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Effect of Sea Water on Epoxy-repaired Concrete

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Abstract

Due to the Gulf War and the harsh environment in Kuwait, many concrete structures have been damaged and consequently repaired using epoxy resins. Some of these repaired buildings are close to the Gulf waterfront and were therefore exposed to sea water. The effect of sea water, at different temperatures, on the epoxy-repaired concrete has been investigated. Two different types of cement, ordinary and sulphate resistant, three different types of epoxy resins available in Kuwait, and different time durations of exposure to sea water at different temperature stations, were investigated. The effect of weather has also been studied, by keeping specimens immersed in tanks full of sea water in the open air for different time durations. Control specimens were also kept in sea water tanks which were put in an oven for different time durations and temperatures. Specimens were tested in compression, tension, flexure and shear-bond. The results presented should help in understanding the expected behavior of epoxy-repaired concrete in Kuwait and other similar marine environments. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: Concrete repair, epoxy resins, resistance to sea water, weathering resistance, engineering properties, marine environment.

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INTRODUCTION

The use of epoxy resins in the building industry is increasing rapidly. The advantages of epoxies include adhesion, versatility, chemical resistance, low shrinkage, rapid hardening and moisture resistance.[1] Epoxies may be used in a wide range of applications in the building industry.[2] They may be used as protective coatings to protect concrete against severe environments, as decorative coatings, as skid-resistant coatings, as grouting and repair materials, as adhesives for cementing various materials to hardened concrete, and as a bonding medium between fresh and hardened concrete. They may also be used as the binder in epoxy mortars or polymer concretes[3], which are used in repair or to construct layers or sections in reinforced concrete structures with higher ductility. Epoxies are also used in producing epoxy-modified concrete and in protecting reinforcing bars against corrosion.[4]

The use of epoxy resins in the repair of concrete members depends on the size of the crack.[5] Epoxy may be applied by injection for very small cracks, by grouting and pumping for moderate cracks, and as epoxy mortar for large cracks. The repaired members are usually subjected to the same environment and loading conditions that caused cracking in the first place. The performance of repaired concrete, therefore, is of major interest.[6]

The research presented in this paper is limited to the behavior of concrete samples repaired using epoxy mortars in the Kuwaiti environment. As the types of epoxies produced by different manufacturers are increasing in the Kuwaiti market, and as most of these types are manufactured and tested in countries where weather conditions are different than those in Kuwait, the evaluation of the performance of concrete samples repaired using different types of epoxy mortars has become essential for the Kuwaiti engineer.

The major characteristic of the environment in Kuwait City is that it is a hot marine environment. The temperature in Kuwait exceeds 50°C in the summer shade, and the structures are subjected to sea water either directly for structures close to the Arabian Gulf front, through ground-water, or due to the water-laden atmosphere for structures a few kilometers in land, depending on the humidity, direction and speed of wind. The behavior of epoxy-repaired concrete samples subjected to sea water at different temperatures is the main objective of this study. The investigated variables include the type of cement, type of epoxy, duration of exposure to sea water and the temperature of sea water.

RESEARCH PLAN AND PROCEDURE

Concrete mix

The material proportions of the used mix are 1:2:3 (cement: sand: gravel) with a water/cement ratio of 0.6. This high w/c ratio is common in small and medium size projects, that usually require repair during use. Quartzite aggregates were used along with two different types of cement, namely ordinary and sulphate resistant cement (type I [ASTM C150-92] and type V [ASTM C150-92]). The cements are manufactured in kuwait. The Tricalcium Aluminate (C_3A) was found to be 8.2% and 1.92% in type I and type V produced cements, respectively.

Epoxy types

Three different types of epoxy resins, produced by three different manufacturers, were utilized in this study. The materials are based on solvent-free epoxy resins containing pigments and fine fillers. They are delivered as base and hardener in prepacked, preweighed containers. The ratio of the base to hardener to filler was found to be 1.62:0.55:2.84.The containers were mixed together for about 5 min. The epoxy mortar was prepared as recommended by the manufacturers and as practised in industry. The three types of epoxy are available in the Kuwaiti market and are recommended by the manufacturers in repair work and in bonding hardened concrete to hardened concrete. They all comply with ASTM C881-90 for type IV epoxy mortars. Concrete surfaces were cleaned using an air gun, and the epoxy mortars were applied on both halves of each specimen. The specimens were then compressed by hand and the excess mortar was removed. The average thickness of the repair mortar was found to be 4 mm.

Sample preparation

Different types of specimens were cast, cured under water for 28 days, dried in air, and then epoxy mortars were applied as follows:

- For flexure testing, standard beams of size 150 × 150 × 750 mm were used. The clear span of each beam is 450 mm. The beams were loaded to failure in flexure (two point loading, ASTM C78) and then repaired with epoxy.
- For tensile splitting testing, standard cylinders of 150 mm in diameter and 300 mm in height were used. The cylinders were loaded in tensile splitting test mode to failure (ASTM C496) and then repaired with epoxy.
- For compressive testing (ASTM C39), standard cylinders of the same size as those used in tensile strength testing were used. The cylinders were saw cut, horizontally, and then repaired with epoxy.
- For shear-bond testing, slant shear bond specimens (ASTM C882) were used.[7] Cylinders of 152.4 mm in height and 76.2 mm in diameter were cast in halves with an inclination line of 30°. A dummy half was prepared, inserted in the cylinder mould and then concrete was poured over it, vertically, to cast the other half. The moulds were then vibrated on a vibrating table. Specimens were cured under water, and dried, and then each pair of halves were assembled and bonded using epoxy.

Some samples were cast in full size for comparison.

Procedure

The required specimens were 300 cylinders, 192 bond test specimens and 108 beams. The specimens were divided into the following four groups.

