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# Durability of polymer-modified lightweight aggregate concrete

João A. Rossignolo *, Marcos V.C. Agnesini

*Department of Architecture and Urbanism, University of São Paulo, Av. Trabalhador Saocarlense 400, São Carlos-SP CEP 13560 583, Brazil*

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**Abstract**

The effects of styrene–butadiene rubber latex (SBR) modification on the durability of lightweight concrete (LWAC) were investigated. Corrosion resistance, chemical resistance and water absorption of SBR-modified LWAC were analyzed and compared with the unmodified LWAC. The 7-day compressive strength as well as the dry concrete density varied from 39.5 to 51.9 MPa and from 1460 to 1605 kg/m$^3$, respectively. The results of this study demonstrate that the performance of SBR-modified LWAC exposed to aggressive environments was better than unmodified one. SBR-modified LWAC led to lower water absorption and significant resistance improvement to chemical attack and corrosion.



*Keywords:* Lightweight aggregate concrete; Polymer; SBR; Durability

## 1. Introduction

Polymer-modified concrete (PMC) has been a popular construction material due to its excellent properties in comparison with ordinary concrete. It is produced using polymer in order to improve its workability, drying shrinkage, strength and durability [1–3]. Papers by Ohama [4] and Fowler [5] review developments and uses of polymer-modified concrete. However, there are a few studies about the use of polymer on lightweight aggregate concrete (LWAC).

On the other hand, there is worldwide environmental, economic and technical impetus to encourage the structural use of LWAC [6,7]. LWAC has been used successfully for structural purposes for many years. For structural applications of lightweight concrete, the structural efficiency is more important than only a consideration of strength. A decreased density for the same strength level reduces the self-weight, foundation size and construction costs. With the rapid development of concrete technology in recent years, higher performance concrete has been produced more easily. Since 1980, several investigations on high-performance lightweight concrete have been reported [8–11].

SBR-modified LWAC is an ideal material for precast components due to its low weight, high strength and high performance under severe service conditions. However, very little information is available on the properties of SBR-modified LWAC with Brazilian lightweight aggregate (rotary kiln expanded clay).

Accordingly, a pilot research project has been developed at the University of São Paulo (São Carlos Engineering School) to investigate the possibilities of producing thin precast concrete components using Brazilian lightweight aggregate (maximum size = 9.5 mm) [12,13]. To broaden the scope of this investigation, corrosion resistance, chemical resistance and water absorption of SBR-modified LWAC has been investigated and compared with unmodified LWAC. The present study is part of a comprehensive investigation carried out on the use of polymers in concrete. The 7-day compressive strength and the dry concrete density varied from 39.5 to 51.9 MPa and from 1460 to 1605 kg/m$^3$, respectively [14].

## 2. Materials

High-early-strength Portland cement (C) was used for the concrete mixes. The density and Blaine fineness of Portland cement were 3120 kg/m$^3$ and 4680 cm$^2$/g, respectively. The density, Blaine fineness and $SiO_2$ ratio of the silica fume (S) used were 2210 kg/m$^3$, 18,000 cm$^2$/g

* Corresponding author.
*E-mail address:* jarossig@hotmail.com (J.A. Rossignolo).

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Table 1
Physical properties of aggregates

| Type of aggregate | Maximum size (mm) | Density ($g/cm^3$) | Bulk density ($g/cm^3$) | Water absorption (% by mass) | | |
|---|---|---|---|---|---|---|
| | | | | 5 min | 60 min | 24 h |
| Sand | 2.4 | 2.63 | 1.49 | – | – | – |
| LWA[a] 1 | 4.8 | 1.51 | 0.86 | 0.7 | 2.7 | 6.0 |
| LWA 2 | 9.5 | 1.11 | 0.59 | 1.3 | 3.5 | 7.0 |

[a] LWA: lightweight aggregate.

and 94.3%, respectively. A natural quartz sand (NS) was used in combination with two types of Brazilian lightweight aggregate (rotary kiln expanded clay) to form the final aggregate. The nominal maximum aggregate size was 9.5 mm. Table 1 shows some physical properties of aggregates. A 'styrene–butadiene rubber' latex (SBR) with an antifoamer agent was used as a cement modifier. The density and total solids of SBR used was 1020 kg/$m^3$ and 50.0%, respectively. The density and total solids of the accelerating superplasticizer (SPA), sulfonated melamine formaldehyde, used were 1.11 $g/cm^3$ and 16.5%, respectively.

