High Performance Concrete Improvement by Styrene-Butadiene Rubber Addition

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ABSTRACT
In this paper, the properties of high performance concretes modified by polymer were studied. Liquid synthetic styrene-butadiene rubber (SBR) was added (5%, 10% and 15%) by weight of cement to high performance concrete (HPC) to elucidate the effect of the polymer additive to their properties. The compressive strength, splitting tensile strength, flexural strength, porosity, dry density and total water absorption were measured. Thermal conductivity, thermal diffusivity and specific heat of HPC is also measured. In addition, SEM micrographs are compared reference and polymer modified HPC. The results show that there is an improvement in the workability for HPC after the addition of the polymer. Furthermore, the density of the set concrete was increased and both the porosity, total water absorption was decreased. Thermal conductivity, thermal diffusivity, and specific heat show improvement after polymer addition, which indicate better endurance. The SBR modified HPC, exhibits a significant improvement in splitting tensile strength and flexural strength, although it was at the expense of the compressive strength to some extent. The HPC has shown balanced microstructure before and after the addition of polymer, although they noticed improved on the ductile properties.
Keywords: High Performance Concrete, Thermal properties, Physical properties, Mechanical properties, Styrene – Butadiene Rubber

INTRODUCTION
High Performance Concrete (HPC) is defined by the American Concrete Institute as "concrete that meets special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices" [1]. The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age, strength, volume stability or service life in severe environments. Concretes possessing many of these characteristics often achieve higher strength. Therefore, HPC has been often of high strength, but high strength concrete may not necessarily be of high performance. This definition falls short of fulfilling the expectations of a high-performance concrete that has engineered to exceed the minimum requirements and to maximize the performance of a special need. A most appropriate definition of a high performance concrete is "a concrete that has been formulated to optimize its material properties to maximize the performance and uniformity requirements of the special need for which it is being designed [2]. **Mohmed Yahya,..et al** [2013] [3] studied the effect of adding the styrene-butadiene-rubber (SBR) latex modified high-performance concrete, in order to evaluate the fracture energy at 28 days. A series of high performance

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concrete (HPC) mixes containing 1.5%, 3% and 5% SBR latex by weight of cement were prepared, cured and tested. Test results show that the fracture energy of the HPC with 1.5% SBR was enhanced by approximately 11%, while with 3% SBR and 5% SBR it decreased by 3% and 6.5% respectively. The compressive strength of the HPC for the 1.5% SBR addition at twenty-eight days increased by 16%, while it decreased by up to 21% for the 3% SBR addition and by 1% for the 5% SBR addition. The corresponding tensile strength of the HPC with 1.5%, 3% and 5% SBR increased by 23%, 10% and 23% respectively. **Z. A. Siddiqi,.. et al** [2013] [4]. The effect of adding Styrene-Butadiene Rubber (SBR) latex on water absorption and compressive strength of concrete has been studied. Latex modified concrete compositions containing 5%, 10% and 20% SBR latex by weight of cement were prepared. Both control and latex modified concretes were tested at 7 and 28 days of age. The results show that the early age compressive strength of the concrete is reduced by the addition of SBR. However, the strength is increased at 28 days of age, The SBR contributes significantly to the reduction of water absorption of concrete at 28 days of age. **G. N. Shete, and K. S. Upase**. [2014] [5]. The effect of Styrene-Butadiene Rubber (SBR) latex on water absorption and compressive strength of concrete has been studied Latex modified concrete compositions containing 5%, 10% and 20% SBR latex by weight of cement were prepared, both control and latex modified concretes were tested at 7 and 28 days of age. The results show that, Early age compressive strength of the concrete is reduced by the addition of SBR latex.However, the strength is increased at 28 days of age. The SBR latex contributes significantly to the reduction of water absorption of concrete at 28 days of curing.

Research Objectives

This research is focused on the determination properties of high performance concrete by adding synthetic rubber (Styrene-Butadiene Rubber) SBR on the engineered (mechanical, physical, and thermal) properties. Our view is an attempt to develop the ductile properties of the HPC to widen its application. In addition, gathering knowledge about polymer modified HPC is useful for materials design purposes.

Experimental work

The properties of materials used in any structure are of considerable importance. The properties of materials used in the current study were measured according to the Iraqi specifications (IQS).

Cement

Ordinary Portland cement manufactured by United Cement Company commercially known (Mass-Bazian) was used and conformed to the Iraqi Specification [6]. The physical and chemical properties of the cement are given in **Tables (1)** and **(2)** respectively.

