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Durability of concrete mixed with fine recycled aggregates

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In this paper, an analysis was conducted on the influence of the use of 20%, 50% and 100% contents of two types of fine recycled aggregates (from demolish concrete and from old masonry) on the following properties of concrete: water absorption by immersion, pore volume, carbonation and resistivity. This analysis was not restricted to compare mixtures from a table of results. All the analysis was based on concrete family behavior. The Mix Design Nomograms (MDN) was made for concrete families: one as reference and six others with different recycled contents to replace the natural fine aggregate. The MDN obtained for the properties studied permitted compare class 20MPa, 30MPa and 40MPa concretes. The results obtained indicate that the carbonation depth reached a minimum and the resistivity reached a maximum when 50% contents of fine recycled masonry aggregates were used. However, this tendency was not repeated for pore volume and water absorption. Thus, it should conclude that the durability like a carbonation and resistivity are physical-chemical phenomena that, in this case, were inversely related to water absorption and volume of pores.

Key words: Concretes. Durability. Fine recycled aggregates.

1 Introduction

At the present time, several research investigations can be found conducted in worldwide (SANTOS, 2007; ETXEBERRIA, 2006; COLLINS, 2000) supporting the production and the use of concrete with recycled aggregate from the technical and economic point of view.

This work was conducted with the aim of understanding the essential properties for predicting the behavior of concretes produced with recycled aggregates during your service life. The objective was a better understanding more about the durability of concretes prepared with recycled aggregates.

The use of fine recycled aggregates for producing concretes with structural purposes has been discussed worldwide, but many authors (VINCKE; ROUSSEAU, 1994; RILEM, 1994) recommend that such aggregates should not be utilized in structural concretes, due to their high water absorption.

This paper shows one analysis of the influence of recycled aggregates on the durability of concretes. To reach that answer 4 (four) properties were selected, such as water absorption, pore volume, carbonation and the resistivity properties intimately related to the durability of a concrete and, consequently, of a structure.

Wirquin, Zahaarieva and Hahdjeva (2000) reported that the processes of water absorption in recycled aggregate and in natural aggregate concretes are similar and obey the same laws. Also Mehta and Monteiro (1994) reported that the water, as a primary agent, is able to deteriorate natural and artificial materials, such as concrete.

Water, ions and gas penetrating the concrete porosity can also accelerate the concrete degradation kinetics during the service life of the structure.

2 Purpose

This work aims to analyze the influence of two types of fine aggregates, one from recycled concrete, and the other from recycled masonry on four (4) properties of concrete: water absorption, pore volume, carbonation and resistivity. These properties has directly influence in the durability of a concrete.

3 Materials and methods

To conduct this work, seven concrete families were prepared, three with fine recycled masonry aggregates, three with fine recycled concrete aggregates and a reference concrete with natural quartz river sand.

The proportions of the aggregates used in the preparation of the seven families are indicated in Table 1.

Table 1: Composition of the aggregates used in the preparation of the concretes

Concrete Family	Fine aggregates content
Reference	100% natural quartz river sand
FRCA* 20-80	20% FRCA - 80% natural quartz river sand
FRCA 50-50	50% FRCA - 50% natural quartz river sand
FRCA 100-0	100% FRCA - 0% natural quartz
FRMA** 20-80	20% FRMA - 80% natural quartz river sand
FRMA 50-50	50% FRMA - 50% natural quartz river sand
FRMA 100-0	100% FRMA - 0% natural quartz river sand

FRCA* fine recycled concrete aggregate

FRMA** fine recycled masonry aggregate

Source: The authors.

3.1 Materials

Blended Portland Cement, comprised of 35% blast furnace slag, with a Blaine fineness of 385m^2/kg, density of 2990kg/m^3 and compressive strength at 28 days of 49MPa (7105psi) was used in all concrete mixtures.

The fine natural aggregate used was natural washed quartz river sand, with a density of 2650kg/m^3, fineness modulus of 2.6, and water absorption of 1.8% at a saturated dry surface condition (SDS), according with ASTM C270.

The coarse natural aggregate used was crushed granite gravel, with a density of 2700kg/m^3, maximum size of 25mm, fineness modulus of 7.0, and 0.8% water absorption at a SDS. Both are usual and sound aggregates in the Sao Paulo city region.