## 3. Experimental program

The mixture proportions and the properties of LWAC are shown in Tables 2 and 3, respectively [14]. The unit cement content varied from 440 to 710 kg/$m^3$. Silica fume was used in a dosage of 10% by mass of cement. The polymer–cement ratio (P/C) (as solid polymer content by mass of cement) of SBR-modified LWACs was 0%, 5% and 10%. The W/(C + S) ratio varied from 0.31 to 0.54, where W is the total water in the mixes. For all mixes the aggregate was composed (by mass) of 30% of natural sand, 35% of lightweight aggregate type 1 (LWA 1) and 35% of lightweight aggregate type 2 (LWA 2). All mixes had 1.5% of superplasticizer by mass of cement. The flow (NBR 7215—flow table) for all mixes was in the range of 200 ± 10 mm.

Table 2
Mix proportion of LWACs

| Mix no. | Mix proportions C:S:NS:LWA1:LWA2:SPA[a] (by mass) | P/C ratio[b] (% by mass) | W/(C + S)[c] |
|---|---|---|---|
| 1 | 1:0.1:0.27:0.315:0.315:0.015 | 0 | 0.37 |
| | | 5 | 0.33 |
| | | 10 | 0.31 |
| 2 | 1:0.1:0.35:0.403:0.403:0.015 | 0 | 0.41 |
| | | 5 | 0.36 |
| | | 10 | 0.34 |
| 3 | 1:0.1:0.42:0.490:0.490:0.015 | 0 | 0.45 |
| | | 5 | 0.39 |
| | | 10 | 0.36 |
| 4 | 1:0.1:0.50:0.578:0.578:0.015 | 0 | 0.49 |
| | | 5 | 0.41 |
| | | 10 | 0.38 |
| 5 | 1:0.1:0.57:0.665:0.665:0.015 | 0 | 0.54 |
| | | 5 | 0.46 |
| | | 10 | 0.41 |

[a] Cement:silica fume:natural sand:lightweight aggregate 1:lightweight aggregate 2:superplasticizer.
[b] Solid polymer content by mass of cement.
[c] Flow = 200 ± 10 mm.

Table 3
Properties of LWACs

| Mix no. | P/C ratio[a] (% by mass) | Unit cement content ($kg/m^3$) | Density oven dry ($kg/m^3$) | Compressive strength 7-day (MPa) | Tensile strength 7-day (MPa) |
|---|---|---|---|---|---|
| 1 | 0 | 710 | 1605 | 51.9 | 4.0 |
| | 5 | 706 | 1585 | 50.0 | 3.9 |
| | 10 | 687 | 1593 | 48.5 | 4.1 |
| 2 | 0 | 613 | 1573 | 48.8 | 3.7 |
| | 5 | 614 | 1554 | 46.5 | 3.8 |
| | 10 | 598 | 1565 | 45.2 | 4.0 |
| 3 | 0 | 544 | 1532 | 45.2 | 3.3 |
| | 5 | 542 | 1548 | 43.3 | 3.6 |
| | 10 | 541 | 1558 | 43.3 | 3.9 |
| 4 | 0 | 484 | 1482 | 42.7 | 3.0 |
| | 5 | 491 | 1520 | 41.9 | 3.5 |
| | 10 | 486 | 1527 | 41.2 | 3.8 |
| 5 | 0 | 440 | 1460 | 39.7 | 2.7 |
| | 5 | 442 | 1505 | 39.5 | 3.4 |
| | 10 | 440 | 1510 | 39.5 | 3.7 |

[a] Solid polymer content by mass of cement.

Materials were mixed in the following order: Firstly, half of the water, cement and sand (mixed for about 2 min); Secondly, remaining water, superplasticizer, SBR and silica fume—premixed—(mixed for about 2 min); and Thirdly, dry lightweight aggregate. Then the mixing continued until the uniform concrete had been obtained, usually for 5 min. This mixing method was based on a study reported by Rossignolo and Agnesini [14].

The specimens were cast in steel molds and compacted on a vibration table. After demolding at 24 h, the specimens of unmodified LWAC were stored in a control room maintained at 23 ± 2 °C and 95% (RH), until the day of the test. The specimens of SBR-modified

LWAC were stored for 1 day in a control room maintained at 23 ± 2 °C and 95% (RH) and subsequent air curing at 23 ± 2 °C and 60% (RH) until the day of test. 28-day-old specimens were used in all tests.

For the water absorption test (NBR 9778) the specimens (100 × 200-mm cylinders) were oven dried at 105 °C for 24 h and immersed in water at 23 °C. The specimens were removed from the water after 72 h and weighed in saturated surface dry condition.

