SUBSEA REPAIR OF CONCRETE AND THE EFFECT OF FOULING

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The intention of the present investigation is to find out if there is a relation between fouling and the bonding strength for subsea repaired concrete. The investigation has been performed at a depth of 10 m below sea level. Specimens which were exposed to seawater for one month have been cleaned from fouling with brushing or brushing combined with sand-mixed water jet and after that repaired by injection of three different cement based materials. Repair was performed on cleaning day and day 3 and 7 after cleaning. It has shown that fouling with an age of one week decreases the bonding strength with approximately 20 to 30%. Some unexpected cracks appeared in the specimens in upper bonding zone with a concentration of ettringite and other salts. In a field investigation like this, it is difficult to control all parameters. Therefore it is recommended to extend this investigation with laboratory tests.

Keywords: Concrete, bonding, fouling, repair, subsea.

1. INTRODUCTION

The extensive use of concrete as the primary material for a lot of different structures in marine environment has received increased attention in recent years. As maintenance cost is expected to increase, considerable efforts have been directed to the development and research of improved methods and construction techniques in rehabilitation projects.

Problems connected with repair of offshore concrete structures are many-sided and complex. Therefore it is important to isolate and study, if possible, simple parameters which can be expected to have influence on repair results. Choice of repair materials is one important thing for obtaining proper results. This choice depends on many factors, as type and size of damage, the environment etc. However, the bond between old and fresh materials will always be very important. The longest time between cleaning and repairing of a damaged concrete structure under water has been the object in many discussions. The fact that sea water is "alive" entail that fouling will appear and might cause reduced bond between old and new concrete. The effect of sea water and also that of freshwater on the repair of concrete surface underwater is neither fully determined.

Due to the fact that the experience of repair of damages on concrete structures in sea is limited, it is very important to get results from investigations made in appropriate environment.

The purpose with this investigation was to determine the influence of fouling when there is a time interruption up to one week between the cleaning and repairing of a subsea concrete surface.

The field work of this investigation in the sea has been performed in Strömstad on the Swedish westcost and the laboratory part has been performed at Chalmers University of Technology in Göteborg, Sweden.

2. MANUFACTURING OF SPECIMENS AND STORAGE

A concrete prism with a notch, FIG 1, was chosen as a test specimen for determining the bond strength between the old concrete and the repair material. The prism was subjected to axial compressive load until the bond was exhausted and the repair material was pressed out. Together with the notched specimens, others were casted without notches as well as Swedish standard concrete cubes and cylinders for determination of reference strengths.

The specimens used have been poured in three sets. Each set consists of 12 pieces with notches, FIG 1, 3 pieces without notches, 12 standard cubes $0{,}15^3$ m^3 and 3 standard cylinders.

The concrete was mixed in a paddle mixer and the composition was as shown in Table 1.

Table 1 Composition of concrete

Cement		502 kg/m^3	The cement is Swedish standard
Water		206 l/m^3	Portland cement
Sand		862 kg/m^3	
Stone	16mm	760 kg/m^3	The sand and stone consisted
Consistence		viscous	of granite
Slumpcone gave 7 cm			The water used was fresh water

The main test specimens and the cubes and cylinders were stripped 2 days after concreting and stored approximately 3 weeks in fresh water before transport to site in Strömstad. There they were exposed to seawater for one month at a depth of 10 m below sea level. The temperature during the storage has been 15-20^{o}C and the salinity of the sea water varied between 1.8% to 2.5%.

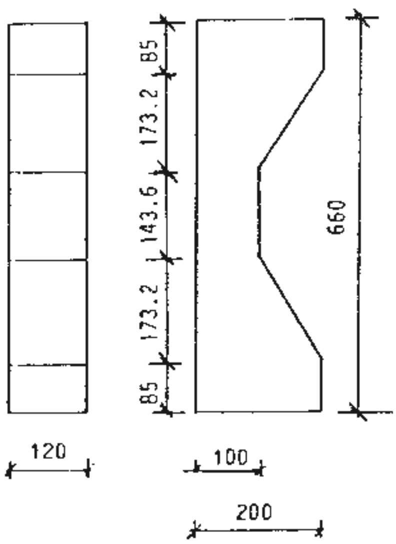

FIG 1. Measures of notched specimen

After this month the specimens were covered by a thin easy removed fouling layer and some harder attached barnacles. The specimens were cleaned from visible fouling and repaired following a certain program. The cleaning methods used have been brushing with a pneumatic propelled brush or a combination of the brush and following treatment with sand-mixed water jet.