The fine recycled concrete aggregate (FRCA) that were used had been obtained from crushing old concrete structures, six months old. These old concrete presented compressive strength of 25MPa, (3626psi) and water cement ratio W/C of 0.66. The FRCA had a density of 2320kg/m^3, maximum particle size of 2.4mm; fineness modulus of 2.5, and 10.3% water absorption at SDS.

The fine recycled masonry aggregate (FRMA) had been obtained from crushing one-year-old clay brick walls covered with bastard mortar (cement, calcium hydroxide and natural sand). The FRMA were composed of 76% clay brick, and 24% bastard mortar, by weight. The density was 1890kg/m^3, maximum particle size of 2.4mm, fineness modulus of 2.5, and 13.0% water absorption at SDS.

In order to obtain the recycled aggregates, the demolished old concrete and masonry were passed through a jaw crusher and the resulting product was later subjected to a sieving operation.

The fractions corresponding to fine and coarse aggregates were used to produce the six (6) recycled concrete families (see Table 1), always with the aggregates at SDS condition. The results were compared to those measured for a reference concrete family, produced exclusively with natural aggregates.

3.2 Concrete mix proportion

Three dry aggregate/cement ratios by mass were used to compose each concrete family: 3/1; 4.5/1 and 6/1. All mixtures had the same fresh workability measured by slump test (70 ± 10) mm, what means, these concretes has the workability enough for many applications like, for instance, columns in buildings. For each mixture the recycled aggregate replaced 0%, 20%, 50% and 100% of natural fine aggregates by mass. In this way, the total of seven concrete families and 21 different mix proportions were produced.

The main tests were performed beginning at 28 days. All specimens were cured in a standard humid chamber during their first 14 days; after that, they were kept exposed to laboratory ambient conditions (55% to 65% RH and 20° to 26° C).

3.3 Properties measured

The following properties were measured: compressive strength by ASTM C 39; water absorption and total pore volume by ASTM C 642; accelerated carbonation by RILEM CPC-18 method, and resistivity by ASTM G57. In addition, the cement content, water content, W/C ratio by mass, entrapped air, slump test and fresh concrete density were measured.

4 Constructing the MDN

A Mix Design Nomogram (MDN) was constructed for each of the seven (7) concrete families, one for the reference concrete family, three for

Table 2: Presents the data results for each mixture. Result for each mixture.

Concrete families	Aggregate replacement	Mix proportion (cement: sand river: fine recycled aggregate: coarse aggregate: W/C)			f_c at 28d MPa		
		1;3	1;4,5	1;6	1;3	1;4,5	1;6
Natural		1:1, 24: 0,0: 1,76: 0,40	1: 2,08; 0,0: 2,42: 0,51	1: 2,92: 0,0: 3,08: 0,75	48,5	41,9	26,5
FRCA	20	1: 0,99: 0,25: 1,76: 0,46	1: 1,64: 0,416: 2,42; 0,58	1: 2,34: 0,58: 3,08: 0,69	56,1	36,7	27,5
	50	1: 0,62: 0,62: 1,76: 0,44	1: 1,04: 1,04: 2,42: 0,61	1: 1,46: 1,46: 3,08: 0,75	46,3	33,8	26,96
	100	1: 0,0: 1,24: 1,76: 0,47	1: 0,0; 2,08: 2,42: 0,61	1: 0,0: 2,92: 3,08: 0,80	46,6	30,2	23,3
FRMA	20	1: 0,99: 0,25: 1,76: 0,39	1: 1,64: 0,416: 2,42: 0,55	1: 2,34: 0,58: 3,08: 0,70	49,0	38,2	26,6
	50	1: 0,62: 0,62: 1,76: 0,45	1: 1,04: 1,04: 2,42: 0,56	1: 1,46: 1,46: 3,08: 0,74	49,5	40,0	29,4
	100	1: 0,0: 1,24: 1,76 0,50	1: 0,0: 2,08: 2,42: 0,66	1: 0,0: 2,92: 3,08: 0,81	42,8	36,6	27,0

Source: The authors.

concrete made with FRCA and three for concrete made with FRMA, as presented in Figure 1, as an example.

Then, the corresponding MDN was used to obtain the W/C for the desired compressive concrete strength of 20MPa, 30MPa and 40MPa, (2900psi; 4350psi and 5800 psi) at 28 days, for each family. The results are presented in Table 3.

