Pergamon

CEMENT AND CONCRETE RESEARCH

Cement and Concrete Research 30 (2000) 259–266

Performance of epoxy-repaired concrete in a marine environment

Moetaz El-Hawary*, Husain Al-Khaiat, Sami Fereig

Department of Civil Engineering, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait

Received 9 December 1998; accepted 15 November 1999

Abstract

The use of epoxy resins is becoming the most common method of concrete repair and rehabilitation. The performance of epoxy-repaired concrete in a marine environment has been investigated. Specimens were cast using two different types of cement, ordinary and sulphate-resistant Portland cement, damaged and then repaired using three different types of epoxy resins available in the Kuwaiti market. Specimens were then hung in the Arabian Gulf, in the tidal zone, so that they were subjected to cycles of wetting and drying for different time durations up to 18 months. The specimens were then tested in split and in slant shear to determine their tensile and bond strength. Results are compared with those of the control specimens, which were kept in a laboratory under controlled conditions.

Keywords: Epoxy; Concrete; Marine; Repair; Performance

1. Introduction

A marine environment is any place where concrete becomes wet with seawater. This could happen to concrete submerged under water, in a tidal zone, in a splash zone, or at any place inland where wind could carry the salt water spray [1]. The marine environment in the Gulf area is characterized by high ambient temperature during the summer, which accelerates the deterioration of concrete and corrosion of reinforcing steel [2].

Deteriorated concrete is usually repaired using some type of epoxy resin. The method of application of epoxy depends on the size of the crack and level of deterioration [3]. Epoxy may be introduced as mortar for wide cracks, by grouting for medium size cracks, and by injection for small cracks. Repaired structures are usually subjected to the same environmental conditions that caused their deterioration in the first place, which necessitates the study of the performance of epoxy-repaired concrete.

This paper is concerned with the performance of epoxy-repaired concrete in the Arabian Gulf environment. To capture the marine deterioration in the most severe conditions, specimens were hung in the Gulf in such a way that they were immersed in seawater during the high tide only. This way they were exposed to the chemical, mechanical, and biological effects along with the effect of wetting and drying cycles. The main variables in this study are the type of cement, type of epoxy, and time of exposure to seawater. The split tensile and the shear-bond strengths were investigated for each set of variables.

2. Research significance

The use of polymer concrete in structural applications, especially in the field of repair and rehabilitation of existing structures, is growing rapidly. The durability of some of those repair materials, however, is still under investigation. The study of the behavior of epoxy-repaired concrete under the combined effect of marine environment and hot climate, which are the main characteristics of the Kuwaiti environment, will help determine if the already existing epoxy-repaired concrete structures will perform according to expectations or if further repair work should be anticipated. The study will also affect the future use of epoxy resins regarding the adequacy of some kinds of epoxy resins to perform under the harsh environment of Kuwait.

3. Sample preparation and testing

The concrete mix was prepared using cement, sand, and gravel of ratio 1:2:3, along with a water cement ratio of 0.6. Two different types of cement were utilized in this study,

* Corresponding author. Tel.: +965-481188, ext. 5756; fax: +956-4817524.

E-mail address: moetaz@civil.kuniv.edu.kw (M. El-Hawary)

0008-8846/00/$ – see front matter
PII: S0008-8846(99)00242-2

namely ordinary Portland cement and sulphate-resistant cement. Specimens were cast in two different sizes. For split tensile testing (ASTM C496), standard cylinders were used and for shear-bond testing, the slant shear-bond specimens (ASTM C882) [4], which are cylinders of 76.2 mm in diameter and 152.4 mm in height cast in halves with an inclination line of 30° from the longitudinal axis, were utilized. To cast the slant shear specimens, a dummy half was prepared, inserted in the cylinder mould, and the concrete was poured over it, vertically, to cast the other half. For both types of specimens, moulds were vibrated using a vibrating table and the specimens were cured under water for 28 days. Split specimens were then loaded in split till failure. Specimens were split in halves. Specimens were then repaired (each two halves in either type of specimens were bonded together) using epoxy mortar. Three different types of epoxy, available in the Kuwaiti market and used in repair work in Kuwait, were used (Ep-1, Ep-2, and Ep-3). Mortars were prepared using preweighed, prepackaged fine aggregates in quantities according to the manufacturers' specifications. All types of epoxy are of type IV according to ASTM C881-90.

