

Four-Year Behavior of Polymer-Cement Coatings for Concrete Protection

by L. Coppola, S. Monosi, C. Pistolesi,
R. Troli, and P. Zaffaroni

Synopsis: An aqueous emulsion of an acrylic polymer (based on 2-ethylhexyl acrylate) was mixed with cement and fine aggregate and was studied as rubber-like coating to protect reinforced concrete beam specimens. Three acrylic polymer-cement coatings (both with water-cement ratio of 0.50, polymer-cement ratio of 0.50 and fine aggregate-cement ratio of 2) were produced by changing the type of the cementitious component (portland cement, pozzolan-portland cement with metakaolin, and slag-based cement). The coatings were applied to a porous concrete substrate with a water-cement ratio of 0.80.

Coated beam specimens were kept for 4 years in three different environments (laboratory at 20°C and 65% R.H.; natural environment exposed to changes in temperature and relative humidity; under water) in order to examine the influence of the ageing on the bond strength as well as the flexibility and therefore the ability of the acrylic coatings to bridge the crack of the concrete substrate. The latter was determined by measuring the crack width of the concrete substrate beam when the coating started to break under flexural stress.

Bond strength of the coatings was substantially unchanged or slightly improved by the exposure to the three different environments. On the other hand, the crack-bridging ability of the polymer-cement coating remained substantially unchanged up to 4 years in laboratory conditions, whereas there was a small flexibility loss of the coating in humid environment, particularly in the permanent underwater exposure. However, even in these less favorable conditions the crack-bridging ability of the three coatings was still satisfactory after 4 years.

Keywords: acrylic resins; durability; flexural strength; surface coatings

Luigi Coppola is a research civil engineer and technical director of Enco, Spresiano, Italy. He has authored numerous papers on various aspects of concrete technology, durability and mix-design.

Saveria Monosi is assistant professor of Materials Technology in the University of Ancona. She is author or co-author of numerous papers in the area of concrete durability and chemical admixtures.

Carlo Pistolesi is a research civil engineer, director of the Building Materials Laboratory of Mapei, Milan, Italy. He has authored several technical paper on concrete technology and durability.

Roberto Troli is a research civil engineer and director of the Enco laboratory. He is author of several papers in the field of concrete technology and in particular of chemical and mineral admixtures.

Pasquale Zaffaroni is the R&D manager of the Building Materials Division, Mapei, Milan, Italy. He has authored several technical papers on concrete technology. He is member of the European Norms Committee for polymer or cement repairing mortars.

INTRODUCTION

In addition to what happens in laboratory specimens, concrete structures are often subjected to static and/or cyclic dynamic loading. Moreover, they are also subject to restrained hygrometric and thermal length changes.

Due to microcracking from any of the above causes, the concrete surface becomes permeable during service since microcracks are preferential paths for the penetration of environmental agents (air, water, sulphate, chloride and alkali ions); the concrete cover can thus be penetrated by aggressive agents independently of the porosity of the cement matrix. This promotes the corrosion of the reinforcement and the deterioration of the cement matrix itself as well as that of any reactive aggregate. Once these aggression mechanisms, all having an expansive and disruptive nature, are initiated, the microcracks grow and became macrocracks. After an initial induction period - whose length time depends on the specific aggressive environment, concrete composition and curing conditions - the deterioration process increases very rapidly and involves the concrete cover as well as the reinforcing bars (1).

If a service life less than 50 years is needed, a limit in the water-cement ratio according, for instance, to the European norms (2) or the ACI recommendations (3) is sufficient to guarantee the required durability, provided that an adequate cover depth and proper early curing are also adopted. In such a case, the mechanism of microcracks and their transformation into macrocracks can be of negligible importance for concrete durability.

