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Concretes and mortars recycled with water treatment sludge and construction and demolition rubble

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ABSTRACT

There are about 7500 water treatment plants in Brazil. The wastes these plants generate in their decantation tanks and filters are discharged directly into the same brooks and rivers that supply water for treatment. Another serious environmental problem is the unregulated disposal of construction and demolition rubble, which increases the expenditure of public resources by degrading the urban environment and contributing to aggravate flooding and the proliferation of vectors harmful to public health. In this study, an evaluation was made of the possibility of recycling water treatment sludge in construction and demolition waste recycling plants. The axial compressive strength and water absorption of concretes and mortars produced with the exclusive and joint addition of these two types of waste was also determined. The ecoefficiency of this recycling was evaluated by determining the concentration of aluminum in the leached extract resulting from the solubilization of the recycled products. The production of concretes and mortars with the joint addition of water treatment sludge and recycled concrete rubble aggregates proved to be a viable recycling alternative from the standpoint of axial compression strength, modulus of elasticity, water absorption and tensile strength by the Brazilian test method.

1. Introduction

All water treatment plants produce wastes in the process of purifying water for human consumption. The volume discarded as waste depends on the characteristics of the operational units involved in the water treatment and the quality of the raw water. These wastes consist of organic and inorganic compounds in solid, liquid and gaseous form, whose composition varies according to their physical, chemical and biological characteristics [1].

The chemical products commonly employed to treat water are aluminum salts ($Al_2(SO_4)_3 \cdot 18H_2O$), ferric ion salts (e.g., $FeCl_3 \cdot 6H_2O$), and ferrous iron salts (e.g., $FeCl_2$, $FeSO_4 \cdot 7H_2O$). The addition of these chemical products during the treatment of water may result in a sludge rich in iron or aluminum. These salts may be present in high concentrations and they can be toxic for the aquatic biota. To avoid this toxicity, the salts should be treated prior to their disposal. The sludge from water treatment plants may also contain other heavy metals originating from the raw water or from contaminants resulting from the addition of coagulants [2,3].

Water treatment sludge contains a large portion of insoluble aluminum hydroxide that can be used as a coagulant in the primary treatment of sewage water to improve the removal of polluting particles. The removal efficiency of suspended solids and the chemical oxygen demand can be improved by adding aluminum from water treatment sludge. This removal is attributed principally to relatively fine particles ranging in size from 48 to 200 μm. The appropriate dosage of aluminum from sludge is 18–20 mg Al/L [4].

The recovery of aluminum by acidification renders the sludge more concentrated and facilitates its dewatering. The recovered Al(III) can be utilized in the removal of phosphorus in the treatment of domestic effluent, but it cannot be reused as a coagulant in water treatment plants. In extremely acid conditions, colloidal organic matter and some heavy metals such as cadmium, copper, and lead are recovered together, and the reuse of the aluminum increases the formation of trihalomethane (THMs) in the treated water [5].

Studies have shown that sludge from water treatment plants can immobilize phosphorus in the ground [6]. Recent studies evaluated the possibility of phosphorus absorption by sludge and its use in other applications [7].

Water treatment sludge can be applied to soil for agricultural purposes, for the recovery of areas degraded by mining activities, and even in sanitary landfills. However, regardless of the purpose of its application, one must take into account the possibility that it may alter not only the water retention capacity but also other structural properties of the soil [8]. The high concentrations of aluminum in sludge tend to fix phosphorus in the soil and hamper the growth of plants. In addition, the contaminants that are present in the coagulant usually contain high concentrations of Pb, Cr, Cd and

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other heavy metals that cause local degradation [9]. Among sludge deposition practices, the sanitary landfill is adopted by approximately 20% of cities with a population of up to 100 thousand in the US [10].

The addition of water treatment sludge to the ceramic mass worsens its technological properties. However, these properties can remain within acceptable limits for the production of bricks, roof tiles and ceramic blocks, depending on the firing temperature and concentration of the mixture. Sludge obtained with aluminum-based coagulants (aluminum sulfate) is more detrimental to the properties of ceramics than sludge obtained with iron-based coagulants (iron chloride) [11]. Ceramic blocks for straight walls into which have been incorporated 12.5% of sludge from the Cubatão water treatment plant in the state of São Paulo, Brazil meet the specifications of the Brazilian standards [12]. The sludge generated in water filtration and cleaning operations can also be used as a concrete hardening retarder and regulator of mortar workability [13].

In Brazil there are approximately 7500 water treatment plants that generate their sludge in decantation tanks and filters and discharge them directly into the same brooks and rivers (Fig. 1) from which the water to be treated is taken [14].

The greater the accumulation of sludge in decantation tanks, the higher the concentration of metals in it and, hence, the greater the environmental impact caused by its unregulated disposal. Table 1 lists the physicochemical characteristics of sludge from the water treatment plants in the municipalities of São Carlos, Araraquara and Rio Claro, in the state of São Paulo, Brazil. At the Araraquara water treatment plant, the sludge is removed up to three times per day. In contrast, the removal of sludge from the São Carlos and Rio Claro water treatment stations is done every three months [14].

Another serious environmental problem is the unregulated disposal of construction and demolition debris. The irregular disposal of these wastes increases the spending of public resources, for in addition to degrading the urban environment (Fig. 2), it contributes to flooding and the proliferation of vectors harmful to public health.