Some specimens were put in fishing nets that were tied in ropes and hung from a pier on the Arabian Gulf in Kuwait. The length of the ropes were determined so that specimens were immersed in water at high tide only and allowed to dry at low tide (Fig. 1). Specimens were kept in seawater for time durations of 6, 12, and 18 months. The time durations for all specimens started at the month of April. Other specimens were put in tanks full of seawater and kept in a lab at room temperature for time durations of 1, 3, 6, 12, and 18 months. The water in the tanks was increased to compensate for evaporation using a combination of sea and tap water in such a way as to keep the amount of salts in accordance with seawater. The Gulf water is characterized by having a high chloride content. The amount of chlorides is 24 g/L and the amount of sulphates is 3.4 g/L [5]. Two repetitions were used for each case, type of specimen, type of epoxy, type of cement, and time duration. For comparison, control specimens were tested 1 week after repair and were not subjected to seawater. Split prepared specimens were tested in split along a plane of repair to determine the tensile strength, while the slant shear specimens were tested in compression, and the bond strength was calculated.

Fig. 1. Suspended specimens.

Fig. 2. Buildup of seashells.

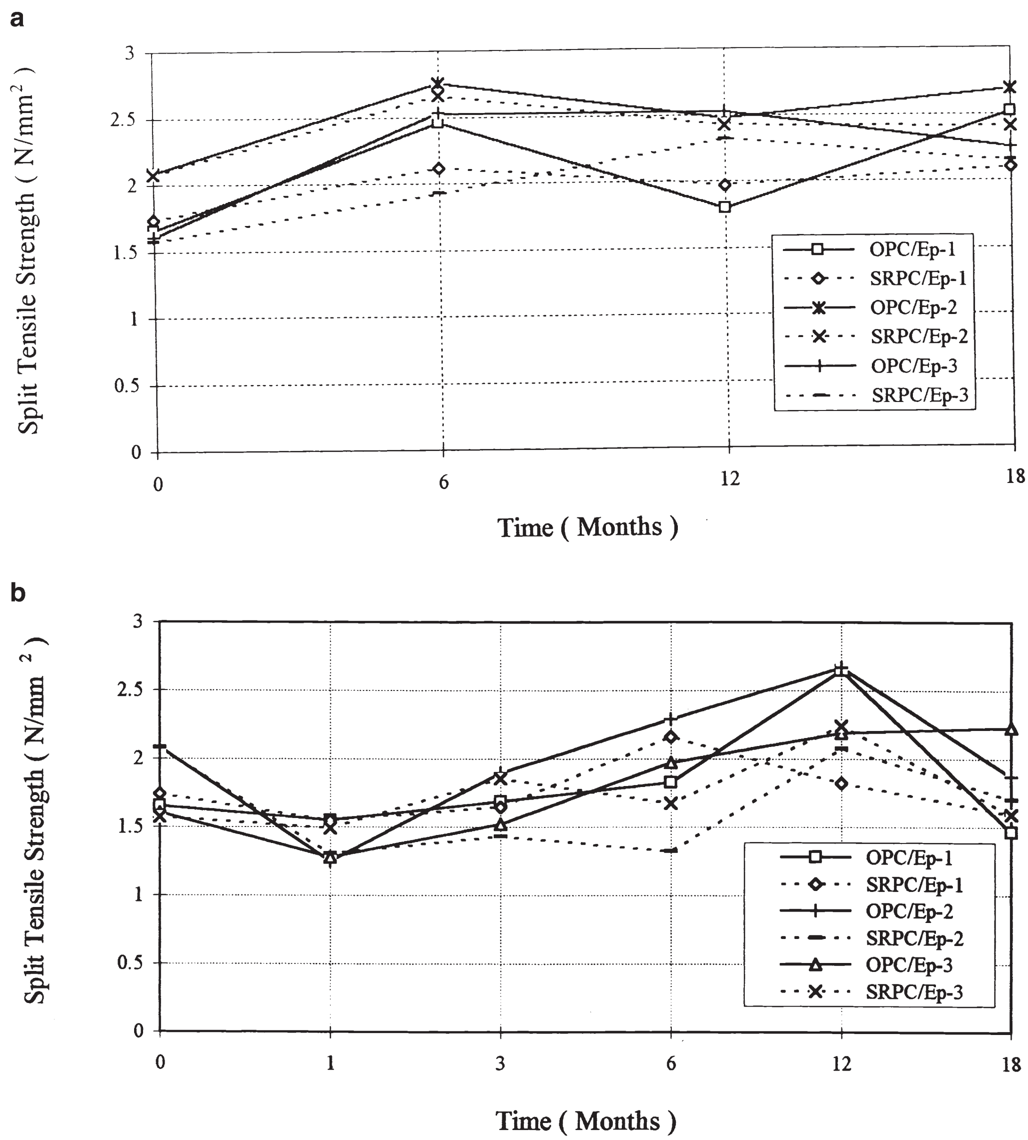

Fig. 3. Split tensile strength vs. time: (a) specimens kept in marine environment; (b) specimens kept in laboratory.

4. Results and discussion

