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Mechanical properties of polymer-modified lightweight aggregate concrete

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Abstract

This paper deals with the properties of styrene–butadiene rubber (SBR)-modified lightweight aggregate concretes (LWACs) for thin precast components, made with two Brazilian lightweight aggregates (LWAs). Properties in the fresh state, compressive strength, splitting tensile strength, flexural strength, and water absorption of LWACs were tested. The 7-day compressive strength and the dry concrete density vary from 39.7 to 51.9 MPa and from 1460 to 1605 kg/m^3, respectively. The inclusion of SBR latex in LWACs decreases the water–(cement + silica fume) [W/(C + S)] ratio and water absorption and increases the splitting tensile and flexural strengths. The results of this pilot study suggest that there are possibilities of producing thin precast components using SBR-modified LWACs with Brazilian LWAs.

Keywords: Polymer-modified concretes; SBR latex; Lightweight aggregates; Mechanical properties

1. Introduction

Polymer-modified concrete (PMC) has been a popular construction material due to its excellent properties in comparison with ordinary concrete. Polymers are used in producing PMC in order to improve its workability, drying shrinkage, strength, and durability [1–3]. Recent papers by Ohama [4] and Fowler [5] review the recent developments and uses of PMC. 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, high-performance concrete has been produced more easily. Since 1980, several investigations on high-performance lightweight concrete have been reported [8–11].

LWAC is an ideal construction material in Brazil because of weather conditions and low costs. However, very little information is available on the properties of LWAC with Brazilian lightweight aggregate (LWA, expanded clay).

Accordingly, a pilot research project has been developed at University of São Paulo (São Carlos Engineering School, EESC) to investigate the possibilities of producing thin precast components using styrene–butadiene rubber

Table 1
Physical properties of aggregates

Type of aggregate	Maximum size (mm)	Density (g/cm^3)	Bulk density (g/cm^3)	Water absorption (mass%)		
				5 min	60 min	24 h
Sand	2.4	2.63	1.49	–	–	–
LWA 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

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Table 2
Mix proportions for SBR-modified LWACs

Mix number	Mix proportions C:S:NS:LWA 1:LWA 2:SPA[a] (by mass)	W/(C + S)[b] (Flow = 200 ± 10 mm)		
		P/C, 0%[c]	P/C, 5%[c]	P/C, 10%[c]
1	1:0.1:0.27:0.315:0.315:0.015	0.37	0.33	0.31
2	1:0.1:0.35:0.403:0.403:0.015	0.41	0.36	0.34
3	1:0.1:0.42:0.490:0.490:0.015	0.45	0.39	0.36
4	1:0.1:0.50:0.578:0.578:0.015	0.49	0.41	0.38
5	1:0.1:0.57:0.665:0.665:0.015	0.54	0.46	0.41

[a] Cement:silica fume:natural sand:lightweight aggregate Type 1:lightweight aggregate Type 2:superplasticizer.
[b] W is the total water in the mixes.
[c] Solid polymer content by mass of cement.

(SBR)-modified LWACs with Brazilian LWAs (maximum size = 9.5 mm) [12–14]. To broaden the scope of this investigation, the properties of five SBR-modified LWACs were investigated.

In this sense, the main objective of the present study is to provide some basic information on the properties of high-performance LWACs using Brazilian LWAs, natural sand, superplasticizer, silica fume, and SBR latex. Properties in the fresh state, compressive strength, splitting tensile strength, flexural strength, and water absorption of LWACs were tested.

