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# DURABILITY OF STYRENE-BUTADIENE LATEX MODIFIED CONCRETE

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## ABSTRACT

The durability of reinforced concrete structures represents a major concern to many investigators. The use of latex modified concrete (LMC) in construction has urged researchers to review and investigate its different properties.

This study is part of a comprehensive investigation carried on the use of polymers in concrete. The main objective of this study to investigate and evaluate the main durability aspects of Styrene-Butadiene latex modified concrete (LMC) compared to those of conventional concrete. Also, the main microstructural characteristics of LMC were studied using a Scanning Electron Microscope (SEM).

The SEM investigation of the LMC showed major differences in its microstructure compared to that of the conventional concrete. The LMC proved to be superior in its durability compared to the durability of conventional concrete especially its water tightness (measured by water penetration, absorption, and sorptivity tests), abrasion, corrosion, and sulphate resistance. *© 1997 Elsevier Science Ltd*

## Introduction

The subject of concrete durability has been studied and investigated for the last 50 years. The importance of concrete structures durability issue arises from its economic effect (1). Mehta 1991 (1) reviewed the major publications on the subject during the last 50 years and pointed out the progress achieved in this field. Usually, the durability of concrete is associated with its quality, although the term quality is a very subjective one (Pomeroy 1987) (2). The difficulty in studying the durability of concrete structures may result from it being a dynamic property which depends on the continuous development of concrete microstructure (Mehta 1986, Basheer et al. 1994) (3,4).

The wide applications of LMC urges researchers to carry out extensive work in order to establish a good base for this development. On the other hand, comparison of test results obtained by different researchers is difficult. This could be attributed to the differences in the raw materials used (cement, aggregates, and latex), the mixture proportions, curing regimes, and the preparation of specimens and testing methods.

TABLE 1

Concrete Mixture Proportions and Properties

| | Conventional Concrete | LMC |
|---|---|---|
| **Mixture Proportions (kg/m³)** | | |
| **Cement** | 400 | 400 |
| **Gravel** | 1150 | 1150 |
| **Sand** | 550 | 550 |
| **Water (W/C)** | 150 (0.42) | 36 (0.09) |
| **P/C ratio*** | ---- | 15% |
| **Measured Slump (mm)** | 80 - 90 | 80 - 90 |
| **Density (kg/m³)** | 2480 | 2520 |
| **28 day Compressive Strength (MPa)**** | 38.7 | 40.8 |
| **28 day Indirect Tensile Strength (MPa)**** | 3.2 | 5.1 |

* P/C ratio represents the solid polymer to cement ratio by weight of the cement. The used polymer material constitutes 47% by weight of the used latex.

** The average of three test results.

This study is part of a comprehensive investigation carried on the use of polymers in concrete. The main objective of this study was to investigate and evaluate the main durability aspects of Styrene-Butadiene latex modified concrete (LMC) compared to those of conventional concrete. Also, the main microstructural characteristics of LMC are studied using a Scanning Electron Microscope.

## Experimental Program

2.1. Materials, Mixture Proportions and Curing. The materials used in this work were; natural siliceous sand (Suez region), natural gravel (Katamya-Cairo), Ordinary Portland Cement Type I, and tap drinking water. The polymer latex used was Styrene-Butadiene Rubber (SBR) from Fosroc-Egypt. The SBR is in a liquid state of low viscosity having a solids content of 47%, pH value of 11.0, and specific gravity of 1.0. A dosage of 15% solid latex material to cement by weight (P/C ratio) was found to be the optimum dose to be used (5,6). The polymer latex used was added to the mixing water and added to the mixed dry concrete ingredients, then mixing was completed for about 5 minutes. Table 1 shows the mixture proportions (based on dry masses of aggregates) and the properties of the fresh and hardened concrete for the mixtures used.

The air curing regime proved to be the most suitable regime for LMC (5,7,8). After being cast the LMC specimens were covered with wet burlap for 48 hours, then after being de-molded the specimens were air cured at 23°C and 50% R.H. until the test date. The conventional concrete was cured after being de-molded by complete immersion in water until the test date.

