

**AN INICIAL ANALYSIS OF THE EFFECT OF GYPSUM PLASTER IN RECYCLED MORTARS FROM C&D WASTE**

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# AN INICIAL ANALYSIS OF THE EFFECT OF GYPSUM PLASTER IN RECYCLED MORTARS FROM C&D WASTE

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**Key words:** recycled aggregate, ettringite, sulfate, construction and demolition waste, mortar, accelerated cycling.

## Abstract

For one type of recycling unit a study was made of the use of recycled sands containing gypsum plaster impurities as mortar for laying masonry. Such mortars, when in contact with moisture, can cause the outset of delayed ettringite and affect the performance of the masonry depending on the porosity of the materials used. Materials characteristic of the region of the recycling plant produced 4 recycled sands (0% up to 0,5% of theoretical sulfate contamination). The mortars were produced with a cement content around 220 kg/m<sup>3</sup>, including a reference mortar of cement, lime and quartz sand.

The materials quantities used, density and consistency of mortars in the plastic state; and in the hardened state at 63 days of age, the compressive strength, flexural modulus, static and dynamic modulus of elasticity, water absorption and apparent porosity are described in this paper. In between the 63rd and 175th days the mortars were submitted to 8 cycles of 7 days at > 95% R.U., alternating for 7 days at 40 °C. At the end of 8 cycles there was dimensional change and loss of tensile and compressive strength in all mortars studied. Analysis of the microstructure will confirm if such alterations can be associated to delayed ettringite.

## 1. INTRODUCTION

In Brazil federal, environmental and academic institutions are increasingly promoting the recycling of construction and demolition waste (C&DW) as a way of reducing the already well-known environmental impact caused by such remnants.

The Escola Politécnica at Universidade de São Paulo plays its part and it has nowadays several researchers working to contribute to the advancement and promotion of recycling of C&DW, in Civil Engineering Construction Department, with many contributions already made on a broad range of subjects that can be found at [www.reciclagem.pcc.usp.br](http://www.reciclagem.pcc.usp.br).

The present work belongs in the context of a broader research under way on the production of mortars using recycled sand that is discussed elsewhere<sup>[1], [2]</sup> and main technically based in previous Brazilian academic researches as<sup>[3], [4], [5], [6], [7]</sup>.

The main scope of the C&DW recycled mortar production research is the establishment and broadcasting of innovative technologies for communities and institutions involved in the sustainability of the built environment and who endeavour to offer to the market just recycled materials of distinguished quality and therefore with added technical and commercial value.

With a view to reaching this final scope the research has been done in a progressive technological partnership<sup>[8]</sup> with a small company, Usina de Reciclagem Irmãos Preto Ltda, at the town of Socorro, in the State of São Paulo, Brazil, that had the pioneering initiative of promoting the recycling activity of C&DW, with their own investment, and also won a prize with the national press for such an activity in 2002.

The need for the present work came about during the preliminary studies<sup>[8], [9]</sup>, when it was found that 4 out of 20 samples of recycled sand, collected in a period of four months in the aforementioned recycling unit, presented a sulfate content greater than 0.1 % by weight of aggregate. Such a value can be considered excessive by the Brazilian standard<sup>[10]</sup> for natural aggregates, as there is no Brazilian standard for recycled aggregates. It should be noted that there is some disagreement between the foreign limits like those in the references<sup>[11], [12], [13], [14], [15]</sup>.

## 2. DETERIORATION OF SULFATE CONTAMINATED MORTARS THROUGH DELAYED ETTRINGITE

Ettringite is a by-product of the hydration of cement components, and its formation is always related to the expansive reaction between calcium sulfate and tricalcium aluminate, in the presence of water, in Portland cement pastes.

When such reaction takes place in the fresh state, its expansive character is not harmful. But it can become harmful when it happens in the already hardened state of the cementitious material,<sup>[16], [17], [18], [19]</sup> when it is said that the ettringite is delayed, as the intrinsic porosity of the material is going to start a stress level that could or not cause its deterioration, in a sudden or gradual way, or even be of minor importance. It should be noted, that some experts<sup>[20]</sup> could prefer to name this ettringite as “secondary ettringite”, because it maybe would come from the recrystallization of a primary ettringite and not from the monosulfate phase.

