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THE BOND BETWEEN REPAIR MATERIALS AND CONCRETE SUBSTRATE IN MARINE ENVIRONMENT

K. Behfarnia*, H. Jon-nesari and A. Mosharaf,
Isfahan University of Technology, Isfahan, Iran

ABSTRACT

In this paper, the results of an experimental study of the bond between repair materials and concrete substrate in marine and crude oil environment is presented. Old concrete samples were made based on BS6319, Part 4 standard. Ordinary concrete, and concrete containing microsilica were used as repair materials. Repaired samples were cured in water curing tank and then held in the marine environment, or immersed in crude oil up to 180 days. The bond between repair materials and concrete substrate was evaluated based on slant shear test method. The work was also aimed at studying the effect of various factors such as initial curing periods and surface preparation method on bond strength. The obtained results are tabulated and presented in this paper.

Keywords: concrete, bond strength, repair, surface preparation, crude oil

1. INTRODUCTION

The occurrence of concrete deterioration and cracking in marine environment is more severe than in any other terrestrial environment. The causes of concrete deterioration have always been the object of concern and research. This interest is increasing due to the high cost associated with the repair and maintenance of the concrete structure. Repairs, however, are successful in the long-term if the causes of the original damage have been understood and appropriate repair materials are applied to resist future deterioration. Repair materials should be compatible with old concrete and have good adhesion. In repair of concrete, the bond strength between repair materials and old concrete is of vital importance. Strength and integrity of the bond depends on not only the physical and chemical characteristics of the repair component, but also other factors such as initial curing periods, surface preparation method, and environmental conditions. The effects of these factors were studied in this work.

2. EXPERIMENT

* E-mail address of the corresponding author: kia@cc.iut.ac.ir

Old concrete samples were made based on BS6319 Part 4 Standard [1]. Four methods including, smooth as-sawn, wire-brushed, hand-chiselled, and acid etching were used in order to prepare the surface of old concrete samples. Ordinary concrete, made with type II portland cement, and concrete containing 15 percent microsilica were used as repair materials. The mix proportions, specimen preparation and repair procedure are explained in next sections.

2.1 Mix proportions

Type II portland cement (ASTM C 150 specification) was used in this research. Crushed stone with a maximum size less than 9.5 mm and sand with a fineness modulus of 2.9 were used for producing concrete. The composition of old concrete mixes (OC mix) was 0.5:1.0:2.35:1.04 (water: cement: sand: gravel) by weight. The uniaxial compressive strength of old concrete samples was 35 MPa. MSOC mix was produced with replacement of 15% of cement in OC mix (by weight) with microsilica in order to investigate the effect of microsilica on bond strength.

2.2 Specimen preparation

Old concrete samples were made based on BS 6319: Part 4 standard, figure 1. They were cast as 55x100x150 mm prisms and then cut at 30 deg to the vertical axis using a diamond saw. The acid etching method with use of hydrochloric acid was used to prepare the surface of samples.

For acid etching, with reference to ACI committee 549 [2], a hydrochloric acid solution was chosen. HCl can primarily react with the $Ca(OH)_2$ of the hydrated cement paste to form $CaCl_2$, making the substrate more porous[2]. Because no adequate information concerning the influence of acid consistency on bond strength was available in current literature, hydrochloric acid solutions of 5% were chosen for testing [3]. The etching of surface was carried out in such a way that the hydrochloric acid solution was brushed on the surface of concrete substrate with a soft nylon brush at a rate of 20 times/min. The etched surface was then flushed under flowing tap water for 2 min.

2.3 Repair procedure

For slant shear test, the samples were formed in the moulds in which they were cast. The repair material, OC or MSOC mixes, was then applied and hand-compacted. Samples were stripped after 24 hr and placed in curing tank for 3 days. At this stage samples were divided by two sets. One set was left in laboratory environment and the other set was immersed in crude oil or sulphate solution up to 180 days.

A wide range of test method has been proposed to evaluate bond properties and performance of repair materials in general. The slant shear test has become the most widely accepted test for evaluating the bond of resinous repair materials to concrete. However, there seems to be no standard test for testing the bond to concrete of cementitious and modified cementitious repair materials. To compare the bond strength of repair materials, slant shear test method was used in this work. This method, which puts the bond interface into a combined state of compression and shear is adopted in BS6319: Part4 [1], was used as a test method for evaluating repair materials, figure 2.

Figure 1. Concrete samples prepared based on BS 6319: Part 4

Figure 2. Slant shear test

3. RESULTS AND DISCUSSIONS

Strength and integrity of the bond depends on not only the physical and chemical characteristics of the repair component, but also other factors such as initial curing periods and surface preparation method. The effects of these factors were studied in this work. The obtained results are presented and discussed briefly in following sections.

3.1 The effect of initial curing period

To study the effect of initial curing on bond strength, samples repaired with OC mix were cured in curing tank for 1, 3, and 7 days and then held in laboratory environment. At age of 28 days samples tested by slant shear test method. The results of bond strength are given in Table1.