2.2. Testing of Specimens. The specimens used for the SEM were 90 days of age. The LMC and the conventional concrete were oven dried at 105°C for 24 hours, then they were cooled to room temperature in an air tight container. The specimens used for the investigation were obtained from the fracture surface of the concrete just before coating and placing the specimen into the microscope.

The specimens used for the water penetration test were prisms (20 × 20 × 10 cm). The specimens were tested according to DIN 1048 Part 1, 4.7 (9). The specimens were subjected to water under a specifed pressure for a fixed time period. The penetration depth was measured at several points and an average value was recorded.

The water absorption and sorptivity tests were carried out on concrete slices of thickness 5 cm cut from the middle of a cylindrical specimen of diameter 10 cm. The absorption test was carried out according to ASTM C462-90 (10), and the absorption percentage was calculated after 48 hours of immersion into the water. While the sorptivity test was carried out based on Hall's test (11), and the sorptivity (rate of absorption S mm/min$^{1/2}$) was calculated for a test interval of 25 minutes. The absorption and sorptivity tests required dry specimens. The drying process was carried out by oven drying at temperature 105°C until the weight of the specimens was constant.

The specimens used in the abrasion test were concrete prisms (5 × 5 × 4 cm). The specimens were tested according to ASTM C779-89a (12) using a revolving disk abrasion test machine. This test determines the relative abrasion resistance by measuring the weight and height loss due to abrasion.

The specimens for the corrosion resistance consisted of concrete cylinders (10 × 20 cm) in which a steel reinforcing bar (10 mm in diameter and about 25 cm in length) was embedded (the specimen is usually referred to as Lollipop specimen). The steel bar was embedded into the concrete cylinder such that its end is at least at 5 cm from the bottom of the cylinder. The corrosion resistance was measured using an accelerated corrosion cell (5,13). In this

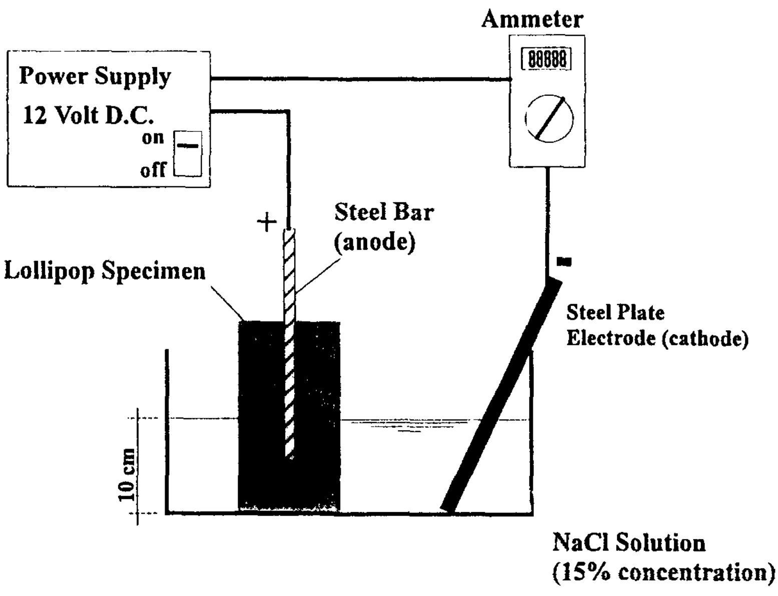


FIG. 1.
Schematic diagram of the accelerated corrosion cell (5,13).

cell, the specimen was immersed to its half height into a 15% sodium chloride (NaCl) solution at room temperature, and connected to a constant 12 volt D.C. power supply such that the steel bar acts as the anode. A steel plate electrode was used as the cathode. The steel plate was cleaned periodically to prevent the deposition of calcium on the surface. Figure 1 shows a schematic diagram of the corrosion cell. The current intensity showed sudden rise which indicates the cracking of the specimen by corrosion. So, in order to determine the time at which the specimen cracked (refereed to as corrosion time), the intensity of the electric current was recorded at different time intervals.

