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DRYING SHRINKAGE OF CONCRETE CONTAINING RECYCLED CONSTRUCTION AND DEMOLITION AGGREGATE

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ABSTRACT

This paper reports the results of an experimental program whose aim was to evaluate drying shrinkage of recycled construction and demolition waste (CDW) aggregate concrete compared with those containing natural aggregate. The natural aggregates used were quartz sand (Dmax=1.2mm and Dmax=2.4mm) and granite crushed rock (Dmax=9.5mm). To evaluate the effects of fine and coarse recycled aggregate on the volumetric deformations of concrete, it was used a normal strength concrete with a water/cement ratio of 0.80. The concretes were produced with different percentage of fine and coarse natural aggregate replacement (0. 50 and 100%), by volume. Three prismatic specimens of (7.5x7.5x28.5) cm were cast in steel moulds to evaluate the drying shrinkage. The test results indicate that the drying shrinkage of the recycled concrete containing 100% of CDW was higher than that of the conventional concrete. Mixtures containing 50% of CDW presents, however, lower drying shrinkage up to the age of 116 days.

KEYWORDS: Drying shrinkage, Recycled concrete, Recycled aggregate.

INTRODUCTION

Building activity is currently demanding remarkable amounts of inert materials (such as gravel and sand) that are usually provided by alluvial sediments and/or by rocky formation areas. In Brazil, the use of natural resources to aggregate production reached about 336,5 million tons in 2005 [1]. Considering the environmental impact caused by natural aggregate mining, it is appropriate to investigate other sources of raw materials in order to reduce the consumption of precious natural resources [2], [3]. In the same way, the construction work causes several environmental impact, as natural resources depletion (energy, water, rock and river aggregates) and waste generation. Construction and demolition waste (CDW) is composed of materials such brick, concrete, mortar, blocks, tile (inert materials) and timber, paper, glass, plastic and metal (recycled materials). Markets for recycled materials are already well developed. However, most of the volume of CDW is composed by inert materials which hadn't found well defined recycled form yet. For these reasons, it has been observed in the last decades the re-use of CDW, provided by continuous urban redevelopment, in the concrete industry.

Several studies have been carried out to evaluate the influence of recycled aggregates on mechanical and durability characteristics of concrete made with CDW [2, 4-11]. The results have shown that the changes in the properties of recycled concrete depend on the properties of the recycled aggregate and on the percentage of replacement of fine and coarse natural aggregates by CDW. This happen due to the wide variation in the properties of the available recycled aggregate from CDW. Therefore, the properties of each concrete obtained must be carefully studied. Considering the scarcity of results about the influence of recycled aggregates on the drying shrinkage of concrete, this paper reports the results of an experimental program whose aim was to evaluate the drying shrinkage of recycled concrete compared with those of conventional concrete.

EXPERIMENTAL PROGRAM

Materials

The CDW used in the present study was obtained in four different building sites of Feira de Santana City in the Northeast of Brazil. The construction and demolition debris were transported to the laboratories, separated, broken into pieces by a jaw crusher to sizes smaller than 12,5 mm and sieved, as shown in Figure 1. Recycled material is basically composed by mortar (55%), brick (26%) and concrete (16%).

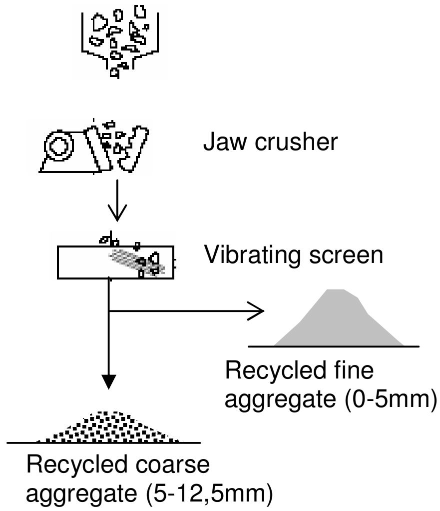

FIGURE 1 - FLOW CHART OF RECYCLED AGGREGATE PRODUCTION

The natural aggregates used were granite crushed rock and two available quartz sands. Table 1 shows the properties of the natural and recycled aggregates. As expected, the absorption rate is significantly larger in recycled aggregate, due to the porous brick and old mortar material present at the CDW composition. High-early strength Portland cement, similar to ASTM Type III in composition and properties was used in the present study.

