Comparative Study of Several Repair Mortars in Simulated Persian Gulf Conditions

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Abstract

Concrete and reinforced concrete are used as durable materials in the construction of many structures but the durability and long term performance of this material has shown that its physical structure and structural behavior is a function of environmental conditions. Unless all environmental and geographical parameters are met in concrete design and construction, its service life and durability are reduced considerably and its need for repair increases. The concrete structures on the southern coasts and ports of the Persian Gulf region are continually exposed to extremely aggressive environmental conditions, namely a highly humid, hot atmosphere charged with corrosive ions (such as chloride and sulfate ions). The premature deterioration of concrete structures in the severe environmental conditions of the Persian Gulf region increases the importance and need for a comprehensive maintenance and repair system regarding these structures. Correct selection of the appropriate repair materials and techniques is necessary to ensure a durable repair. Performance of repair materials should be evaluated at the specific environmental conditions in order to select the most durable materials for the condition at hand.

This paper investigates the physical and durability characteristics of three repair mortars, assessed under normal laboratory and simulated hot weather conditions. A cement-based mortar was used as control, a polymer modified mortar, and a mortar containing silica fume were tested in the two conditions stated. Mechanical properties such as compressive and flexural strengths of mortars were compared. Capillary water absorption of mortars was measured and durability of specimens was evaluated in chloride solution.

The test results obtained in this study show that some mortars are not durable in conditions where they are exposed to salt solutions and high temperatures and humidities. Mortars containing polymer or silica fume exhibit better performance when compared with other mortars. The use and application of appropriate polymers can enhance the durability of repair mortars.

Keywords

concrete deterioration, hot weather conditions, repair mortars, durability, silica fume, styrene butadiene rubber (SBR), polymer-modified mortars.

Introduction

In recent years many researchers have been paying increasing attention to concrete deterioration, namely in hot and humid environments, resulting in the need for extensive and costly repair operations. In this regard, there is great significance placed on choosing suitable and compatible repair mortars.

It is the combination of salty materials and the extreme climate in the Persian Gulf region which makes the environment potentially more aggressive to concrete structures than anywhere else in the world [1]. This region is characterized by adverse geomorphic and climatic conditions such as severe ground and ambient salinity, high temperature and humidity regimes and also wide daily and seasonal fluctuations of heat and humidity.

The severe hot environment of the Persian Gulf is most damaging for reinforced concrete, due to the combined effects of the following factors :

- High concentrations of chloride and sulfate salts which attack the reinforcement and concrete matrix respectively
- Elevated ambient temperatures, together with strong winds, causing to rapid drying, accelerate the rate of corrosion and deterioration and also compromise the quality of concrete during its early exposure
- Large daily fluctuations in temperature and humidity which produce progressive micro-cracking in concrete during service

These factors all affect the durability of concrete structures in this region, and causing significant concrete deterioration, namely corrosion of reinforcement, chloride and sulfate attack, salt weathering and non-structural environmental cracking, over a relatively short period of time [3].

In this type of environment, when the severity of the environmental conditions is compounded with poor quality concrete, namely inadequate design specifications, contaminated raw materials and poor construction practices, the process of deterioration then becomes interactive and very rapid [2].

Polymer modified mortars are being widely used in the construction industry recently, because of their improvement to concrete performance [4]. In particular, they are used as repair materials for damaged reinforced concrete structures, due to their superior penetration resistance to harmful substances [5,6]. These materials have the same alkaline passivation protection, similar modulus of elasticity, thermal coefficient of expansion, creep and strength associated characteristics as conventional cementitious materials and the properties of the repair mortar are enhanced by the addition of the polymer, such as improved bond between old and new concretes, reduced permeability, etc. [7]

Until recently, compressive strength of concrete was the main criteria for indicating compatibility between the concrete substrate and repair material; now it has been comprehended that quite a number of other properties are important for a successful repair. These properties include low shrinkage, good bond strength and low permeability of the repair materials [8].

A common approach to the selection of repair materials is to assess individual properties against defined criteria; which has limited value as the relationship between different properties of the repair, between the repair and substrate and also exposure conditions normally determine field performance [9]. In order to evaluate the suitability of using repair materials, it is essential to assess their properties, interaction of these properties and also their actual behavior in service conditions, prior to use.

This paper reviews the properties of two types of repair mortars; a cementitious repair mortar containing silica fume and a latex modified repair mortar containing SBR; in comparison with a control mortar, in a simulated hot and humid Persian Gulf environment. With the results of this investigation one can predict the behavior of these repair mortars in actual service conditions in the south of Iran.