Table (1): Physical properties of ordinary Portland cement.

Physical properties	Result	Limits of IQS No.5
Specific surface (m^2/kg).	395	>230
Setting time (Vicats method) **-Initial setting(hrs:min)** **-Final setting (hrs:min)**	 90min 210 min	 ≥ 45 min ≤ 10 hrs
Compressive strength of Mortar **3-days** **7-days**	 20.3 Mpa 30.1 Mpa	 ≥ 15 ≥ 23
Soundness (Autoclave) %	0.05	≤ 0.8

Table (2): Chemical composition and main compounds of ordinary Portland cement.

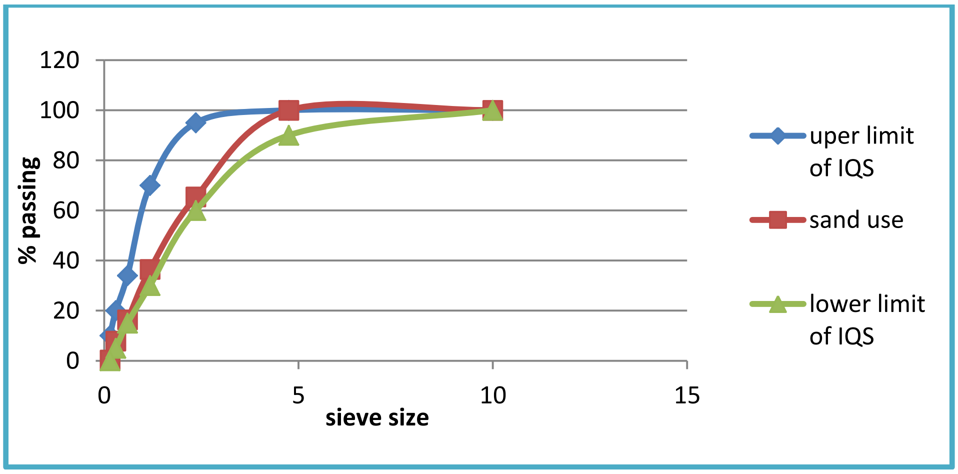
Oxide composition	Abbreviation	% by weight	Limits of IQS No.5/1984
Lime	CaO	61.11	-
Silica	SiO_2	20.38	-
Alumina	Al_2O_3	5.82	-
Iron oxide	Fe_2O_3	3.28	-
Sulphate	SO_3	2.12	$\leq$ 2.8%
Magnesia	MgO	4.27	$\leq$ 5%
Loss on Ignition	L.O.I.	2.16	$\leq$ 4%
Lime saturation factor	L.S.F.	0.88	0.66-1.02
Insoluble residue	I.R.	0.36	$\leq$ 1.5
Main compounds (Bouge eq.)		% by weight of cement	
Tricalcium silicate	(C_3S)	44.3	
Diacalcium silicate	(C_2S)	29.6	
Tricalcium aluminate	(C_3A)	6.55	
Tetracalcium aluminoferrite	(C_4AF)	10.2	

Fine Aggregate

Al-Ukhaider natural sand was used as fine aggregate. The grading and selected physical and chemical properties were measured. The results showed that conform within the requirements of the Iraqi specification [7]. As shown in **Table (3)** and **Fig (1).**

Table (3): Chemical analysis of fine aggregate.

Chemical analysis	results	Limits of Iraqi spec. No. 45/1984 (%)
Specific gravity	2.65	
Clays and Fine material	3.818%	Max. = 5.0%
Sulphate content	0.270%	Max.= 0.5%
Fineness modulus	2.61	
Absorption	1.75%	



