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DRYING SHRINKAGE OF RECYCLED AGGREGATE MORTAR

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ABSTRACT

The use of fine recycled aggregates as raw material in the production of mortars appears as a good alternative to minimize waste disposal, so as to reduce natural resources consumption and to find and supply suitable substitutes for natural aggregates. However, the use of this alternative material in a safe way must be carried out by a wide investigation of its long term behavior. In this way, this paper will examine the mechanical strength, physical properties and drying shrinkage of mortar, which use recycled fine aggregates that have originated from construction and demolition waste. Mortar with natural aggregates only was used as reference. Two recycled mortars were made with 50 and 100% of substitution rate of natural aggregate by recycled one. Two matrix were produced with cement/sand ratios of 1:4 and 1:8 (by weight) and a fixed consistency index of 260±10mm. Results show that recycled mortars present higher total porosity, absorption rate and drying shrinkage than reference mortar.

KEYWORDS: recycled mortar, construction and demolition waste, drying shrinkage, recycled aggregate.

INTRODUCTION

In the search for a sustainable model of production, the construction industry is particularly important as it is not only responsible for consuming natural resources and energy but also for its capacity of absorbing other industries waste and by-products. The construction and demolition waste (CDW) (building site's waste), is one of those alternative materials that have been used as partial or complete substitution of natural aggregates in the production of mortars [1-4], concretes [4-5], mould blocks [6], asphalt concrete [7] and as base and sub-base materials [8]. The use of CDW to make aggregates for production of mortars comes as a good alternative to make possible the offer of a raw material with technological quality and costs compared with those of the conventional materials. Besides, the utilization of CDW as recycled aggregate contributing for solving the environmental problems resultant of its irregular deposition at streets, river edge or strip of land.

Durability issues must be well established to permit the use of this alternative material. To recycled mortars, one of the main problems reported is linked with intensive cracking due to high water requirement, grain size distribution and total porosity [1-3; 9]. Miranda [2] has reported that the distribution of the pore sizes generated by the presence of high amount of fines in the mixtures plays a higher effect on drying shrinkage than that of the porosity introduced by the effective water cement/ratio.

The aim of this study is to investigate the influence of recycled fine aggregate in the production of mortar. The properties of both fresh and hardened mortars are illustrated and the analysis of the influence of recycled fine aggregates on the absorption, compressive strength and shrinkage drying of the mortar is presented.

EXPERIMENTAL PROGRAM

Materials

Portland cement CP V ARI (ASTM Type III) with specific gravity of 3.13 g/cm^3 was used.

The natural fine aggregates used were one medium river quartz sand (specific gravity of 2.59 g/cm^3 and fineness of 1.68) and one fine quartz sand (specific gravity of 2,55 g/cm^3 and fineness of 2,90). Both are regularly commercialized in Feira de Santana City (Northeast Brazil). Tap water supplied by the local water supply company was used on the mortar mixtures.

Recycled aggregate sourced from a CDW irregular deposition sites of Feira de Santana was crushed into pieces using a jaw crusher and screened in a 4.8 mm sieve as shown in Figure 1.

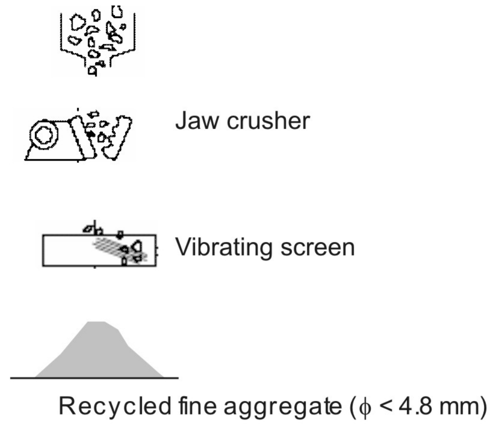

FIGURE 1 - FLOW CHART OF RECYCLED AGGREGATE PRODUCTION

The physical properties of the recycled fine aggregate were determined in the Laboratory of Construction Materials at the University of Feira de Santana. The construction and demolition composition is basically composed by mortar, brick material and concrete. The fine recycled aggregate presented a fineness of 2.56, specific gravity of 2.51 g/cm³, material passing the 75µm sieve of 10.4% and absorption rate of 21.0%.