On the other hand, in concrete structures designed to serve for more than 50 years the above requirements cannot guarantee this longevity because of the

microcracking and its subsequent development into macrocracking. This problem is enhanced for concrete structures exposed to very hostile environmental conditions or subject to very serious dynamic loading (4-8). In such a case, an additional flexible skin could be used on the concrete surface, even for concrete structures designed to serve not more than 50 years.

PURPOSE OF THE WORK

This investigation is a part of a larger research project to develop a thin protective coating based on polymer-cement mixture characterized by durability, bond strength, and flexibility.

In previous papers (9-10) preliminary results were presented for rubber-like coatings made from different binders and an aqueous emulsion of an acrylic polymer. In particular, the durability behavior of these coatings was studied. The plain concrete substrate, manufactured intentionally porous for its high w/c (0.80), was transformed into durable and impermeable material when treated with these coatings. They performed very well in terms of impermeability to water, CO_2 , sulfate and chloride ions (10).

The purpose of the present work is to study the behavior of these polymer-cement coatings in terms of flexibility and bond strength after a 4-year exposure to different environments.

EXPERIMENTAL

Materials

Three cementitious binders were used to produce the polymer-cement coatings (Table 1). The cement *P* was a portland cement type CE II/A-L 42.5 according to the European Norm 197/1. Binders *M* and *S* were obtained by blending the *P* cement with metakaolin (15%) or slag (60%) respectively.

Polymer-cement flexible coatings were manufactured by mixing 1 part of 2-ethylhexyl acrylate polymer latex, 1 part of binder and 2 parts of fine sand (0-0.2 mm). Since the rubber-like latex was a 50% aqueous emulsion of polymer, both water-cement ratio and polymer-cement ratio were 0.50. Table 2 indicates the composition and the properties of the three polymer-cement coatings.

A 2 mm thick coating was applied on concrete substrate specimens for flexibility and bond-strength tests. The composition of the concrete substrate is the same as that previously studied (10) for the durability behavior of the coatings and it is shown in Table 3.

FLEXIBILITY AND LONGEVITY TESTS

These tests were carried out to assess the flexibility and the flexibility change of the polymer-cement coatings applied on concrete beams reinforced with three steel rods (8 mm in diameter) and exposed up to 4 years to three different environmental conditions: in laboratory conditions (20°C and 60% R.H.); under water (20°C); in an outdoor natural environment on the North Italy (Venice area), with thermal excursions of 0-30°C and hygrometric changes in the range of 50-100% RH.

After preliminary curing of the concrete beams for three months at 20°C and 60% R.H. the coatings were applied and cured for additional 7 days before the exposure to the above three different conditions.

The coatings were applied in form of strips (45 mm wide and 600 mm long) only to the beam face (150 x 600 mm) further from the steel reinforcements (Fig. 1). The rest of this beam surface was left bare, so that the appearance and the growth of the cracks produced by flexural loading were evaluated in the uncoated and the coated areas of the same face.

At regular intervals of exposure time up to 4 years in each of the environmental conditions, three point bending tests were carried out on the beam specimens. The load was applied on the face of the beam closest to the steel reinforcement and furthest from the coated face. Due to application of a load, a crack formed in the bottom face. The beam was reinforced in the compressive face in order to control easily the crack-opening in the tensile face. A mirror under the beam allowed to observe the appearance and the growth of the crack in the uncoated area as well as the behavior of the coating. The crack opening of the uncoated concrete substrate increased by increasing the flexural loading and was measured by means of an electronic dial gauge mounted between two pins inserted on the bottom of the beam. At low flexural loading, the flexible coating remained intact. Then, at higher loading the polymer-cement coating started to break as recorded by visual observation through the mirror. When this occurred, the crack opening of the uncoated concrete surface was recorded through the dial gauge and this value was considered to be a measure of the flexibility of the coating.

The flexibility of the coating - in terms of the crack opening of the concrete substrate corresponding to the initial breakage of the coating - was measured as a function of the exposure time to the different environments. The initial flexibility of the coating - just before the exposure to the three environments - was about 1.1 mm with portland cement (*P*) and about 1.4 mm with slag (*S*) or metakaolin (*M*) blended cements.