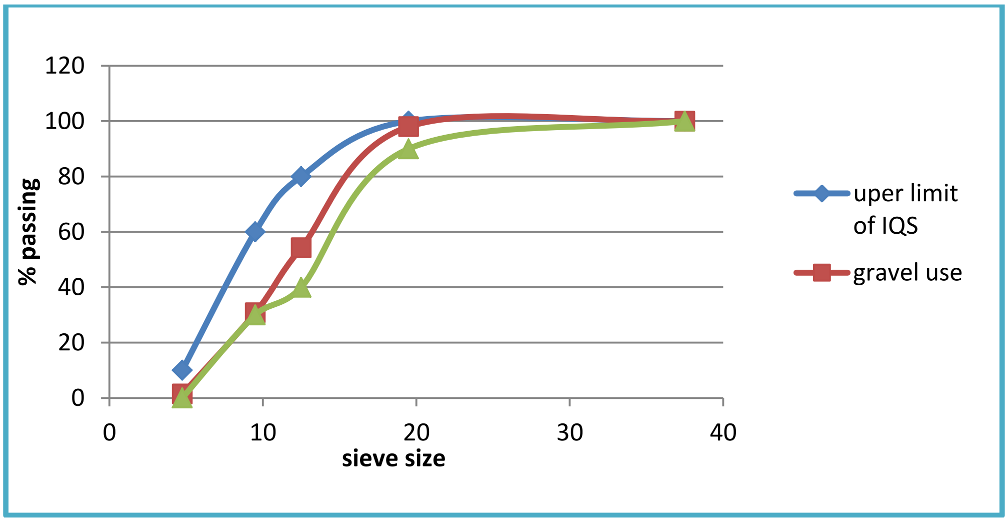
Figure(1): Grading curve for Al-Ukhaider natural sand compared with the requirements of IQS [7]

Coarse Aggregate

Crushed gravel (5-19 mm) gradation was used as a coarse aggregate. It was brought from east of the Baghdad region (Al-Nabaai). **Table (4)** and **fig(2)** show that the grading and sulfate content conform to Iraqi standard specification No.45/1984[7].

Table (4): Chemical analysis of coarse aggregate.

Chemical analysis	results	Limits of Iraqi spec. No. 45/1984 (%)
Specific gravity	2.68	< 0.1 %
Sulphate content	0.072 %	
Bulk density (kg/m^3)	1630	
Absorption	0.58 %	



Figure(2): Grading curve for gravel used compared with the requirements of IQS [7].

Water

The water used was potable water from the water-supply network system (tap water).

High-Range Water Reducing Admixture (Super-plasticizer)

A high-range water, reducing admixture, highperformance concrete super- plasticiser based on modified polycarboxylic ether (GLENIUM® 54) produced by the chemical company (BASF). This type of admixture conforms to ASTM[C 494] Types A and F. The technical descriptions of admixture are shown in **Table (5).**

Table (5):- Technical description of admixture.

Properties	Technical description
Appearance	Whitish to straw colored liquid
PH Value	5-8
Relative density	1.07
Chloride content	Nil

Styrene-Butadiene Rubber Latex (SBR)

Styrene butadiene rubber (SBR) which is commercially named Nitobond SBR is used as a polymer modifier in this investigation. The FOSROC COMPANY, manufactured this polymer and the typical properties of SBR polymer is shown in **Table (6)** .

Table (6): Physical and chemical properties of SBR latex polymer

Physical and chemical properties	Value
Color	White
Total solid content %	45
Specific gravity	1.04

Concrete Mixtures

Table (7):Mix proportions for concrete used through this work.

Mixes	Cement (Kg/m^3)	Sand (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water ($1/m^3$)	W/C	SP (% of cement)	SBR (%of cement)
HPC0	425	740	1027	144.5	0.34	1	0
HPC5	425	740	1027	144.5	0.34	1	5
HPC10	425	740	1027	144.5	0.34	1	10
HPC15	425	740	1027	144.5	0.34	1	15

*SP: High-Range Water Reducing Admixture (Super-plasticizer).
*SBR: Styrene-Butadiene Rubber Latex (SBR).
*W/C : Water cement ratio.
*(kg/m^3): weight of materials per one cubic meter.

Mixing Procedure

A pan mixer of (0.1 m^3) capacity was used to prepare the concrete mixtures. Dry materials (sand and coarse aggregate) were first mixed for 2 minutes, and then cement was added and shovel mixed by hand. Then, superplasticizer (High-Range Water Reducing Admixture) was added to the water and stirred, then this liquid was added to the dry mix during the mixing procedure and all were mixed for 10 minutes. Then, the mixing process was stopped to shovel the mix by hand and then restarted for 2 additional minutes. This step was repeated in two cycles to ensure the homogeneity of the mixture. The total mixing time was about 10-15minutes.

The same procedure of mixing was carried out for the HPC with addition liquid Styrene-Butadiene Rubber (SBR). Note that ,SBR is added to the water with superplasticizer and then added to the mixture, This ensures not get conglomerate or non-homogeneous distribution of the polymer inside the concrete mix.

Casting Procedure

The molds were lightly coated with mineral oil before use, according to ASTM C-192 [8]; Samples of concrete was casting in three thickness, each thick was compacted by using a manual piston by using Tamping Rods until no air bubbles emerged from the surface of the concrete, and the concrete is levelled off smoothly to the top of the molds by using steel trowel. Then the specimens were kept covered with polyethylene sheet in the laboratory for about(24±2) hrs, as show in **Fig(3)**.