Table 1
Properties of the sludge from the water treatment plants in the municipalities of Araraquara, Rio Claro and São Carlos, SP, Brazil.

Physicochemical characteristics of sludge	Sludge from the water treatment plants in the municipalities		
	Araraquara	Rio Claro	São Carlos
Concentration of solid (%)	0.14	5.49	4.68
pH	8.93	7.35	7.20
Color (uC)	10,650	–	–
Turbidity (uT)	924	–	–
Chemical oxygen demand (mg/L)	140	5450	4800
Total solids (mg/L)	1620	57,400	58,630
Suspended solids (mg/L)	775	15,330	26,520
Dissolved solids (mg/L)	845	42,070	32,110
Aluminum (mg/L)	2.16	30	11,100
Zinc (mg/L)	0.10	48.53	4.25
Lead (mg/L)	0.00	1.06	1.60
Cadmium (mg/L)	0.00	0.27	0.02

Note: It makes no sense to determine turbidity and color in concentrated sludge. Color unit (uC). Turbidity unit (uT).

According to Brazilian regulations, construction and demolition rubble is classified as inert solid waste (Class III). However, this waste may contain elements such as asbestos, which renders it non-inert (Class II) and even dangerous (Class I) [15].

In southern Brazil, the first construction and demolition waste recycling plants were established in the 1990s. However, the market for recycled material only began to grow after CONAMA (Brazil's National Environmental Agency) published its resolution 307 in 2002. According to this regulation, whoever generates these wastes is responsible for their management and final disposal. In 2006, the municipal administration of São Paulo made it obligatory to use material from recycled rubble in paving works and services. However, the balance between offer and demand of these wastes will only be achieved through the commercialization of these materials for the production of mortars and structural concretes. The variability of the composition and strength of these wastes makes this application difficult [15,16].

Fig. 1. Final deposition of the sludge from the water treatment plant of São Carlos, SP, Brazil.

Fig. 2. Degradation of the urban environment in the municipality of São Carlos, SP, Brazil as a result of the unregulated disposal of construction and demolition rubble.

In other countries such as Japan, the United States and China, construction and demolition (C&D) rubble is used for different applications. In Japan, these wastes have been studied for over three decades. However, the use of C&D wastes in engineering applications is hampered by the fact that Japanese standards do not include specifications for concrete containing recycled C&D wastes [17]. In the US, the use of C&D wastes is common, especially in structural concrete (60–70%) [18].

Several studies in China have focused on expanding the use of the inert portion of C&D wastes. An example of this is a study of the viability of using crushed brick and tile derived from C&D wastes as a substitute for fine aggregates in concrete [19].

An analysis of the reports originating from the aforementioned countries indicates that the use of recycled aggregates in concretes requires not only changes in procedures and equipment in recycling facilities but also changes in waste management and in current legislation. Large scale applications are possible through selective demolition and the application of specific techniques for the homogenization of recycled aggregate [20].

2. Objective

The purpose of this research was to evaluate the possibility of recycling water treatment sludge in C&D waste recycling plants, producing concretes and mortar with the exclusive and joint addition of these two types of recycled wastes. In addition, a study was also made of the level of danger of the new materials produced with these wastes.

3. Materials and methods

The construction materials used in southern Brazil and which were employed in this study were Portland CPII-E32 cement, coarse quartzous sand from the Mogi River, and crushed basaltic rock. The wastes used in the development of the recycled products were sludge from the São Carlos water treatment plant and concrete rubble from the solid waste recycling plant in the same municipality. Before their application, the materials were characterized. The recycled products were developed and characterized by axial compression and water absorption tests, and were classified according to their level of danger to the environment. All the tests were conducted following the recommendations of the Brazilian ABNT (Brazilian Technical Standards Association) standards.

3.1. Characterization of the materials

CPII-E-32, a compound Portland cement that meets the Brazilian standards, was used in this study. The granulometric composition of the natural aggregates (sand and crushed stone) was determined in order to define standards for the production of the concretes and mortars under study. The sand presented a characteristic maximum dimension of 4.8 and a fineness modulus of 2.53, while the crushed stone had a characteristic maximum dimension of 19 mm and a fineness modulus of 0.85. The granulometric composition of all the aggregates recycled from construction rubble was determined from the granulometric composition of the natural aggregates (Table 2).

The sludge used in the production of the concretes and mortars studied here was collected from the São Carlos water treatment plant on a day the decantation tanks were cleaned. This plant currently treats about 600 l/s of raw water. The decantation tanks are cleaned every three months. The cleaners climb into the decantation tanks and hose them down with jets of water to loosen and remove the sludge. This cleaning operation lasts about four hours and is done with treated water (Fig. 3).

The sludge is collected during the cleaning process, before the employees enter the decantation tank (Fig. 3). No sludge was collected at any other time because it was too diluted (Fig. 4).

The sludge was oven-dried (Fig. 5) completely and then milled (Fig. 6) in a fine aggregate mill until its grains reached a maximum characteristic dimension smaller than or equal to that of the coarse sand characterized previously.

Table 2
Granulometric composition of the natural aggregates.