The sulphate resistance for the LMC and the conventional concrete was measured by the loss in the compressive strength due to immersion in sodium sulphate solution ($Na_2SO_4$) at different time intervals. The specimens used were cubes (10 × 10 × 10 cm) which were immersed in 5.0% $Na_2SO_4$ solution (the concentration was according to ASTM C1012-89 (14)). The specimens were immersed into the solution at 28 days of age.

The tests for water penetration, absorption, sorptivity, abrasion resistance and corrosion resistance were carried out at 28, 56 and 90 days of age. The sulphate resistance test was conducted at 1, 3, 6 and 12 months after immersion in the sulphate solution. The experiments were conducted on three replicates and the average of the three results is reported and used in the discussion of test results.

## Test Results and Discussion

3.1. Microstructure Features. The LMC is characterized by a dense microstructure compared to that of the conventional concrete. The polymer latex was observed to form a polymer film which is well dispersed throughout the cement matrix forming a dense network which is interwoven with the cement matrix as shown in Figure 2. Also, great reduction was observed in the size of the crystals formed throughout the polymer cement matrix, such as calcium hydroxide crystals, indicating a more dense microstructure than that of the conventional concrete.

The LMC was observed to have a pore size which is much smaller than that of the conventional concrete. Also, no crystal deposition, nor microcracks were found inside the pores. Most of the pores were found to be filled with the polymer latex. These characteristics

FIG. 2.
SEM micrograph of the LMC showing the interweaving between the polymer film and the cement matrix (X5000).

FIG. 3.
SEM micrograph of the conventional concrete showing the existence unbridged microcracks (X3000).

FIG. 4.
SEM micrograph of the LMC showing the bridging of the microcrack with the polymer films (X2000).

highly reduce the possibility of fluid permeation through the LMC and greatly increase its durability performance. While, crystal deposition and existence of microcracks inside the capillary pores of the conventional concrete indicates the large size of these pores and their interconnection, thus being responsible for the relatively higher permeation through the concrete and adversely affecting its durability.

The microcracks observed in the LMC were found to be bridged with the polymer film and also exhibited a smaller width compared to those microcracks found in the conventional concrete as shown in Figures 3 and 4.

Finally, observations of the transition zone of the LMC showed a lack of the well formed crystals of calcium hydroxide in the vicinity of the aggregate indicating a less porous zone, and thus overcoming the weakest link in the conventional concrete, as shown in Figure 5. Also, an obvious reduction of the fracture crack width in the aggregate-paste interfacial region as shown in Figure 5, associated to specimen preparation, indicates a well developed bond between the aggregate and the polymer-cement co-matrix. The polymer film seems to form a connecting phase between the aggregate and the cement matrix. This can be noticed

FIG. 5.
SEM micrograph of the LMC showing the aggregate-paste interfacial zone (X1000).

TABLE 2

Test Results of Water Penetration, Absorption and Sorptivity Tests at Different Test Ages for LMC and Conventional Concrete

| | Test Age (days) | Water Penetration (mm) | Absorption % | Sorptivity ($mm/min^{1/2}$) |
|---|---|---|---|---|
| LMC | 28 | 12 | 0.8 | 0.023 |
| | 56 | 8 | 0.6 | 0.014 |
| | 90 | 3 | 0.4 | 0.008 |
| Conventional Concrete | 28 | 26 | 4.3 | 0.284 |
| | 56 | 22 | 4.0 | 0.273 |
| | 90 | 20 | 3.8 | 0.239 |

in the increase in the tensile strength of the LMC (about 59.4%) over that of the conventional concrete.