2. Materials

High-early-strength Portland cement 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 content of the silica fume used were 2210 kg/m^3, 18000 cm^2/g, and 94.3%, respectively. A natural quartz sand was used in combination with two types of Brazilian LWAs (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. An SBR latex with an antifoamer was used as a polymeric admixture. The density and total solids of SBR latex used was 1.02 g/cm^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 method adopted for the design was experimental, and mix proportions for five SBR-modified LWACs are given in Table 2 [14]. The unit cement content varied from 440 to 710 kg/m^3. Silica fume was used in a dosage of 10 mass% of cement. The polymer–cement ratio (P/C, as solid polymer content by mass of cement) of SBR-modified LWACs was

Table 3
Properties in the fresh state

Mix number	P/C[a] (%)	Flow (mm)		W/(C + S)[b]	Water reduction (%)[c,d]	Unit cement content (kg/m^3)	Density (kg/m^3)	Air content (%)
		Initial	After 2h					
1	0	198	172	0.37	–	710	1717	2.3
	5	205	171	0.33	11	706	1704	3.0
	10	195	169	0.31	17	687	1679	4.0
2	0	203	184	0.41	–	613	1658	3.2
	5	195	164	0.36	12	614	1652	3.8
	10	200	173	0.34	17	598	1629	4.0
3	0	199	182	0.45	–	544	1633	2.5
	5	210	165	0.39	13	542	1615	4.0
	10	205	165	0.36	20	541	1618	3.8
4	0	198	164	0.49	–	484	1592	3.3
	5	197	158	0.41	16	491	1598	3.7
	10	208	160	0.38	22	486	1589	3.9
5	0	198	163	0.54	–	440	1583	2.5
	5	192	156	0.46	15	442	1570	3.9
	10	202	157	0.41	24	440	1562	4.4

[a] Solid polymer content by mass of cement.
[b] W is the total water in the mixes.
[c] Flow = 200 ± 10 mm.
[d] Water reduction=$[(W_{un} - W_{pol})/W_{un}] \times 100$, where W_{un} is the unit water content (kg/m^3) of unmodified LWAC, W_{pol} is the unit water content (kg/m^3) of SBR-modified LWAC.

Table 4
Compressive, tensile, and flexural strengths, and density

Mix number	P/C[a] (%)	Compressive strength (MPa)				Tensile strength (MPa)	Flexural strength (MPa)	Density in oven-dried condition (kg/m^3)
		1 day	7 days	28 days	63 days	7 days	7 days	
1	0	40.4	51.9	53.6	53.7	4.0	5.3	1605
	5	39.3	50.0	50.0	51.2	3.9	5.9	1585
	10	33.6	48.5	47.6	48.0	4.1	6.6	1593
2	0	36.5	48.8	50.0	51.2	3.7	5.0	1573
	5	36.0	46.5	47.3	48.4	3.8	5.5	1554
	10	35.6	45.2	45.2	46.5	4.0	5.8	1565
3	0	32.0	45.2	45.9	48.2	3.3	4.3	1532
	5	32.0	43.3	44.0	45.5	3.6	4.8	1548
	10	32.0	43.3	43.5	45.5	3.9	5.3	1558
4	0	28.8	42.7	43.0	46.2	3.0	3.8	1482
	5	30.1	41.9	42.9	43.2	3.5	4.6	1520
	10	30.1	41.2	42.0	44.3	3.8	4.9	1527
5	0	25.0	39.7	39.5	43.8	2.7	3.3	1460
	5	25.8	39.5	38.9	40.5	3.4	4.3	1505
	10	30.3	39.5	41.0	43.3	3.7	4.6	1510

[a] Solid polymer content by mass of cement.

0%, 5%, and 10%. The water–(cement + silica fume) [W/(C + S)] varied from 0.31 to 0.54, where W is the total water in the mixes. For all mixes, the aggregate fraction was composed (by mass) of 30% of natural sand, 35% of LWA Type 1 (LWA 1), and 35% of LWA Type 2 (LWA 2) [14]. All mixes had 1.5% of accelerating superplasticizer by mass of cement. The flow (NBR-7215, flow table) for all mixes was within 200 ± 10 mm.

The cylinder and prism specimens were cast with SBR-modified LWACs in steel molds, and compacted on a vibration table. After demolding at 24 h, the specimens of unmodified LWACs 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 LWACs 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.

Materials were mixed in the following this order: Firstly, half of the water, cement and sand were mixed for about 2 min; secondly, the remaining water, superplasticizer, SBR latex, and silica fume were premixed for about 2 min, and the premixed one was added to the water–cement–sand mixture; and thirdly, dry LWA was added to the water–cement–sand–superplasticizer–silica fume–SBR latex mixture. Then, the mixing continued until a uniform concrete had been obtained, usually for 5 min. This mixing method was based on a study reported by Rossignolo and Agnesini [15].