Specimens subjected to the tidal and wetting and drying cycles experienced a thick buildup of sea shells, algae, and other marine organisms, as shown in Fig. 2. The variation of split tensile strength with time for both types of cement and all types of epoxy is shown in Fig. 3a for marine specimens and Fig. 3b for lab specimens. For lab specimens, an initial drop in tensile strength was observed, followed by an increase in strength, which was followed again by a drop in strength after the age of 1 year. The initial drop may be due to the crystallization of salts inside the concrete pores, while the increase in strength may be due to the hydration of cement with time and the later drop may be due to the chemical deterioration in concrete due to sulphate attack, which became apparent after 1 year. For marine specimens, however, the initial drop in strength is not shown, since no specimens were tested before the 6-month period and the deterioration was not apparent for the whole duration of 18 months. This may be due to the buildup of shells, which protected specimens from deterioration and increased their apparent strength.

It must be noted that at low ages most of the split specimens failed in concrete while at later ages most specimens failed along the repair plane, which means that epoxy mortar is generally stronger than concrete, but its rate of deterioration is higher. The split tensile strength is shown for marine, open air, and lab specimens at the ages of 6, 12, and 18 months in Figs. 4a, b, and c, respectively. A comparison with specimens kept in seawater tanks [6] in open air, in oven at 60°C, and in oven at 80°C is also shown at the same