1- Experimental Program

Three repair materials were selected and tested in this study. These include a conventional cementitious repair mortar and cementitious polymer and silica fume modified repair mortars. An experimental study was carried out to determine the physical, mechanical and durability characteristics of these three repair mortars in two different curing environments (laboratory and simulated Persian Gulf environments).

The repair mortars studied in this project were as follows:

-Control mortar, referred to as "Ctrl" mix

-Cementitious mortar containing silica fume, referred to as "SF" mix

-Latex modified cementitious mortar containing styrene butadiene rubber latex, referred to as "SBR" mix

1-1- Materials

Chemical analysis of the type II Portland cement and silica fume used in this study is shown in Table1.

Table (1) Chemical analysis of Portland cement and silica fume.

Chemical analysis	Portland cement %	Silica fume %
SiO_2	20.52	91.1
Al_2O_3	5.5	1.55
Fe_2O_3	4.3	2.00
CaO	62.78	2.24
MgO	1.6	0.60
NaO_2	0.5	-
K_2O	0.4	-
Ignition Loss	1.74	2.10
Free lime	0.84	-
SO_3	1.44	0.45

Natural siliceous sand was used in all mixtures, with a maximum size of 4mm. The latex used was styrene-butadiene co-polymer with the properties shown in Table 2.

Table 2: Properties for styrene-butadiene latex.

Typical properties	
Physical state	Milky white liquid
Total solids (by weight of polymer)	40%
Specific gravity	1.01
PH	10.5
Mean particle size	0.17 microns

A superplasticizer based on melamine sulphonated naphthalene was also used where needed to adjust the flow of the mixtures.

1-2- Mixture Design

Details of the mixture design of the repair mortars considered in this study are shown in Table 3. The water-cement (w/c) and sand-cement (s/c) ratios were kept constant in all three mixtures.

Table (3) Mix proportions and properties of mortars.

Mix	c/a *	W/C *	SP ** %	Silica * Fume %	SBR * %	Flow cm	Density Kg/m^3
Ctrl	1:1.25	0.35	0.5	-	-	13	2205
SF	1:1.25	0.35	1	7	-	14	2153
SBR	1:1.25	0.35	-	-	20	15.5	2169

* by weight of cement ** Melcrete superplasticizer

After casting and demolding, the specimens were fog cured at 20°C for seven days, then they were kept in two curing regimes, as follows :

(A) - Laboratory conditions (20°C, 45% RH)

(B) - Simulated Persian Gulf environment (35°C, 65%RH)

1-3- Test Procedure

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

-Compressive and flexural strengths, in accordance with the relevant British Standards: BS 1881, Parts 116 and 118 [10,11].

-Capillary water absorption, in accordance with the RILEM Standard No. CP 11.2 [12].

-Drying shrinkage, the samples were made based on the ASTM Standard C 490 [13] and the curing and environmental conditions of the specimens were normal laboratory and simulated Gulf conditions, as stated in previous sections.

-Chloride penetration, in accordance with the B.R.E. Specification [14]: 15cm cubes were immersed in a 15.7% NaCl solution at the age of 28 days, and tested at various periods.

-Bonding strength: Substrate concrete specimens ($30\times40\times20cm^3$ blocks) were sand blasted and repaired with each repair mix, using suitable primers Bonding strength was tested after 28 days by drilling core samples and using the pull-off test method, in accordance with the DIN Standard No. 1048 [15].

2- Test Results and Discussion

2-1- Compressive and Flexural Strengths

The compressive strength development of the mixtures for both curing conditions are shown in Fig.1. As it can be seen, the specimens cured in the hot simulated environment with lower values than those cured in the laboratory. The SF-A mix showed the highest compressive strength at 360 days.

Repair mortars with high initial compressive strengths will also have a high dynamic modulus of elasticity, resulting in the increase of stresses at the substrate-repair interface, therefore by adding polymers to the repair mortar, the compressive strength and modulus of elasticity are reduced.