In this process, the simultaneity of the following three factors<sup>[19]</sup> is necessary, and in the case of recycled aggregate, with an internal source of sulfates, by contamination of C&DW, the following mechanism can be presumed:

- **Prolonged presence of moisture in the mortar:** water is the vehicle for the occurrence of chemical reactions involved in the process. The prolonged presence of water filling the pore system of the mortar would be essential for the migration of ions  $\text{SO}_4^{-2}$ ,  $\text{Al}(\text{OH}_4)^-$  and  $\text{Ca}^{+2}$  into the microcracks where the deposition of ettringite can take place;
- **Delayed release of sulfate ions within the paste:** the mechanism of deterioration by sulfates coming from an internal source occurs on environments with free sulfate due to its delayed release from the cement (thermal decomposition of ettringite) or of aggregates contaminated by gypsum building plaster (Plaster of Paris, for example);
- **Existence of micro cracks in the mortar:** it is through microcracks that water can enter, make sulfates soluble and start the reactions. It is also within such microcracks that the ettringite formed will get deposited.

As recycled aggregates are concerned,<sup>[21]</sup> this is a deterioration process that should be taken into account because of the lack of selective waste pickup and the lack of control of the source of the sulfate-based residues that come to the recycling plant, as is the case of gypsum plaster (or plaster of Paris).

In fact, at the recycling plants it is not very difficult to sort out gypsum drywall boards or scraps of finish coat paste wasted at jobsites and that come in large pieces, as they are usually visible. But the same cannot be said of gypsum plaster applied as finish coating on walls and ceilings, because it has a high bond<sup>[22]</sup> to all types of mineral substrates, occurs in fine layers and will be hidden under the protective coating film, in the fragments of demolished masonry and concrete. As this kind of plastering is very common in Brazilian buildings, it is important to know how fine recycled aggregate can perform when it comes from C&DW with this type of contamination.

On the other hand, the masonry laying mortars focused on this research can be composite materials of medium to high porosity, according to the type of masonry, and therefore occasional stresses caused by delayed ettringite could or not affect the performance of the new masonry.

### 3. EXPERIMENTAL PROGRAM

Because of the context of the work explained on items 1 and 2, the following experimental program is under way, within the scope of a project for a Master of Science degree of the main author of this paper.<sup>[23]</sup>

The program was established with the objective of assessing the effects of gypsum plaster as a contaminant in recycled sands, in the formation of delayed ettringite, and its consequences on the performance of masonry laying mortars, under different processes of accelerated weathering.

By considering the simultaneous conjugation of the factors causing the formation of delayed ettringite, listed on item 2, the following variables were considered for study in the project that gave birth to this work, namely:

- **The sulfate contamination content in recycled sand**, defined by growing and feasible thicknesses of gypsum plastering applied on a ceramic bricks masonry, as described on item 3.1;
- **Other mortar mix design parameters**, related to the sand/cement ratio and the nature of the cement, by considering that in addition to the nature of the recycled sand, they are also going to influence the intrinsic resultant porosity of the mortars, and as detailed on item 3.2;
- **Exposition of the mortars to alternate cycles of moisture and temperature**, aiming at producing favourable conditions to the volumetric instability and the formation of effloresce in mortars through the outset of delayed ettringite and as described in 3.3.

#### 3.1 The production of recycled aggregates contaminated with sulfates and others aggregates of reference

In order to get the least dispersion in the analysis of data and for better assessing the variables under study in this work, it was decided to produce artificially the recycled sands used in the research.

So four 2.00 m x 1.50 m x 0.20 m walls were built surrounded by a 0.20 m x 0.20 m concrete frame and filled with solid ceramic brick laid with mixed mortar, as shown on Figure 1. Such dimensions relate to the average volume proportion between masonry and concrete structures in Brazil, although in the town object of study very little use is made of reinforced concrete, as it is a local practice the execution of solid brick masonry reinforced with steel

bars in some layers. Nevertheless the remnants of concrete flooring can get mixed to those of masonry and this because it was chosen to use the aforesaid frame as a generating element of recycled aggregates in this work.