3.2. Water Tightness. The water tightness of the LMC was superior to that of the conventional concrete as measured by the water penetration, absorption, and sorptivity tests. Table 2 gives the average test results at the different test ages. For the water penetration test the LMC showed higher resistance to water penetration, and this improvement was observed at all test ages and increased as the test age increases, as shown in Figure 6. The reduction in

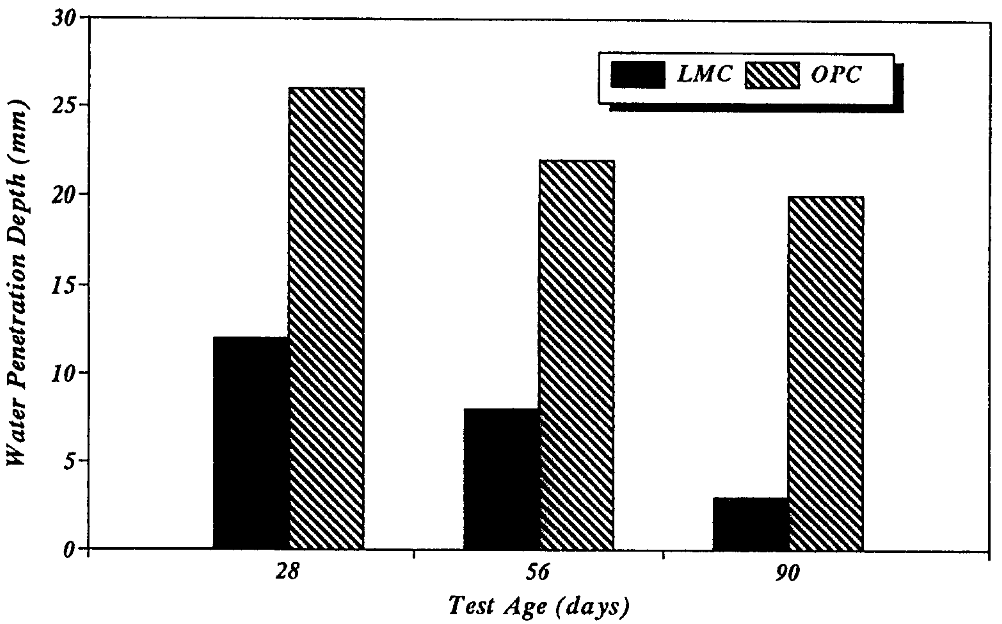


FIG. 6.
Water penetration depth at different test ages for LMC and conventional concrete.

TABLE 3

Dimensional and Weight Loss % at Different Test Ages for LMC and Conventional Concrete

| | Dimensional Loss % | | | Weight Loss % | | |
|---|---|---|---|---|---|---|
| | 28 days | 56 days | 90 days | 28 days | 56 days | 90 days |
| LMC | 14 | 13 | 10 | 1.6 | 1.4 | 1.0 |
| Conventional Concrete | 24 | 24 | 20 | 2.5 | 2.3 | 1.9 |

the water penetration depth was about 75% for the LMC, however, a reduction of about 23% was only recorded for the conventional concrete as test age increased from 28 days to 90 days.

The water absorption and sorptivity tests showed similar results to that of the water penetration depth. The reduction in the absorption test with test age was about 50%, while it was about 10% for the conventional concrete. Since the water absorption test was conducted under a very low water pressure, the water flow through the concrete mainly is dependent on the capillary suction and the connectivity of the pores. This could explain the high reduction in water absorption values of the LMC at all test ages compared to the conventional concrete.

The sorptivity test showed improvement in the water flow resistance through the conventional concrete as the test age increased. The LMC showed similar improvement but the results showed wide scatter especially at latter ages (56 and 90 days). The correlation coefficient for the relationship between the rate of absorption (in mm) and the square root of time ($min^{1/2}$) ranged between 0.89 to 0.96, according to Hall (11) the linear relationship is consid-