Group I

The specimens in this group were immersed in tanks full of sea water, and the tanks were then put in an oven. Two different temperature stations were used, 60° and 80°C. At 80°C the specimens were kept for time durations of 1, 3, 6 and 12 months, while at 60°C the specimens were kept for 1, 3 and 6 months. Investigating the behavior for temperatures below 60°C does not require an oven. These results are included in group III. The 80°C station represents an upper limit, and any temperature above that is unrealistic. The number of time stations was limited by the duration of the project, and the

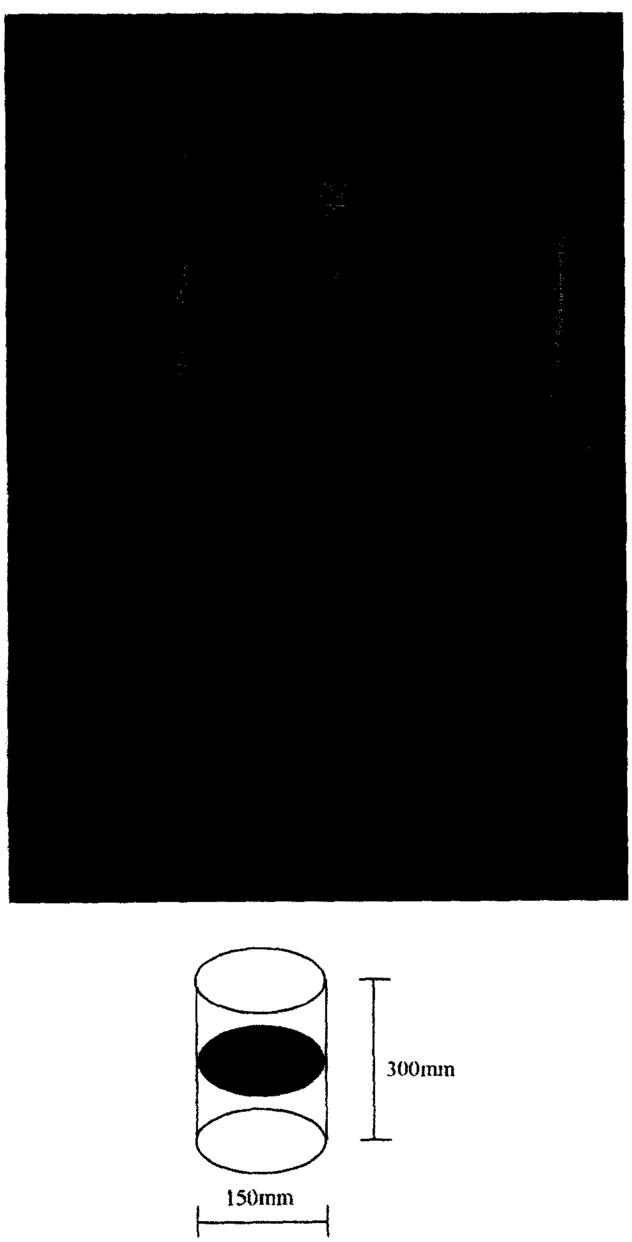


Fig. 1. Compression test.

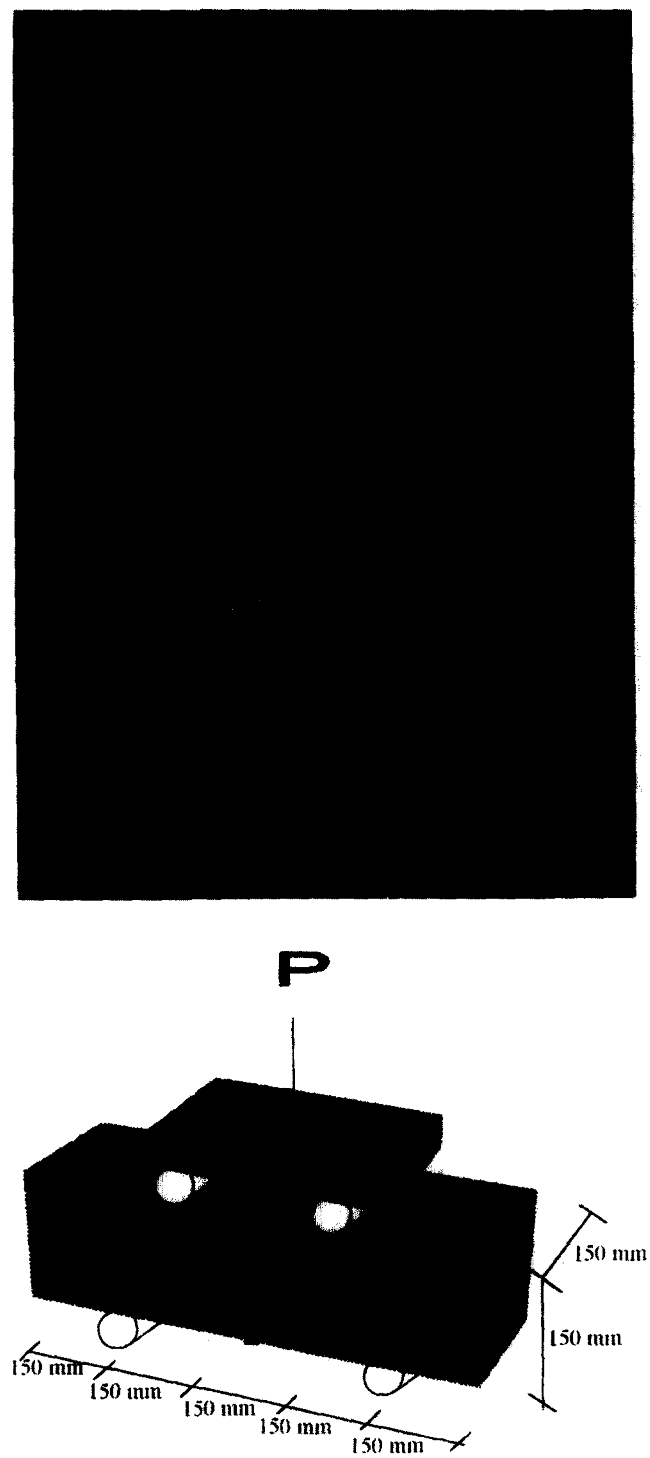


Fig. 2. Flexure test.