Table 3: Water cement ratio from MDN for desired compressive strength.

Concrete families	Aggregate replacement	W/C ratio		
Compressive strength at 28d		20MPa	30MPa	40MPa
Natural	0%	0.91	0.68	0.52
FRCA	20%	0.80	0.66	0.57
	50%	0.92	0.69	0.52
	100%	0.87	0.68	0.54
FRMA	20%	0.86	0.65	0.50
	50%	0.95	0.73	0.57
	100%	1.03	0.76	0.56

Source: The authors.

Figure 2 shows the correspondence between pore volumes and water absorption with W/C. Figure 3 shows the carbonation behavior and Figure 4 presents the resistivity property as a function of W/C ratio.

Knowing each W/C ratio for each compressive strength, were possible to construct the correspondence between the durability properties (water absorption; pore volume; carbonation and resistivity) with the amount of fine recycled aggregate replacing natural aggregates, as showed in Figure 5, Figure 6, Figure 7 and Figure 8. Also was possible to find the cement content, resistivity, carbonation, pore volumes and water absorption for each W/C to reach the specified compressive strength, as showed in Tables 4 and 5.

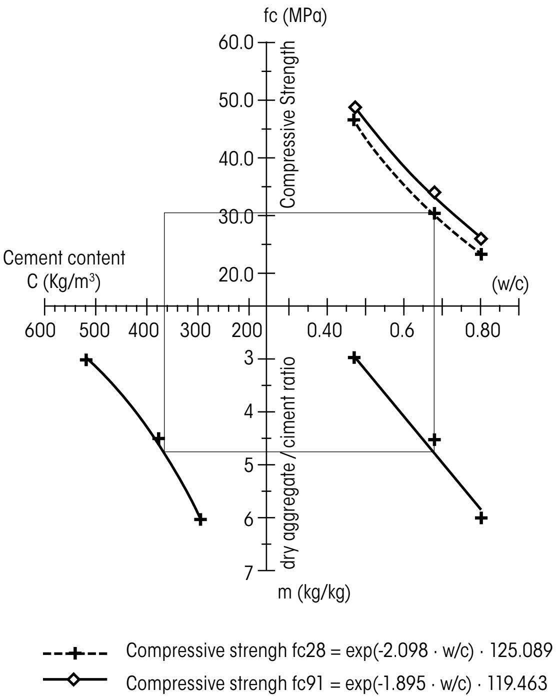

Figure 1: Strength MDN for concrete family FRCA 100%-0%

Source: The authors.

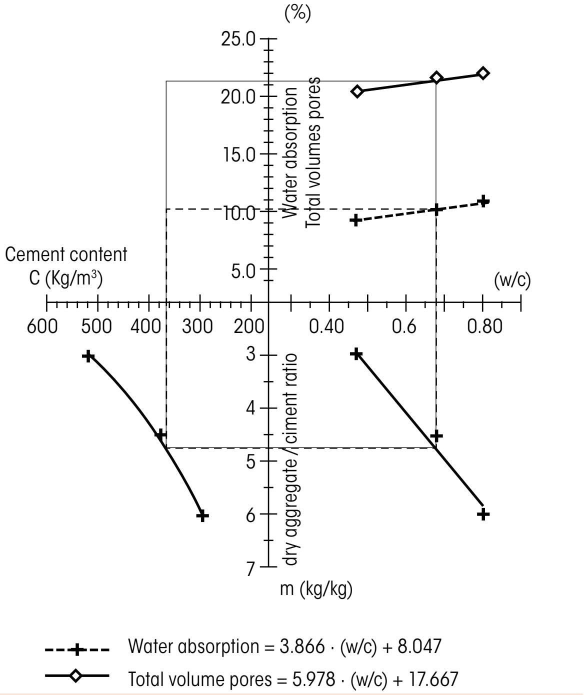

Figure 2: Water absorption and total volume pore for concrete family FRCA 100% - 0%

Source: The authors.