Mortars Mix Proportions

Two series of mortars were produced with the cement/sand ratios of 1:4 and 1:8 (by weight), to evaluate two substitution rates of natural fine aggregate by recycled aggregate. The aggregate substitution rates are 50 and 100%. The workability of the mortars was determined through the flow table test according to Brazilian Standard, NBR 13276 [10], and was fixed as a consistency index of 260±10mm.

The recycled mortars were produced with the same mix proportions as the reference mortar except for those minor adjustments in weight proportions of aggregates that were made to compensate the differences in density between natural and recycled fine aggregates. The recycled aggregate also required an increase in mixing water content for compensating water absorption of recycled aggregate to achieve the same workability as the reference mortar. The mix proportions and consistency index of the mortars are given in Table 1.

TABLE 1 – MORTAR MIXTURE PROPORTIONS (KG/M³)

Mixtures	Cement	NFA 1 (60%)	NFA 2 (40%)	RFA	Water	Additional water	W/C	Consistency Index (mm)
Reference – T40	381	914	609	0	267	0	0,70	256
50%RFA – T41	381	457	305	754	267	44	-	264
100%RFA – T42	381	0	0	1508	267	80	-	255
Reference – T80	201	966	644	0	290	0	1,44	260
50%RFA – T81	201	483	322	797	290	57	-	261
100%RFA – T82	201	0	0	1595	290	95	-	270

NFA – Natural Fine Aggregate / RFA – Recycled Fine Aggregate

Mortars mixtures were carried out in a mechanical mixer of 100 dm³, observing the sequence of mixing prescribed in Brazilian Standard, NBR 13276 [10]. External vibration was used during casting. After removing the specimens from the molds they were cured at the humid chamber at 23±2°C and relative humidity of 100% until they have reached an age of 28 days.

Test procedures

Compressive Strength and Absorption and Porosity Tests

Eleven specimens (cylinders of 50mm in diameter x 100mm in height) were cast for each mortar mixture, using manual compaction. Four samples were cast for compression tests at the age of 7 and 28 days according to NBR 7215 [11]. And, three samples were cast for the determination of absorption rate and total porosity, at the age of 28 days, according to NBR 9778 [12].

Drying shrinkage

One set of three plates of 10mm of thickness, 150 mm in width and 500 mm in length were cast from each mortar mixture to evaluate drying shrinkage. Plates were cast in steel molds and removed from them at an age of 24hours. The plates were marked with a waterproof indelible ink and were immediately done an initial linear length measurement in four different points of each plate, as shown in Figure 2.

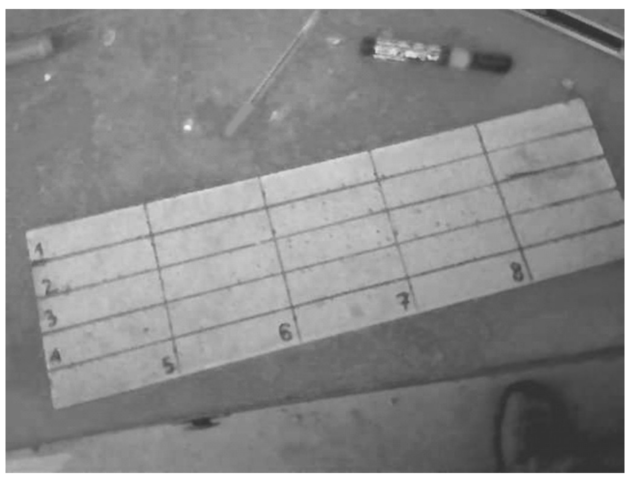

FIGURE 2 – PLATE OF MORTAR MARKED ALONG THE LENGTH TO BE MEASURED

After the initial linear measurement the plates were stored in lime-saturated water at 23±2ºC until they have reached an age of 28 days. The specimens were than removed from water storage one at a time, and wiped with a damp cloth and made another linear length measurement and determined the specimen weight. Upon removal the specimens from water and took length and weight measurements, they were placed in air storage for drying. Drying conditions are a relative humidity of 50±4% and a temperature of 23±2ºC. Lengths and weight measurements of each specimen have been taken after periods of air storage after curing of 1, 2, 3, 4, 5, 6, 7, 14, 21, 28 days and after 8, 12, 16, 20 weeks.