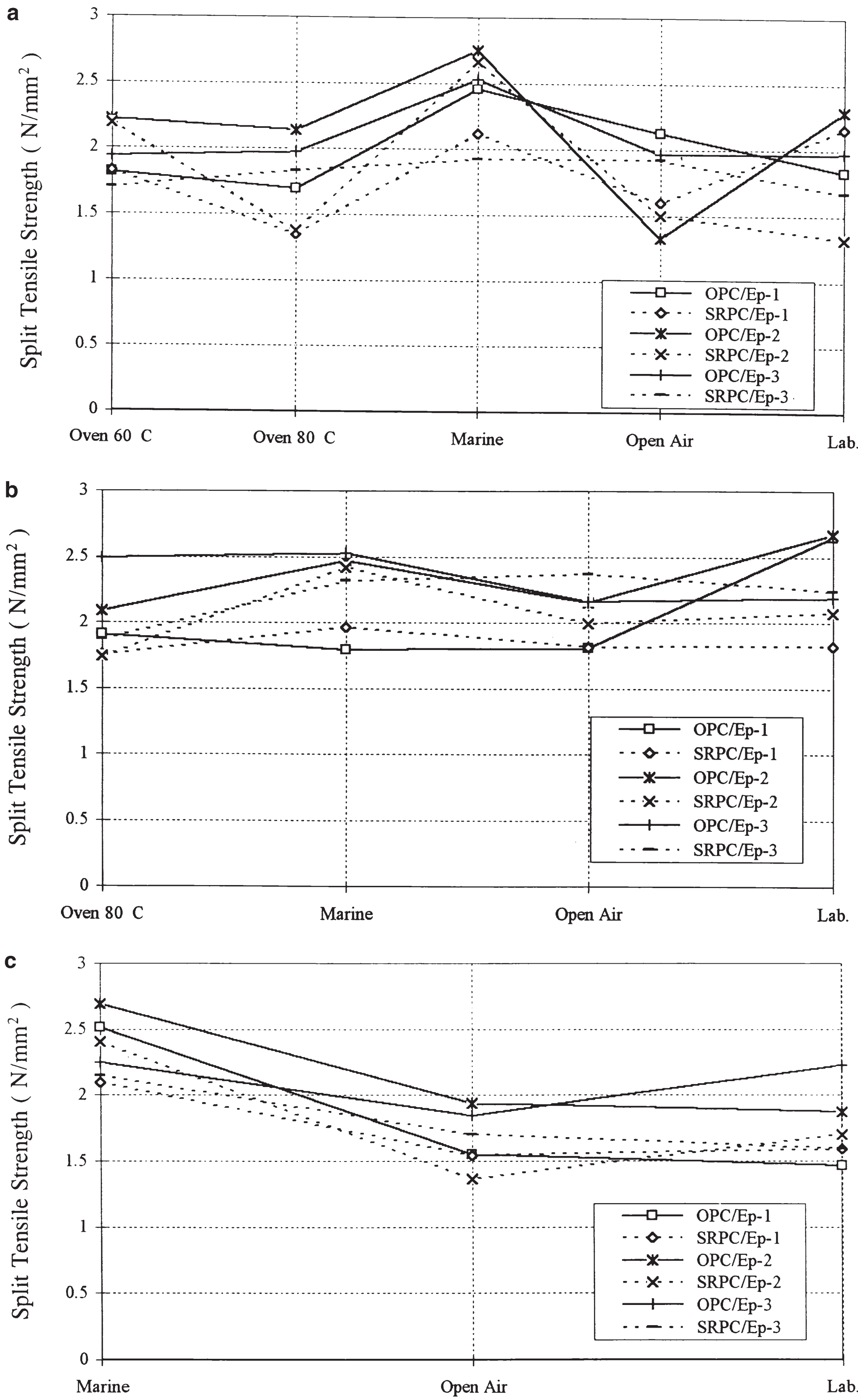

Fig. 4. Split tensile strength for different groups: (a) specimens kept for 6 months; (b) specimens kept for 12 months; (c) specimens kept for 18 months.