Figure (3): Casting method

Curing of Specimens

The term "curing" is frequently used to describe the process by which a hydraulic-cement concrete matures and develops hardened properties over time as a result of the continued hydration of the cement in the presence of sufficient water and heat [9]. After casting the specimens were covered with a polyethylene sheet and kept in the laboratory for 24 hours to ensure a humid air around the specimens

Moisture curing method

The specimens were totally immersed in the curing water tank at 21±2 ℃ controlled by water heater until the time of measurement (7 or 28 days). Curing process show in Figure(4):- curing of specimen

Figure(4): Curing of specimen

Shape and Size of Concrete Specimens

Steel, plastic and wooden molds are used throughout this investigation. Four kinds of molds are used:

1- Cubic specimens of 150 mm for compressive strength.
2- Cylindrical specimens of 150 D*300 H mm for splitting tensile strength.
3- Prismatic specimens of 100W*100H*400Lmm for flexural strength and toughness.
4- Rectangle specimens of 80*50*30 mm for thermal conductivity.
*D: diameter of mold *H: high of mold *W:width of mold *L: length of mold

Characterization of Hardened Concrete

Compressive Strength measurement

The compressive strength was determined according to BS 1881: part 116 [10], using 150 mm^3 . The compressive strength cubes were measured by using hydraulic self indicating universal test machine (EVERY DENISON) of 2000 kN capacity and applied load rate according to ASTM C-39 [11] corresponding to stree on the specement of [0.25 ± 0.05 MPa/S].

Splitting Tensile Strength

The splitting tensile strength of concrete was carried out in accordance with ASTM C-496 [12]. Cylinders of (150 D×300 H mm) were measured using a standard test. According to ASTM C-496 applying load continuously and without shock, at constant rate within range [0.7 to 1.4 MPa/min] until failure of a specimen.

Flexural Strength Measurement

This measurement was done according to ASTM C-78 [13]. It was carried out on 100×100×400mm simply supported prisms three–point loading method. According to ASTM C-78 applying load continuously and without shock, at constant rate within range [0.86 to 1.21 MPa/min] until rupture occurs.

Dry Density

The dry density can be concluded by using the procedure specified according to ASTM C642-2003[14].

Porosity measurement

The porosity can be concluded by using the specified accordance with ASTM C642-2003 [14].

Total Absorption

The Total Absorption can be concluded by using the procedure specified according to ASTM C642-2003 [14].

Thermal conductivity

Hot disk method was used for determining the thermal conductivity (K), thermal diffusivity and specific heat, Special mold used to prepare a specimen. The Hot Disk TPS 500 Thermal Constants Analyzer, quickly and accurately measures the thermal conductivity of a wide range of materials [15].

Scanning Electron Microscope Test (SEM)

Scanning Electron Microscopy (SEM) has become a very versatile tool for study of microstructure, Interfacial Transition Zone (ITZ) and hydration progress [16]. Conducting this test requires preparing a sample of test with the suitable thickness.Specimen was prepeared in special size according to device required by cut small part from specimen.

Results and Discussions

Mechanical properties

The change of the Compressive strength, Splitting Tensile strength and Flexural strength of polymer modified concrete by adding (SBR) with respect to reference concrete is presented in **Table (8)** and plotted in **Fig(5, 6 and 7).**

The compressive strength of Polymer modified concrete is lower than that of reference concrete at all test periods and the percentage decline increase with the increase in P/C ratio. Also, it can be seen that the polymer modified concrete has splitting tensile strength and flexural strength higher than that of reference concrete and this percent increase with the increase in the P/C ratio at all ages except 15% SBR is lower than that of concrete reference.

This behavior may be due to the two reasons :- First, the addition of polymers (SBR) leads to form a continuous three dimensional polymer network which interpenetrates the cement paste. Second the partial filling of the pores with the polymer particles reduces the porosity of the polymer modified concrete (SBR). These factors increase the ductility of concrete and decrease its brittle nature [17].

