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Properties of the New Type of HPC in Simulated Conditions of Persian Gulf

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ABSTRACT:
Durability of concrete structures is the main issue in the aggressive environments of south coasts of Iran. Due to high average temperature of 35°C, relative humidity of 50 percent and also the presence of high concentrations of sulfate and chloride ions in the Persian Gulf sea water, climatic conditions of the southern coasts of Iran are envisaged as one of the most destructive macroclimates for concrete.

A comprehensive survey of the concrete structures in the south coasts of Iran has been conducted in the last fifteen years. Evaluations show that the dominant deterioration problem is the corrosion of reinforcement in the concrete structures due to chloride-ion diffusion and sulfate attack.

This paper investigates the effect of application of silica fume and mix design to improve properties of concrete and its durability in laboratory accelerated simulated conditions of the Persian Gulf. The test results of compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, depth of penetration of water under pressure, chloride permeability (RCPT test method) and drying shrinkage show that the dense packing method for mix design and the use of silica fume have suitably improved all these properties in the simulated conditions of the Persian Gulf.

Keywords:
High performance Concrete, Concrete mix proportion, Minimum cement content, silica fume, Persian Gulf climatic conditions, Durability.

1 INTRODUCTION

The local environment of the Persian Gulf region is extremely aggressive to concrete and its reinforcement. The main factors influencing concrete deterioration in this region include high concentrations of chloride and sulfate salts, high ambient temperature and humidity and also large daily and seasonal fluctuations of heat and humidity [1].

The durability of reinforced concrete structures in this region is greatly affected by these factors and the concrete deterioration resulting is namely corrosion of reinforcement, chloride and sulfate attack, salt weathering and non-structural cracking [2, 3].

In the recent years, concrete industry has found that high performance concrete (HPC) allows is a suitable system for durable and cost effective concrete structures. HPC is being used for construction in aggressive environments, marine structures, highway bridges and pavements, pre-cast units, etc [4, 5].

The major difference between conventional concrete and HPC is essentially the use of chemical and mineral admixtures [6].

The reduction in water content to a very low value with new generation of superplasticizer can reach to higher strength. Mineral admixtures, also called as cement replacement materials (CRM), act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened cement matrix becomes denser and stronger [7].
Existing methods of proportioning generally require high cementitious materials, very low water content and thereby cost of these high performance concretes not comparable with conventional concrete. Therefore, a modified mix design procedure based on the dense packing has been proposed in this paper. Experimental investigations were carried out at the Building and Housing Research Center of IRAN to verify the proposed mix proportioning method. The mechanical and durability characteristics of a concrete mix proportioning method in two curing condition (laboratory and simulated Persian Gulf environment) are presented in this paper.

2 EXPERIMENTAL PROGRAM

The physical, mechanical and durability characteristics of two mixtures were evaluated and compared; a conventional cementitious HPC (as control) and also a cementitious concrete which was modified with silica fume. A special mix design was used for both mixtures assessed in this research; a very dense packing of the aggregates was used.

The experimental study was carried out in two different curing regimes:
1- Laboratory conditions (average temperature of 25 ° C and R.H. of 32 %)
2- Simulated Persian Gulf environment (average temperature of 35 ° C and R.H. of 50 %)

The tests carried out in this research include compressive, flexural and tensile strengths, modulus of elasticity, water permeability, chloride ion permeability and also drying shrinkage.

2.1 MATERIALS

AGGREGATE

The aggregates used in the mixtures were classified in three groups, with a maximum size of 16 mm. the course and fine aggregates used were supplied from surrounding river-bed provinces of Tehran and the filler used was obtained from the north of Iran. The physical and chemical characteristics of the aggregates are shown in Table 1.