The pneumatic rotation brush, which is a common tool, was used on all specimens and was found effective and easy to move, but it is loud and vibrates a lot which means that it is a tiring work to clean big surfaces with this due to the fact that only small brushes are available. The air bubbles are also a problem as they disturb the sight.

Then half of the specimens were cleaned also with sand-mixed water jet to remove eventual roots in the pores. This sand-mixed water jet had a pressure of 150 kg/cm^2, which is probably too low. It is also a very slow method.

Besides these two methods another brush system was tested. In this system a portable motor pump sends pressure water into the underwater cleanship brush turbine, which propels two brushes at 1000 rpm. Water evacuation takes place through an omni directional jet nozzle, which also allows diver propulsion, brush adherance and rear dirt ejection. These brushes are quiet, nearly weightless, easy to handle and does not disturb the sight. Unfortunately these could not be used on the test specimens because the necessary small type of brush was not available at that moment.

For the repair work three cement based liquid grouts from different manufacturers were used, Table 2. The repairing was performed immediately, three days and seven days after the cleaning. These intervals were chosen due to the fact that such interruptions might occur on site due to bad weather etc and result in different degrees of fouling. One set of specimens was prepared for each time of repair. Within each set 4 specimens with notches were repaired with each repair material.

Table 2 Composition of repair materials

Rescon 400 UV	Armorex	Cementa
25 kg Rescon 400 UV 3,75-3,90 l Water	20 kg Armorex 2 l Sika Latex 1,7 l Water	50 kg Portland cement 50 kg Sand (grain size 1mm) 50 kg Sand (grain size<1mm) 10 kg GLX 15 l Water

At repair the notches in the specimens were filled with grout 10 m below sea level by injection. The outlet for the injected grout was changed, according to FIG 2. To increase the pressure in the repair grout the outlet was changed to position b. A repaired specimen is shown in FIG 3 after testing.

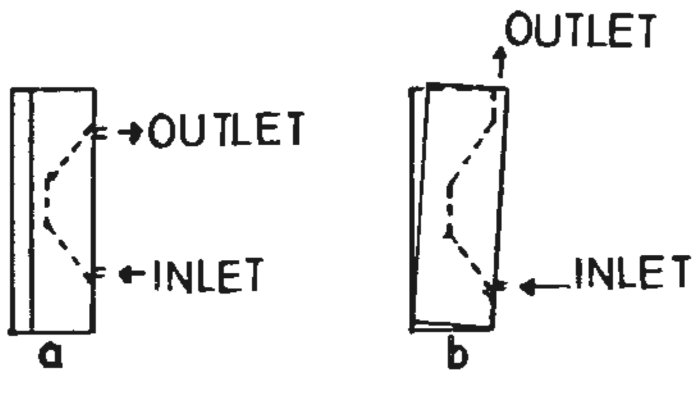

FIG 2. At injection the outlet was changed after day 1 from a to b.