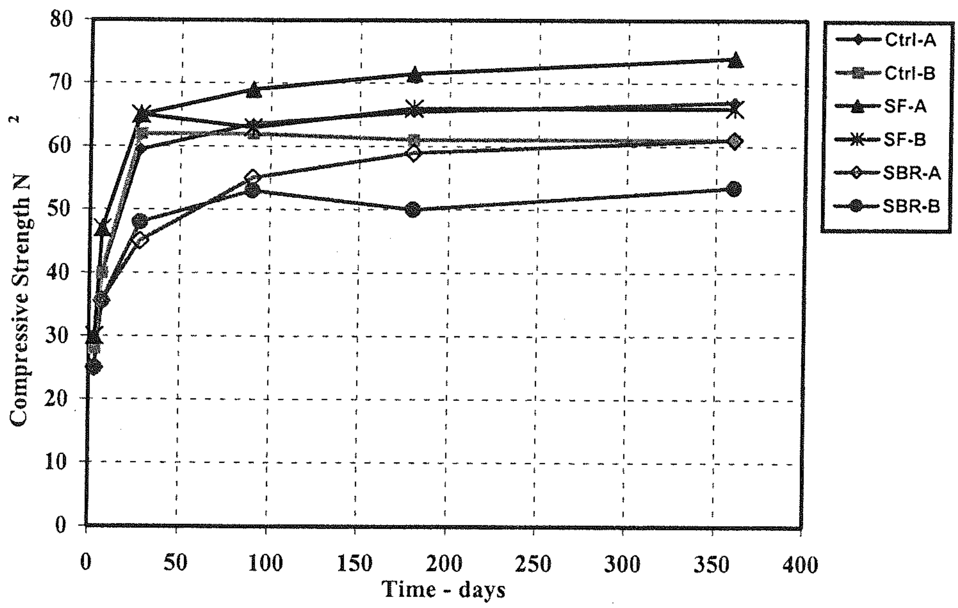

Fig (1) Compressive strength test results.

The flexural strength for all mixtures (cured in both A and B conditions) is shown in Fig.2 respectively. In both tests the SBR specimens had higher strengths. The simulated Persian Gulf environment caused loss of strength in all mixtures, but the SBR B mix had higher values than all the mixtures cured in the hot environment.

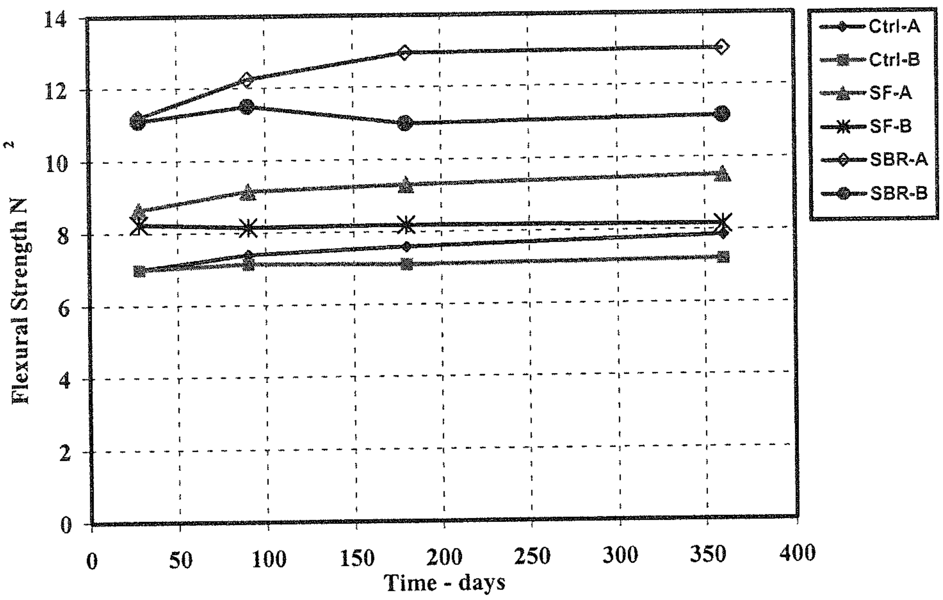

Figure (2) Flexural strength test results.

2-2- Capillary Water Absorption

The capillary water absorption (at 72 hours) test results is shown in Fig.3. The results indicate that the addition of latex significantly decreases the absorption characteristics of the repair mortars. The Ctrl B and SBR A mixtures had the highest and lowest amounts of sorptivity . The test results show that by using the SBR latex in the mixtures, the capillary water absorption decreases dramatically, even lower than the mixtures containing silica fume.

These results may be attributed to the pore-filling characteristics of latex polymers, when incorporated in concrete or mortar mixtures.