Table 1 - Physical and chemical characteristics of aggregates

Aggregates	Grading curve	Specific Gravity	Water Absorption (%)	Passing Sieve 75 µm. (%)	Chloride Ion (%)	Sulfate Ion (%)	A.A.R. using Mortar Bars (%)
Coarse Aggregates	Fig. 1	2.53	2.64	2.6	0.001	0.001	0.09
Fine Aggregates	Fig. 2	2.56	2.71	2.46	0.001	0.002	0.09
Filler	Fig 1	2.57	4.0	0.7	0.002	-	-

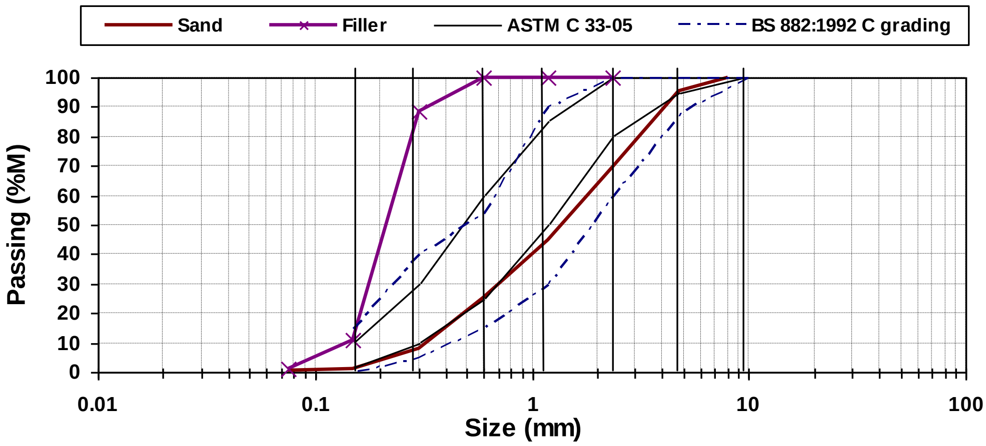

Fig 1 – Grading curves of river sand and filler

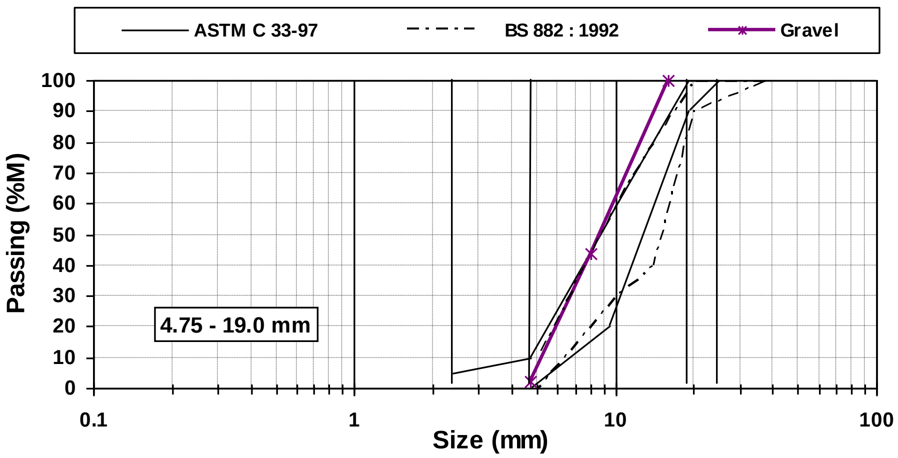

Fig 2 – Grading curve of semi crush of river gravel

CEMENT AND SILICA FUME

Chemical analysis of the type II (accordance ASTM C150) Portland cement and silica fume used in this study is shown in Table 2.

Table 2 - Chemical analysis of Portland cement and silica fume

Chemical analysis	Portland cement (%)	Silica fume (%)
SiO_2	20.96	91.1
Al_2O_3	4.2	1.55
Fe_2O_3	4.6	2.00
CaO	61.88	2.24
MgO	3.4	0.60
NaO_2	0.5	-
K_2O	0.4	-
Ignition Loss	1.74	2.10
Free lime	0.84	-
SO_3	1.79	0.45

SUPERPLASTICISER

Two superplasticizers based on melamine sulphonate naphthalene (Melcrete TB 101F), and an optimized carboxilate (Glenium) were used to adjust the flow of the mixes.