The flexibility-exposure time curves for *P*, *M* and *S* coatings are shown in Figs. 2,3 and 4 respectively.

There was a small flexibility loss (particularly between 3 and 12 months) of the coating with portland cement permanently exposed to water, whereas no

significant change was recorded in this coating when exposed to laboratory or natural conditions (Fig. 2).

In the presence of metakaolin the reduction in the flexibility of the coating was much higher when kept underwater and negligible when exposed to the dry laboratory conditions (Fig. 3). An intermediate trend was observed when this coating was exposed to natural conditions.

The coating with slag addition performed better than the other coatings in terms of flexibility longevity: there was no significant flexibility loss when the coating was exposed to water, and a small improvement in the other environmental conditions (Fig. 4).

BOND STRENGTH TESTS

These tests were carried out on the same beam specimens employed for the flexibility tests. The bond strength was determined through a dynamometer by measuring the tensile force required to debond the polymer-cement coating from the concrete substrate.

Figs 5,6 and 7 show the bond strength as a function of the exposure time to the different environmental conditions for the coating *P* (with portland cement alone), *M* (with metakaolin) and *S* (with slag), respectively.

The initial bond strength was in the range of 0.4-0.6 MPa. Then, the bond strength increased with the exposure time except for the coating *P* which was substantially constant when permanently exposed to water.

For a given exposure condition, the increase in the bond strength was higher in the *M* coating than in the *S* and *P* coatings.

For each coating, the bond strength in the underwater environment was lower than in permanently dry laboratory environment (60% R.H.). In a natural environment, where dry and wet conditions alternated, the bond strength was intermediate between those determined in the other two environments. The failure of the coating during the bond strength test was in general within the coating itself when the specimens were kept under water and at the coating-concrete interface when the specimens were exposed to the laboratory environment. It would seem that exposure to water reduces the bond strength improvement in the time since it negatively affects the tensile strength of the coating.

CONCLUSIONS

The flexibility of the polymer-cement coatings, in term of ability to bridge the cracks of the concrete substrate caused by bending stress did not change up to 4 years when the coated concrete specimens where exposed to the dry laboratory conditions. However, when exposed to natural environments (where dry and wet conditions alternated) and especially when permanently kept under water, there was a flexibility loss of the coating with portland cement

particularly in the presence of metakaolin. No flexibility loss was recorded in the polymer-cement coating in the presence of slag, independently of the environmental exposure.

The bond strength of these coatings to the concrete substrate increased in time except for the coating with portland cement alone which was substantially constant when permanently exposed to water. The increase in the bond strength was higher for the coating with metakaolin and, for each coating, with exposure to dry conditions.

All the above results indicate that a polyacrylate-slag cement coating appears to perform very well in terms of bond strength and ability to bridge the cracks of the concrete substrate independently of the environmental conditions in service.

ACKNOWLEDGEMENT

The work in preparing the text and the Figures by Mara Meneghel and Alessandra Galletti is acknowledged.

REFERENCES

1. Mehta, P.K. "Durability-Critical Issues for the Future", *Concrete International*, V. 19, No. 7, pp. 27-33, 1997.
2. European Prestandard ENV 206, "Concrete. Performance, Production, Placing and Compliance Criteria", 1988.
3. ACI Committee 201, "Guide to Durable Concrete", *ACI Manual of Concrete Practice 1995*, Part 1.
4. Sato, T., Sakai, K. and Kumagai, M. "Effectiveness on Coatings on Concrete Under Freezing and Thawing Conditions", *Concrete Under Severe Condition. Environment and Loading*, Vol 1, 1995, pp. 927-934. Editor: K. Sakai, N. Banthia and O.E Gjrv.
5. Swamy, R.N., Hamada, H., Fukute, T., Tanikawa, S. and Laiw, J.C. "Chloride Penetration into Concrete Incorporating Mineral Admixtures or Protected with Surface Coating Material Under Chloride Environments", *Concrete Under Severe Conditions. Environment and Loading*, Vol 1, 1995, pp. 935-944. Editor: K. Sakai, N. Banthia and O.E Gjrv.
6. Kamimoto, H., Wakasugi, M. and Miyagawa, T. "Performance of Concrete Coated with Flexible Polymer Cement Mortar" *Concrete Under Severe Conditions. Environment and Loading*, Vol 1, 1995, pp. 945-953. Editor: K. Sakai, N. Banthia and O.E Gjrv.
7. Al-Juraifani, E.A. "Evaluation Scheme for Penetrating Sealers to Prevent Concrete Deterioration in Saudi Arabia" *Concrete Under Severe*