Sieve (mm)	Retained and accumulated amount (g)	
	Crushed stone	Coarse sand
25	0	0
19	112	0
9.5	8437	0
6.3	9880	5
4.8	10,000	12
2.4	0	48
1.2	0	255
0.6	0	489
0.3	0	776
0.15	0	952
0	0	1000

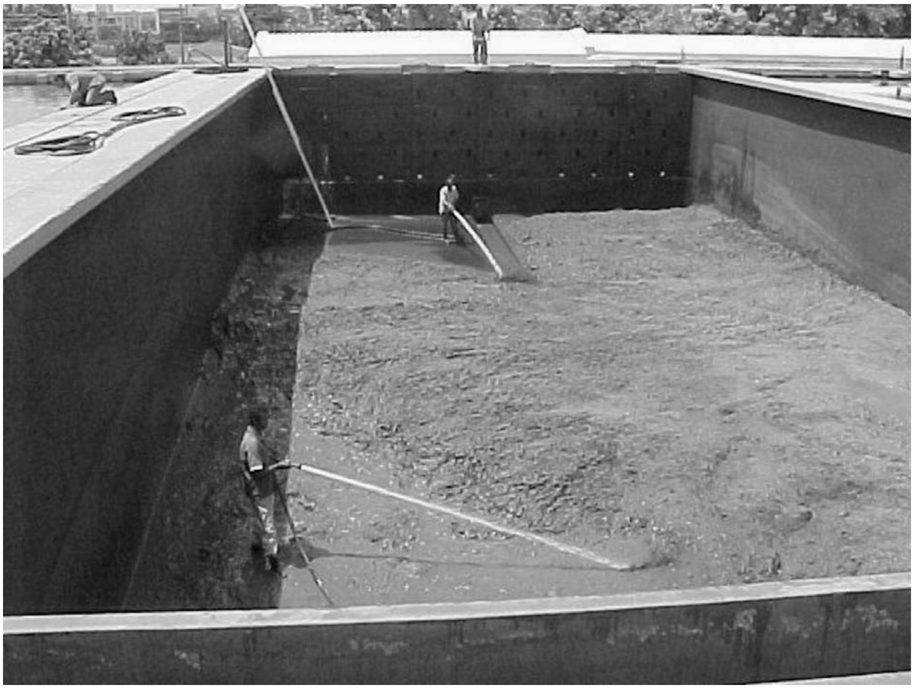


Fig. 3. Cleaning staff inside a decantation tank.

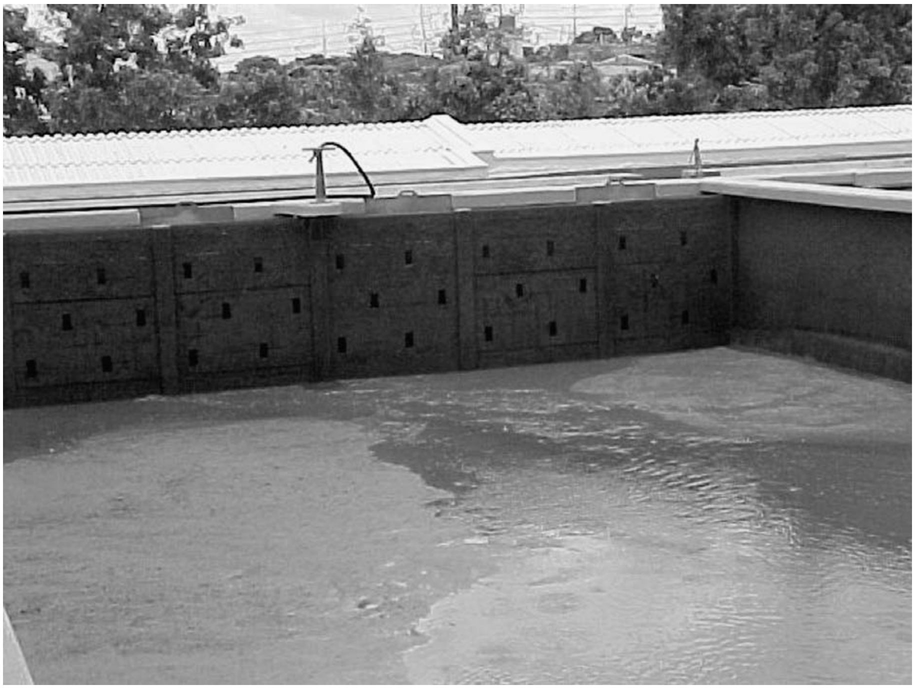


Fig. 4. State of the sludge at the moment of collection.

The construction rubble was collected from the São Carlos waste recycling plant and the recycled aggregates were produced in a laboratory, because the aggregates produced at the plant contained a large proportion of ceramic wastes.

Initially, the construction rubble was crushed and completely dried in an oven. It was then ground, sieved and its granulometric composition ascertained based on the granulometric composition of the natural aggregates.

3.2. Concretes and mortars of this study

The concretes and mortars under study were produced for three construction applications, namely, medium strength structural concrete, underlayment concrete, and blocklaying mortar. The mass ratio of the materials (cement, fine aggregate and coarse aggregate) was set at 1:2:3 for the medium strength concretes, 1:4.6:5.97 for the underlayment concretes, and 1:8 for the blocklaying mortars.

The water-to-cement ratio used in the production of these materials was determined as a function of the consistency established for them. The consistency was set at 50 mm both for the medium strength concrete produced with natural aggregates (CC) and for the concretes containing natural aggregates and partial substitution of sand for sludge (CCL). The partial substitutions of sand for sludge ranged from 1% to 5% and the resulting concretes were dubbed CCL1, CCL2, CCL3, CCL4 and CCL5, respectively.