2.2 MIX DESIGN

Details of the mix design of the two high performance concretes considered in this study are shown in Table 3. These mixes were made using a very dense packing of the aggregates and also with the lowest possible amount of cement. Grading curve of combination of aggregates is shown in Fig.3.

After casting and demolding all specimens were fog cured at 20ºC for seven days, then transferred to the two curing conditions as below:

(A) - Laboratory conditions (LAB-C), (25 ± 2 ºC , 32 ± 1 % R.H.)

(B) - Simulated Persian Gulf environment (SPG-E),(35ºC, 50 ± 2 % R.H.)

Table 3 - Mix proportions and properties of concretes

Mix	Cement Kg/m^3	Silica Fume Kg/m^3	Coarse Agg. 5-16 mm Kg/m^3	Fine Agg. 0-5 mm Kg/m^3	Filler 0-0.6 mm Kg/m^3	Water Kg/m^3	Superplasticizer * Melcrete %	Superplasticizer * Glenium %
CON	350	-	1107	554	184	140	0.8	-
C-S7	325.5	24.5	1107	554	184	140	-	0.54

**by weight of cement*

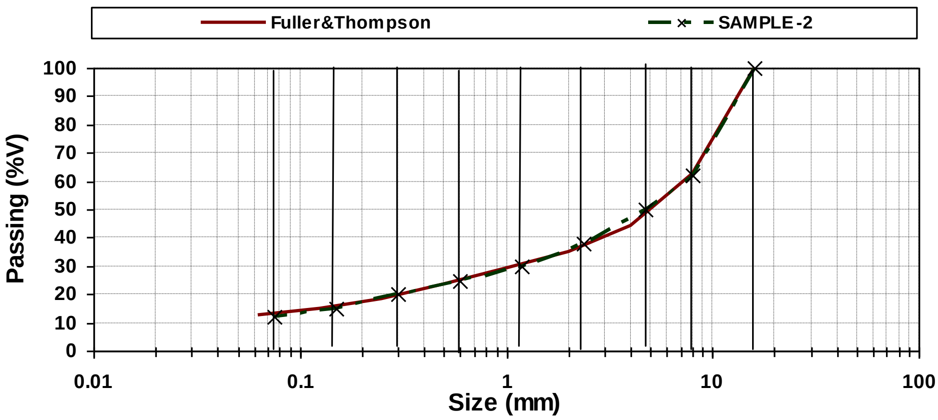

Fig. 3 – Combination curve of aggregates

2.3 TEST PROCEDURE

The tests performed on the mixes in this study are as follows:

Compressive, flexural and tensile strengths, in accordance with the relevant British Standards,BS 1881, Parts 116, 117 and 118 [8, 9, 10].

- Modulus of elasticity in accordance with the relevant British Standard BS 1881: Part 121 [11].
- Water penetration under pressure according to the DIN Standard 1048 [12].
- Chloride penetration, in accordance with the ASTM Standard C 1202 [13].
- Drying shrinkage, the samples were made using the ASTM Standard C 490 [14] and the curing and environmental conditions of the specimens were normal laboratory and simulated Gulf conditions, as stated in previous sections.

3 TEST RESULTS AND DISCUSSION

3.1 FRESH CONCRETE

Fresh concrete properties such as concrete density, slump, and percentage of air entrained and also temperature of fresh concrete have been summarized in Table 4.

Table 4 - Properties of fresh concrete

Mix	W/C	Density (kg/m^3)	Slump (cm)	Air Entrained in Fresh Concrete (%)	Temperature of Fresh Concrete (° C)
CON	0.4	2376	8	2.1	21
C-S7	0.4	2393	7.5	5/2.5	20

3.2 HARDENED CONCRETE

COMPRESSIVE STRENGTH

The compressive strength development of the mixtures in both curing conditions is shown in Table 5. The CON-B (Control Specimens that cured in SPG-E) had a lower compressive strength in comparison with another samples, under laboratory conditions (at 28 days, the CON-B samples had 88% strength of corresponding C-S7-B samples). The C-S7-B showed improved strength from 28 days to 90 days, in comparison to the CON-B mix, where the strength decreased under the severe conditions of the simulated Persian Gulf environment.