- Conditions. Environment and Loading, Vol 1, 1995, pp. 954-963. Editor: K. Sakai, N. Banthia and O.E Gjrv.
8. Abuazza, O.A and Ibrahim, A.A. "Internal Protection of Concrete Pipeline for the Conveyance of Aggressive Water (CO₂)" Concrete Under Severe Conditions. Environment and Loading, Vol 1, 1995, pp. 974-983. Editor: K. Sakai, N. Banthia and O.E Gjrv.
 9. Coppola, L., Pistolesi, C., Zaffaroni, P. and Collepari, M. "The Ageing Effect on the Properties of Flexible Surface Coating for Concrete Protection", ACI SP 170, pp. 1247-1270, 1997.
 10. Coppola, L., Pistolesi, C., Zaffaroni, P. and Collepari, M. " Properties of Polymer-Cement Coating for Concrete Protection", ACI SP 173, pp. 267-285, 1997.

Table 1 - Composition of binders used for the polymer-cement coatings.

BINDER:	Portland cement CE II/A-L 42.5	Metakaolin	Slag
P	100	-	-
M	85	15	-
S	40	-	60

Table 2 - Composition and properties of the polymer-cement coatings.

Ingredients:	P Coating	M Coating	S Coating
Polymeric Latex (50% 2-ethyhexyl acrylate)	25%	25%	25%
P binder	25%	-	-
M binder	-	25%	-
S binder	-	-	25%
Fine sand (0-0.2 mm)	50%	50%	50%
Water-cement ratio*	0.50	0.50	0.50
modulus of elasticity (N/mm ²)**	220	180	170
Strain at failure stress (%)**	24	28	27

*water only from the polymeric latex (50%)

**measured at 28 days on specimens stored at 20°C and 60% RH

Table 3 - Composition and properties of the concrete.

Cement CE II/A-L 42.5	Sand (FM=2.6)	Gravel (5-20 mm)	Water	W/C	Slump	Compr. Strength at 28 days
310 kg/m ³	710 kg/m ³	1060 kg/m ³	215 kg/m ³	0.80	215 mm	25 N/mm ²