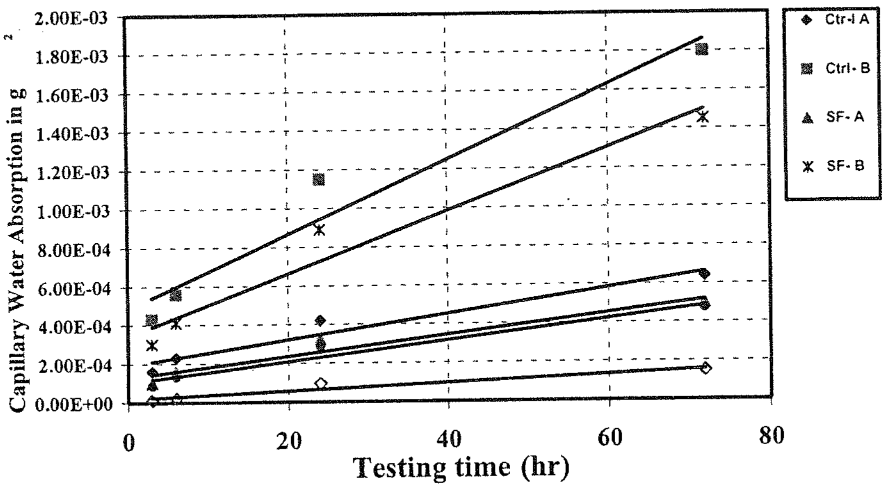

Figure (3) Capillary water absorption test results.

2-3- Drying Shrinkage

The drying shrinkage curves for all the mixtures considered in this investigation are presented in Fig.4. The SBR A mix had the lowest and the Ctrl B mix showed the highest drying shrinkage. The reduction in shrinkage of latex modified mortar may result from reductions in moisture movements in the presence of the latex. All mixtures cured in the simulated hot environment had higher shrinkage amounts. Polymer addition reduced the initial drying shrinkage in the SBR mixtures and by adding silica fume (SF mixtures), initial drying shrinkage increases. Thus polymer addition enhances the shrinkage characteristics of the repair mortar.

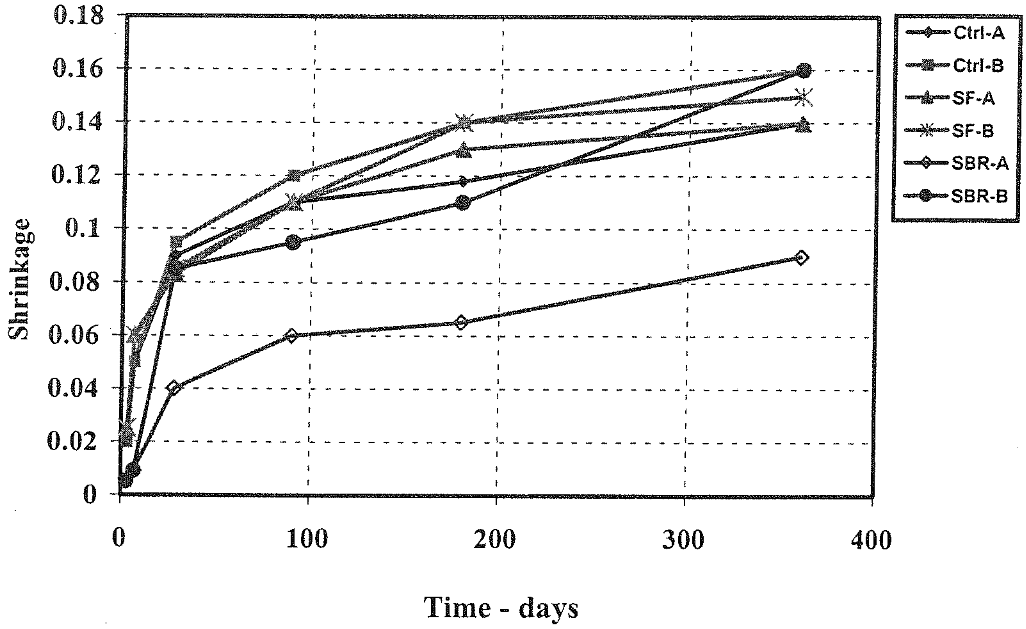

Figure (4) Drying shrinkage test results.

2-4- Chloride Penetration

The chloride penetration test results (obtained after 60 days immersion in chloride solution) for all mixtures are shown in Fig.5. It can be seen that latex and also silica fume addition increases the chloride penetration resistance of the repair mortar. This reduction in permeability can be attributed to the fact that in each case latex polymer and silica fume particles, being much smaller than the sand and cement particles, fill the smaller pores, and prevent the formation of microcracks, thereby improving impermeability characteristics of the repair mortar.

