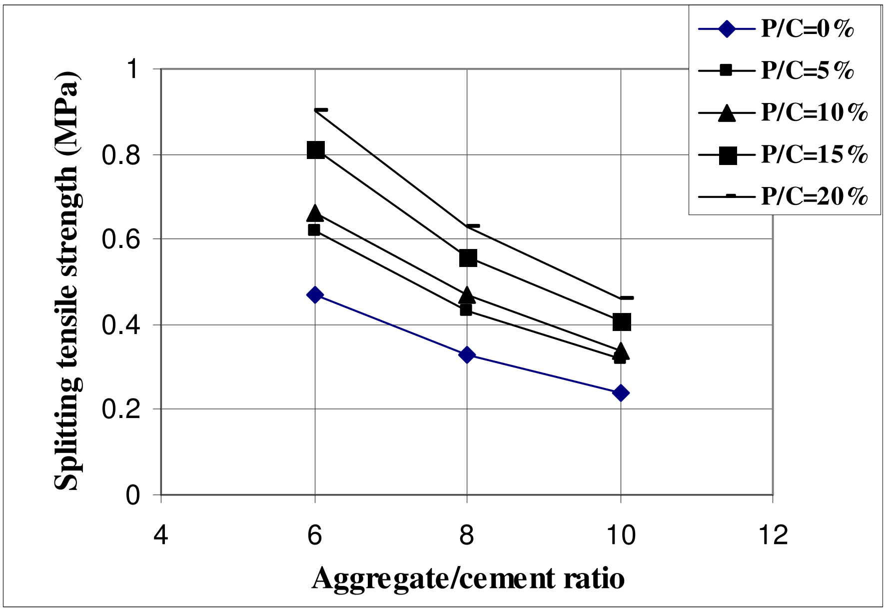

Fig. 4. Effect of polymer/cement ratio on the splitting tensile strength of no-fine concrete

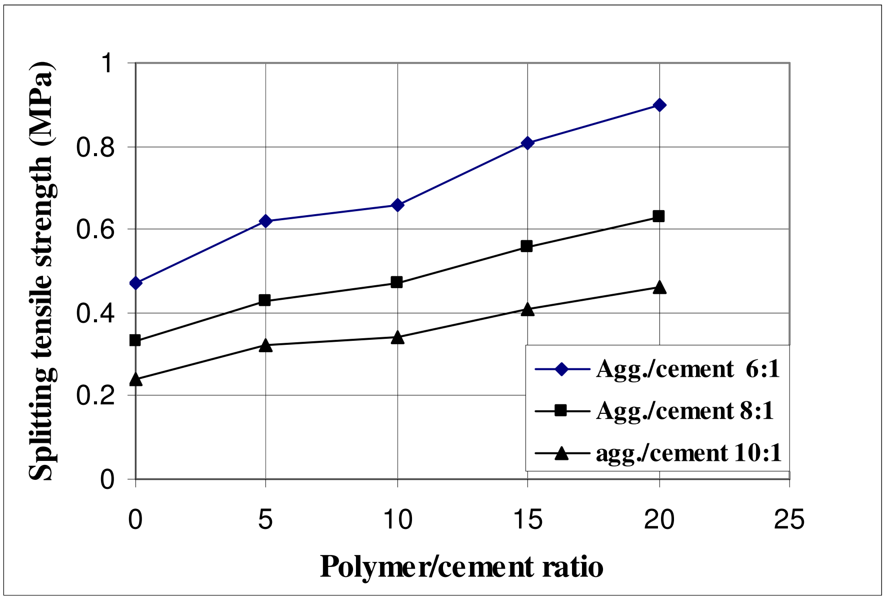

Fig.5. Relationship of splitting tensile strength, P/C and aggregate/cement ratio for no-fine concrete

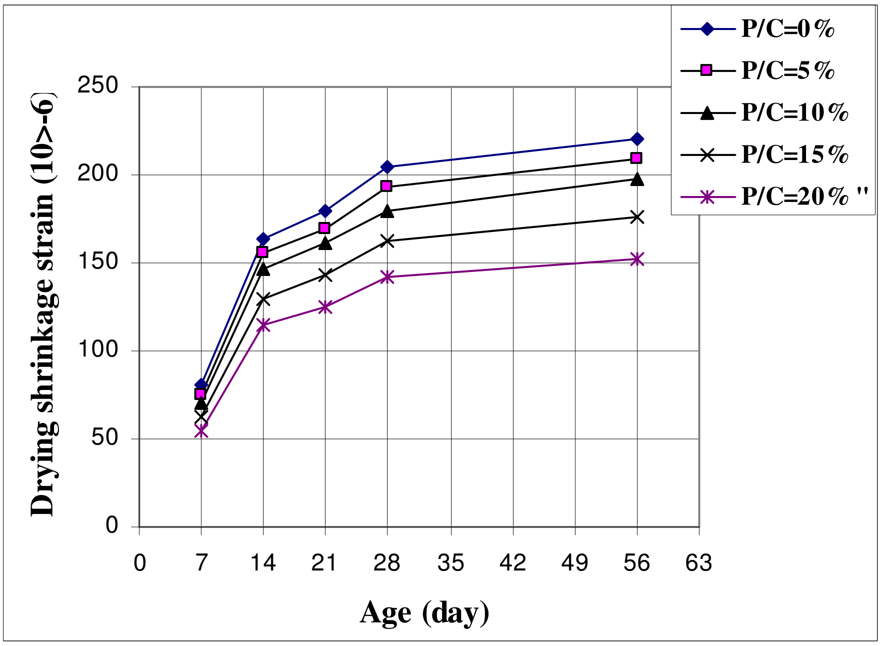

Fig.6.Influence of polymer/cement ratio on the drying shrinkage of no-fine concrete (A/C = 6:1)