capacity and availability of space in the oven. As the 80°C station represents an upper limit, four time stations were used, while three were used for the 60°C station. The behavior at any other time can be predicted by interpolation or extrapolation. The specimens in this group were limited to repaired cylinders, prepared by splitting and bond test specimens.

Group II

The specimens in this group were immersed in tanks full of sea water, and the tanks were kept in the open air to follow the effect of temperature variations in the Kuwaiti environment. The specimens were kept for time durations of 6, 12 and 18 months and, as before, the behavior at any other time duration could then be produced by interpolation. All four types of test specimens were included in this group.

Group III

The specimens in this group were immersed in sea water tanks, and then kept in the laboratory (at room temperature) for time durations of 1, 3, 6, 12 and 18 months. As the room temperature is almost fixed, this group could be considered a continuation of the first group, and could be used along with the first group to predict the behavior at any other temperature by interpolation. Some cylinders in this group will be kept in tanks for long time monitoring. All four types of specimens were included in this group.

Group IV

This is the control group. Specimens in this group were not subjected to either sea water or higher temperatures. This group was tested shortly after repair, at room temperature.

TESTING

The testing of specimens was performed through visual observation for cracks or apparent deterioration, and testing for the strength through the standard tests. The saw cut cylinders were tested in compression (Fig. 1), beams were tested in flexure (Fig. 2), cylinders prepared by splitting were tested through the split test along the epoxy-repaired section (Fig. 3) and the special cylinders were tested in compression to measure the bond strength (Fig. 4). Two specimens were tested for each group: temperature, time duration, type of cement and type of epoxy.

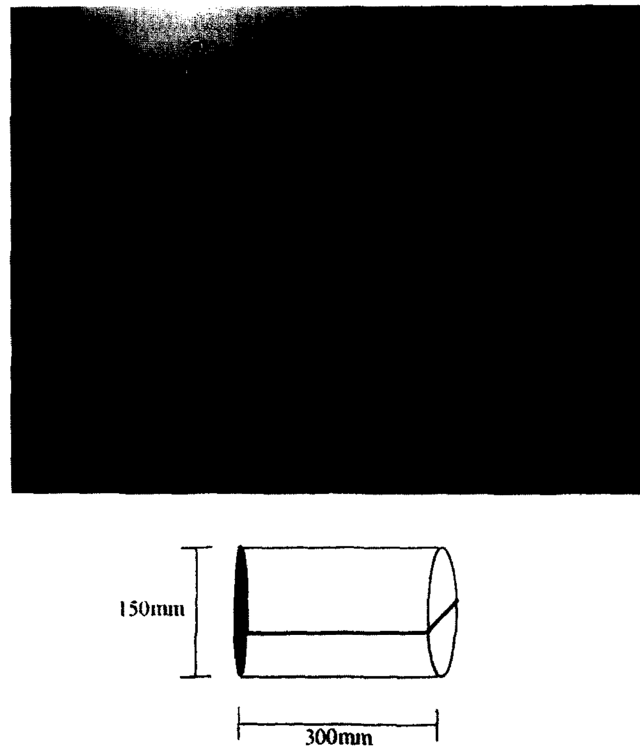


Fig. 3. Tension test.

RESULTS

Tensile strength

The variation of the split tensile strength with time for specimens repaired using the three types of epoxy and the two types of cement is shown in Fig. 5a for specimens kept in the laboratory (group III), Fig. 5b for specimens kept in the oven at 80°c (group I) and Fig. 5c for specimens at 60°c (group I). The average splitting tensile strength for all types of epoxy is shown versus time for ordinary and sulphate resistant cements in Fig. 6a and b respectively.

Compressive strength

The effect of immersing time on the compressive strength of repaired specimens is shown for specimens stored in the lab (group III) and for those in the open air (group II) in Fig. 7a and b, respectively. Its effect on the average com-

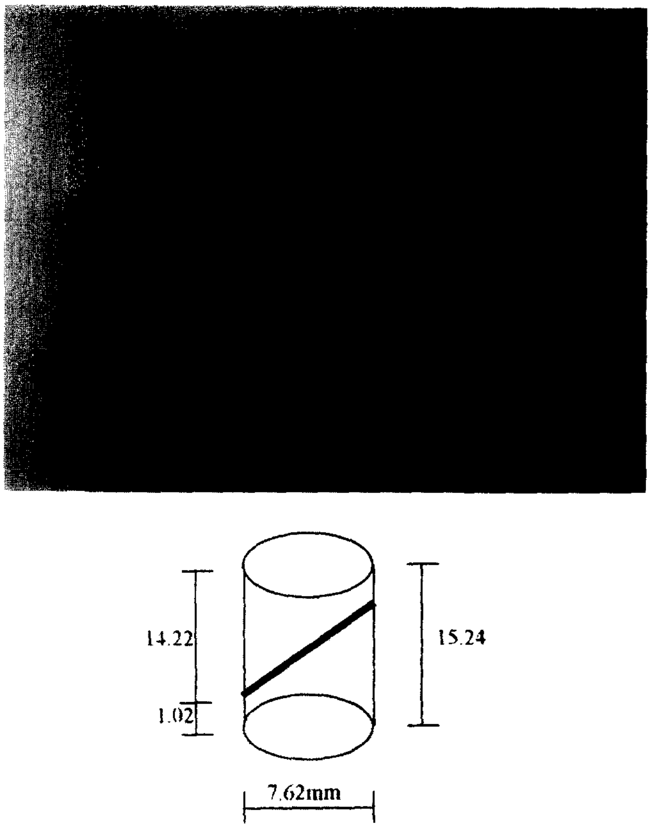


Fig. 4. Shear-bond test.

pressive strength for the three types of epoxy is shown in Fig. 7c.