The compressive strength, splitting tensile strength, and water absorption were tested for 100 × 200-mm cylinder specimens, while the flexural strength was done for 150 × 150 × 500-mm prism specimens. All the tests followed the Technical Standards Brazilian Association ABNT-NBR. For the water absorption test, the specimens were oven-dried at 105 °C for 24 h, and immersed in water at 23 °C. The specimens were removed from the water, and weighed in saturated surface-dry condition after 72-h lapses.

As LWACs were designed for high-early-strength development, all tests were carried out at 7 days except for the compressive strength (at 1, 7, 28, and 63 days) and water absorption (at 28 days).

4. Results and discussion

4.1. Properties of fresh concrete

Table 3 shows the properties of fresh SBR-modified LWACs. All LWACs used in this study are very cohesive and workable. However, SBR-modified LWACs are more cohesive than unmodified LWACs, reducing the possibility of LWA segregation. The maximum and minimum values of the density of the fresh LWACs are 1717 and 1562 kg/m^3, respectively. Although the aggregates are used in dry state (without previous saturation), LWACs provide, on average, a flow loss of 28 mm in 2 h after the completion of mixing.

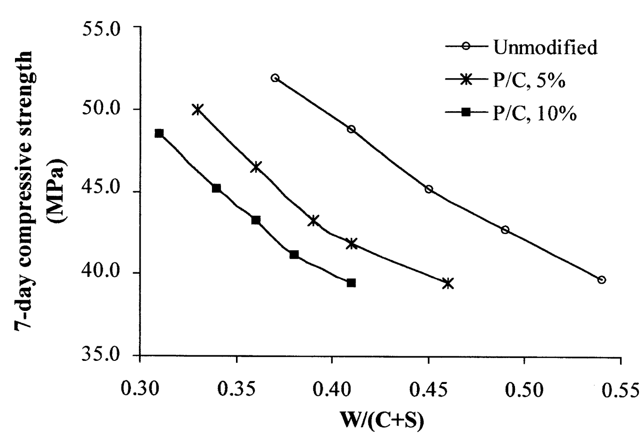

Fig. 1. Relationship between 7-day compressive strength and W/(C + S).

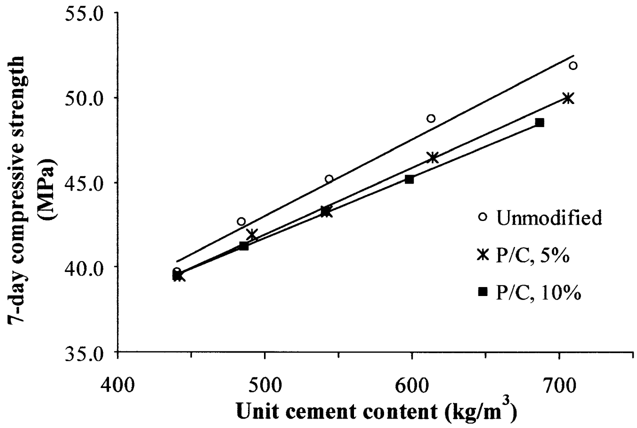

Fig. 2. Relationship between 7-day compressive strength and unit cement content.

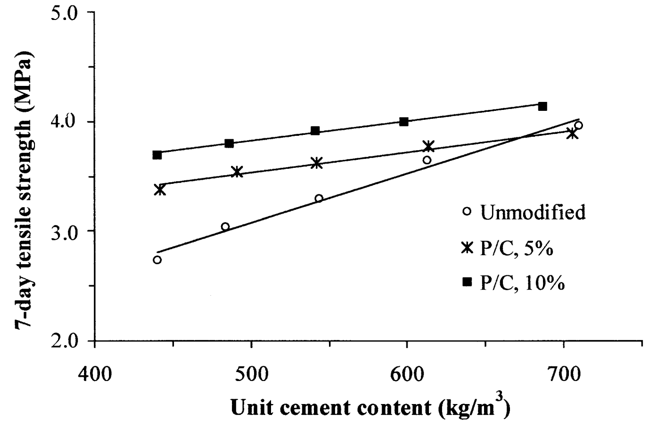

Fig. 4. Relationship between 7-day tensile strength and unit cement content.