The consistency was set at 60 mm both for the medium strength concrete produced with coarse aggregates of recycled construction rubble (CRE) and for the concretes containing coarse aggregates of recycled construction rubble and partial

Fig. 5. Sludge oven-dried for 24 h at 110 °C.

Fig. 6. Dried and ground sludge.

substitution of sand for sludge (CREL). The partial substitutions of sand for sludge ranged from 1% to 5% and the resulting concretes were dubbed CREL1, CREL2, CREL3, CREL4 and CREL5, respectively.

Based on the results obtained for the medium strength structural concretes, three types of underlayment concretes were produced: conventional underlayment concrete with natural aggregates (CCC), underlayment concrete with natural aggregates and 3% of sand replaced by sludge (CCCL3), and underlayment concrete with coarse aggregate of recycled construction rubble and 3% of sand replaced by sludge (CCEL3). The consistency of all the underlayment concretes was set at 40 mm.

Three kinds of blocklaying mortars were produced: conventional blocklaying mortar with only natural aggregates (AAC), blocklaying mortar with 2% of sand replaced by sludge (AACL2), and blocklaying mortar with fine aggregate of recycled construction rubble and 2% of the fine aggregate replaced by sludge (AAEL3). The consistency of all the blocklaying mortars was set at 250 mm.

All the concretes and mortars were molded, cured and their axial compressive strength and water absorption determined according to the Brazilian ABNT standards. Some concretes had it modulus of elasticity and tensile strength determined: the concrete produced with coarse aggregates of recycled construction rubble and the concrete produced with coarse aggregates of recycled construction rubble and partial substitution of sand for sludge (5% in mass). The tensile strength was determined by the Brazilian test method.

3.3. Evaluation of the ecoefficiency of recycling

The ecoefficiency of the recycling was evaluated by determining the aluminum present in extract leached from the solubilization of the CREL3 concrete, in line with the procedure described in the ABNT NBR 10.006 standard [21].

Initially, the most representative part of the CREL3 broken at 28 days was immersed and left to stand in deionized water at ambient temperature. At preestablished intervals, aliquots of 20 ml of the leached extract resulting from the solubilization of the CREL3 concrete were collected to determine its pH and ionic conductivity.

The pH tests were carried out to check if the solution became acid or basic over the time the samples were left in immersion.

The ionic conductivity tests were conducted to verify if the concentration of loaded species would increase over the time the samples were left in immersion.

The concentration of aluminum was determined by induction coupled plasma-optical emission spectrometry (ICP-OES), based on the results of the pH and ionic conductivity tests.

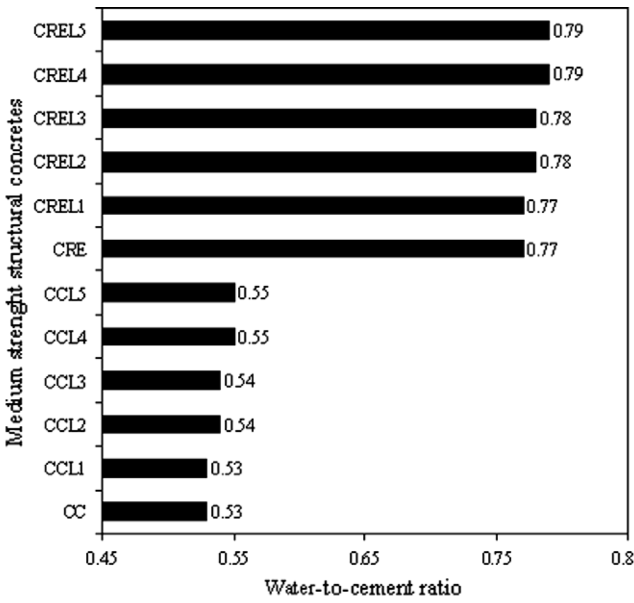


Fig. 7. Water-to-cement ratio of the medium strength structural concretes under study.

The recycled product was classified according the list number 8 of Attachment H of the ABNT NBR 10.004 standard [22], as a function of the concentration of aluminum in the extract leached from the solubilization process.

4. Results and discussion

The partial replacement of natural fine aggregate for water treatment sludge proved feasible in several civil construction applications, namely, in the production of medium strength structural concretes, underlayment concretes, and blocklaying mortars.

4.1. Medium strength structural concretes

The more the quantity of fine aggregates substituted by sludge, the greater the need for water in order to produce concrete or mortar with the same consistency. In the medium strength structural concrete, the water-to-cement ratio increased by 0.01 with every 2% of substituted fine aggregate, using as coarse aggregate either conventional crushed stone or coarse recycled construction rubble (Fig. 7).