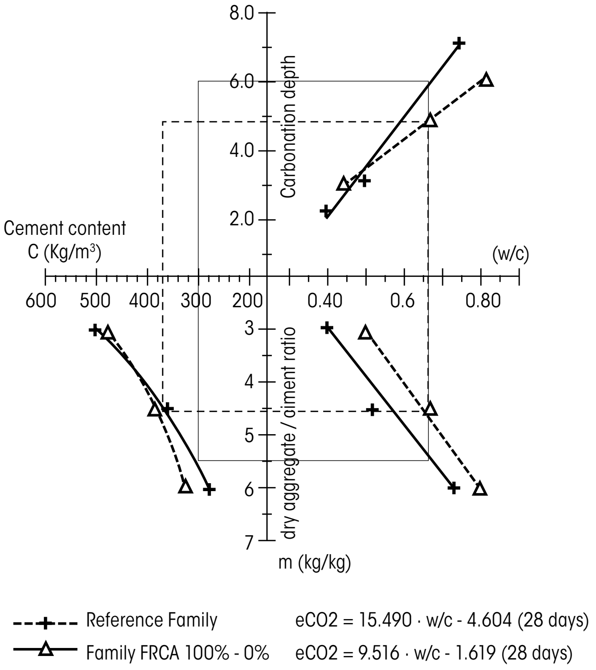

Figure 3: Carbonation MDN for concrete reference family and FRCA 100%

Source: The authors.

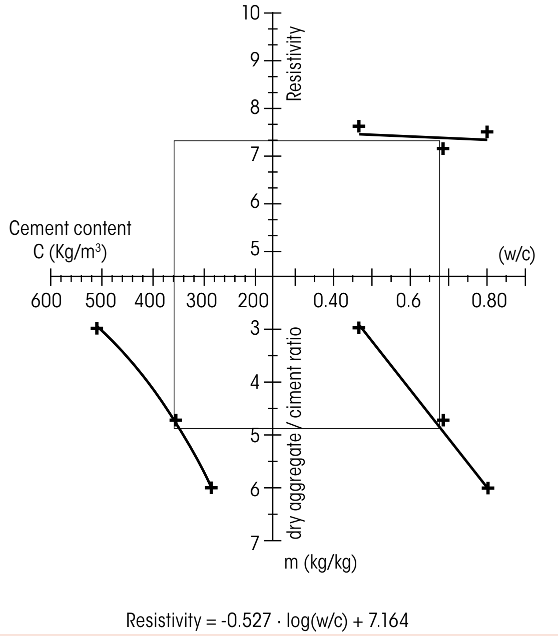

Figure 4: Resistivity for concrete family FRCA 100% - 0%

Source: The authors.

5 Discussion

The water absorption, as well as the total pore volume, increases with the amount of natural aggregates replaced by recycled aggregates. This behavior was expected, since the absorption of the fine recycled aggregates, FRCA and FRMA, was 6 to 10 times higher than the natural aggregates.

The carbonation depth, for the same compressive strength, reached an optimal value when 50% of the natural aggregate was replaced by FRMA. When the natural aggregate was replaced by FRCA, no significant alterations were recorded in the carbonation depth, independently of the replacement content.

When using FRCA or FRMA, also with 100% of replacement, the carbonation depth is still lower when compared to reference concrete families made by natural aggregates (see Figure 3). The explanation of this behavior is supported by the highest cement content of recycled concretes to achieve the same compressive concrete strength of natural aggregates concrete. Fine recycled aggregate concretes need a higher cement content to achieve the same compressive strength as compared to reference concrete, as shown in Table 4 and Table 5. This higher alkaline reserve acts to protect the concrete surface against carbonation mechanism.

Clifton (1993) reported that the positive effect of the alkaline reserve in relation to carbonation can increase the service life of concrete structures, because they last longer without depassivation of reinforcement, which means an increase in the corrosion initiation period (TUUTTI, 1982).

Concerning resistivity, the Comité Euro-International du Béton (bulletin CEB 192) presents criteria for assessing the reinforcement corrosion probability as a function of concrete resistivity, classifying concretes from 5kΩ.cm to 10kΩ.cm, as high corrosion probability and concretes with more than 10kΩ.cm as low and negligible risks of steel reinforcement corrosion. All the resistivity measurements were conducted under the same conditions. Comparing data results with CEB criteria, only when the FRCA replace 100% of natural aggregates the corrosion probability can be considered high. In all the others mixtures the corrosion probability is low or negligible.