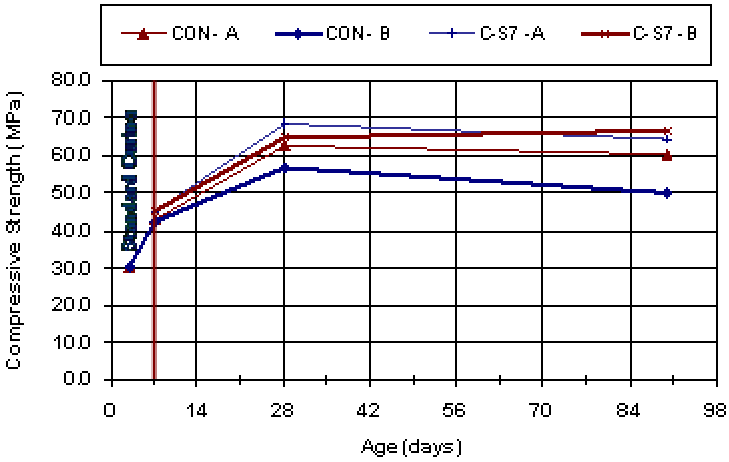

Fig 5 - Compressive strength test results

FLEXURAL STRENGTH

The flexural strength for both mixtures (cured in both A and B conditions) are shown in Table 5 respectively. Silica fume improved the flexural strength of the C-S7 mixture compared to the CON mix. This extent of improvement was not recorded for the samples cured under the simulated hot and humid conditions.

TENSILE STRENGTH

The tensile strength for both mixtures in different conditions) is shown in Table 5 respectively. As seen in the flexural test, silica fume improved the tensile strength of the C-S7 mixture compared to the CON mix. This improvement was not as high for the simulated Persian Gulf environment, the C-S7 B mix had higher tensile strength compared to the CON B control mixture.

MODULUS OF ELASTICITY

The modulus of elasticity test results for the two high performance concretes tested is shown in Table 5. The results indicate that the addition of silica fume improves the modulus of elasticity characteristics of the C-S7 mixture, compared to the control repair concrete.

Table 5 – Flexural and Tensile splitting Strengths and Modulus of elasticity

Mix ID.	**Curing Condition**	**Flexural Strength (MPa)**			**Tensile Splitting Strength (MPa)**			**Modulus of elasticity (GPa)**		
		7 days	**28 days**	**90 days**	**7 days**	**28 days**	**90 days**	**7 days**	**28 days**	**90 days**
CON	LAB-C	3.95	5.37	-	3.09	3.76	-	25.8	26.2	-
	SPG-E	3.95	6.64	7.99	3.09	3.81	4.02	25.8	28	30.1
C-S7	LAB-C	5.02	5.96	-	4.34	4.54	-	24.6	26.2	-
	SPG-E	5.02	6.3	6.41	4.34	4.49	4.34	24.6	28.5	30.5

WATER PERMEABILITY

The permeability characteristics of the concrete are one of the most important durability parameters of concrete. As noted before, this parameter was tested by using the DIN 1045 standard. The test results for the two mixtures are shown in Fig. 6. As seen in this fig., and according to the classification in the DIN standard, both repair concretes are in the low permeability range but the C-S7 modified concrete had lower permeability in both laboratory and also simulated hot and humid curing conditions, in comparison to the control concrete samples.