Flexural strength

The modulus of rupture for all types of epoxies and cements is shown against time for specimens kept in the lab (group III) and the open air (group II) in Fig. 8a and b, respectively, and the average modulus of rupture is shown in Fig. 8c.

Bond strength

The bond strength is shown versus time for specimens kept in the lab (group III), specimens kept in the oven at 80°c (group I), and specimens at 60°c (group I), in Fig. 9a, b and c, respectively. The average bond strength for ordinary cement and sulphate resistant cement is shown in Fig. 10a and b, respectively.

DISCUSSION

In split tensile strength and flexural strength testing, almost all the specimens subjected to sea water for time durations of 0 and 1 month failed away from the plane of repair. At 3 and 6 months, some of the specimens failed along the repair planes. For the specimens subjected to sea water for 1 year, most of them failed along the plane of repair. This means that the deterioration in epoxy, due to sea water, is more rapid than that in concrete.

For specimens tested in bond, however, almost all the specimens at all time durations failed along the plane of repair, which means that bond test is an actual test for epoxy mortar. For the crushing failure of specimens tested in compression, there was no visible plane of failure.

A drop in strength was noticed, in general, for all four types of test methods, followed by an increase in strength. This initial drop may be due to the effect of the crystallization of some salts as specimens were allowed to dry for a day before testing. The following increase in strength may be due to hydration of cement under water.

The difference in strength between the specimens repaired using different types of epoxy is apparent. In general, type 3 gives better results for split and flexural testing and type 2 is better in bond specimens. The discrepancies between specimens prepared using different types of epoxy increase with the increase in time duration of sea water exposure. The difference in strength reached 37.6% for the split test, 20.9% for the compression test, 31.8% for the flexural test and 86% for the bond test for the ordinary portland cement specimens and 38.8%, 31.2%, 27.1% and 77.7% respectively, for the corresponding tests using sulphate resistant cement. In general, specimens cast using ordinary portland cement gave higher strength than those cast using sulphate resistant cement.

For specimens subjected to sea water at different temperatures, the deterioration of specimens increases with temperature. The tensile and bond strength after 6 months of sea water exposure are higher for 20°C than 60°C and the latter is higher than those at 80°C exposure, as seen in Fig. 6a and Fig. 10a.

CONCLUSIONS

The behavior of epoxy repaired concrete specimens immersed in sea water has been investigated. Three types of epoxy available in