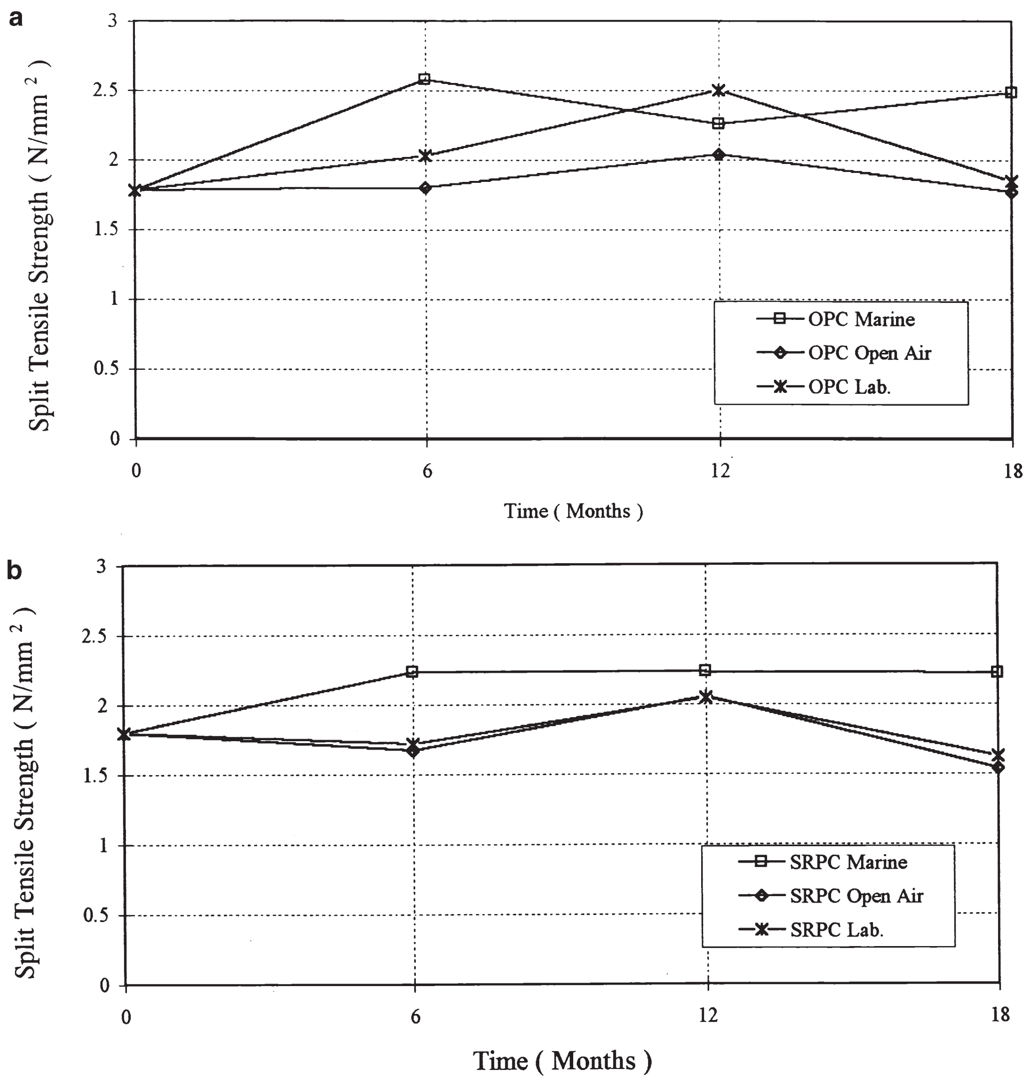

Fig. 5. Average split tensile strength vs. time: (a) ordinary Portland cement; (b) sulphate-resistant cement.

ages. Due to the buildup of shells, the marine specimens present a higher apparent strength at all ages.

Some discrepancies are shown in the results for the different types of epoxies and cements. However, in general, epoxy number 2 is superior at most ages and ordinary Portland cement gives better results than sulphate-resistant cements. The average split tensile strength is shown vs. time for marine, lab, and open air specimens in Figs. 5a and b for ordinary Portland cement and sulphate-resistant cement, respectively. The figures show that the tensile strength is higher, in general, for marine specimens. For bond strength specimens, most cylinders failed along the epoxy mortar plane at all ages. The bond strength is shown for marine and lab specimens at the ages of 6, 12, and 18 months in Figs. 6a, b, and c, respectively, along with comparisons with open air and oven specimens at some ages.

The same trend with split specimens was observed for bond specimens, except that for bond, most specimens failed along the plane of repair, which means it is an actual test of the strength of epoxy mortar systems, while in split specimens at low ages, the strength of concrete was more dominant. The large discrepancies between the different types of epoxy indicate the large variation between the different types of epoxy used in Kuwait. As for split specimens, marine cylinders presented higher strength due to buildup of shells, and the ordinary Portland cement specimens were superior to sulfate-resistant specimens. The average bond strength is shown vs. time for marine, lab, and open air specimens for ordinary and sulphate-resistant cements in Figs. 7a and b, respectively.

5. Conclusions

The performance of epoxy-repaired concrete specimens, hung in the Arabian Gulf in the tidal zone, has been investi-