The specimens for the corrosion resistance test consisted of concrete cylinders (100 × 200-mm) in which a steel reinforcing bar (10 mm of diameter and approximately 25 cm of length) was embedded (the specimens are usually referred to as Lollipop specimen). The steel bar was embedded in the concrete cylinder in such way that its end is at 5 cm from the bottom of the cylinder. The corrosion resistance was measured using an accelerated corrosion cell [15,16]. In this cell, the specimen was immersed to its half height in a 15% sodium chloride (NaCl) solution at room temperature and connected to a constant 12 V DC power supply so that the steel bar could act as the anode. A steel plate electrode was used as the cathode. The steel plate was cleaned periodically to prevent calcium deposition on the surface. Fig. 1 shows a schematic diagram of the corrosion cell. The current intensity showed a sudden rise indicating the cracking of the specimen by corrosion. Thus, in order to determine the time at which the specimen cracked (referred to as corrosion time), the intensity of the electric current was recorded at different time intervals and the specimens were monitored periodically by visual inspection.

The chemical resistance (ASTM C 267 96) was tested in 50 × 100-mm cylinders. The weight change of specimens immersed in six types of chemical solutions was measured: 20% sulphuric acid ($H_2SO_4$); 10% acetic acid ($CH_3COOH$); 10% chloridric acid (HCl); 10% sodium hydroxide (NaOH); 10% sodium hypochloride (NaClO); and 20% sodium chloride (NaCl). The weight change of specimens was examined after 1, 7, 14, 28, 56 and 84 days of immersion.

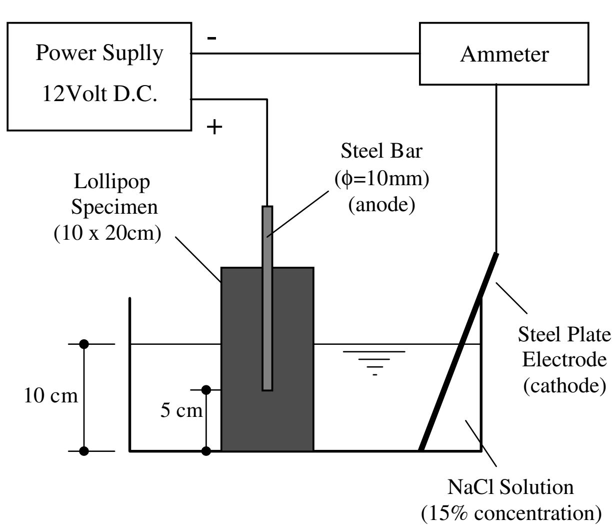


Fig. 1. Schematic diagram of the accelerated corrosion cell.

## 4. Results and discussion

### 4.1. Properties of fresh concrete

All LWAC used in this study was very cohesive and workable. However, the SBR-modified LWAC was more cohesive than the unmodified one, decreasing the possibility of lightweight aggregate segregation. Although the lightweight aggregates were used in dry state (without previous water saturation) the LWAC showed very good workability for approximately 1 h after mixing completion.

The inclusion of SBR in the LWAC mix reduced the water content, on average, by 13% at a polymer–cement ratio of 5% and 20% at a polymer–cement ratio of 10%.

### 4.2. Corrosion resistance

Figs. 2 and 3 show the curves of corrosion current versus time and average corrosion time, respectively, for unmodified and SBR-modified LWACs. Mixes 1, 3 and 5 of LWAC (Table 2) were analyzed. The corrosion time can be defined as the time from the start of the experiment to the instant when a sudden rise of the current (cracking of the specimen) is observed.

The SBR-modified LWAC showed a longer time for corrosion compared to the unmodified LWAC, which indicates that SBR-modified LWAC offers better protection to steel reinforcement against corrosion. The

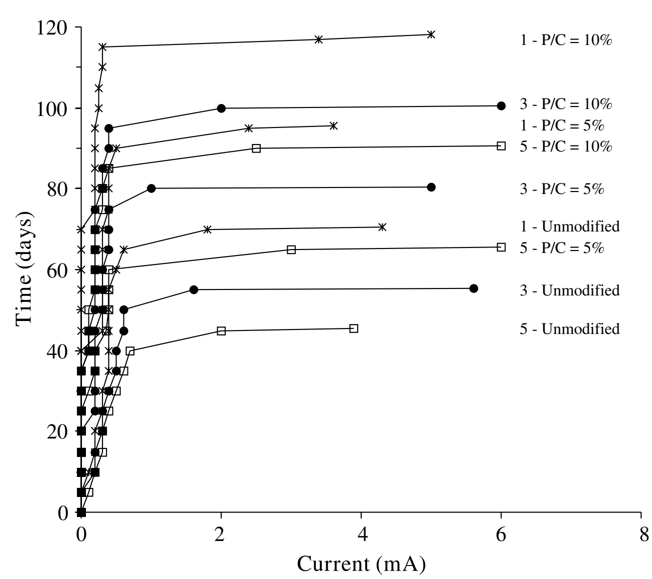


Fig. 2. Curve of corrosion current for LWACs.