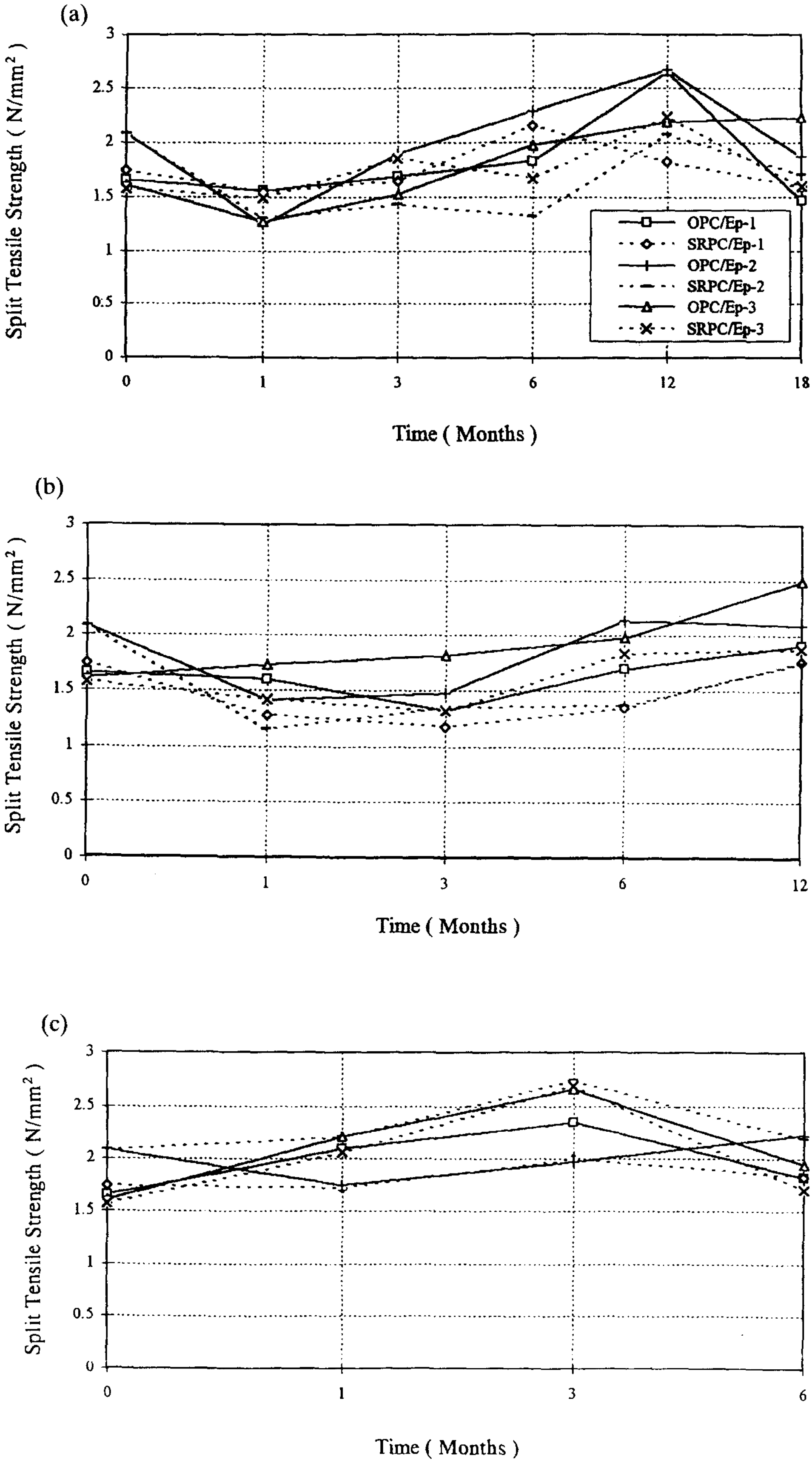


Fig. 5. Split tensile strength versus time for specimens kept in sea water. (a) Specimens kept in the laboratory. (b) Specimens kept in an oven at 80°C. (c) Specimens kept in an oven at 60°C.

Kuwait were used, along with two types of cements, namely ordinary and sulphate resistant cements. The split tensile strength, compressive strength, flexural strength and bond strength were determined for different time durations and temperatures. The investigation showed that:

- Failure of specimens in split or flexure is governed by the strength of concrete for low exposure durations. For longer durations (more than 6 months) the failure occurs in epoxy, which means that deterioration of epoxy is faster than concrete. For bond test, however, failure occurs in epoxy at all durations studied.
- Large variations in strength of specimens repaired using different types of epoxy were observed. However, no single epoxy type gave good results in all tests, which suggests that larger factors of safety should be utilized with any type of epoxy.
- A drop in strength due to salt crystallization, followed by an increase due to cement hydration, was the general trend for behavior of specimens with time. A

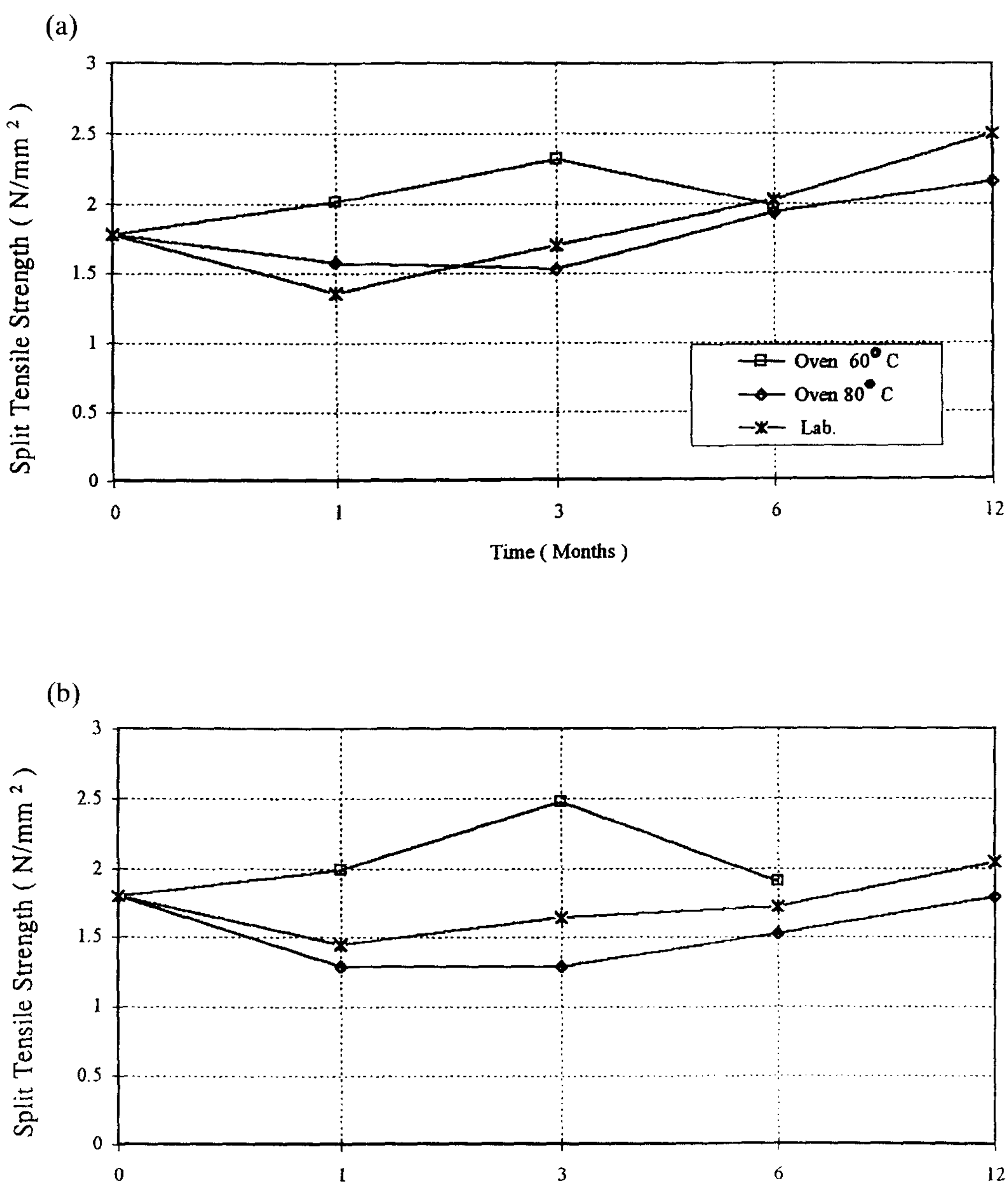


Fig. 6. Average split tensile strength versus time for specimens kept in sea water. (a) Ordinary Portland cement. (b) Sulphate resistant Portland cement specimens.