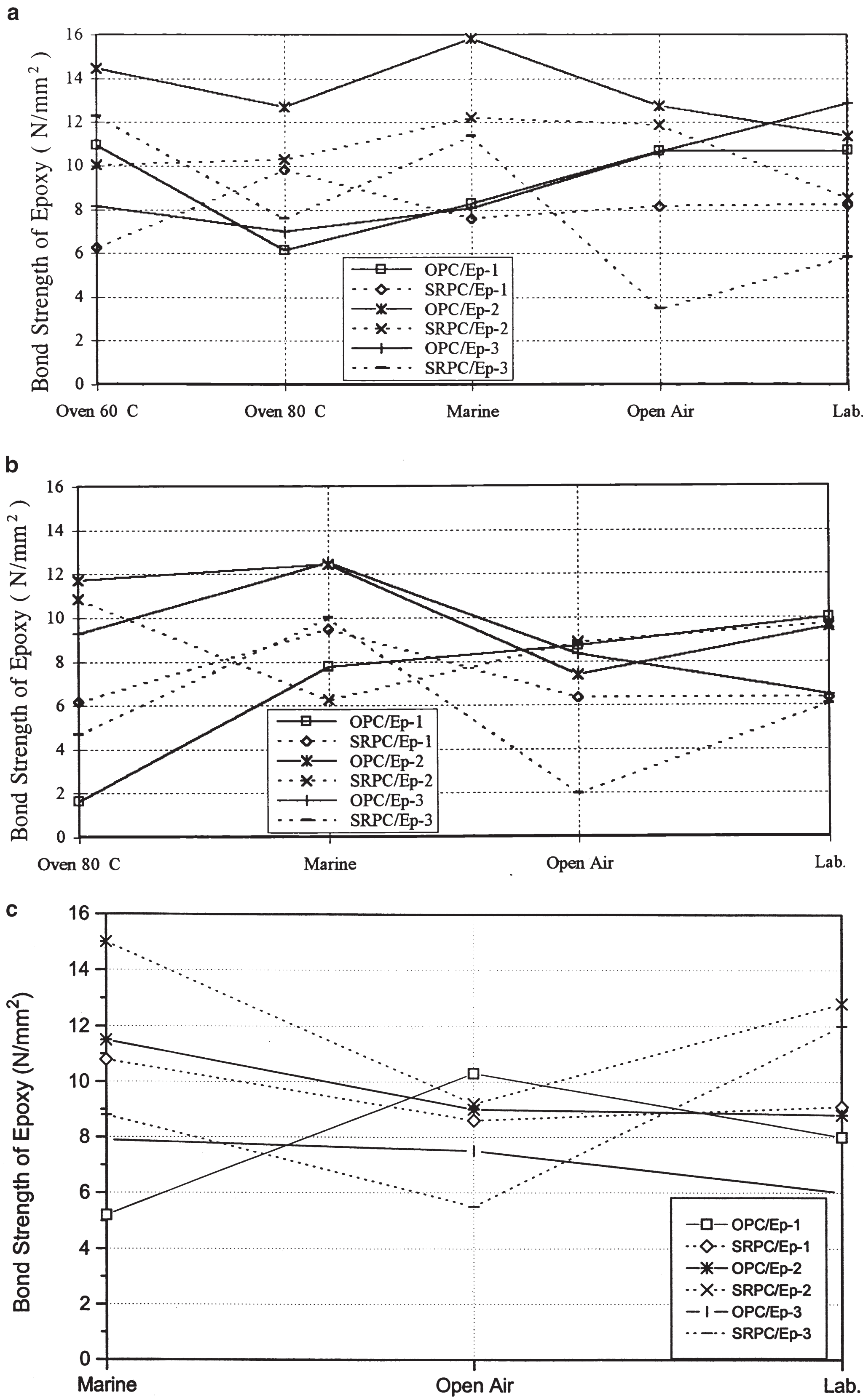

Fig. 6. Bond strength for different groups: (a) specimens kept for 6 months; (b) specimens kept for 12 months; (c) specimens kept for 18 months.