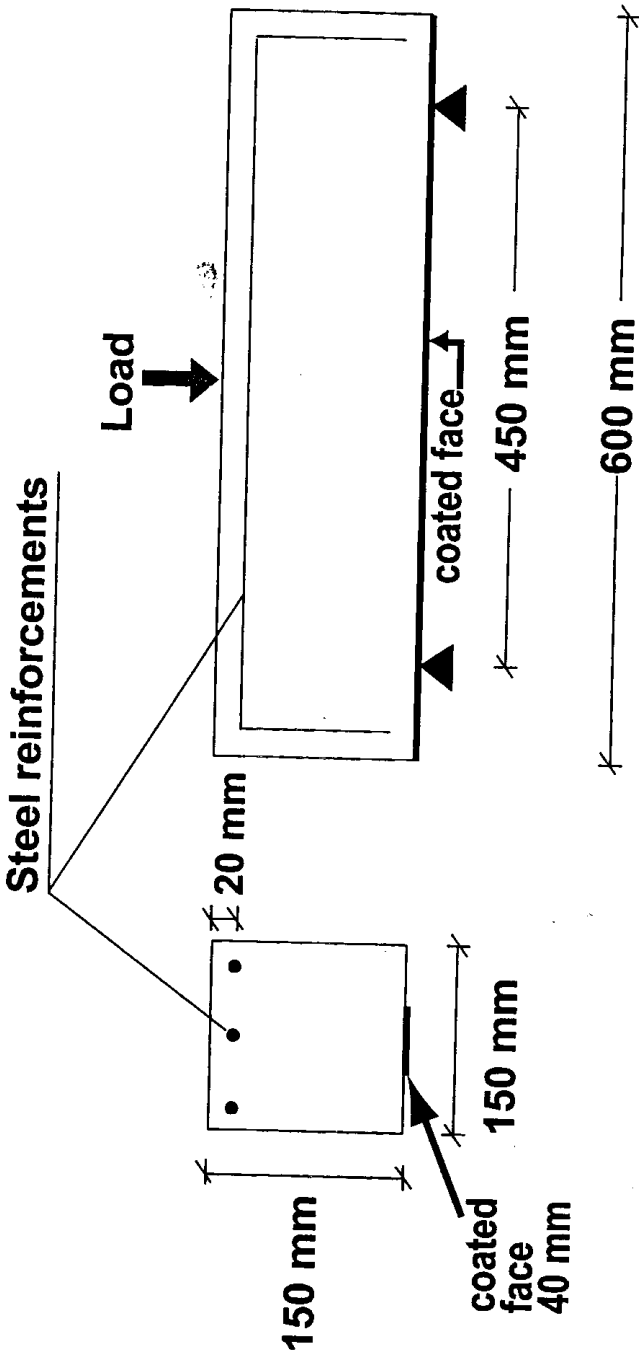


Fig. 1 - Reinforced beam (150x150x600 mm) for flexibility and longevity tests.

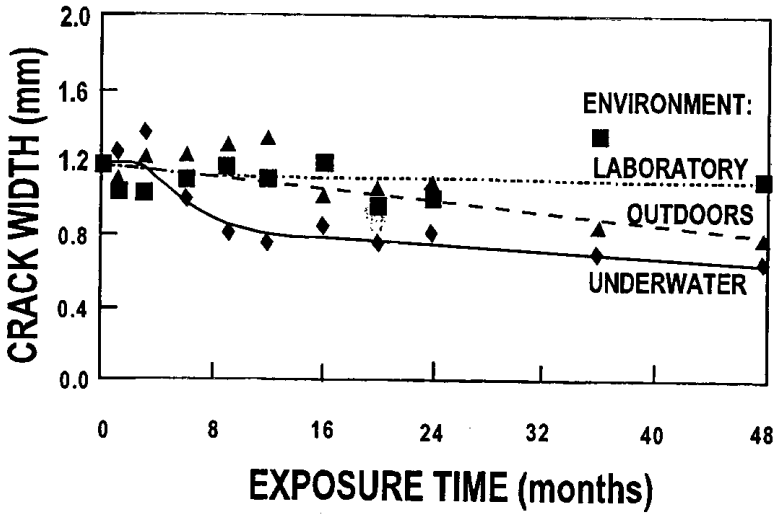


Fig. 2 - Influence of the environmental exposure on the substrate crack opening produced by flexural loading and measured at the breakage of the flexible *P* coating.