The SBR-modified and unmodified LWACs show very good workability for approximately 1 h after the completion of mixing.

The inclusion of SBR latex in LWACs reduces the water content by 13% at a P/C of 5% and 20% at a P/C of 10%, on average. The air content of SBR-modified LWACs is 3.7% at a P/C of 5% and 4.0% at a P/C of 10%, on average, and is higher than that of the unmodified LWACs, 2.8% on average.

4.2. Compressive strength and density

The compressive, tensile, and flexural strengths, and density of SBR-modified LWACs are summarized in Table 4. The 7-day compressive strength and the density in oven-dried condition vary from 39.5 to 51.9 MPa and from 1460 to 1605 kg/m^3, respectively. If one takes the density of normal-weight concrete as 2300 kg/m^3, there is a saving in the self-weight between 30% and 37%.

All LWACs essentially stop strength development between ages of 7 and 63 days. This may be attributed to the use of the high-early-strength Portland cement and accelerating superplasticizer. In addition, it indicates that the compressive strength probably reaches an upper level for the aggregates, and the strength does not benefit very much from a further improvement in the matrix strength. This may be attributed to the influence of the LWAs.

The compressive strength of SBR-modified LWACs is slightly lower than unmodified LWACs. A decrease in the 7-day compressive strength is, on average, 3.0% at a P/C of 5% and 4.4% at a P/C of 10% (Table 4). This may be attributed to an increase in the air content of SBR-modified LWACs.

Fig. 1 shows the W/(C + S) vs. 7-day compressive strength of SBR-modified LWACs. Fig. 2 represents the unit cement content vs. 7-day compressive strength of SBR-modified LWACs. From this figure, it is found that the unit cement content of unmodified LWACs was slightly higher than that of SBR-modified LWACs for the same 7-day compressive strength level.

Fig. 3 shows the relationship between the 7-day structural efficiency (compressive strength/density ratio) [11,16] and unit cement content of SBR-modified LWACs. For comparison, a similar relationship for normal-weight concrete based on basalt aggregate, reported by Ferreira [17], is

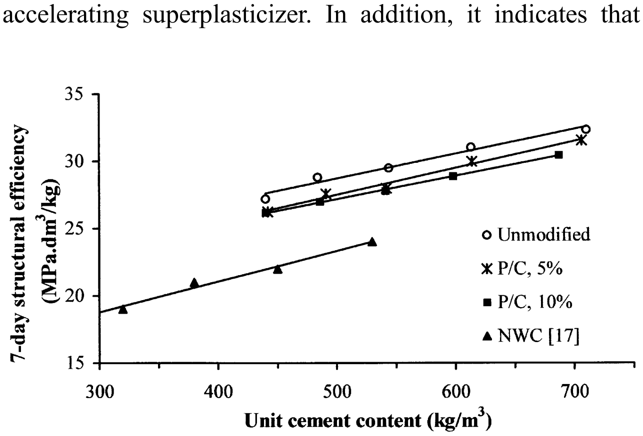

Fig. 3. Relationship between 7-day structural efficiency and unit cement content.

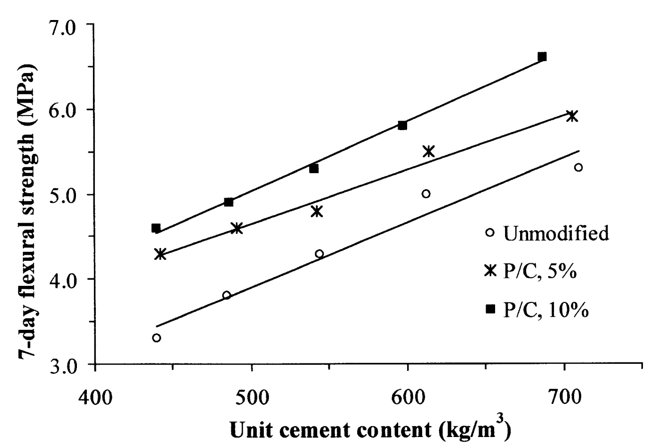

Fig. 5. Relationship between 7-day flexural strength and unit cement content.