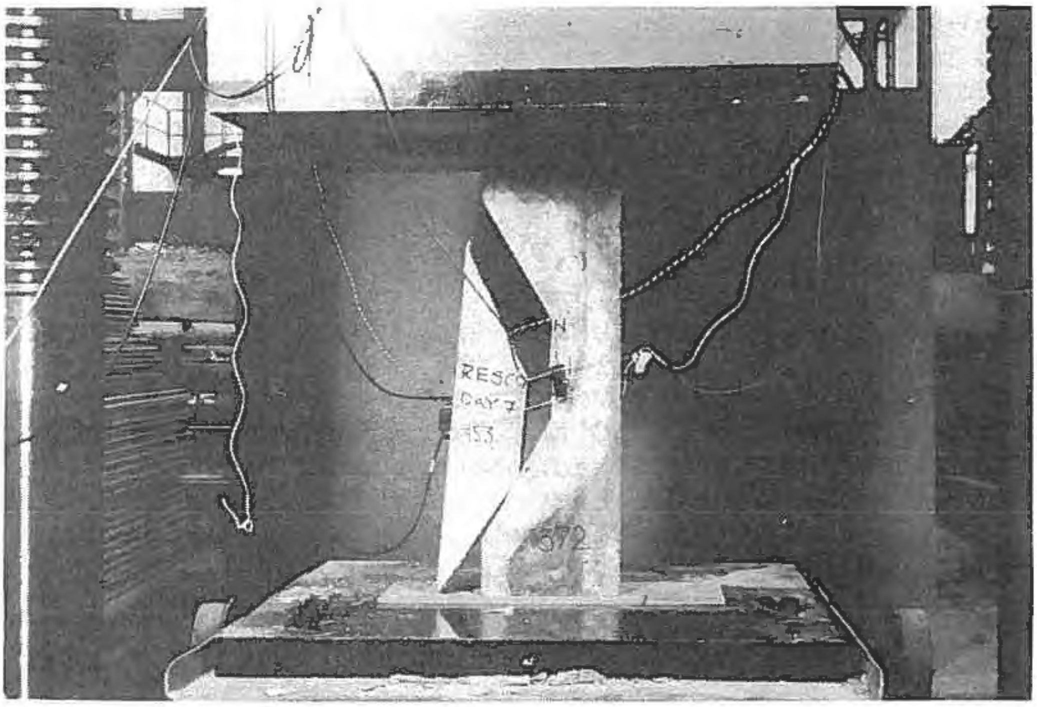

FIG 3. Specimen after test by axial compression

3. TEST RESULTS

The mean concrete strength of the basic material (36 tests) and the repair material (18 tests each) determined on standard cubes ($0,15^3$ m^3) and stardard cylinders (ϕ 150 mm, h = 300 mm) (3 tests each) at time of determination of bonding strength is shown in Table 3.

Table 3 Compressive strength

Material	Density kg/m^3	Compressive strength	
		cubes MPa	cylinders MPa
Basic concrete	2440	59,7	56,9
Rescon 400 UV	2139	41,9	37,2
Armorex	2009	43,0	39,1
Cementa	2019	22,4	23,1

The determination of the bonding strength started one month after the repair work was finished and was performed by axial loading in a hydraulic 10 MN press and with strain gauges at four points, see FIG 4. The load was increased until the repair material broke out of the specimen at failure.

Results from a representative test can be seen in FIG 4. The graphs show the sequence of the testing procedure. The stress is calculated as the mean stress of the specimen, i.e. the load evenly distributed on the top area. The mean stress at ultimate bond failure is registered as a measure of the bonding strength.

The basic material has higher value of the modulus of elasticity and compression strength than the repair material. This may cause the situation that the stress-strain graph of the specimen will be influenced by internal excentricity, because of the dominating influence of the basic material, which partly hides the real qualities of the repair material. Deterioriation of bond causes reduction of load in the repair material and corresponding load increase in the basic material.