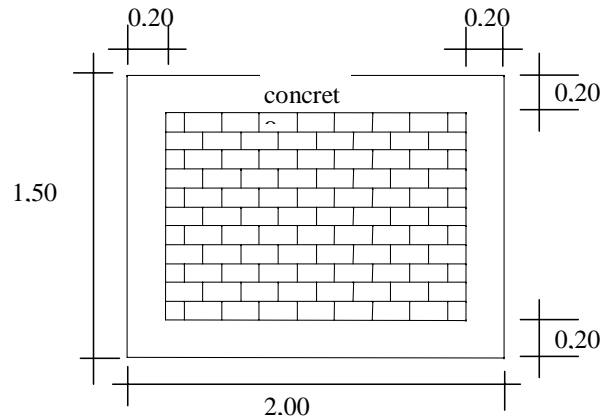


Figure 1: Sketch of the base wall generating the recycled aggregates, made up by solid ceramic brick masonry and surrounded by four structural concrete elements.

In the four walls a cement : lime : sand undercoating was used, and three of the walls received a gypsum plaster finish coating on different thickness, as indicated on Table 1.

Each wall was then demolished separately and later broken in a hammer mill, producing four recycled sands with theoretically increasing and different contamination contents, as shown on Table 1.

In between the laying of the masonry and the application of the plastering, a time greater than 30 days took place, and for the grinding of the walls a time of 30 days was also waited.

Besides the recycled sands, named A2, A3 and A4, a non-contaminated recycled sand (A1) and another essentially quartz sand, named AN, were graded similarly and both were used as reference. The quartz sand is of quality controlled by the Instituto de Pesquisas Tecnológicas do Estado de São Paulo – IPT, for Brazilian cements quality control tests.

Table 1: Identification of recycled aggregates generated from built walls in Figure 1.

Base wall					Generated fine recycled aggregate	
Code	Composition	First coating	Gypsum plaster finish coating		Code	Predicted SO <sub>4</sub> content
			Use	Thickness		
P1	Concrete and solid brick masonry (Figure 1)	Cement: lime : river sand	No	-	A1	-
P2			Yes	Fine	A2	≅ 0.1 %
P3			Yes	Medium	A3	≅ 0.3 %
P4			Yes	Coarse	A4	≅ 0.5 %

Tables 2 and 3 next summarize the characteristics physical and chemical composition of the materials utilized in this work.

Table 2: Chemical composition of the materials used in this study, mass %.

Material	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>	PF
A1	65,9	12,2	5,19	<0,10	1,50	6,23	0,45	1,62	1,22	0,10	<0,10	5,77
A2	65,1	11,8	5,41	<0,10	1,62	6,88	0,50	1,58	1,24	0,11	0,12	5,67
A3	65,3	11,4	5,55	<0,10	1,66	7,00	0,52	1,58	1,26	0,11	0,24	5,08
A4	65,5	11,5	5,84	<0,10	1,73	7,08	0,56	1,55	1,31	0,11	0,12*	4,69
Cal CH III	5,5	0,55	0,23	<0,10	28,4	41,3	<0,10	0,12	<0,10	<0,10	<0,10	22,1
CP III E 32	29,8	10,3	1,44	0,43	4,33	49,2	0,20	0,48	0,45	<0,10	0,93	0,67

\* This value was not expected and the test should be repeated.

Table 3: Physical characteristics of the aggregates used in this study.

Material	Bulk density (kg/m <sup>3</sup> )	Material finer than 75 µm (%)	Specific gravity (kg/m <sup>3</sup> )	Water Absorption (%)
Recycled sand - A1	1272	17,8	2719	4,7**
Recycled sand - A2	1301	17,1*	2740	4,7**
Recycled sand - A3	1264	16,9*	2722	3,5**
Recycled sand - A4	1292	16,4*	2715	3,5**
Hydrate lime	-	-	2591	-
Cement CP III E 32	-	-	3080	-

\* Results to be confirmed by laser analyses.

\*\* By now, the water absorption was done just for the fraction aggregate coarser than 75 µm.

### 3.2 Mix proportion and binders used in the mortars

In the main project, the sand/cement ratio of mortars, for being a determinant factor of its intrinsic porosity, was varied as the following three values: 6, 9 and 12, in kg/kg of dry materials, by field of application intended for the mortars under study.

In this work, it will be discussed only the results of the series with a ratio of 6 for being this the one of higher cement content and the one resulting in the lowest porosity.

Therefore for each one of the recycled aggregates (A1 to A4) results will be presented for mix proportions of 1:6 (cement : recycled sand, mass proportioning), being intended at first for use as laying mortar for embedded or structural masonry.