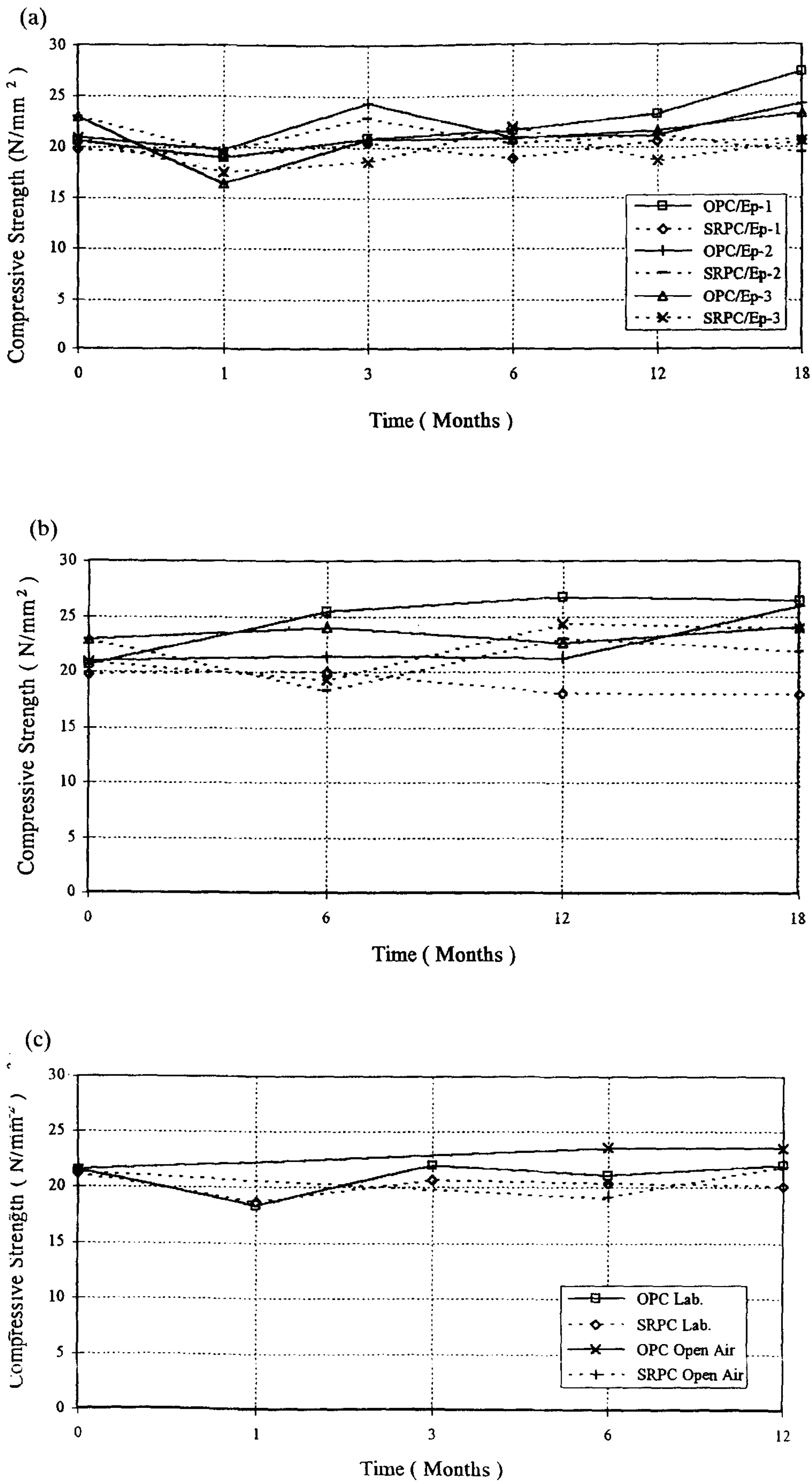


Fig. 7. Compressive strength versus time for specimens kept in sea water. (a) Specimens kept in the laboratory. (b) Specimens kept in the open air. (c) Average compressive strength for specimens kept in the laboratory and in the open air.