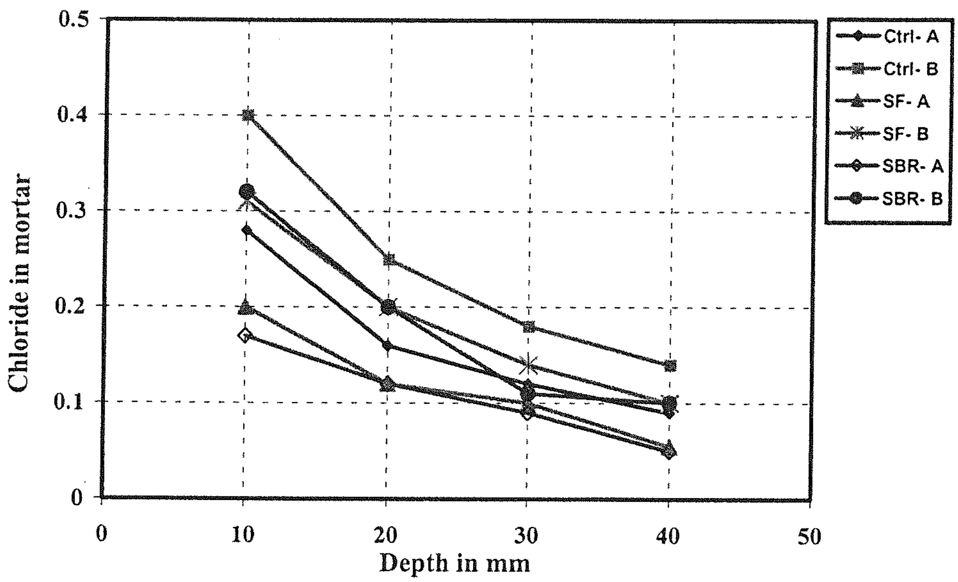

Figure (5) Chloride profile for all mixtures.

2-5- Bond Strength

The bond strength results obtained from the pull-off test for all mixtures are shown in Fig.6. It can be seen that the hot environment (B) causes lower bonding strengths in all three mixtures. The results also show that latex modification greatly enhances bond strength of the repair mortar. This can be attributed to improved bonding between the cement matrix and aggregates and also better adhesion to the substrate. The SBR B mix still had significant bonding strength to the old concrete.

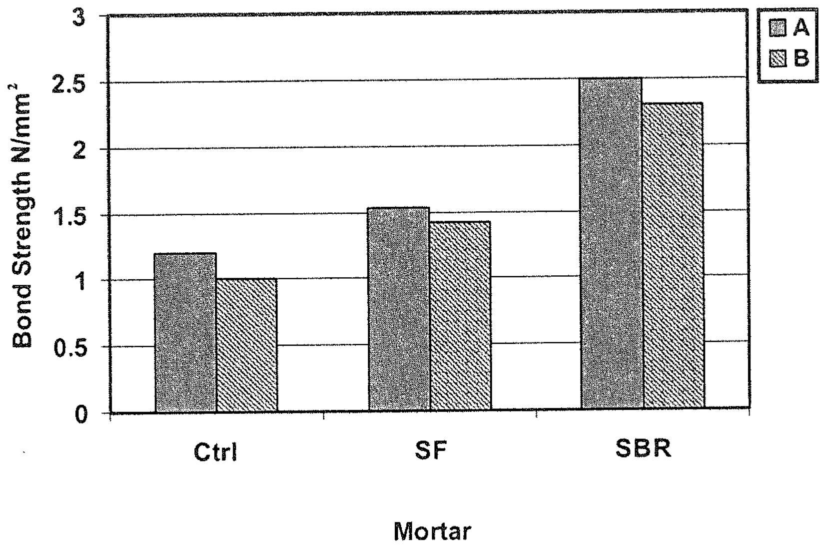

Figure (6) Bonding strength of repair mortars.

4- Conclusion

From the test results in this study the following conclusion can be drawn:

1-By adding silica fume and styrene butadiene latex to the cementitious repair mortars, the physical properties and durability of the repair mortars are enhanced and have better properties in comparison to the control mix.

2-The simulated Persian Gulf environment has a negative effect on the characteristics of all mixtures, which is mainly due to accelerated hydration, resulting in non-uniform distribution of hydration products in the mortar specimens cured in the hot environment, increasing the porosity of these mixtures.

3-Latex modification greatly increases the flexural strength and leads to significant improvements on reducing the drying shrinkage. The reduction in the drying shrinkage of polymer modified mortar results in stress reduction at the substrate/repair mortar interface. The SF and SBR mixtures both showed improved durability to penetration of water and chloride ions, due to the similar pore filling characteristics of silica fume and the SBR latex, reducing microcrack formation and improving durability characteristics.

4-Major improvement in bonding strength and adhesion of the repair mortar was achieved through latex modification.

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