Table(8): Mechanical properties of reference and polymer modified concretes

	P/C ratio	Compressive strength (Mpa)		Splitting tensile strength (Mpa)		Flexural strength (Mpa)	
		7 days	28 days	7 days	28 days	7 days	28 days
HPC	0 %	58.6	67.7	4.4	4.8	5.5	6
HPC	5 %	42	55.61	4.8	5.2	5.63	6.16
HPC	10%	40.2	43.2	5	5.55	6.15	6.9
HPC	15%	28.3	31.61	4	4.9	4.93	5.3

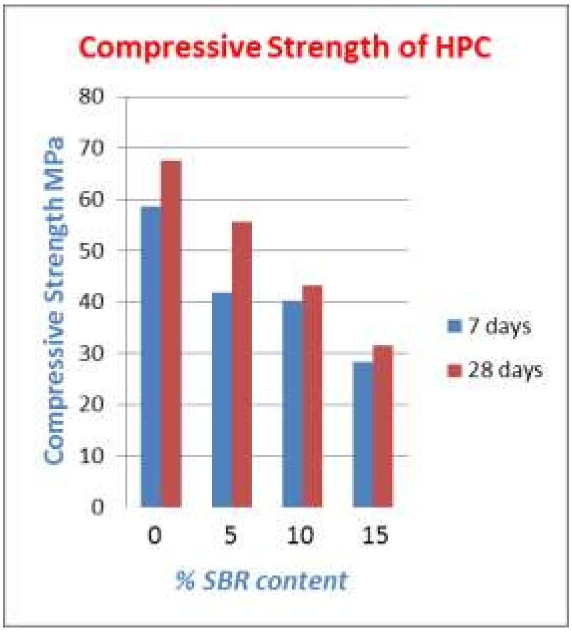


Figure.(5): Compressive Strength of HPC with and without adding of SBR at various weight percent at (7&28) days

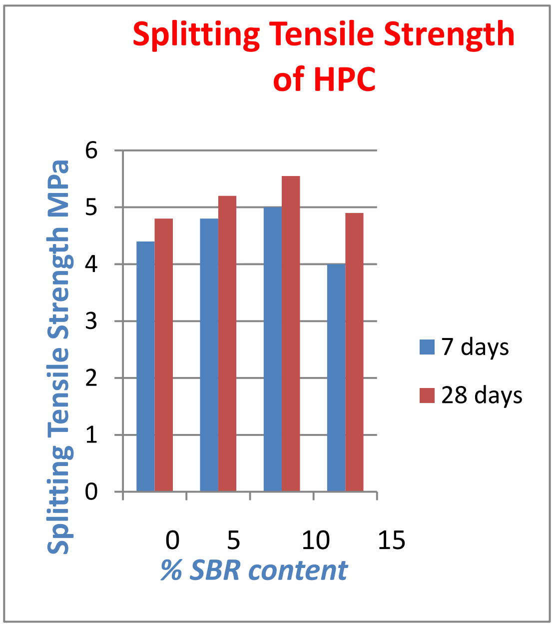


Figure.(6) Splitting Tensile Strength of HPC with and without adding of SBR at various weight percent at (7&28) days