All the properties investigated – absorption, total pore volume, carbonation and resistivity – could be expected to present consistent behavior. For the concrete family produced with the replacement of 50% of natural aggregate by FRMA, minimum values were obtained for carbonation and maximum values were obtained for resistivity. The reason for this observation can be justified

Table 4: Cement content and carbonation depth for all concrete families

Concrete families	Aggregate replacement	Cement content (kg/m^3)			Carbonation depth (mm)			Resistivity (kΩ.cm)		
Compressive strength at 28d		20MPa	30MPa	40MPa	20MPa	30MPa	40MPa	20MPa	30MPa	40MPa
Natural	0%	179	291	397	9.6	6.0	3.5	13.3	17.0	20.4
FRCA	20%	239	325	404	6.0	4.6	3.6	14.2	15.0	15.8
	50%	216	330	445	6.5	4.6	3.3	11.7	10.7	9.8
	100%	266	366	461	6.7	4.9	3.6	7.2	7.4	7.5
FRMA	20%	220	329	434	6.4	4.3	2.8	19.3	18.3	17.3
	50%	191	300	407	5.8	4.0	2.7	30.6	26.8	23.3
	100%	217	332	455	9.0	5.8	3.5	26.6	23.9	21.3

Source: The authors.

Table 5: Water absorption and pore volume for all concrete families

Concrete families	Aggregate replacement	Water absorption (%)			Pore volume (%)		
Compressive strength at 28d		20MPa	30MPa	40MPa	20MPa	30MPa	40MPa
Natural	0%	7.3	6.6	6.1	16.0	14.6	13.6
FRCA	20%	7.3	7.2	7.1	15.8	15.7	15.6
	50%	9.7	9.0	8.5	20.2	19.0	18.1
	100%	11.4	10.7	10.1	22.9	21.7	20.9
FRMA	20%	7.5	6.9	6.5	15.9	15.1	14.4
	50%	8.0	7.6	7.3	16.7	16.2	15.8
	100%	8.2	8.9	9.4	19.0	18.6	18.3

Source: The authors.

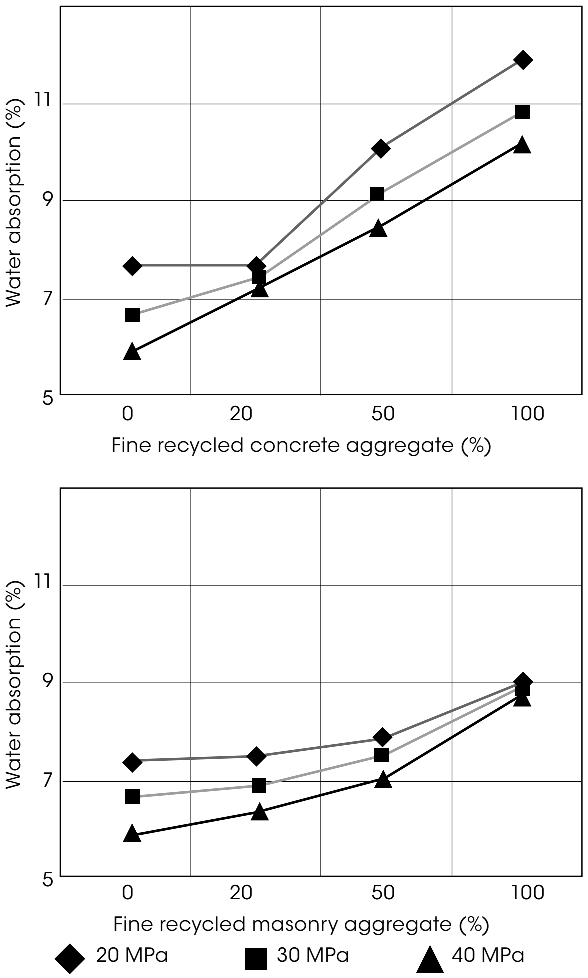

Figure 5: Evolution of water absorption with the amount of natural aggregate being replaced by FRCA and FRMA to achieve 20MPa, 30MPa and 40MPa at 28 days

Source: The authors.