It must stressed that from the point of view of workability slaked lime is not necessary in the mix design with sand/cement ratios up to 9. But in the quartz aggregate AN, of reference, it was necessary to include lime in a proportion close to that of standardized empirical mortars, and the mix proportion used was 1:1:6 (cement : hydrated lime: sand AN).

Cement used was blast-furnace slag (Brazilian type CP III E-32), chosen as a prevention to the formation of ettringite, as it contributes with a lower content of C<sub>3</sub>A.

### 3.3 Mixing method, casting and cure of mortars

The following procedure was used as a mixing method for mortars in a planetary orbit mortar mixer of 12 L volume: **(a)** add water to the mixer; **(b)** add dry aggregate and mix for thirty seconds in slow speed; **(c)** let stand for nine minutes and a half with the bowl open, so that the aggregate can reach an adequate level of saturation; **(d)** add cement (or dry cement

and lime previously homogenised) within thirty seconds, in slow speed; (e) mix a further one minute in fast speed.

For each mortar, 4 cm x 4 cm x 16 cm test samples were cast for testing in the hardened state. Moulds were filled in a single layer and compaction was by applying 20 strokes of a mechanical compactor.

After casting, the samples were taken to the moist chamber (23 °C ± 2 °C; > 95% R.U.), released from moulds after 72 hours and stood there up to 7 days of age, when they were transferred to the dry chamber (23 °C ± 2 °C; 50 % ± 4 %), where they stood up to 63 days.

The choice of the initial 7 days moist cure process, besides nowadays being adopted in European methods of mortar quality control, had the following objectives:

a) Make possible the potential formation of delayed ettringite by admitting that the presence of moisture in masonry executed on the jobsite can occur for the period adopted (7 days) and that at this initial age the tensile strength of mortar can be lower and cause a more intense scenario of micro cracking;

b) Promote cement hydration, both that used in the production of mortars and that one residual eventually present in the recycled aggregates;

The drying phase in the dry chamber, from 7 to 63 days, had the objective of promoting potential shrinkage of mortars and their volume stability, and this might make them more vulnerable to expansion of delayed ettringite, which was expected for the subsequent cycles of wetting and drying.

### 3.4 Initial characterization of mortars at 63 days and cycling up to 175 days

At 63 days of age, sets of three test samples of each mortar were characterized by physical and mechanical tests, summarized in Table 4, which also presents the tests done on the fresh mortar. Should be noted that microstructure mortars will be discussed later, when the main project<sup>[23]</sup> will be concluded.

Table 4 – Fresh and hardened mortar characterization presented in this paper

Mortar condition	Characterization	Test method
Fresh mortar	Flow table – consistence index	NBR 13276/95
	Fresh bulk density	NBR 13278/95
Hardened mortar at 63, 91, 119 and 175 days (3 samples by age)	Compressive strength	EN 1015 Part 11
	Flexural strength	EN 1015 Part 11
	Dinamic elasticity modulus, theoretical value (samples of flexural strength)	Ultra-sonic equipament (PUNDIT)
	Static elasticity modulus, experimental value (samples of compressive strength)	Third cycle, secant modulus between 10 % and 50 % of the strength failure
	Water absorption	EN 1015 Part 10 (similar)
	Dimensional control	EN 1015 Part 13

The accelerated cycle adopted consisted of the exposition of the mortars to a moist chamber for 7 days, with the possibility of capillary suction by the contact face with the chamber shelves, followed by drying in ventilated oven at 40 °C for another 7 days. The choice of this cycle, with total duration of 14 days, was made based on the following criteria:

a) Several studies have adopted wetting and drying to analyze the formation of delayed ettringite, and wetting is necessary for the dissolution of sulfate ions and the occurrence of chemical reactions;

b) Drying allows for better analyzing the effects of crystallization of salts formed in the moist phase and correlates the mass and length variation or the alterations of mechanical strength with the formation of saline products. The option by the temperature of 40 °C was because this one is not aggressive for gypsum products, thus avoiding the risk of thermal decomposition of primary ettringite (above 70 °C).

Eight cycles of 7 days wetting and 7 days drying were programmed. At the ages of 91, 119 and 175 days mechanical tests of samples indicated on Table 4 was expected to take place, besides carrying out dimensional and mass control during the cycling. All mechanical tests were done with samples cast in a single mortar layer, whereas for the dimensional change tests another batch was done.