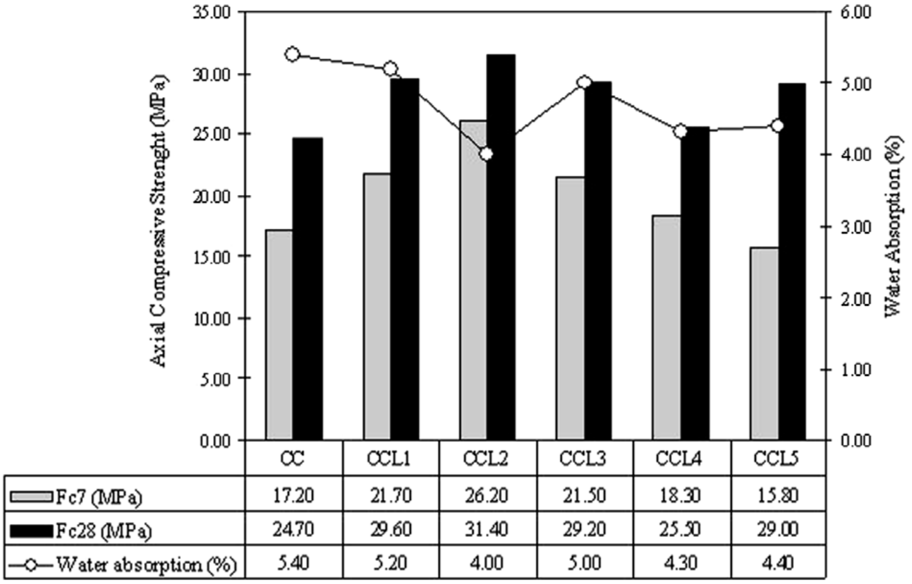
Substitutions of up to 4% of sand by sludge increased the axial compressive strength of all the medium strength structural concretes produced with natural coarse aggregates. However, this substitution diminished the axial compressive strength of all the medium strength concretes produced with coarse aggregates of recycled construction rubble (Figs. 8 and 9).

The best medium strength concrete was obtained with natural aggregates (sand and crushed stone) and 2% of the sand replaced with sludge. This concrete showed greater axial compressive strength and water absorption than the other concretes (Fig. 8).

In all the additions studied here, there was a decrease in the percentage of water absorption of the most representative part of the concretes broken at 28 days (Figs. 8 and 9). Therefore, if the durability of the medium strength concretes is affected, it will not be due to the addition of sludge.

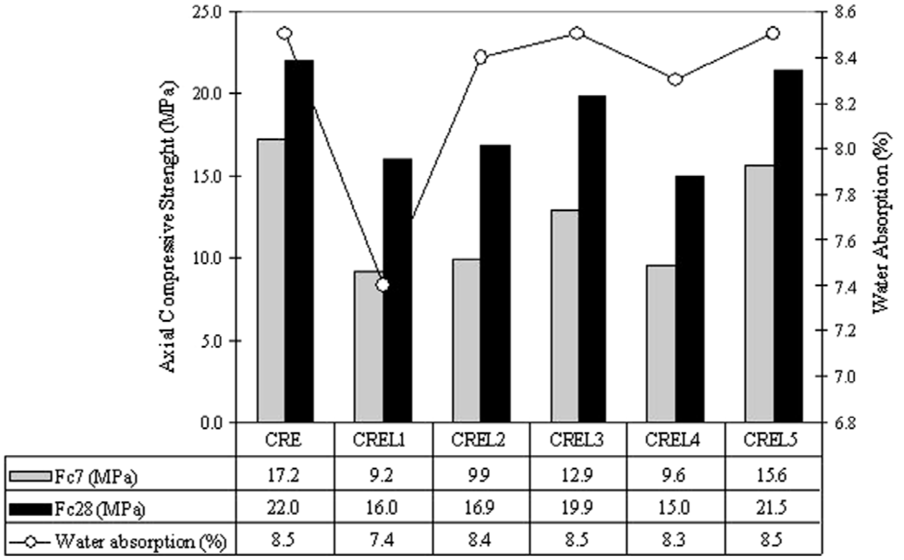
4.2. Underlayment concretes

The underlayment concretes produced with natural aggregates and 3% of the sand replaced by sludge showed a similar axial compressive strength and water absorption as that of the conventional underlayment concretes (Fig. 10).



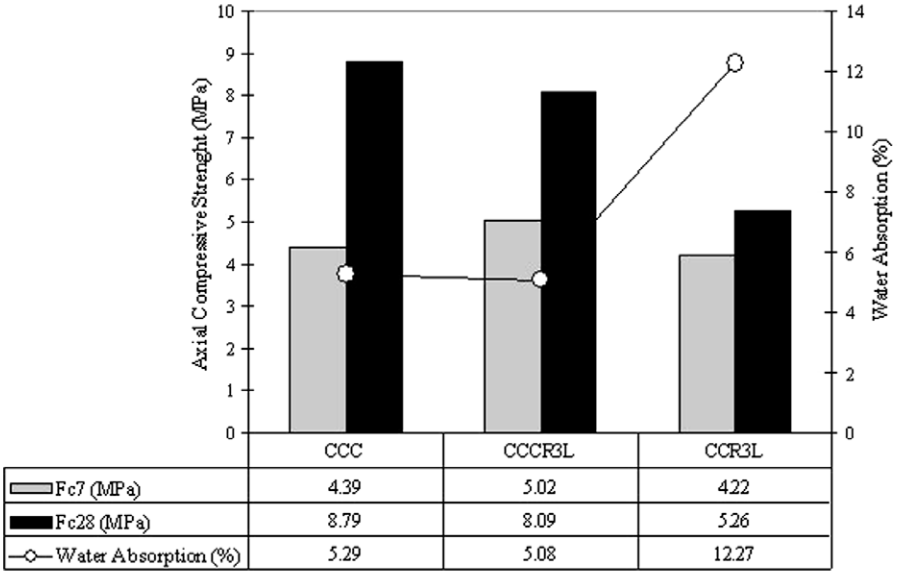
	CC	CCL1	CCL2	CCL3	CCL4	CCL5
▭ Fc7 (MPa)	17.20	21.70	26.20	21.50	18.30	15.80
■ Fc28 (MPa)	24.70	29.60	31.40	29.20	25.50	29.00
—○— Water absorption (%)	5.40	5.20	4.00	5.00	4.30	4.40

Fig. 8. Axial compressive strength and water absorption of the medium strength concretes produced with natural aggregates and substitution of fine aggregate by sludge.