TABLE 1 - PHYSICAL PROPERTIES OF NATURAL AND RECYCLED AGGREGATES

	NFA 1	NFA 2	RFA	NCA	RCA
Maximum Size Aggregate	1,2 mm	2,4mm	4,8	9,5mm	12,5mm
Fineness Modulus	1,68	2,9	2,56	5,43	6,23
Apparent Specific Gravity	2,59 kg/dm^3	2,55 kg/dm^3	2,55 kg/dm^3	2,73 kg/dm^3	2,41 kg/dm^3
Bulk density	1,53 kg/dm^3	1,39 kg/dm^3	1,27 kg/dm^3	1,38 kg/dm^3	0,99 kg/dm^3
Water Absorption (24h)	0,1%	0,2%	21%	0,5%	11,3%
Material passing the 75µm sieve	1,7%	0,7%	10,4%	1,2%	0,7%

NFA – Natural Fine Aggregate ; RFA – Recycled Fine Aggregate ; NCA – Natural Coarse Aggregate ; RCA – Recycled Coarse Aggregate

Mix Proportions and Concrete Production

Mix proportions for 1 m³ of six different aggregate substitution rates in concrete are presented in Table 2. All recycled concretes were produced with the same mix proportions as the reference concrete. Minor adjustments in weight proportions of aggregates were made to compensate for differences in density between natural and recycled aggregates. The recycled concrete also required a slight increase in the mixing water content (due to the different water absorption capacity of recycled aggregate) in order to achieve the same workability as the reference concrete.

Nine cylinders specimens (100mm in diameter x 200mm in height) were cast for each concrete mixture, using internal vibration. Three samples were used for the compression tests, three samples for the determination of elastic modulus, and three samples were cast for the determination of water absorption, total porosity and density, at the age of 28 days, according to Brazilian Standards, NBR 5739 [12], NBR 8522 [13] and NBR 9778 [14], respectively. One set of three 75x75x285 mm beams were cast from each concrete mixture to evaluate drying shrinkage according to ASTM C157 [15].

TABLE 2 – CONCRETE MIXTURE COMPOSITION (KG/M³)

Mixtures	Cement	NFA 1 (60%)	NFA 2 (40%)	RFA	NCA	RCA	Water	Additional water	Total water	Slump (mm)
REF	297	568	379	-	763	-	238	0	238	170
50%RFA	297	284	189	469	763	-	238	39	277	155
100%RFA	297	-	-	938	763	-	238	79	317	80
50%RCA	297	568	379	-	381	337	238	13	251	115
100% RCA	297	568	379	-	-	673	238	27	265	85
50%RFA-RCA	297	284	189	469	381	337	238	53	291	115

After casting, the specimens were kept in their moulds during the first 24 hours. During this period the moulds were covered with a damp cloth and polythene sheet in order to prevent water loss. After 24 hours, the specimens were cured at the humid chamber at 23±2°C and RH of 100% until the age of the test.

The specimens used to drying shrinkage test had their initial length and mass measured immediately after demoulding. After 28 days of curing, the length and mass were also determined. The specimens were then placed in climatized room for drying. Drying conditions during the test were 52±3% R.H. and 19,5±1,0°C temperature. Length change and weight loss measurements of each specimen have been taken from the first instant of air storage until 116 days of drying.

ANALYSIS AND DISCUSSION OF RESULTS

Compressive Strength and Elastic Modulus

Table 3 presents the results for compressive strength and elastic modulus of concrete for all mixtures.