The drying shrinkage of any plate is calculated at any age after initial period of air storage with the Eqn.1:

$$\varepsilon = \frac{\Delta L}{L} 10^6 \qquad (1)$$

where:

ε = drying shrinkage of specimen (με),
ΔL = difference between the length reading of specimen at any age and the initial length reading at an age of 28 days after curing (mm), and
L = initial length reading at an age of 28 days after curing (mm).

ANALYSIS AND DISCUSSION OF RESULTS

Compressive strength, absorption rate and voids

Table 3 presents the results for compressive strength, absorption rate and porosity.

TABLE 3 – RESULTS OF THE COMPRESSIVE STRENGTH, ABSORPTION AND POROSITY TESTS

Mixtures	T40	T41	T42	T80	T81	T82
fc (MPa)	25,4	17,3	19,7	10,6	9,7	13,2
Absorption (%)	10,4	15,3	10,5	13,11	17,4	14,2
Porosity (%)	20,3	27,8	19,5	25,2	30,8	25,1

The influence of recycled aggregate on compressive strength can be observed in Figure 3. The mixtures with 100% of substitution result higher strength than that with 50%. Compared with reference mortar, it was verified a decrease of compressive strength of about 32% and 25% with the substitution of 50% and 100%, respectively, to richer mixture - T40. To the other mixture, however, an increase of strength is observed when 100% of natural aggregate is substituted. This phenomenon can be explained by three factors: i) better packing of grains with the utilization of recycled aggregate, which possess grains finer than natural aggregate; ii) reduction of effective water/cement ratio due to an increase of amount of pores of recycled aggregate; iii) better matrix-recycled aggregate bond caused by texture of recycled aggregate.

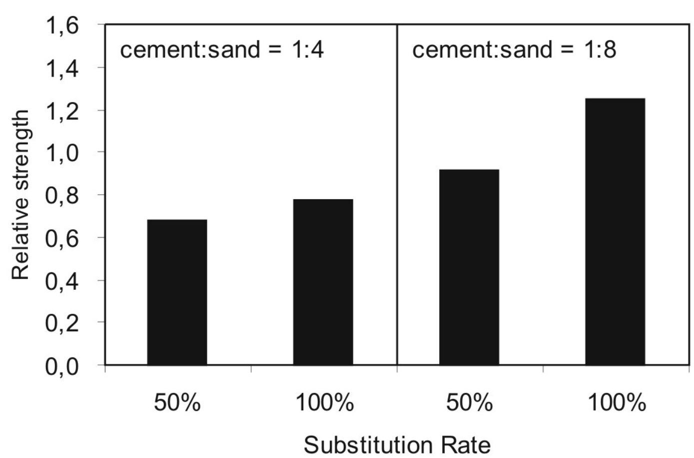

FIGURE 3 – INFLUENCE OF AGGREGATE SUBSTITUTION RATE ON RECYCLED MORTAR COMPRESSIVE STRENGTH RELATED WITH NATURAL MORTAR COMPRESSIVE STRENGTH

The addition of 50% of recycled aggregate increases the porosity and absorption significantly, while mixtures with 100% of recycled aggregate didn't show relevant variation of these properties, when compared with reference mortar.

Drying Shrinkage

Drying shrinkage of conventional and recycled mortar was determined at various time intervals and is presented in Figure 4 as average values of four measures from three specimens.