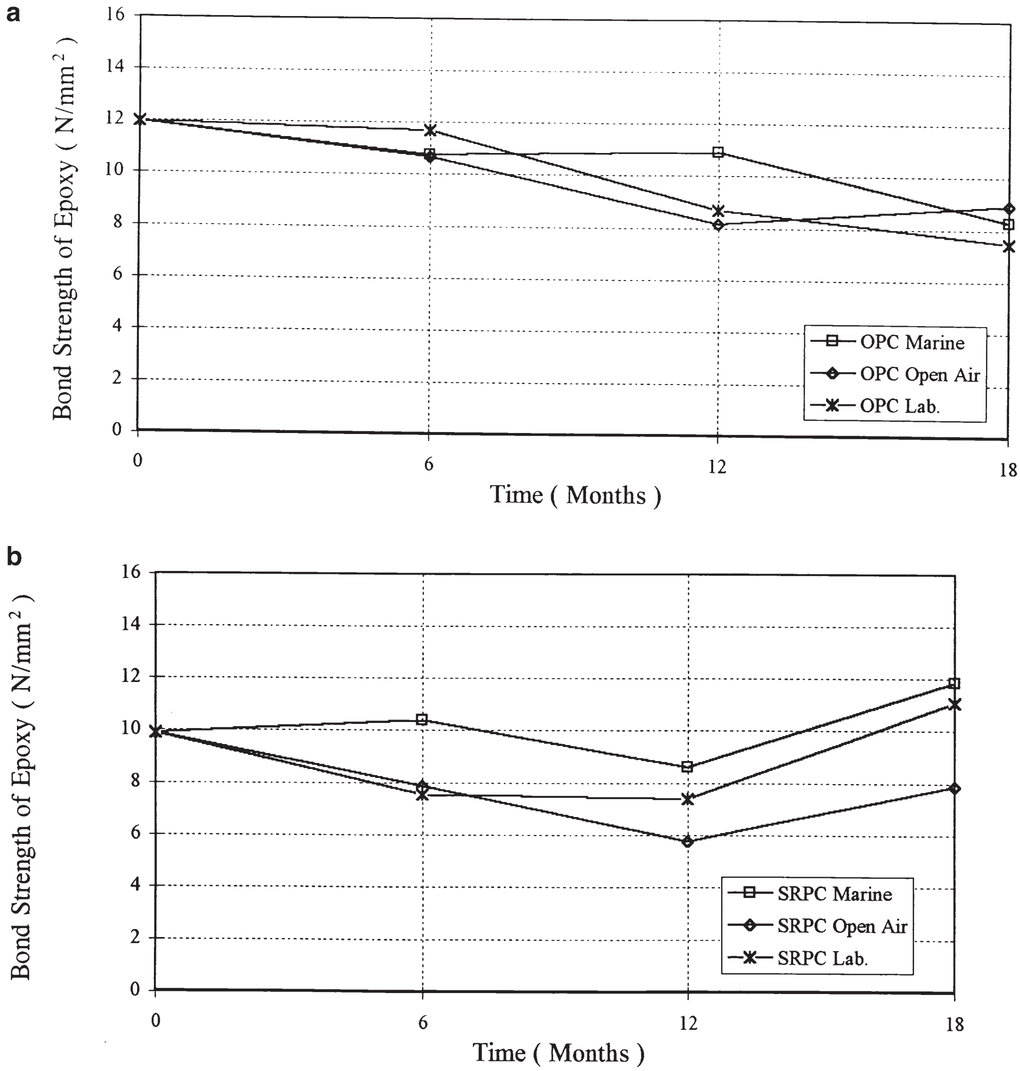

Fig. 7. Average bond strength vs. time: (a) ordinary Portland cement; (b) sulphate-resistant cement.

gated and compared to control specimens in lab conditions. Three different types of epoxy resin available in Kuwait were used, along with two types of cement, namely ordinary and sulphate-resistant cement. Specimens were tested in slant shear to measure bond strength and in split for tensile strength. Performance was tested after time durations of up to 18 months.

The results showed that although the deterioration of epoxy-repaired concrete is faster for specimens hung in the sea in a tidal zone and subjected to biodeterioration and cycles of wetting and drying, an increase in strength was observed at all ages due to buildup of seashells. Ordinary Portland cement proved superior to sulphate-resistant cement and large variations between the different types of epoxy were observed, especially for bond test, although no particular type was clearly superior at all ages. Care and experience are needed in selecting the most suitable type of epoxy for each repair job. The slant shear test is the best test to measure the performance of epoxy since failure occurs along the repair plane, while in the split test failure occurs in the concrete at low ages.

Acknowledgments

Kuwait University is gratefully acknowledged for its support of this research through Grant EV-064.

References

[1] G.W. Geymayr, Repair of concrete in tropical marine environment, Proceedings of the Performance of Concrete in Marine Environment Conference, CANMET, St. Andrews, NB, Canada, 1980.

[2] T.K. Jadkowski, E.A. Wiltsie, Biodeterioration of concrete piling in the Arabian Gulf, Proceedings of the 4th Middle East Oil Show, Man-

ama, Bahrain, published by Soc. of Petroleum Engineers of AIME, Richardson, TX, USA, 1985.
[3] I.A. Basunbul, A.A. Gulati, G.J. Al-Sulaimani, M. Baluch, Repaired reinforced concrete beams, ACI Materials J 87 (4) (1990) 348–354.
[4] L.I. Knab, C.B. Spring, Evaluation of test methods for measuring the bond strength of Portland cement based repair materials to concrete, Cement, Concrete and Aggregates, CCA GDP 11 (1) (1989) 3–14.
[5] F. Al-Awadhi, A study of the composition of marine bitterns using atomic absorption, MS and neutron activation, Ph.D. Thesis, Victoria University of Manchester, UK, 1974.
[6] M.M. El-Hawary, H. Al-Khaiat, S. Fereig, Effect of sea water on epoxy-repaired concrete, Cement and Concrete Composites Journal 20 (1998) 41–51.