TABLE 3 - COMPRESSIVE STRENGTH AND ELASTIC MODULUS OF CONCRETE MIXTURES(MEAN VALUE AND COEFFICIENT OF VARIATION)

Mixtures	REF	50%RFA	100%RFA	50%RCA	100% RCA	50%RFA-RCA
fc (MPa) (CV%)	22,3 (2,7)	23,0 (3,4)	19,8 (5,7)	23,2 (1,6)	19,6 (4,3)	20,6 (4,5)
E (GPa) (CV%)	26,2 (1,6)	23,3 (2,4)	18,7 (2,9)	23,4 (2,8)	18,8 (6,4)	19,4 (13,5)

Reduction in compressive strength (by about 7%) was observed for the concrete containing 50% of RFA + 50% of RCA. When 100% of RFA and 100% of RCA were added to the reference mixture, the reduction in compressive strength reached 12%. The mixtures 50%RFA and 50%RCA presented compressive strength similar to that of the reference mix (difference ≤ 2%). Regarding to the elastic modulus of recycled concretes, the results indicate that it is smaller than that of the conventional concrete made from similar mix proportions. The reductions in elastic modulus are in the order of 11% for 50%RFA and 50%RCA concrete mixtures. For the mixtures 50%RFA + 50%RCA, 100%RFA and 100%RCA the reduction in the elastic modulus can reach 25%.

The results indicate that when the level of the aggregate replacement is increased occur a reduction in both compressive strength and elastic modulus of recycled concrete compared to the reference mixture. This reduction can be attributed to the higher porosity of the recycled aggregate as well as to the additional water used in recycled concrete mixtures in order to compensate the higher water absorption of aggregate.

Water absorption, total porosity and density

The results of water absorption, porosity and density of the studied concretes are presented in Table 4. The porosity and absorption increases significantly with the use of recycled aggregate when compared with those of the reference concrete. For example, the water absorption of mixtures 100%RFA, 100%RCA, and 50%RFA-RCA is increased by about 70% whereas for the mixtures 50% RFA and 50%RCA the increase in water absorption reached 50%. The porosity accessible to water was increased by about 50% to the mixtures 100%RFA, 100% RCA and 50%RFA-RCA. The mixtures 50% RFA and 50%RCA presented an increase in porosity of about 40%. The concrete density was only slightly changed by the aggregate replacement (a maximum reduction of about 2.5% was observed to the mixture 100%RCA).

TABLE 4 – ABSORPTION, POROSITY AND DENSITY OF CONCRETE MIXTURES (MEAN VALUE AND COEFFICIENT OF VARIATION)

	REF	50%RFA	100%RFA	50%RCA	100%RCA	50%RFA-RCA
Water Absorption – 24h % (CV%)	6,4 (5,6)	9,5 (0,7)	10,6 (3,2)	9,1 (0,4)	10,9 (1,0)	10,8 (1,6)
Porosity - % (CV%)	14,0 (5,7)	19,4 (0,4)	20,8 (3,0)	18,6 (0,4)	21,0 (0,7)	21,0 (1,2)
Density - kg/dm³ (CV%)	2,53 (0,5)	2,54 (0,2)	2,47 (0,6)	2,51 (0,4)	2,45 (0,0)	2,47 (0,4)

Drying Shrinkage

Drying shrinkage and loss of mass results for the conventional and recycled concrete are presented in Figure 2 and Figure 3, respectively (average values from three specimens). Results of drying shrinkage and loss of mass after 116 days of air storage are presented in Table 5.

The results indicated that the mixtures with 50% of CDW (mixtures 50%RFA and 50%RCA) presented smaller drying shrinkage than the reference mixture up to the age of 112 days. This behavior, however, is more pronounced at early ages. After 112 days of drying the mixtures containing CDW present shrinkage only 10% lower than that of the reference mixture. The mixtures containing 100% of CDW (mixtures 100%RFA, 100% RCA and 50%RFA-RCA) presented, on the other hand, drying shrinkage higher than that of the reference mixture (the drying shrinkage was increased by about 16-32% after 112 days of drying).