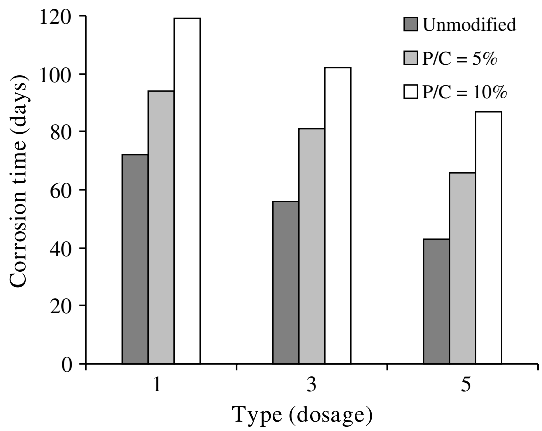


Fig. 3. Corrosion time of LWACs.

increase in the corrosion time was, on average, 45% at a polymer–cement ratio of 5% and 85% at a polymer–cement ratio of 10%. An increase in corrosion time with an increase in cement content was also observed.

The crack propagation was very different for both concretes. A fast longitudinal crack was observed for the unmodified LWAC, while a slow and curved multi-directional crack was observed for the SBR-modified LWAC. This could be attributed to the increase in the tensile strength of the SBR-modified LWAC compared to the one of the unmodified LWAC.

A decrease in the initial current intensity was observed for the SBR-modified LWAC compared to de unmodified LWAC, which indicates a higher electric resistivity for the SBR-modified LWAC.

### 4.3. Chemical resistance

The chemical attack was analyzed in mixes 1 and 5 of LWAC (Table 2). Figs. 4–6 show the effects of acid solutions attack, 20% sulphuric acid ($H_2SO_4$), 10% acetic acid ($CH_3COOH$) and 10% chloridric acid (HCl), respectively, in the loss weight of LWAC. The test of sulphuric acid attack was interrupted at 14 days because of high loss weight, about 35%. The loss weight of SBR-modified LWAC immersed in acid solutions was significantly lower than the one observed in unmodified LWAC. This indicates that SBR-modified LWAC offers better protection to acid attack compared to unmodified LWAC.

For the solutions of 10% sodium hydroxide (NaOH), 10% sodium hypochloride (NaClO) and 20% sodium chloride (NaCl) the loss weight of unmodified and SBR-modified LWAC at 84 days was lower than 1%.

### 4.4. Water absorption

Generally the water absorption was considerably high (over 10%) for the concrete with the lightweight aggregate investigated [17], but with the use of silica fume and superplasticizer this problem could be solved. In this study, unmodified LWAC with silica fume and superplasticizer provides a water absorption of 6.5% on average (Fig. 7).

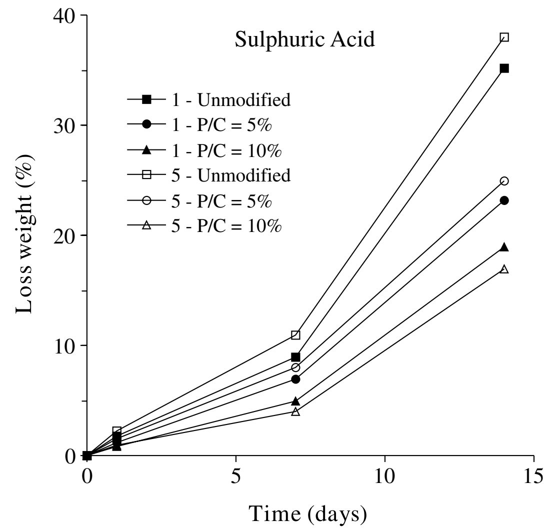


Fig. 4. Loss weight of LWAC by sulphuric acid attack.