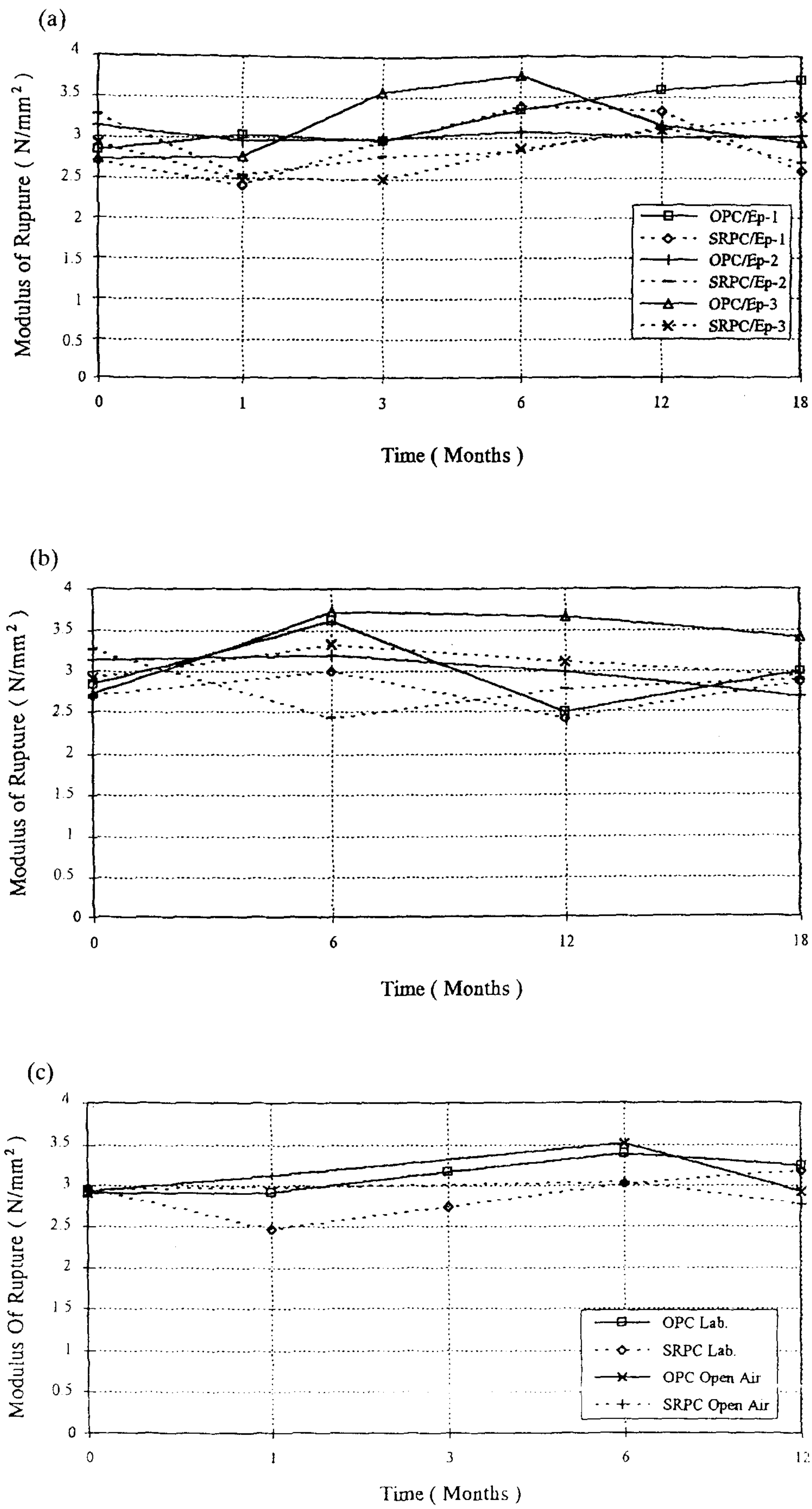


Fig. 8. Modulus of rupture versus time for specimens kept in sea water. (a) Specimens kept in the laboratory. (b) Specimens kept in the open air. (c) Average compressive strength for specimens kept in the laboratory and in the open air.