It is important to observe that the mixture 100%RFA presents smaller shrinkage than that of the reference mix up to the age of 98 days. These results indicate that although presenting higher total water absorption than the coarse aggregate, the rate of water liberation of the fine aggregate is lower and, therefore, the shrinkage of concrete containing this type of aggregate is, at lower ages, smaller than that of the concrete containing coarse CDW.

TABLE 5 – DRYING SHRINKAGE AND LOSS OF MASS OF CONVENTIONAL AND RECYCLED CONCRETE AFTER 116 DAYS OF AIR STORAGE

Drying Shrinkage (με) (Drying shrinkage of the CDW concrete/drying shrinkage of conventional concrete after 116 days of drying)					
REF	50%RFA	100%RFA	50%RCA	100%RCA	50%RFA-RCA
-600	-530 (0,88)	-710 (1,18)	-560 (0,93)	-690 (1,15)	-795 (1,33)
Loss of Weight (%) (Loss of mass of the CDW concrete/loss of mass of conventional concrete after 116 days of drying)					
REF	50%RFA	100%RFA	50%RCA	100%RCA	50%RFA-RCA
-39,5	-40,5 (1,03)	-39,5 (1,00)	-43,5 (1,10)	-47,0 (1,19)	-44,0 (1,11)

The loss of mass-time curve presented in Figure 3 indicate that the mixtures containing recycled coarse aggregate presented higher loss of mass than those of the reference mixture and of the mixture containing recycled fine aggregate. For example, at the age of 116 days, the loss of mass of the concrete 100%RCA is 19% higher than that of the mixture 100%RFA (see Table 5). It is important to observe that the specimens of the mixture 100%RFA presents smaller loss of mass than that of the reference one up to the age of 82 days, showing the same trend observed for the drying shrinkage of concrete.