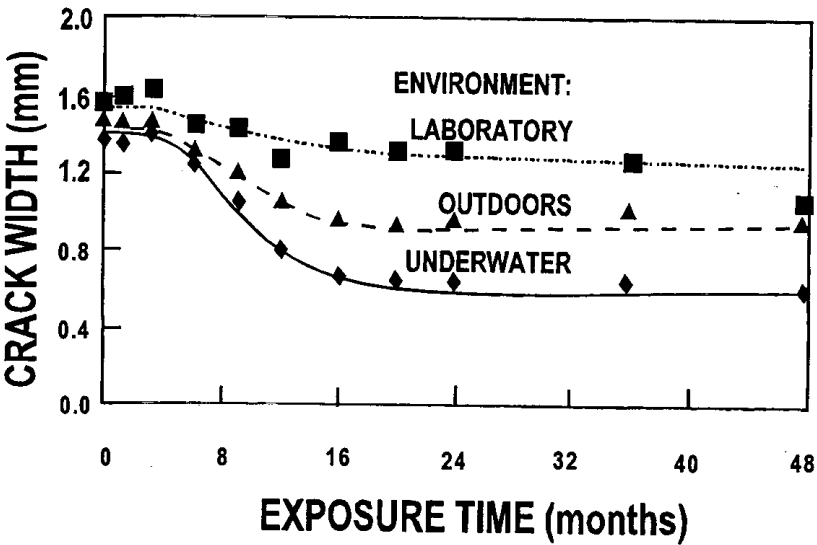


Fig. 3 - Influence of the environmental exposure on the substrate crack opening produced by flexural loading and measured at the breakage of the flexible *M* coating.

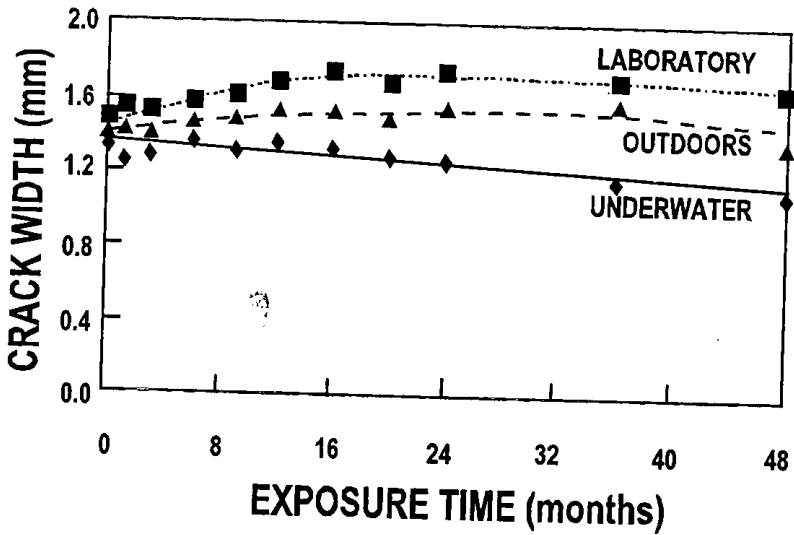


Fig. 4 - Influence of the environmental exposure on the substrate crack opening produced by flexural loading and measured at the breakage of the flexible S coating.

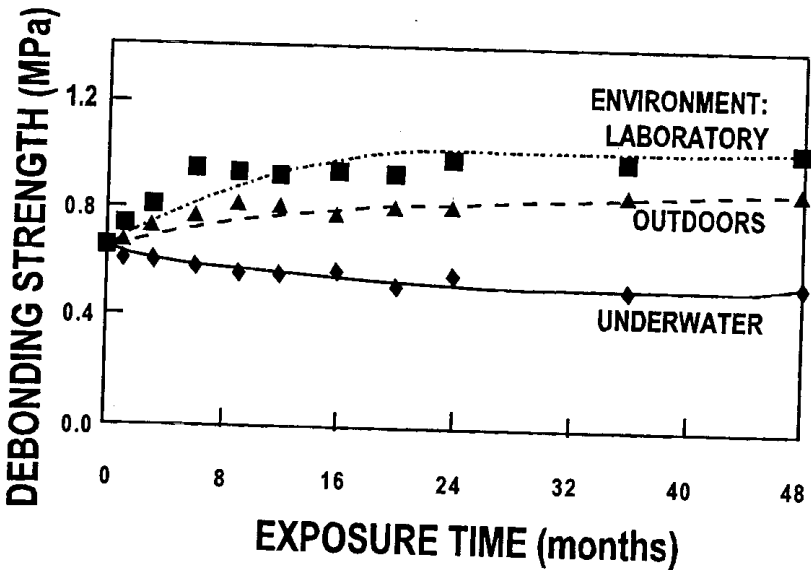


Fig. 5 - Influence of the environmental exposure on the debonding strength of the P coating from the concrete substrate.