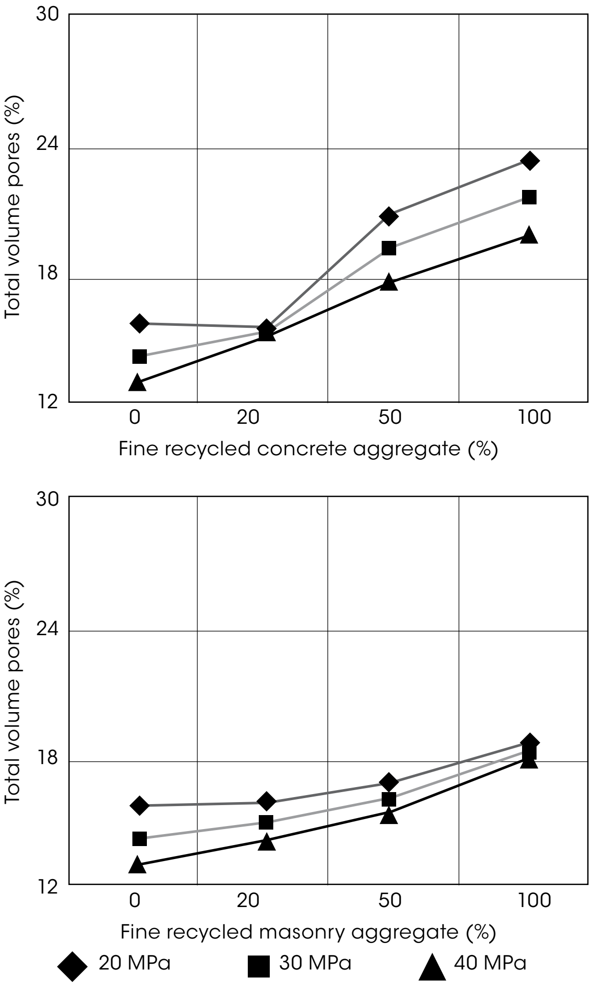

Figure 6: Evolution of total pore volume and carbonation depth as a function of replacement of natural aggregate by FRCA and FRMA to achieve 20MPa, 30MPa and 40MPa at 28 days

Source: The authors.

why the replacement of natural aggregate reach better compaction, the high density.

7 Conclusions

By applying the very clear concepts proposed for experimental concrete mix design by Helene and Monteiro (1993) to the properties studied in this work, it was possible to observe and compare the behavior of concrete families and not only between isolated mixtures.

Under the conditions of this research it is possible to conclude that:

Concrete made with recycled aggregates (20%; 50% and 100% replacement) from old masonry or from old concrete can have the same fresh workability and can achieve the same 28-day compressive strength as concrete made with natural aggregates in the range from 20MPa to 40MPa.

The carbonation depth always decreased when the replacement was 20% or 50%. For FRMA concrete family this improvement in behavior also

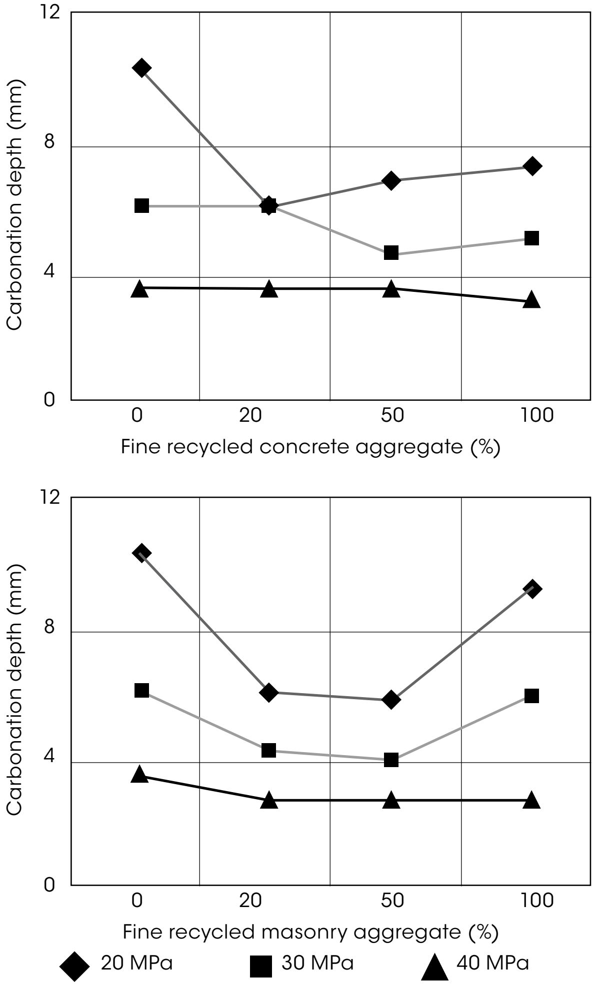

Figure 7: Evolution of carbonation depth as a function of replacement of natural aggregate by FRCA and FRMA to achieve 20MPa, 30MPa and 40MPa at 28 days

Source: The authors.