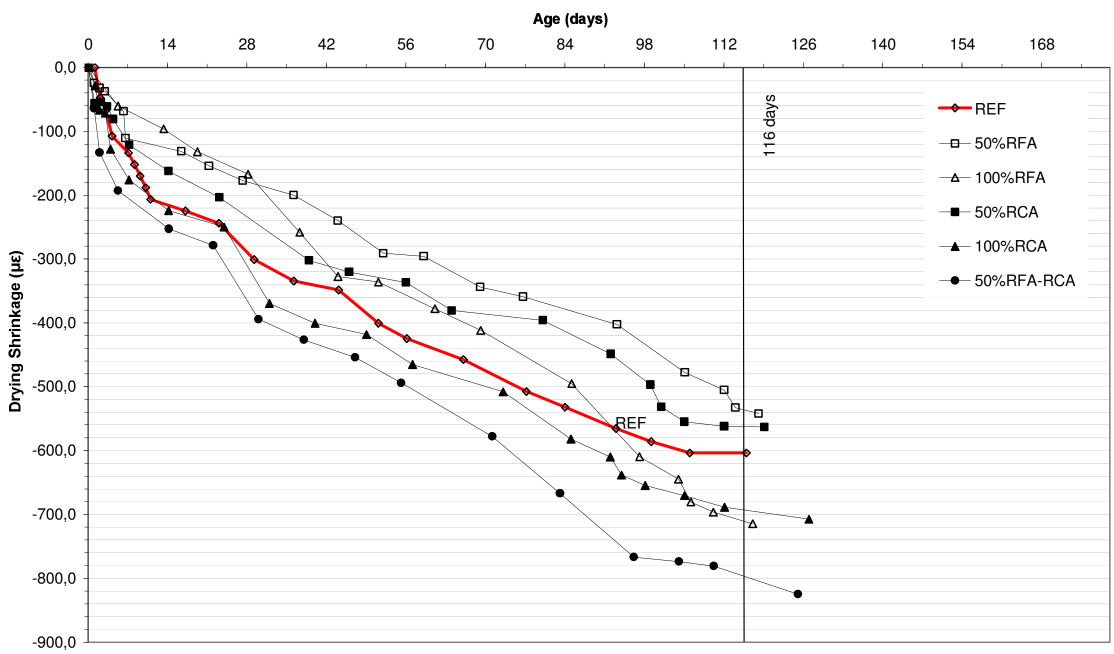

FIGURE 2 – DRYING SHRINKAGE VS. AGE, MEASURED AT DIFFERENT INTERVALS OF TIME

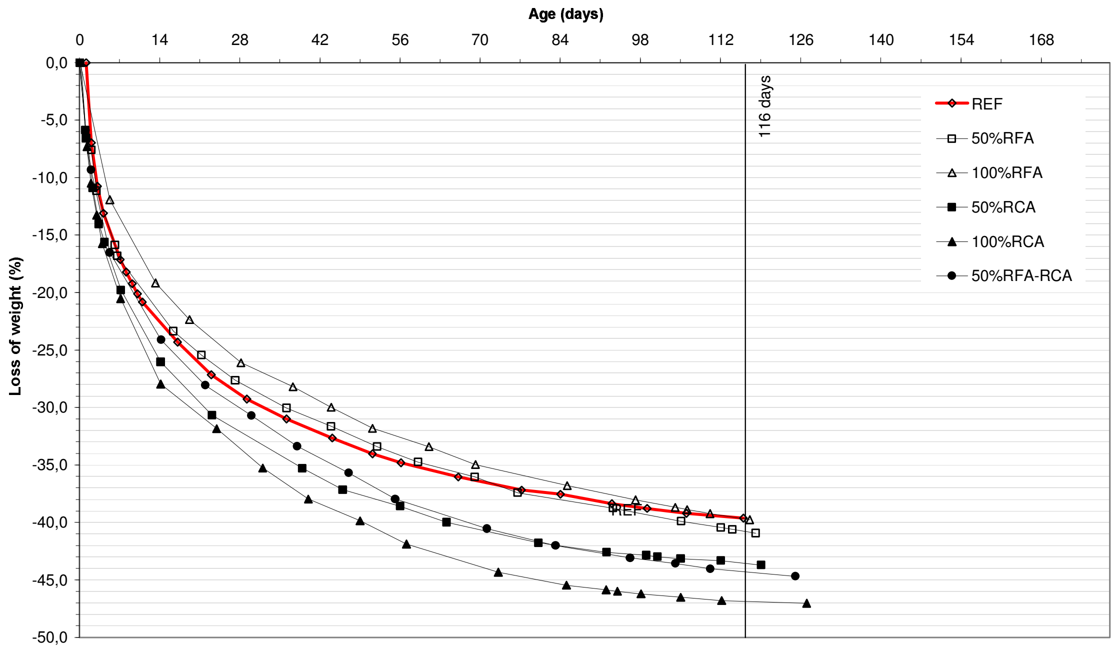

FIGURE 3 – LOSS OF WEIGHT VS. AGE, MEASURED AT DIFFERENT INTERVALS OF TIME

4. CONCLUSION

The results obtained indicate that the recycled concrete presented a reduction in compressive strength ranging between 7% and 12% when compared with the results of the reference mixture. Regarding to the elastic modulus, the reduction ranged between 10% and 30%. The porosity and water absorption increases significantly (about 50% to 70%) with the use of recycled aggregate when compared with those of the reference concrete. Regarding to the drying shrinkage, the results indicated that the mixtures with 100% of natural aggregate replacement presents higher drying shrinkage than that of the reference mixture .The mixtures with 50% of CDW (mixtures 50% RFA and 50%RCA) presented smaller drying shrinkage than the reference mixture up to the age of 112 days. This behavior, however, is more pronounced at early ages. The mixtures containing recycled coarse aggregate presented higher loss of mass than those of the reference mixture and of the mixture containing recycled fine aggregate. The mixture 100%RFA presents smaller loss of mass than that of the reference one up to the age of 82 days, showing the same trend observed for the drying shrinkage of concrete.

5. ACKNOWLEDGMENTS

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