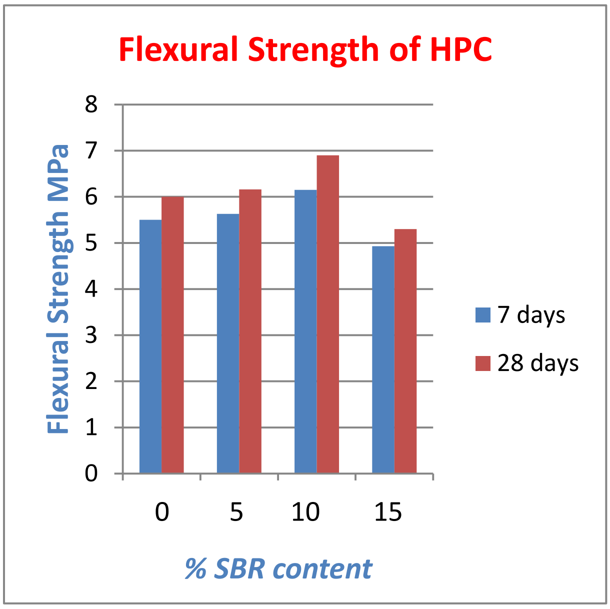


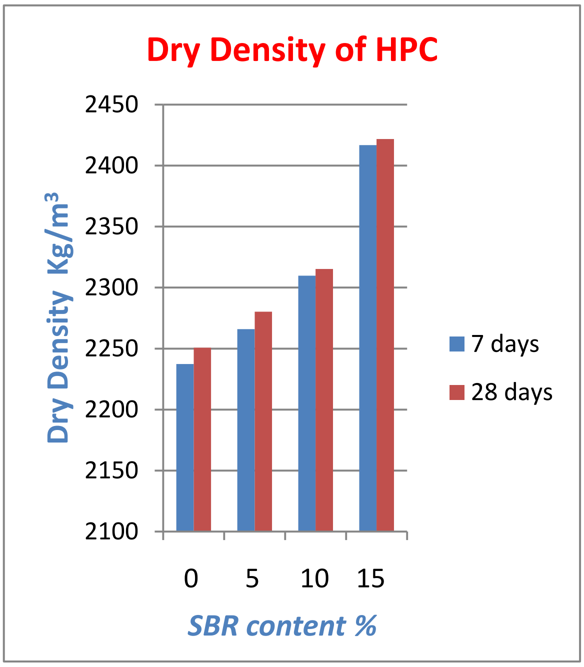
Figure (7):- Fig.(5): Flexural Strength of HPC with and without adding of SBR at various weight percent at (7&28) days

Density, Porosity and Water absorption

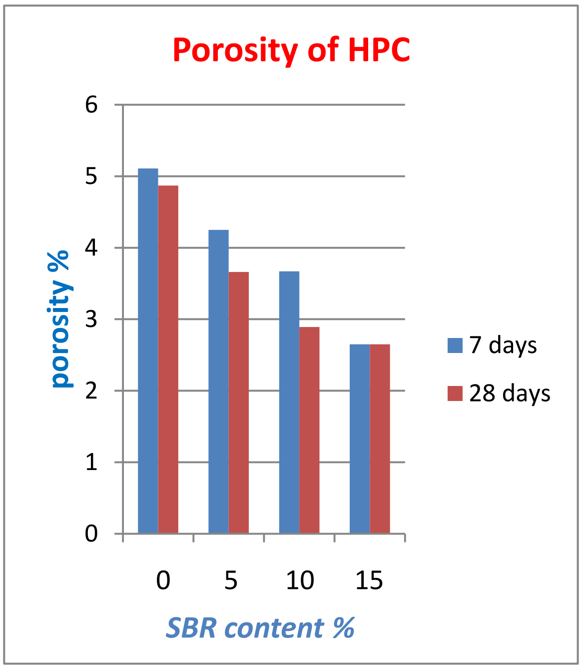
Depending on the results as show in **Table (9)** and presented in **Figs.(8, 9 and 10)**. The real dry density of reference and polymer modified concrete increases gradually with the increase in P/C ratio additives at both (7 & 28 days) but porosity and water absorption decrease. The density of polymer modified concrete is higher than that of reference concrete, but the porosity and absorption of polymer modified concrete are lower than that of concrete reference, This behavior according to two reasons firstly the addition of SBR leads to reduce porosity this leads to decrease the water absorbtion and second reason cement shrinkage process which occurs during periods bettwen 7 to 28 days lead to reduce porosity and voids.

Table (9): Reference and polymer modified concrete properties

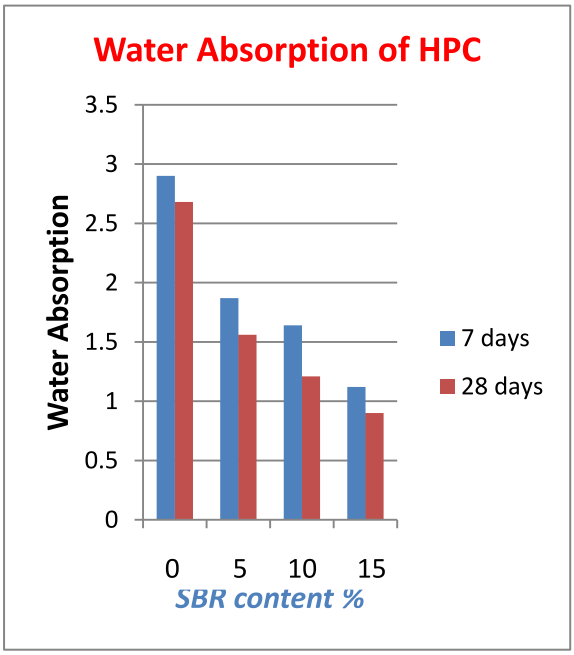
	P/C ratio	Dry density (kg/m^3)		Porosity %		Total water absorption	
		7 days	28 days	7 days	28 days	7 days	28 days
HPC	0 %	2237.31	2250.75	5.11	4.87	2.9	2.68
HPC	5 %	2265.96	2280.22	4.25	3.66	1.87	1.56
HPC	10%	2309.82	2315.31	3.67	2.89	1.65	1.21
HPC	15%	2416.78	2421.81	2.65	2.65	1.12	0.9