## 4. RESULTS

### 4.1 Characterization of mortars in the fresh and hardened state at 63 days

Table 5 shows the characterization of mortars studied in the fresh state, and it can be verified that the water requirement for recycled sand mortars and quartz sand ones was different, as the latter makes use of hydrated lime whereas the former had a high content of materials finer than 75 µm, besides water absorption of aggregates being included.

Table 5: Characterization of mortars in the fresh state. Mass dry proportioning: 1:6 (cement : recycled sand) and 1:1:6 (cement : hydrated lime: sand AN).

Type of aggregate	Mortar	Content (kg/m <sup>3</sup> )			Fresh bulk density (kg/m <sup>3</sup> )	ABNT, consistence index (mm)
		Cement	Dry sand	Water		
A1	T1	218	1310	393	1921	283
A2	T2	215	1290	387	1892	285
A3	T3	221	1325	397	1943	255
A4	T4	217	1303	391	1911	263
AN	T5	217*	1305	326	2066	252

\*Additional hydrated lime content equals 217 kg/m<sup>3</sup>.

The average values of compressive strength, flexural modulus, static and dynamic modulus of elasticity of mortars can be seen in Figures 2 and 3 next. The total water absorption at the age of 63 days was uniform for recycled sand mortars with average values in between 26% and 27%. The quartz sand mortar presented value quite lower for such property like 16%.

### 4.2 Variation of the properties by the accelerated test method from 63 days

Figures 2 and 3 also show the results of variation on mechanical strength and modules of elasticity of mortars through the 8 accelerated cycles.

The compressive strength increased from 63 days up to 91 days of age, maybe due to some microstructure changing during the first and second cycles, later it stood stable up to the fourth cycle, with a tendency to a fall in the last cycling considered (119 up to 175 days) in the case of recycled sand mortars. The same comment applies to the flexural strength, but in a much more meaningful way a loss on this property was perceived, and this indicates some

probable process of evolutionary micro cracking that needs to be evaluated by microscopic analysis of cycled and non cycled mortars.

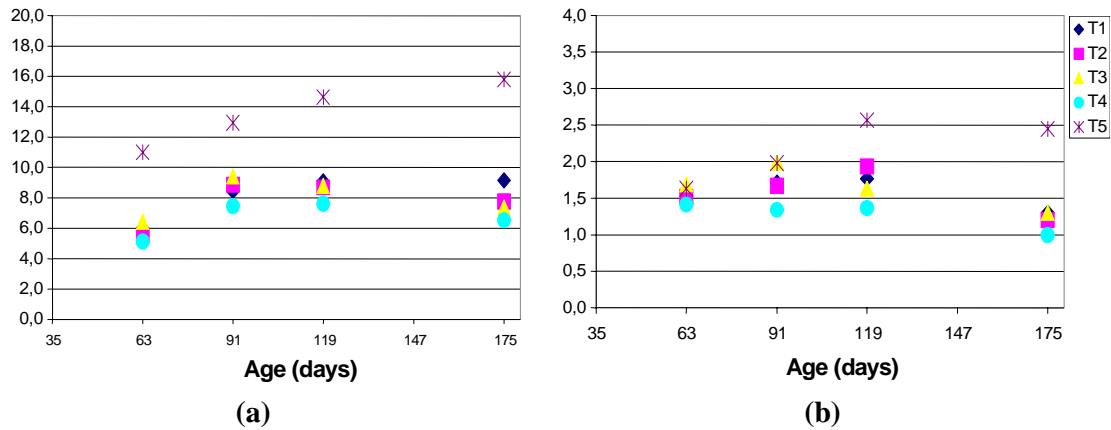


Figure 2 – (a) Average compressive strength (MPa); (b) Average flexural strength (MPa) of mortars during the 8 cycles of wetting and drying, for the properties evaluated in the 2nd, 4th and 8th cycles.