Table 1. The effect of curing period on bond strength

Curing period (day)	**1**	**3**	**7**
28-day bond strength (MPa)	24.1	28.5	29.4

As can be seen from Table 1, samples with longer period of initial curing gain higher bond strength. Based on the obtained results, the bond strength of samples with 3 and 7 days initial curing is increased by 11.8% and 12.2% comparing to that in samples with 1 day curing, respectively. It can be noted that with increase of curing period from 3 to 7 days, bond strength is not considerably increased. In practical situation, since it is often impossible to provide ideal condition of initial curing over a long period of time, it is suggested to cure the repair patches for at least 3 days.

3.2 The effect of surface preparation method

To study the effect of surface preparation method on bond strength, four surface preparation methods, smooth as-sawn (SS), wire-brushed (WB), hand-chiselled (HC), and acid etching (AE) were used to prepare the samples, figure 3. Samples tested by slant shear test method at age of 28 days. The results of bond strength are given in Table2.

Table 2. The effect of surface preparation method on bond strength

Surface preparation method	**SS**	**WB**	**HC**	**AE**
28-day bond strength (MPa)	8.5	23.5	25.9	28.5

Figure 3. Concrete samples prepared with different surface preparation method

The obtained results show that with use of surface preparation methods the bond strength could considerably be increased. Based on the given results in Table 2, the bond strength of repaired samples is increased 176%, 204%, and 235% with use of WB, HC, and AE methods compare to that of samples with no surface preparation, respectively.

3.3 The effect of crude oil on bond strength

There are many concrete structures related to oil industry, which are located in marine environment. To investigate the effect of crude oil on bond strength of repair materials, two sets of OC samples were provided. Microsilica is often used in production of high performance concrete and its effect on mechanical properties and durability of ordinary concrete is reported in many publications [4-5]. In order to study the effect of microsilica on bond strength of repair materials, two sets of MSOS samples were also provided. Surface of all samples were prepared with acid etching method. After 1 day of water curing, one set of samples was left in laboratory environment and the other set were immersed in crude oil for 180 days. Then, slant shear test was used to evaluate the bond strength of repair materials. The obtained results are given in Table 4.

Generally, as can be seen from Table 4, the bond strength of repair materials immersed in crude oil is decreased compare to that of samples held in Lab environment. Based on the obtained results, the bond strength of OC repair material is decreased by 11% in crude oil environment. As expected, with use of 15% microsilica the permeability of the repair material (MSOC mix) is considerably reduced and therefore the bond strength is only reduced by 1%.

Table 4. The effect of crude oil on bond strength

Repair material	180-day bond strength (MPa)	
	Lab	**Crude oil**
OC mix	31.2	27.8
MSOC mix	34.1	33.8

3.4 The effect of marine environment on bond strength

Concrete in marine environment is susceptible to deterioration caused by a wide range of chemicals. Sulphate attack is one of the common types of chemical attacks on concrete. The chemical reactions that take place between sulphate ions and portland cement result in reaction products that have a greater volume than the original solid constituents. This volume change causes the development of stresses in the concrete that eventually lead to cracking and deterioration. The objective of this part of study was to investigate the effect of sulphate ion on bond strength of repair materials. Since corrosion of concrete due to sulphate attack happens after long period of time, an accelerated test method used by Monterio et al [6] were used in the current study and similar test set up designed by them has been used in this work.

To carry out the test, two sets of OC and MSOC repaired samples were provided. After 1 day of water curing, one set of samples was remained in water tank and the other set were put in a polypropylene container containing 22 litre of 15% $MgSO_4$. The solution was circulating in the container using a control pump. To stabilize pH on 7, 0.1N H_2SO_4 added to solution if any grow of pH was observed.

After 90 and 180 days of immersion of specimens in sulphate solution, bond strength of concrete specimens was measured by slant shear test method. The results of test are given in Table 5.

Table 5. The effect of sulphate ion on bond strength of repair materials

Repair material	**OC**		**MSOC**	
Environment	water	sulphate solution	water	sulphate solution
90-day bond strength (MPa)	34.4	30	37	35
180-day bond strength (MPa)	36	29	38	34.7

As can be seen from Table 5, the bond strength of repair materials immersed in sulphate solution is decreased compare to that of samples held in water curing tank. Based on the obtained results, the bond strength of concrete specimens repaired with OC repair material is decreased by 12.8% and 19.4% after 90 and 180 days of immersion in sulphate solution, respectively. The decrease in bond strength can be lowered with use of microsilica in composition of repair material. The given results show that the bond strength of concrete specimens repaired with MSOC repair material is decreased by 5.4% and 8.7% after 90 and 180 days of immersion in sulphate solution, respectively.

4. CONCLUSIONS

The following conclusions can be drawn from the present work:

Initial curing has a considerable effect on bond strength of repair materials. With longer periods of initial curing, higher bond strength will be developed in repair materials. Based on the obtained results of this study, it is suggested to cure the repair patches at least for 3 days.

The bond strength of repair materials can be considerably increased with use of a surface preparation method in repair process. The results show that the acid etching method is the most effective method among the four methods implemented in this study.

The bond strength of repair materials reduces in crude oil environment. With use of a proper percentage of microsilica in composition of repair material the damaging effect of crude oil can be highly reduced.

Concrete structures are subjected to deterioration due to aggressive nature of marine environments. Sulphate attack is one of the common types of chemical attacks on concrete that causes physical damage in concrete and reduces the bond strength of repair material. With use of microsilica in composition of repair concrete the reduction of bond strength can be lowered.

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