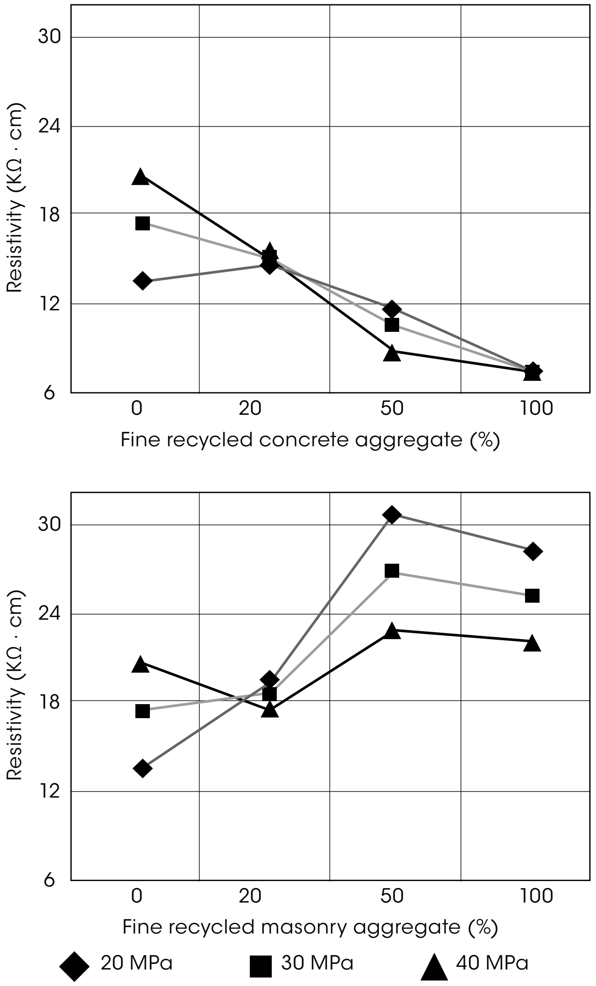

Figure 8: Evolution of resistivity with the amount of natural aggregate was being replaced by FRCA and FRMA to achieve 20MPa, 30MPa and 40MPa at 28 days

Source: The authors.

occurred when the replacement was 100%. This behavior shows that carbonation depth strongly depends on the chemical composition of the concrete and not only on its physical aspects.

When 50% of the natural fine aggregate was substituted by FRMA, the resistivity reached maximum values.

The replacement of natural aggregates by recycled ones has been shown to be technically viable; however, it will be necessary to take into account that the recycled aggregates had water absorption about 10 times higher than that of natural aggregates, and this fact increased both total pore volume and water absorption of the concrete.

When the natural aggregate is replaced by the 20% or 50% of recycled aggregates from old concrete or old masonry, the resulting recycled concrete may have the same, and sometimes better, behavior than the reference concrete made with natural aggregates. This fact justifies the efforts to use these concretes, which can contribute to the preservation of the environment and can achieve the same final performance at probably lower costs than those of ordinary concretes.

This investigation shows that it is possible to evaluate the influence of recycled aggregates in the depth of carbonation concrete. Also shows that the traditional approach by pore volume is not enough for understand the phenomena. The CO_2 gas penetration depends not only from porosity but also from concrete materials, which means chemicals aspects.

The use of Mix Design Nomogram (MDN) introduced by Helene and Monteiro (1993) allows the researchers to make a correct and relevant comparison between the different concrete families, adopting the same reference compressive concrete strength, instead of the usual poor comparison between individual mixture results.

The results obtained in this work point towards the effective possibility of using fine recycled aggregates in the production of new concretes, since the maximum substitution limits of 50% are complied with.

Ednote

1 N. Ed.: Texto originalmente apresentado na International Conference on Sustainable Construction Materials and Technologies, Coventry – UK. 2007. Proceedings. ISBN 0.415.446.899. Coventry: Sustainable Construction Materials and Technologies. p. 45-51.

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