	CRE	CREL1	CREL2	CREL3	CREL4	CREL5
▭ Fc7 (MPa)	17.2	9.2	9.9	12.9	9.6	15.6
■ Fc28 (MPa)	22.0	16.0	16.9	19.9	15.0	21.5
—○— Water absorption (%)	8.5	7.4	8.4	8.5	8.3	8.5

Fig. 9. Axial compressive strength and water absorption of medium strength concretes produced with coarse aggregate of recycled construction rubble and substitution of fine aggregate by sludge.



	CCC	CCCR3L	CCR3L
▭ Fc7 (MPa)	4.39	5.02	4.22
■ Fc28 (MPa)	8.79	8.09	5.26
—○— Water Absorption (%)	5.29	5.08	12.27

Fig. 10. Axial compressive strength and water absorption of the underlayment concretes.

However, the same substitution of underlayment concrete produced with coarse aggregate of recycled construction rubble showed a 40.2% loss of axial compressive strength at 28 days and a 7% increase of water absorption (Fig. 10). This result suggests the substitution of a lower amount of sand by sludge and does not prevent its application in underlayments. However, the use of this concrete should be restricted to weather and humidity free spaces.

4.2.1. Stress–strain curve and modulus of elasticity

The results showed that there wasn't notable difference between the compressive stress–strain curve of concrete produced with coarse aggregates of recycled construction rubble and the compressive stress–strain curve of concrete produced with coarse aggregates of recycled construction rubble and partial substitution of sand for sludge (5% in mass) (Figs. 11 and 12).

4.2.2. Tensile strength

The tensile strength was determined by the Brazilian test method. The obtained results went 2.85 MPa to the concrete produced with coarse aggregates of recycled construction rubble and 3.05 MPa to the concrete produced with coarse aggregates of recycled construction rubble and partial substitution of sand for sludge (5% in mass). Result without significant difference.

4.3. Blocklaying mortars

The blocklaying mortar produced with the substitution of 2% of the natural fine aggregate by sludge showed lower axial compressive strength than the conventional blocklaying mortar (without the addition of sludge). The same held true of the blocklaying mortar containing the same quantity of sludge and fine aggregate of recycled construction rubble (Fig. 13). This result can be explained

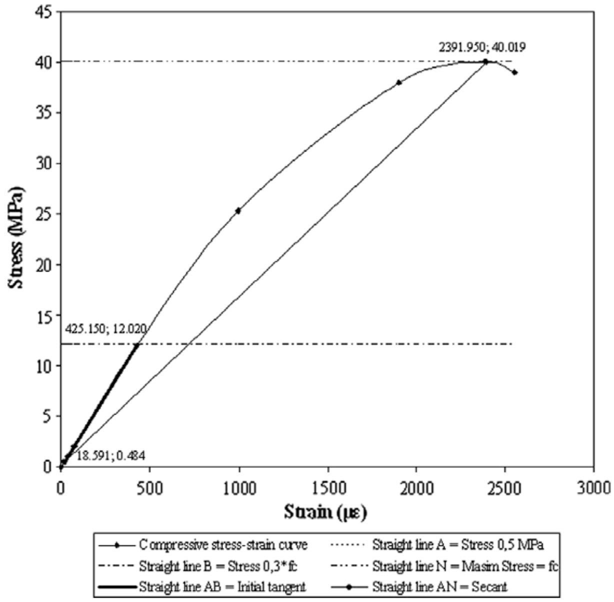


Fig. 11. Compressive stress–strain curve of concrete produced with coarse aggregates of recycled construction rubble.

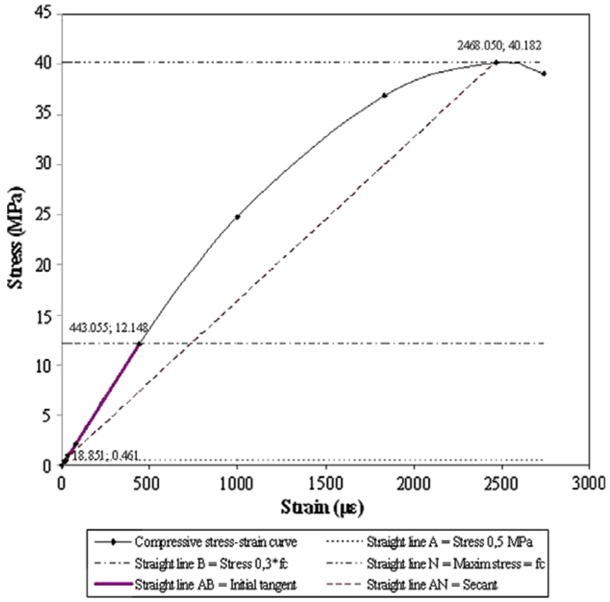


Fig. 12. Compressive stress–strain curve of concrete produced with coarse aggregates of recycled construction rubble and partial substitution of sand for sludge (5% in mass).

by the fact that the blocklaying mortar produced with natural fine aggregate and 2% of sludge was prepared with a smaller amount of water than the other mortars. In addition, the sludge shows greater absorption, thus reducing the cement's hardening ability.