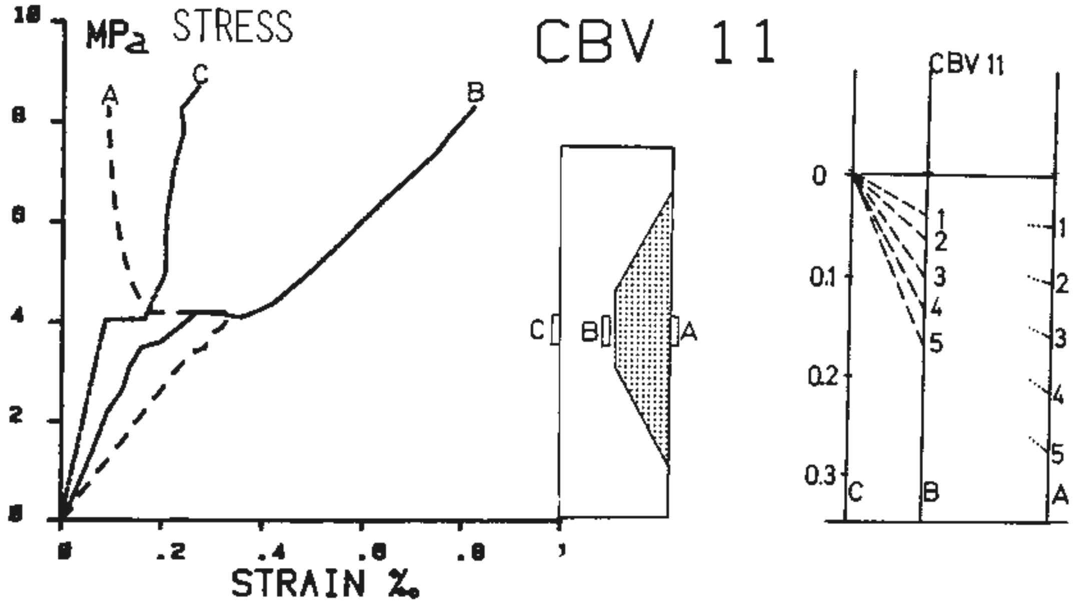

FIG 4. Stress-strain in specimen CBV 11

At testing cracks were observed in the upper interface between repair material and concrete, FIG 5. These cracks occured on every specimen and in these cracks a white salt had been accumulated. This salt was analysed in a x-ray spectrograph and showed that ettringite was present among the salts. This ettringite has an expanding effect and is probably the reason for the widening of the cracks originally appearing as setting cracks. The cracks disturbed the determination of the bonding strength. However, if the disturbance is assumed to be the same for all specimens a comparison of the strengths of the specimens can be done. The strength represented by the mean ultimate compressive stress on the top area of the specimens are shown in FIG 6 at different times of repair. This strength is an indirect measure of the bonding strength.

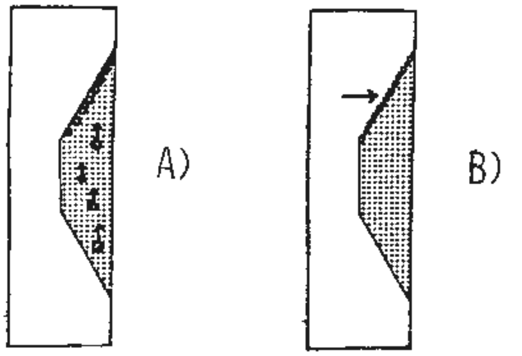

FIG 5. Concentration of air bubbles a) resulting in cracks b).

The graph, FIG 6, shows that there is a change in the bonding strength between day 1 and day 7. Generally it is a decrease of the bonding strength except for the Cementa grout between day 3 and day 7. An explanation for this deviation is based upon the fact that at casting of the Cementa specimens the pump failed and the grout must be removed. It is possible that this procedure also removed the biofilm from the specimens. Therefore the regrouted Cementa specimens probably got a better bond.

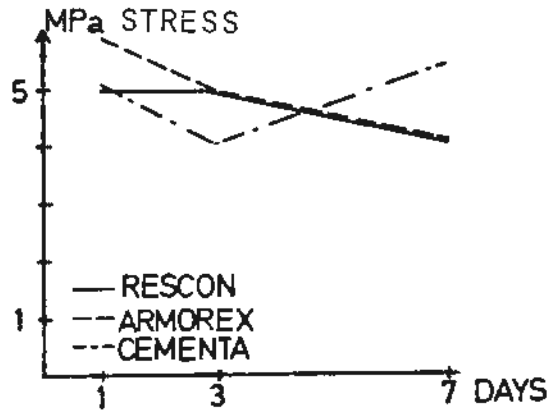

FIG 6. Average stress on specimens

The test procedure has shown that there is a decrease of the bonding strength. The decrease in bonding strength is 20 to 30% when the casting is done 7 days after the cleaning in comparison with if it is done immediately after it, FIG 6. If the casting is done 3 days after the repair the reduction in bond strength is about 10%. No influence of cleaning methods on bond was observed.

4. CONCLUSIONS

The present investigation has shown that:

- Fouling-biofilm with an age of one week decreases the bonding strength with approximately 20 to 30% and with an age of 3 days with about 10%
- The cleaning results on the bonding strength are the same for both methods used
  1) brushing with a pneumatic propelled brush
  2) brushing and a following treatment with sand-mixed water jet
- Brushes are preferable for the cleaning work and especially water-propelled ones, due to the divers health and working comfort
- The cement-based repair materials used have shown resemblance regarding different qualities as workability, bonding capacity etc.
- Effects and problems with setting and bleeding of the fresh grout and chemical reactions between seawater and concrete, especially in setting cracks, must be taken into consideration.

5. ACKNOWLEDGEMENT

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6. REFERENCE

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