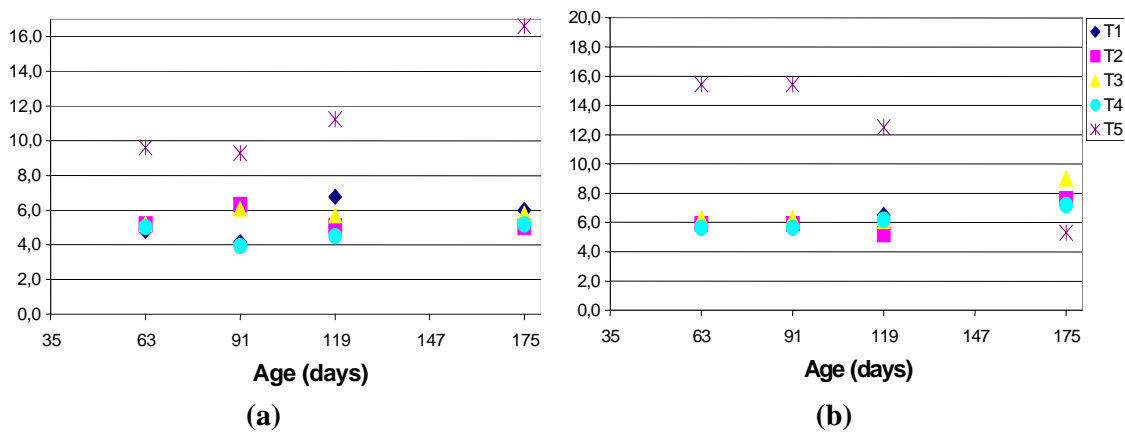


Figure 3 – (a) Average static modulus of elasticity (GPa); (b) Average dynamic modulus of elasticity of mortars (GPa), during the 8 cycles of wetting and drying, for the properties evaluated in the 2nd, 4th and 8th cycles.

The variation in the static and dynamic modulus was similar among the four recycled aggregate mortars and stood in the same range of magnitude up to the 4th test cycle. At the age of 175 days the dynamic modulus test seems to have better reflected the microstructure variations detected by the fall in the tensile strength. Some sealing process of the pores can explain the increase in the dynamic modulus of recycled sand mortars at 175 days during the 8th cycle.

The dimensional change data obtained so far are not shown because they are not conclusive, but they have already permitted to find out that in the recycled sand mortars there was expansion in the range of 1 % during the 1st and 2nd cycles (of 63 to 91 days), thus

confirming that really there was some reaction that started from the first cycling weeks. It should be emphasized that the test samples were cast from another batch.

## 5. CONCLUSIONS

The wetting and drying cycles adopted between 63 and 175 days have shown efficient in the process of accelerated deterioration, as the results of mechanical strength decreased considerably at the end of the cycling.

An increase in the strength of mortars in the 1st and 2nd accelerated cycles (119 days of age) was observed, and this must have been caused by some microstructure changing or reaction hydration, although the mortars have been kept in the moist chamber for 7 days, right after casting.

At the end of the cycling, at 175 days of age, the four mortars studied with recycled sand (cement content in the range of 220 kg/m<sup>3</sup>) lost about 11% to 16% compressive strength as compared to the value at 119 days, excepted those with the non contaminated recycled aggregate (A1). Also, there was an indication that the mortar with the aggregate of higher contamination (A4) would have been the one most impaired as to stability of mortar tensile strength (a loss of 29 %).

The dimensional expansion of mortars up to the end of the 1st cycle (91 days of age) showed values, around 1% with relation at 63 days of drying and that concern us. Such tests will be followed up using the same time range of the mechanical tests, but they already partially confirm the possibility of increase in the strength as seen at this same phase. Microstructure analysis should confirm if this process had any relation to delayed ettringite.