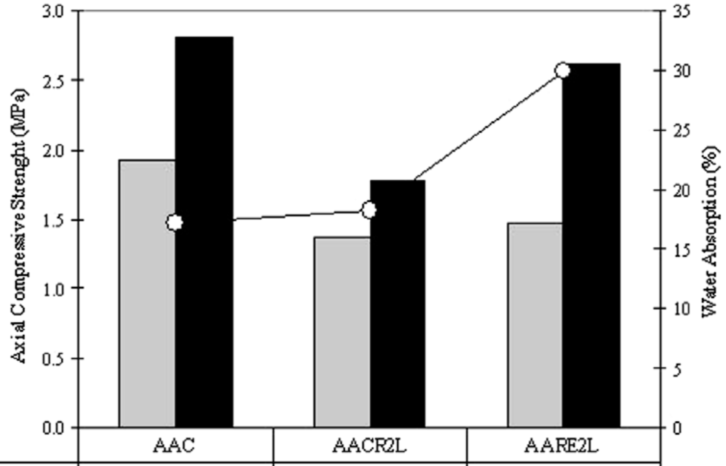
The fact that the blocklaying mortar containing the two recycled wastes shows a 12.8% higher water absorption than the conventional bricklaying mortar (Fig. 13) does not preclude its application, but restricts its use to humidity free spaces.

4.4. Ecoefficiency of the recycled concretes and mortars

A significant increase was found in pH and in ionic conductivity in the leached extract of the solubilized CREL3 sample (72 h of immersion in deionized water). After 72 h of immersion, there was a gradual reduction and the pH and ionic conductivity tended to stabilize (Fig. 14). This enables us to state that leaching occurred more rapidly at the beginning of solubilization and carried more alkaline species into the water. These species may have originated from the sludge or from the hydration of the cement itself (hydroxides).

To ascertain the order of magnitude of the concentration of aluminum to which the values of ionic conductivity refer, these values were compared with the values of a KCl solution. This solution is considered the standard for measures of ionic conductivity and is used to calibrate conductivity meters (Table 3).

If there are monovalent ions in solution, the concentration of this species will be higher than 74.246 g/L for a conductivity of 111.340 mS/cm at 25 °C. When one considers bivalent and trivalent species, this concentration is even lower, for the conductivity increases with the ion load and the conductivity is a value that refers to the total load of species.



	AAC	AACR2L	AARE2L
▨ Fc7 (Mpa)	1.92	1.37	1.47
■ Fc28 (MPa)	2.80	1.78	2.62
—○— Water Absorption (%)	17.20	18.21	29.97

Fig. 13. Axial compressive strength and water absorption of the blocklaying mortars.

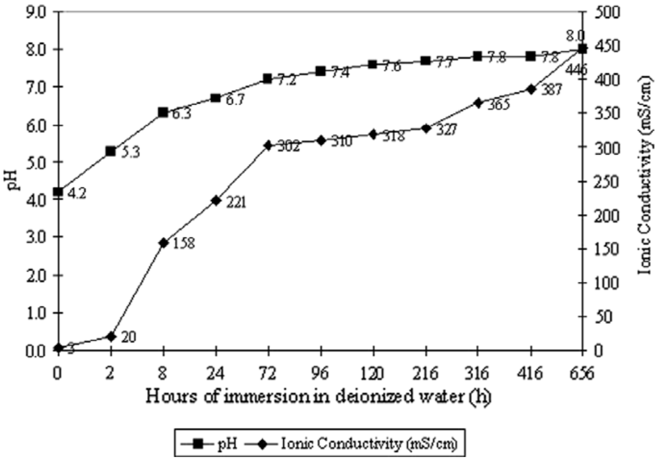


Fig. 14. pH and ionic conductivity of the leached extract resulting from the solubilization of CREL3 in deionized water.

Table 3
Values of ionic conductivity as a function of the KCl concentration in g/L.

Concentration (KCl g/L)	Ionic conductivity (mS/cm) at 25 °C
74.246	111.340
7.437	12.860
0.744	1.409
0.074	0.147

Table 4
Concentration of aluminum (mg/L) in the leached extract of the solubilized CREL3 concrete.

Sample	Hours of immersion (h)	Concentration of aluminum (mg/L)
4	72	1.92
10	656	<Detection limit (0.13)

The concentration of aluminum in the leached extract from the solubilized CREL3 was determined for the samples collected after 72 and 656 h of immersion in deionized water. These time intervals represent the regions of highest and lowest increase of the pH and ionic conductivity, respectively (Table 4).

It can therefore be stated that the concentration of each species was lower, for the concentration of aluminum decreased after longer immersion times, reaching such a low concentration that it became undetectable by the device (Table 4). Knowing that more than one species originates from the hydration of cement in the form of calcium carbonate and aluminates, it can also be stated that the concentration of each species was even lower.

The results indicated aluminum concentrations that exceeded water potability standards, without, however, rendering the leachate from this concrete harmful.