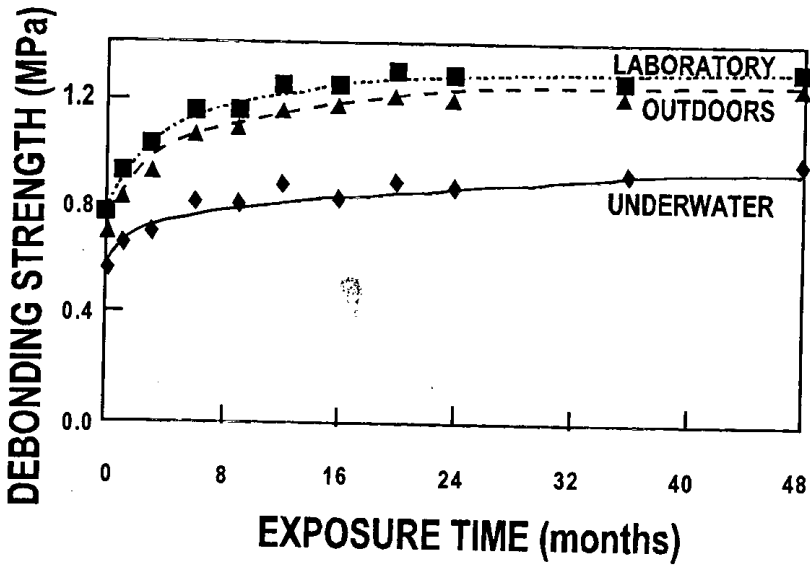


Fig. 6 - Influence of the environmental exposure on the debonding strength of the *M* coating from the concrete substrate.

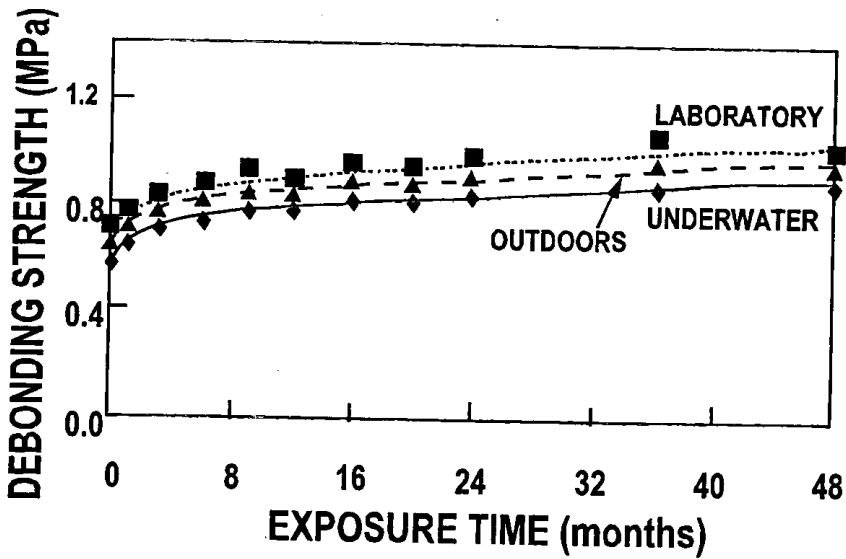


Fig. 7 - Influence of the environmental exposure on the debonding strength of the *S* coating from the concrete substrate.