## ACKNOWLEDGEMENTS

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## REFERENCES

- [1] Selmo, S.M.S., 'Produção de argamassas em usinas de reciclagem de RCD', Projeto de Auxílio à Pesquisa (FAPESP n.º 01/11966-9, São Paulo, 2002)
- [2] Miranda, L, Selmo, S. 'Argamassas com areia de entulho reciclado', *Téchne* **74** (11) (2003) 68-71.
- [3] Miranda, L.F.R, Selmo, S. M. S. 'Desempenho de revestimentos de argamassa com entulho reciclado', *BT/PCC/277*, ISSN 0103-9830, 2001, 12 p.
- [4] Miranda, L.F.R., 'Estudo de fatores que influem na fissuração de revestimentos de argamassas com entulho reciclado', Dissertação de Mestrado (Escola Politécnica, Universidade de São Paulo, São Paulo, 2000).
- [5] Levy, S. M. 'Reciclagem do entulho de construção civil, para utilização como agregado de argamassas e concretos', Dissertação de Mestrado (Escola Politécnica, Universidade de São Paulo, São Paulo, 1997).
- [6] Selmo, S. M. S. 'Dosagem de argamassas com cimento portland para revestimentos externos de fachada de edifícios', Dissertação de Mestrado (Escola Politécnica, Universidade de São Paulo, São Paulo, 1989)
- [7] Pinto, T.P.P., 'Utilização de resíduos de construção. Estudo do uso em argamassas', Dissertação de Mestrado (Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos. 1986).
- [8] Miranda, L.F.R.; SELMO, S.M.S. 'Construction and demolition waste variability and its influence on masonry and plastering mortars properties'. In: WASCON 2003 - PROGRESS ON THE ROAD TO SUSTAINABILITY. 2003. INASMET. San Sebastian - Spain, 2003.
- [9] Miranda, L.F.R., 'Desenvolvimento de metodologia para controle de produção de argamassas em usinas de reciclagem', Projeto de Pesquisa de Doutorado (Relatório 1, FAPESP n.º 01/00610-6, São Paulo, 2002)

- [10] Associação Brasileira de Normas Técnicas, 'Agregados para concreto – Especificação – NBR 7211' (Rio de Janeiro, 1987).
- [11] Association Française de Normalisation, 'Granulats pour bétons hydrauliques - NF P 18 541' (France, 1994).
- [12] RILEM Recommendation. '121 – DRG Guidance for demolition and reuse of concrete and masonry' Specifications for concrete with recycled aggregates, *Materials and Structures*. **27** (1994) 557-59.
- [13] Deutsche Institut Für Normung e.V. 'Aggregates for concrete and mortar - DIN 4226 - Part 100: Recycled aggregates' (Berlin, 2002).
- [14] Architectural Services Department, Hong Kong 'Particular Specification for designed mix concrete with 20% recycled coarse aggregates' Disponível em: <<http://www.archsd.gov.hk/english/reports/e378.pdf>>. Acesso em: 1 abr. 2004
- [15] Soberón, J.M.V.G., Ramonich, E.V., Fite, L.A., 'Hormigón com áridos reciclados. Una guía de diseño para el material', Monografía n.º 60 (Centro Internacional de Métodos Numéricos en Ingeniería, Barcelona, 2001).
- [16] Taylor, H.F.W., Famy C. and Scrivener, K.L. 'Delayed ettringite formation' *Cement and Concrete Research*. **31** (2001) 683-93.
- [17] Hime, W.G. and Mather, B., 'Sulfate attack, or is it?', *Cement and Concrete Research*. **29** (1999) 789-91.
- [18] Fu, Y., Ding, J. and Beaudoin, J.J., 'Expansion of portland cement mortar due to internal sulfate attack', *Cement and Concrete Research*. **27** (1997) 1299-306.
- [19] Collepardi, M., 'A state-of-the-art review on delayed ettringite attack on concrete', *Cement and Concrete Composites*. **25** (2003) 401-07.
- [20] Odler, I. Letter to the editor – Ettringite nomenclature. *Cement and Concrete Research*. **27** (1997) 473-74.
- [21] Gallias, J.L., 'Action of gypsum on recycled aggregate concrete', in 'CIB BUILDING CONGRESS', Materials And Technologies For Sustainable Construction, Symposium A (1 Suíça, 1998) 175-82.
- [22] Hincapie, A M., Oliveira, C.T.A., Takeashi, M.S., Cincotto, M.A., Selmo, S.M.S. 'Revestimento de gesso liso: avaliação da aderência e dureza superficial sobre diversos substratos.' In 'Feira Internacional de Tecnologias, Produtos, Serviços, Aplicações e Uso do Gesso/Encontro Nacional da Gipsita, 4/Encontro Nacional do Gesso na Construção Civil', Gypsum Fair'97 (Finep/Sectma/Itep, Olinda, 1997) 119-26.
- [23] Aguiar, G. 'Estudo de argamassas de assentamento com agregados reciclados contaminados por gesso de construção', Exame de Qualificação de Mestrado (Escola Politécnica, Universidade de São Paulo, São Paulo, 2004).