5. Conclusions

The production of concretes and mortars with the joint addition of water treatment sludge and aggregated from recycled C&D wastes may offer a recycling alternative that is feasible from the standpoint of axial compression strength and water absorption. Sludge may be applied as a regulator of consistency and plasticity and, in suitable quantities, can even increase the compressive strength of concretes and mortars produced for a given application. The results of this study allow us to state that the application of water treatment sludge in concretes and mortars does not render the future leachate from these products harmful. The joint application of these two types of waste offers an intelligent form of utilizing C&D waste recycling plants to also recycle sludge. The results obtained in this work open new possibilities for future studies, because, for a mortar or a concrete to be applied, other properties such as retraction by drying and chemical retraction must be evaluated. It is also worth pointing out the importance of studies that encourage the use of wastes and the development of ecoefficient materials, especially in developing countries.

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References

[1] Bourgeois JC, Walsh ME, Gagnon GA. Comparison of process options for treatment of water residual streams. J Environ Sci 2004;3:477–84.
[2] Fytianos K, Voudrias E, Raikos N. Modelling of phosphorus removal from aqueous and wastewater samples using ferric iron. Environ Pollut 1998;101:123–30.
[3] Mun KJ. Development and tests of lightweight aggregate using sewage sludge for nonstructural concrete. Constr Build Mater 2007;21:1583–8.
[4] Guan Xiao-Hong, Chen Guan-Hao, Shang Chii. Reuse of water treatment works sludge to enhance particulate pollutant removal from sewage. Water Res 2005;39:3433–40.
[5] Sengupta AK, Shi B. Selective alum recovery from clarifier sludge. J Am Water Works Assoc Lancaster 1992;64(10):96–103.
[6] Makris KC, Harris WG, O'Connor GA, Obreza TA, Elliott HA. Physicochemical properties related to long-term phosphorus retention by drinking-water treatment residual. Environ Sci Technol 2006;39:4280–9.
[7] Razali M, Zhao YQ, Bruen M. Effectiveness of a drinking-water treatment sludge in removing different phosphorus species from aqueous solution. Sep Purif Technol 2007;55:300–6.
[8] Bidone F, Silva AP, Marques DM. Lodos produzidos nas estações de tratamento de água (ETAs): desidratação em leitos de secagem e codisposição em aterros sanitários. In: Resíduos sólidos do saneamento: processamento, reciclagem e disposição final. Rio de Janeiro: RIMA/ABES/PROSAB; 2001. p. 215–44 [cap. 9].
[9] Lenzi E, Nogami EM, Galli D, Morales MM et al. Estudo do lodo da ETA de Maringá (PR) e seu possível destino. In: Proceedings of the 22nd congresso brasileiro de engenharia sanitária e ambiental, Joinville, Brazil; 2004.
[10] AWWA. An assessment of cropland application of water treatment residuals. USA: AWWARF; 1995.
[11] Teixeira SR, Souza SA, Souza NR, Aléssio P, Santos GTA. Efeito da adição de lodo de estação de tratamento de água (ETA) nas propriedades de material cerâmico estrutural. Cerâmica 2006;52:215–20.
[12] Morita DM, Sampaio AO, Miki MK, David AC. Incorporação de lodos de estações de tratamento de água em blocos cerâmicos. In: Proceedings of the 10th encontro simpósio luso-brasileiro de engenharia sanitária e ambiental, Braga, Portugal; 2002.
[13] Raupp-Pereira F, Silva L, Segadães AM, Hotza D, Labrincha JA. Potable water filtration sludge: use as set retarder in one-coat plastering mortars. Constr Build Mater 2007;21:646–53.
[14] Cordeiro JS. Processamento de lodos de estações de tratamento de água (ETAs). In: Resíduos sólidos do saneamento: processamento, reciclagem e disposição final. Rio de Janeiro: RIMA/ABES/PROSAB; 2001. p. 121–42 [cap. 5].
[15] John VM, Agopyan V. Reciclagem de resíduos da construção. In: Seminário nacional sobre reciclagem de resíduos sólidos domiciliares. São Paulo. Anais. Secretaria de Estado do Meio Ambiente. CETESB; 2001.
[16] Carvalho K. Mercado de agregados. Rev Construção Mercado 2007;75:36–41.
[17] Kawano H. The state of using by-products in concrete in Japan and outline of JIS/TR on recycled concrete using recycled aggregate. In: Proceedings of the 1st PIB congress on recycling; 2003. p. 245–53.
[18] Robinson Jr GR, Menzie WD, Hyun H. Recycling of construction debris as aggregate in Mid-Atlantic Region, USA. Resour Conserv Recy 2004;42:275–94.
[19] Poon Chi-Sun, Chan Dixon. The use of recycled aggregate in concrete in Hong Kong. Resour Conserv Recy 2007;50:293–305.
[20] Mesters K, Kurkomski H. Density separation of recycling building materials by means of jig technology. Aufbereitungs Tech 1997;38:536–42.
[21] Associação Brasileira de Normas Técnicas. In: Procedimento para obtenção de extrato solubilizado de resíduos. NBR10006, Rio de Janeiro, Brasil; 2004.
[22] Associação Brasileira de Normas Técnicas. Resíduos Sólidos: Classificação. NBR10004, Rio de Janeiro, Brasil; 1987.