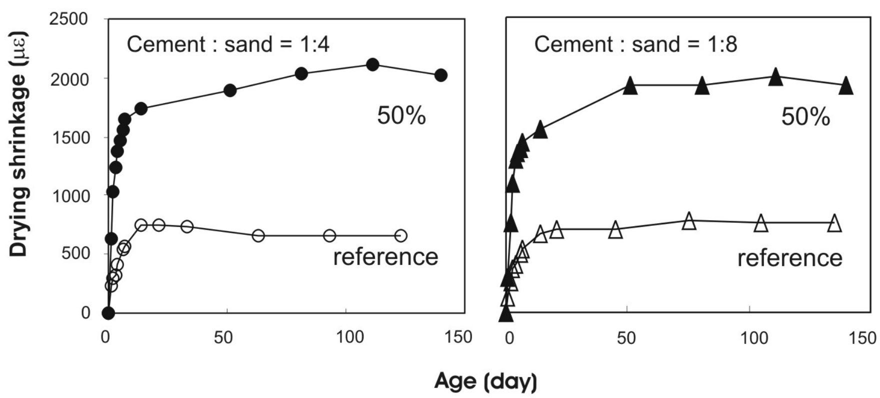

FIGURE 4 –DRYING SHRINKAGE VS. AGE

A large difference between recycled mortar and reference mortar can be observed, independent of the cement/sand ratio. The use of 50% of recycled aggregate substitution rate results on increasing drying shrinkage by 700$\mu\varepsilon$ to 2000$\mu\varepsilon$. This is associated to greater porosity and absorption of recycled aggregate when compared with natural aggregate.

The weight loss is more important for recycled mortars than for natural mortars, as shown in Figure 5. It can be observed three zones, stood out firstly by Mesbah and Buyle-Bodin [1]: a first zone OA starting at the origin corresponds to the shrinkage due to the departure of water from the pores; a second zone between A and B corresponds to the shrinkage due to the departure of water from the capillaries; and a third zone corresponds to a gain of weight which that can be connected to carbonation and explained by the high porosity of these recycled mortars in the ratio of 27 and 30%, which makes the penetration of carbonic gas possible.

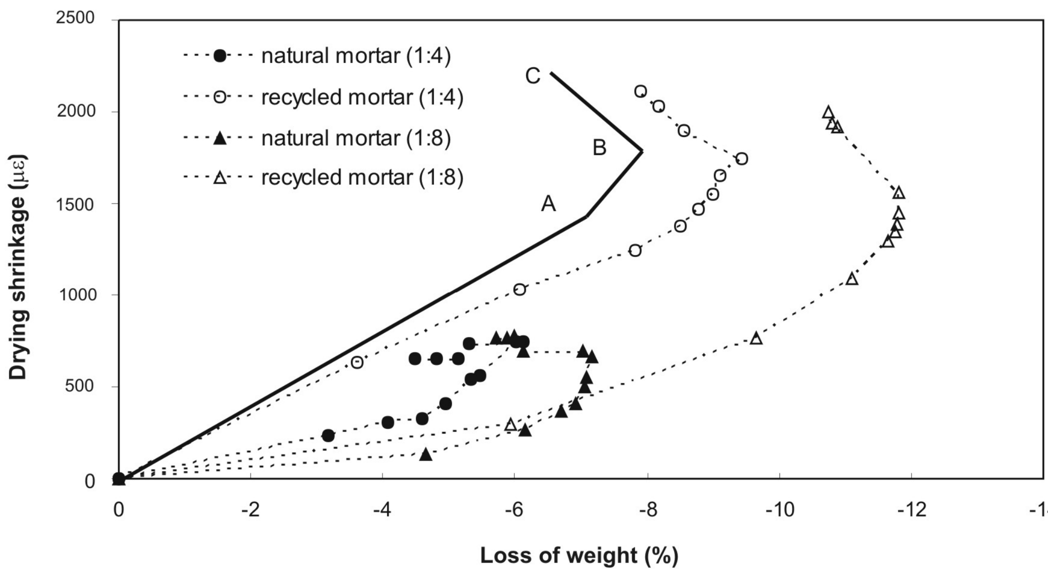

FIGURE 5 –DRYING SHRINKAGE DEFORMATION VS. LOSS OF WEIGHT

It is verified in Figure 5 that recycled mortars shown more weight loss in zone OA. This result indicates a higher presence of water in the pores of recycled aggregates due to major porosity of this material that stores more water than natural aggregate. The zone AB represented a weight loss of about 2% for all mixtures which indicate that the recycled aggregate has small influence on formation of capillaries voids.