Figure(8) :Dry Density of HPC with and without adding of SBR at various weight percent at (7&28) days



Figure(9): Porosity of HPC with and without adding of SBR at various weight percent at (7&28) days



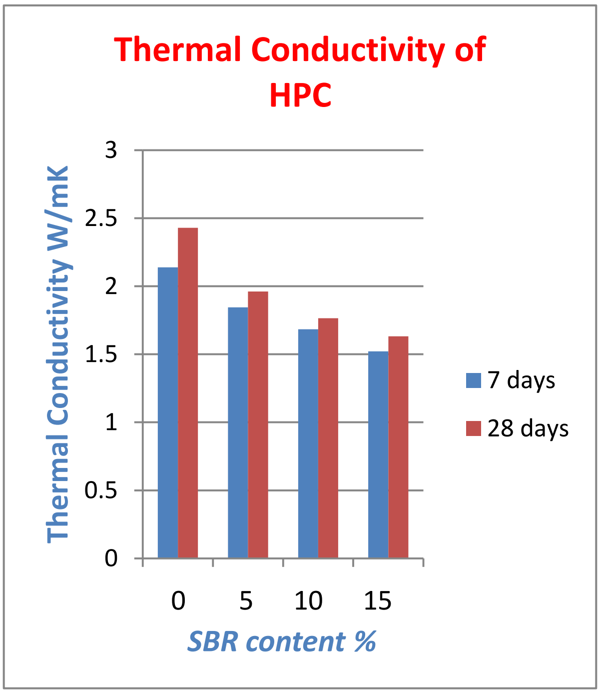
Figure(10): Water Absorbtion of HPC with and without adding of SBR at various weight percent at (7&28) days

Thermal properties

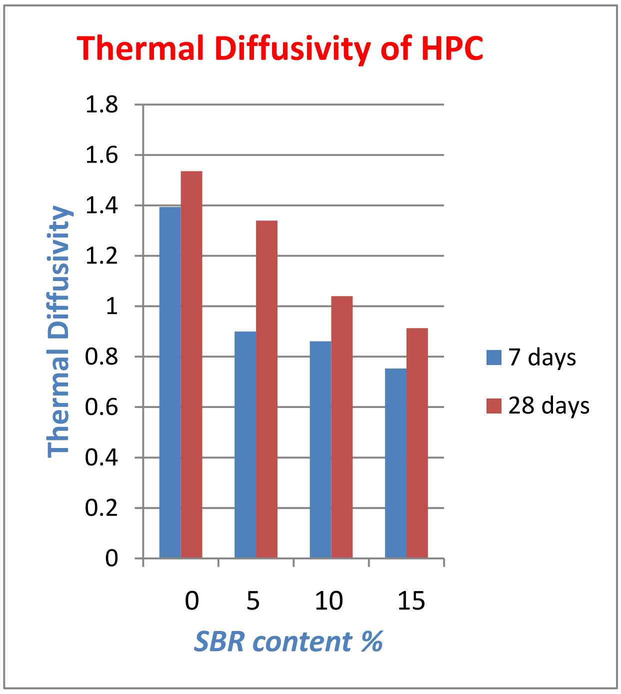
Test results as show in **Table (10)** and **Figs.(11, 12 and 13)** indicate that the thermal conductivity, thermal diffusivity and specific heat of all specimens decrease continuously with the increase in P/C ratio additives at both (7 & 28 days). The thermal conductivity, thermal diffusivity and specific heat decreases when polymer (SBR) is used, [18 and 19].