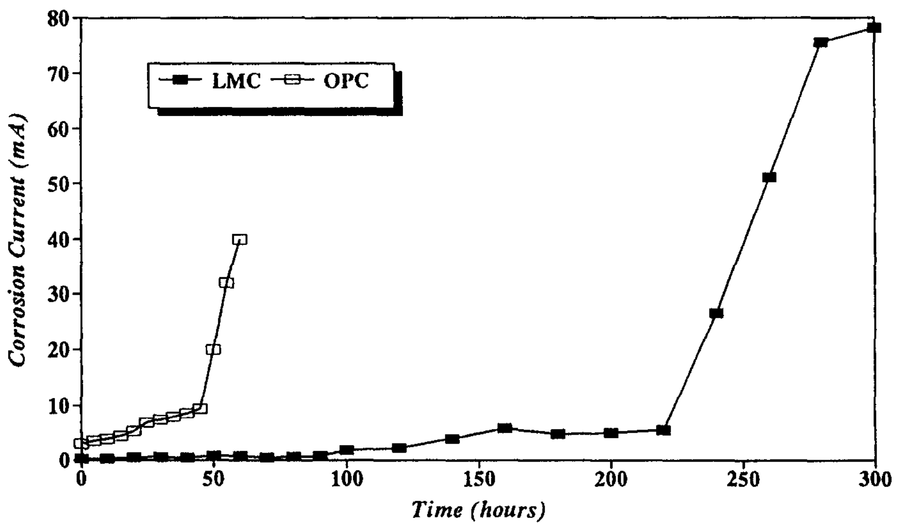


FIG. 7.
Typical curve of corrosion current with time at 28 days for LMC and conventional concrete.

TABLE 4

Corrosion Time at Different Test Ages for LMC and Conventional Concrete

| | Test Age (days) | | |
|---|---|---|---|
| | 28 | 56 | 90 |
| LMC | 230 | 245 | 285 |
| Conventional Concrete | 48 | 48 | 50 |

ered strong if the correlation coefficient is more than 0.98. The wide scatter in the test results for the LMC could be attributed to the short test time (25 minutes) used, as the LMC needs more time to be able to judge its capillary suction (15).

3.3. Abrasion Resistance. A general increase in the abrasion resistance of The LMC was observed compared to the conventional concrete. Table 3 gives the average results for the dimensional and the weight loss percentages at different test ages. The LMC showed a reduction ranging from 36% to 47% in weight loss at the different test ages with respect to the conventional concrete. Also, the LMC showed a reduction ranging from 41% to 50% in dimensional loss at different test ages with respect to the conventional concrete.

3.4. Corrosion Resistance. The LMC showed longer time to corrosion at all test ages compared to the conventional concrete. Figure 7 shows typical curves of corrosion current with time at 28 days of age for the LMC and the conventional concrete (OPC). Table 4 gives the average corrosion time for the LMC and the conventional concrete at different test ages. The increase in the corrosion time with test age was about 23.9% for the LMC, while it was only about 4.2% for the conventional concrete. The increase in corrosion time with test age indicates that LMC has a better protection to steel reinforcement against corrosion than conventional concrete, and this protection is enhanced with age.

TABLE 5

Compressive Strength (MPa) After Different Immersion Periods in Sulphate Solution for LMC and Conventional Concrete, and % Decrease in Compressive Strength

| Immersion Period (month) | LMC | | | Conventional Concrete | | |
|---|---|---|---|---|---|---|
| | Control | Immersed | % | Control | Immersed | % |
| 1 | 38.0 | 37.2 | 2.1 | 40.0 | 39.0 | 2.5 |
| 2 | 39.0 | 37.8 | 3.1 | 40.5 | 38.8 | 4.2 |
| 3 | 40.4 | 39.0 | 3.5 | 41.2 | 39.0 | 5.3 |
| 6 | 41.0 | 36.5 | 11.0 | 42.5 | 34.2 | 19.5 |
| 9 | 41.8 | 33.7 | 19.4 | 44.4 | 29.2 | 34.2 |
| 12 | 42.6 | 32.8 | 23.0 | 45.6 | 22.3 | 51.1 |