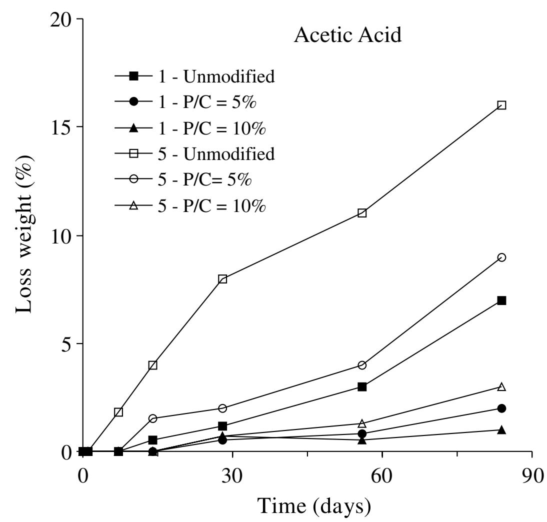


Fig. 5. Loss weight of LWAC by acetic acid attack.

However, there was a significant decrease in the water absorption with the inclusion of polymer in unmodified LWAC. The water absorption of SBR-modified LWAC was, on average, 3.7% at a polymer–cement ratio of 5% and 2.3 at a polymer–cement ratio of 10% (Fig. 7).

A decrease in the water absorption of SBR-modified LWACs is attributed mainly to a reduction in permeability caused by the reduction in W/(C + S). Such W/(C + S) reduction ultimately affects the gel–space ratio, and causes a reduction in the capillary porosity of the system, helping the pore maxima of pore size distribution

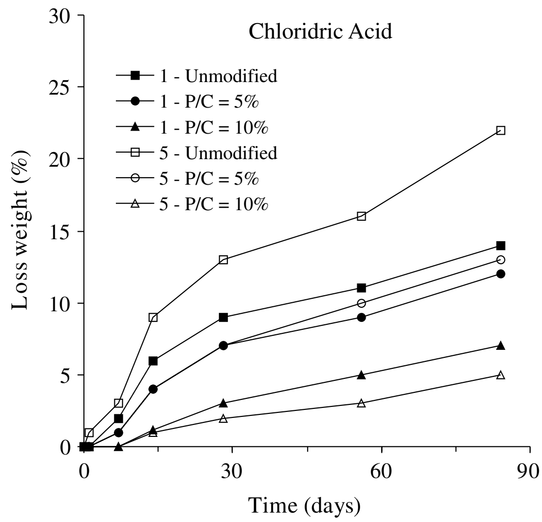


Fig. 6. Loss weight of LWAC by chloridric acid attack.

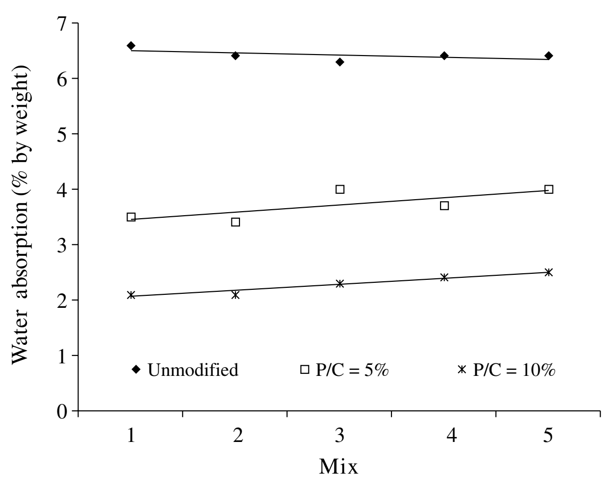


Fig. 7. Water absorption of LWAC.

range shift the pore of the finer porosity. Polymer films present in SBR-modified LWAC surfaces also contribute to a reduction in the water absorption.

## 5. Conclusions

The effects of SBR modification on the durability of LWAC were investigated. The test results indicate that SBR-modified LWAC shows a better performance in aggressive environments than the unmodified LWAC.

In the fresh state the LWACs with Brazilian lightweight aggregates were very cohesive and workable. Although lightweight aggregates were used in dry state, the lightweight concrete showed very good workability 1 h after the mixing completion. The inclusion of SBR reduced significantly the water content in the mix.

The SBR-modified LWAC has a much better corrosion resistance compared to the unmodified LWAC. The corrosion resistance of LWAC increases significantly with both the increase of SBR–cement ratio and the increase of cement content. This higher resistance offers a better protection to a steel reinforcement against corrosion and specially to the penetration of the chloride ions, which suggests the use of such LWAC in structures exposed to marine environments.

There was a significant decrease in the water absorption of LWAC with the inclusion of SBR. The water absorption decreases with increasing polymer–cement ratio.

The loss weight of SBR-modified LWAC immersed in acid solutions was significantly lower than the one observed in unmodified LWAC. This indicates that SBR-modified LWAC offers better protection to acid attack compared to unmodified LWAC. For the solutions of sodium hydroxide, sodium hypochloride and sodium chloride the loss weight of unmodified and SBR-modified LWAC at 84 days was lower than 1%.

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