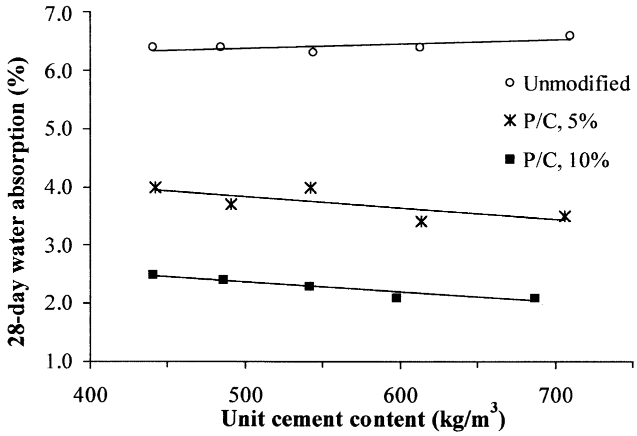

Fig. 6. Relationship between 28-day water absorption and unit cement content.

also included in the diagram. The results clearly demonstrate that SBR-modified and unmodified LWACs have high structural efficiency.

4.3. Tensile and flexural strengths

The tensile and flexural strengths of SBR-modified LWACs vary from 2.7 to 4.1 MPa and from 3.3. to 6.6 MPa, respectively, as seen in Table 4 and Figs. 4 and 5. SBR-modified LWACs show improvements in the tensile and flexural strengths. The tensile strength increase is, on average, 10% at a P/C of 5% and 18% at a P/C of 10%. The rate of the tensile strength increase at a unit cement content of 600–710 kg/m^3 is less pronounced than that at a unit cement content of 440–600 kg/m^3. The flexural strength increase is, on average, 16% at a P/C of 5% and 26% at a P/C of 10%.

Such superior properties are attributed mainly to an overall improvement in cement hydrate–aggregate bond because of a decrease in W/(C + S) and the high tensile strength of SBR films present in SBR-modified LWACs.

4.4. Water absorption

Generally, the water absorption is considerably high (over 10%) for the concrete with the LWA investigated [18], but with the use of silica fume and a superplasticizer, this problem could be solved. In this study, unmodified LWACs with the silica fume and superplasticizer provide a water absorption of 6.5% on average.

However, there is a significant decrease in the water absorption with the inclusion of SBR latex in unmodified LWACs. The water absorption of SBR-modified LWACs is, on average, 3.7% at a P/C of 5% and 2.3% at a P/C of 10%. Fig. 6 shows the relationship between the 28-day water absorption and unit cement content of SBR-modified LWACs.

A decrease in the water absorption of SBR-modified LWACs is attributed mainly to a reduction in permeability, caused by a 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 volume peak in pore size distribution shift the finer pore size range. Polymer films present in SBR-modified LWAC surfaces also contribute to a reduction in the water absorption.

5. Conclusions

In the fresh state, SBR-modified and unmodified LWACs with Brazilian LWAs are very cohesive and workable. Although the LWAs are used in the dry state, SBR-modified and unmodified LWACs show very good workability 1 h after the completion of mixing. The inclusion of SBR latex reduces significantly the water content of LWACs.

The compressive strength of SBR-modified LWACs is slightly lower than that of unmodified LWACs. This may be attributed to an increase in the air content of SBR-modified LWACs. However, SBR-modified LWACs show a high structural efficiency.

SBR-modified LWACs provide a significant improvement in the tensile and flexural strengths.

There is a significant decrease in the water absorption of unmodified LWACs with the inclusion of SBR latex. The water absorption of SBR-modified LWACs decreases with increasing P/C.

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