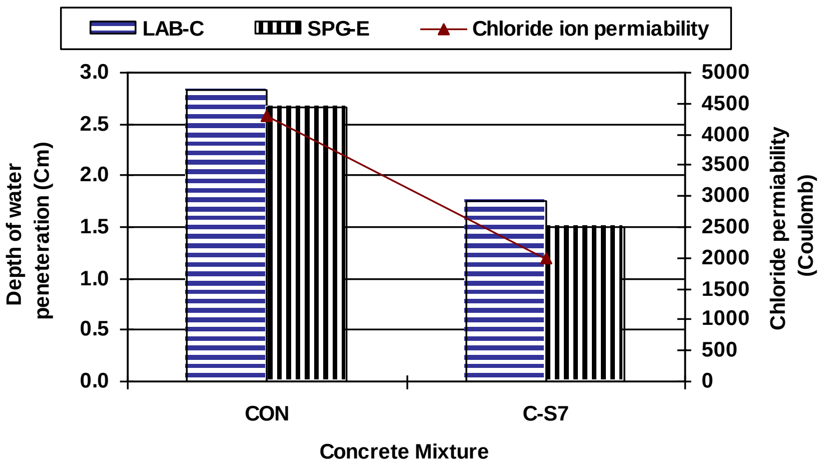

Fig.6 - Water permeability and Chloride penetration test results

CHLORIDE PENETRATION

The chloride penetration test was carried out according to the ASTM C 1202 Standard after 60 days curing. Test results are shown in Fig. 6. These results show that silica fume addition to the concrete increases the chloride penetration resistance of the HPC up to 100 percent. This reduction in chloride ion diffusion can be attributed to the fact that silica fume particles fill the smaller pores and reacts with calcium hydroxide, thereby improving impermeability characteristics of the concrete.

DRYING SHRINKAGE

The drying shrinkage test results for the samples considered in this investigation are presented in Fig. 7. These results indicate that the C-S7, HPC modified with silica fume had lower shrinkage values, specifically in the laboratory condition. This greatly decreases the tendency for cracking in the HPC.

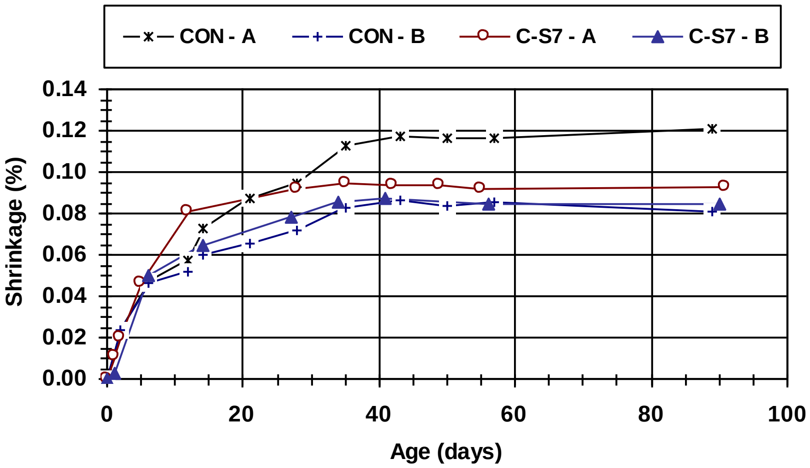

Fig.7 - Drying shrinkage test results

4 CONCLUSIONS

The test results conducted in this study lead to the following conclusions:

1- Proposed mix proportioning method as a dense packing system and the use of cement replacing material is a suitable way to produce HPC.

2- The physical and durability properties of the new HPC are enhanced and have better performance in comparison to the control mixture.

3- The results of this research and also other studies show that HPC, specifically mixtures modified, should be tested under actual service conditions prior to use, in order to evaluate the performance and suitability of these materials in actual service.

4- The simulated hot and humid conditions of the Persian Gulf environment has a negative effect on the comprehensive strength of the CON concrete, which is mainly due to accelerated hydration, resulting in non-uniform distribution of hydration products, increasing the porosity of these mixtures.

5- The HPC mixture modified with silica fume, generally increase the strength and modulus of elasticity of concrete, especially in the simulated hot and humid conditions of the Persian Gulf environment.

6- The mixture modified with silica fume showed lower amounts of drying shrinkage reduction, especially at the laboratory condition.

7- The silica fume modified mixture improved performance of concretes to penetration of water and chloride ions, due to the pore filling characteristics of silica fume and its chemical reaction.

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