CONCLUSION

For two mortars, which differed in cement/sand ratio, tests have shown the following effects of recycled aggregate use:

• to richer mixture (1:4), there is a decrease in compressive strength which is almost 32% for the mortar with 50% of recycled aggregate and 25% for the mortar with 100% of recycled aggregate. The other way round, mortar mixture with cement/sand ratio 1:8 showed a gain in compressive strength with 100% of recycled aggregate, mainly due to high aggregate water absorption rate, that reduce effective water/cement ratio;

• the addition of 50% of recycled aggregate increases the porosity and absorption significantly, while mixtures with 100% of recycled aggregate didn't show relevant variation of these properties, when compared with reference mortar;

• recycled aggregate increase drying shrinkage independent of the mortar matrix, which is linked with greater porosity and absorption of recycled aggregate. The weight loss evaluation indicates: (1) a higher presence of water in the pores of recycled aggregate due to higher porosity of this material that stores more water than natural aggregate, (2) recycled aggregate has small influence on formation of capillaries voids.

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REFERENCES

1. Mesbah HA. Buyle-Bodin F. Efficiency of polypropilene and metallic fibres on control of shrinkage and craking of recycled aggregates mortars. Construction and Building Materials 1999; 13(8): 439-447.
2. Miranda LFR. Estudo de fatores que influem na fissuração de revestimentos de argamassa com entulho reciclado. MSc thesis. Sao Paulo, University of Sao Paulo, 2000. (in Portuguese)
3. Miranda, LFR. Selmo, SMS. CDW recycled aggregate renderings: Part I – Analysis of the effect of materials finer than 75µm on mortar properties. Construction and Building Materials 2006; 20(9): 615-629.
4. Hansen TC. Recycled of demolished concrete and mansory. London: Chapman & Hall, 1992. Part One: Recycled aggregates and recycled aggregate concrete, p. 1-160. (RILEM TC Report 6).
5. Leite MB. Avaliação de propriedades mecânicas de concretos produzidos com agregados reciclados de resíduos de construção e demolição. DSc thesis. Porto Alegre, Universidade Federal do Rio Grande do Sul, 2001. (in Portuguese)
6. Souza JGG. **C**ontribuição ao estudo da relação entre propriedades e proporcionamento de blocos de concreto – aplicação ao uso de entulho como agregado reciclado. MSc thesis. Brasília, Universidade de Brasília, 2001. (in Portuguese)
7. Paranavithana S. Mohajerane A. Effects of recycled concrete aggregates on properties of asphalt concrete. Resouces, Conservation and Recycling 2006.
8. Poon CS. Qiao XC. Chan D. The cause and influence of self-cementing properties of fine recycled concrete aggregates on the properties of unbound sub-base. Waste Manegement 2006.
9. Anjos MAS. Costa CMC. Lima MR. Fernandes PDC. Resíduos da construção Civil – Avaliação inicial para utilização em argamassas. Proceedings IAC-NOCMAT 2005. Rio de Janeiro: ABMTENC, 2005.p.100-109.
10. Associação Brasileira de Normas Técnicas – 13276: Argamassa para assentamento de paredes e revestimento de paredes e tetos – Determinação do teor de água para obtenção do índice de consistência. Rio de Janeiro, 1995.
11. Associação Brasileira de Normas Técnicas – NBR 7215: Cimento Portland - Determinação da resistência à compressão, Rio de Janeiro, 1996.
12. Associação Brasileira de Normas Técnicas - NBR 9778: Argamassa e concreto endurecidos - Determinação da absorção de água, índice de vazios e massa específica. Rio de Janeiro, 2005.