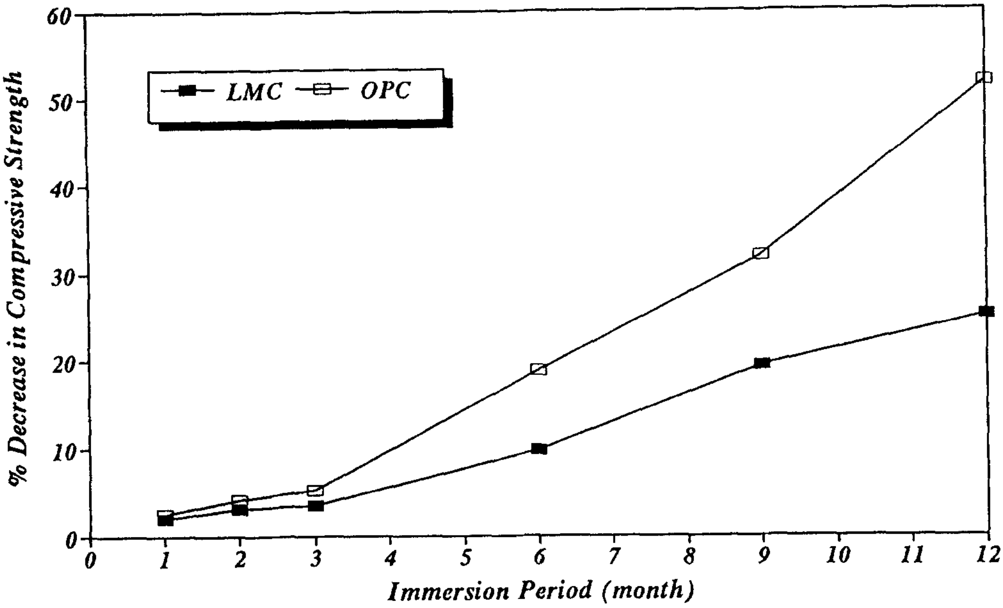


FIG. 8.
Percentage decrease in compressive strength after different immersion periods for LMC and conventional concrete.

The crack pattern observed, when the corrosion occurred, for the LMC was different than that for the conventional concrete. For the conventional concrete a fast longitudinal crack was observed, however for the LMC a slow curved multi-directional crack was observed. This difference in behaviour could be attributed to the higher tensile strength of the LMC and the better bond between the aggregate and the polymer-cement co-matrix (13).

3.5. Sulphate Resistance. The LMC showed a smaller decrease in the compressive strength after different immersion periods in the sulphate solution compared to the conventional concrete. This indicates that LMC has better sulphate resistance than that of the conventional concrete. Table 5 gives the compressive strength for LMC and conventional concrete after immersion in sulphate solution for different immersion periods compared to the control specimens of the same age. Figure 8 shows the percentage decrease in the compressive strength after different immersion periods for LMC and conventional concrete.

## Conclusions and Recommendations

From the test results and the analysis of the experimental work carried out in this study the following are the main conclusions and recommendations:

- LMC was found to have a dense microstructure, smaller discontinuous pores, less porous transition zone, better bond between the aggregate and the cement matrix, and bridged microcracks with respect to conventional concrete.
- The water tightness of the LMC is superior to that of the conventional concrete as measured by the water penetration, absorption and sorptivity tests. The effect of using longer sorptivity test time on the test results of the LMC requires further investigations.

- The LMC provides better protection to steel reinforcement against chloride induced corrosion in structures exposed to severe chloride environment such as bridge overlays.
- The resistance of LMC to abrasion, and sulphate solution were found to be much improved compared to those of the conventional concrete.
- The cost of producing LMC should not be compared to the cost of the production of conventional concrete on short run. Although, LMC has higher initial production cost it should be compared with the sum of the initial production cost of conventional concrete plus the cost of the expected repair works during the service life of the structures, especially those exposed to severe aggressive environment.
- More research work is required to investigate the effect of the sulphate attack on the LMC, and also the effect of using different cement types on the performance of the LMC.
- LMC offers many advantages for structures where durability is the main concern.

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