Table 10: Thermal properties of reference and polymer modified

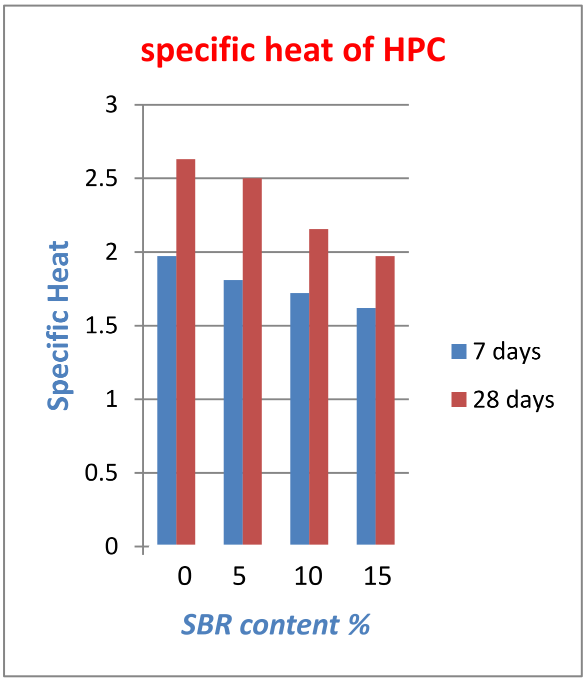
	P/C ratio	Thermal conductivity (W/mk)		Thermal diffusivity (mm^2 / s)		Specific heat (Mj/m^3k)	
		7 days	28 days	7 days	28 days	7 days	28 days
HPC	0 %	2.139	2.429	1.394	1.536	1.973	2.631
HPC	5 %	1.845	1.961	0.9	1.34	1.81	2.5
HPC	10%	1.684	1.765	0.861	1.04	1.721	2.156
HPC	15%	1.521	1.632	0.753	0.913	1.621	1.971



Figure(11): Thermal conductivity of HPC with and without adding of SBR at various weight percent at (7&28) days



Figure(12): Thermal Diffusivity of HPC with and without adding of SBR at various weight percent at (7&28) days

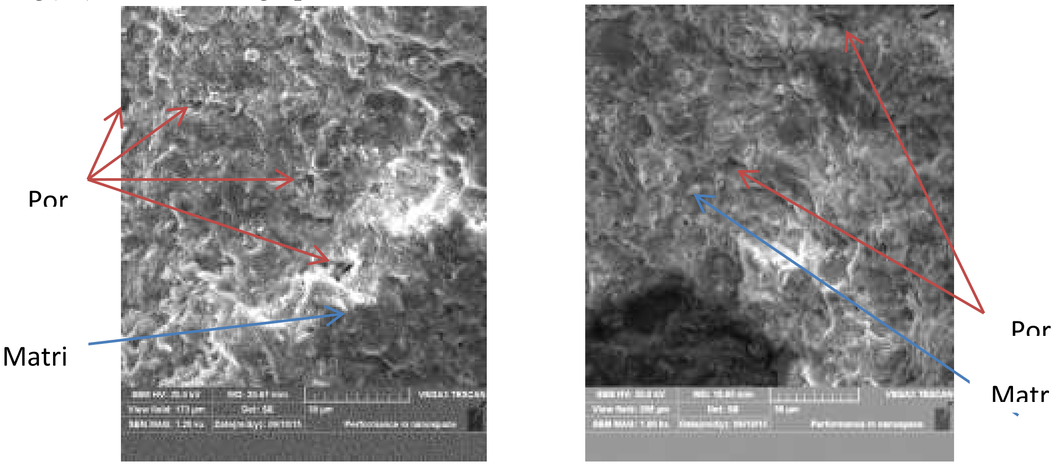


Figure(13): Specific Heat of HPC with and without adding of SBR at various weight percent at (7&28) days

SEM Analyses

As shown in **Fig.(14)**, the SEM micrographs for the HPC shows balanced gel phase and microstructure after the addition SBR. In addition, after the addion SBR microstructure shows less pores and smaller pores reverse case one before adding SBR. In addition, SBR enhances both the Splitting Tensile and Flexural strengths that improve their applicability in cases like bridges and airport purposes.

Fig(14):- SEM micrographs for



A B

Figure (14): SEM micrographs of the prepared HPC before the addition of SBR (A) and after the addition of SBR (B) with higher magnification. Once more, both micrographs show balanced gel phase and microstructure.

CONCLUSIONS

According to above results and findings, the following can be concluded:

1.

2. Compressive strength decrease by adding (SBR).This percent, increases with the increase in the P/C ratio additives at all test ages.

3. Splitting Tensile strength and Flexural strength increase by adding (5% and 10%) SBR. This percent, increases with the increase in the P/C ratio additives at all test ages, but the properties will drop when adding 15% SBR.

4. The density of polymer modified concrete is higher than that of reference concrete. While polymer modified concrete has lower porosity and water absorption than that reference concrete at all test ages.

5. In comparison with reference concrete polymer modified concrete has lower thermal conductivity, thermal diffusivity and specific heat at all test ages, this improvement ratio increases with the increase in P/C ratio additives .

6. SEM photographs show that the high performance concretes containing SBR appear more homogeneous, denser, less pore volume, and less roughness fracture surface than the high performance concrete without SBR.

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