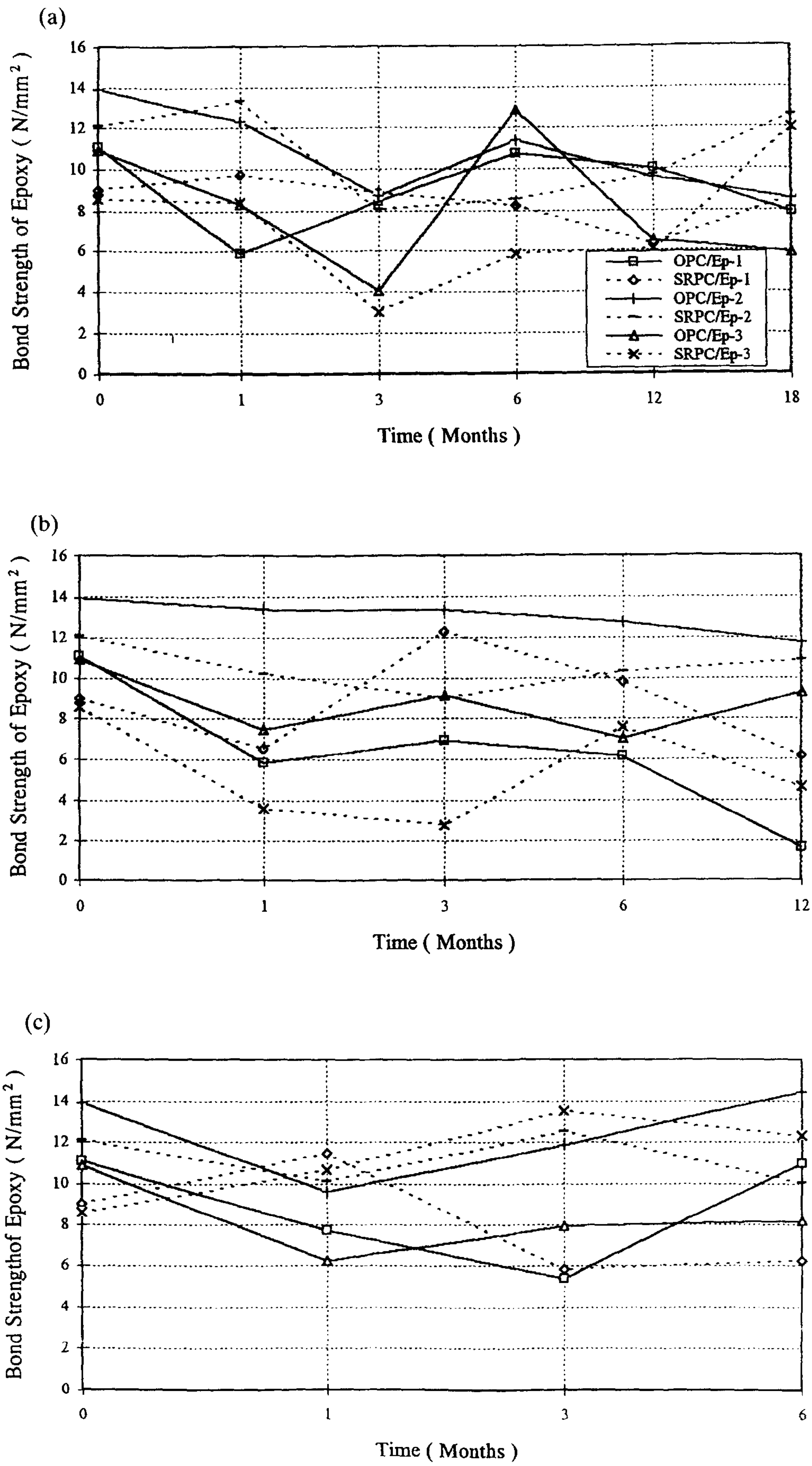
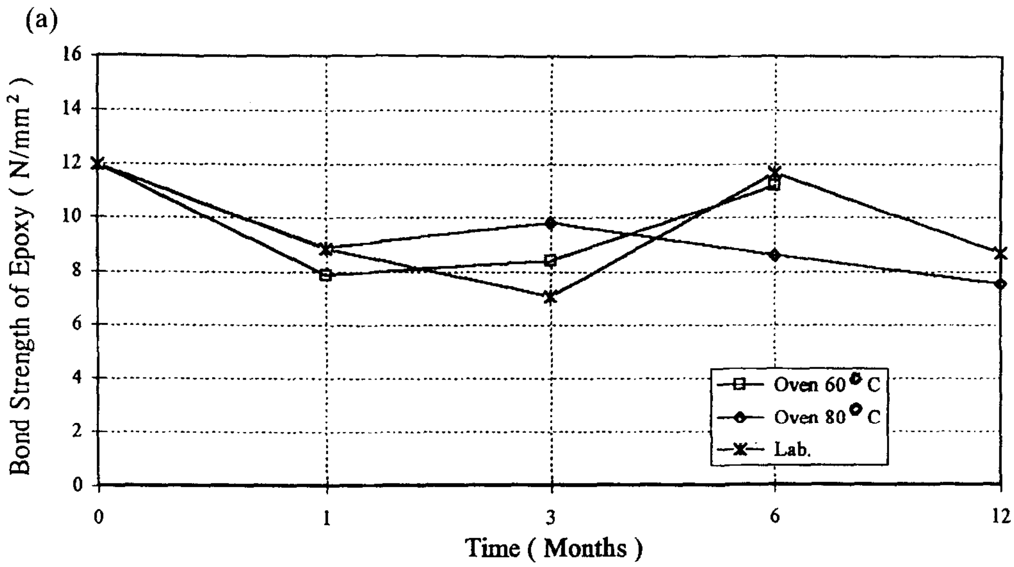


Fig. 9. Bond strength of Epoxy versus time for specimens kept in sea water. (a) Specimens kept in the laboratory. (b) Specimens kept in an oven at 80°C. (c) Specimens kept in an oven at 60°C.



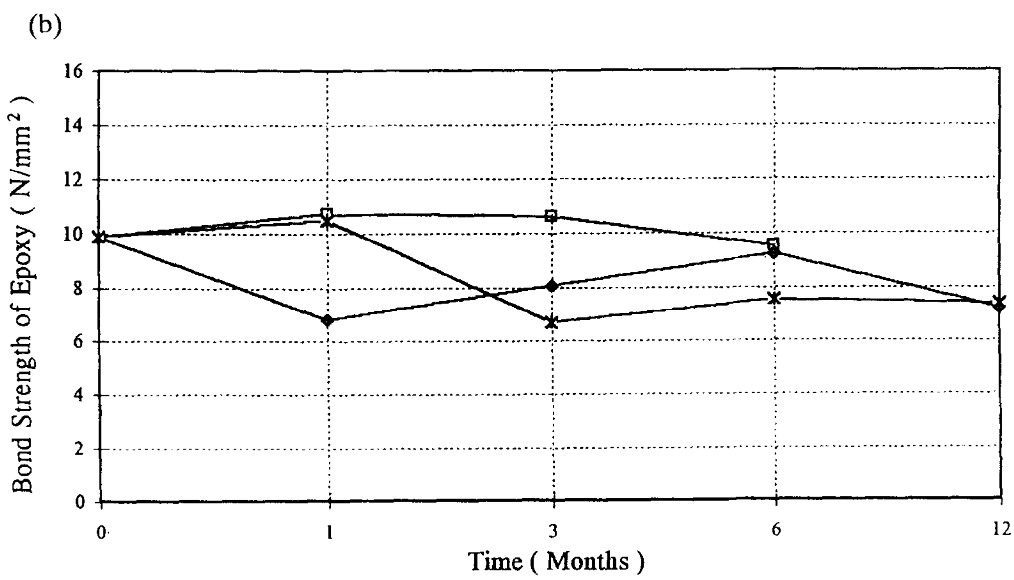


Fig. 10. Aver age bond strength versus time for specimens kept in sea water. (a) Ordinary Portland cement specimens. (b) Sulphate resistant Portland cement specimens.

reduction in strength was also observed for some specimens after a year of sea water exposure.

— Ordinary Portland cement specimens are, in general, superior to those cast using sulphate resistant cement.

— The increase in the temperature of sea water reduced the strength of specimens, which means that sea water exposure is more detrimental in hot weather.

ACKNOWLEDGEMENTS

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