QUALITY UPCYCLING OF MIXED CDW COARSE RECYCLED AGGREGATES

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ABSTRACT

This paper discusses the influence of red ceramic content on the porosity of Brazilian mixed C&D recycled aggregates and how the removal of red ceramic from such aggregates by optical sorting lab tests can upcycle its quality and improve concrete mechanical performance. The available data shows that it is possible to improve mixed CDW recycled aggregate quality for production of conventional strength structural concrete by removing low-density, high-porous particles, which are predominantly ceramic in most Brazilian sources. Colour sorting does not use water and the process is not influenced by water absorption of the particles as is gravity concentration. A similar efficiency can be achieved when the content of cementitious materials with high porosity (water absorption higher than 7%) is secondary (< 10%). Pure concrete aggregates will result in a cleaned colour sorted product, therefore the best process for quality improvement of mixed CDW recycled aggregates (automatic sorting or gravity concentration) must consider the actual composition of the local CDW stream and environmental issues.

Key – words: Mixed Construction & Demolition Waste, Recycling, Upcycling, Recycled Aggregates, High Quality.

1 Introduction

In many countries, Construction & Demolition Waste (CDW) is predominantly a mixture of different materials including ceramic, mortar, concrete and rock with contaminants (Mueller, 2003; Angulo et al., 2004; Tam, Tam, 2007). Table 1 presents some characterization results of CDW in different Brazilian cities. In two of the three cities where research was conducted, the amount of soil mixed into the CDW was high, probably because this material is classified within the same group of concrete and masonry waste according to Brazil Resolution 307 of the National Council for the Environment (CONAMA). Pure concrete waste in Brazil is not common since concrete pavement is not often used and most reinforced concrete buildings use masonry for wall partitioning, and this is not currently sorted by dismantling procedures. Therefore, mixed CDW is the typical material available for recycling and it is very difficult to run a recycling plant that accepts pure concrete waste.

Table 1 - Composition of incoming containers of CDW in different Brazilian cities

Cities (state)	CDW mixed with soil (% of total load)	Pure concrete waste containers (% of total)
Maceió (AL)	ND	0
Macaé (RJ)	27	18
São Paulo (SP)	25	44

The results are expressed as a percentage of the total incoming containers (authors' data).
ND - not determined

Developing economically attractively and sustainable applications of CDW in concrete, including waste with mixed composition, is considered crucial since road applications are not capable of consuming all the CDW (Hendriks, 2000). Most CDW recycled coarse aggregate standards for concrete (DIN, 2002; ABNT, 2004) specify two parameters in order to control the quality of aggregates: composition, which limits the content of phases like masonry and other contaminants, and physical properties. Brazilian CDW recycled aggregates are highly heterogeneous in terms of composition and physical properties (Angulo et al., 2004) and most do not comply with any of these standards.

Angulo et al. (2010) have shown that density separation of coarse mixed C&D recycled aggregates is capable of reducing the overall porosity of grains, and overall porosity is the key aggregate property that controls the mechanical performance of concrete. Maintaining the coarse C&D recycled aggregates porosity at lower than 17% (water absorption < 7%) is especially important for producing concrete up to 20-30 MPa.

At industrial scale, this density separation can be achieved by jigs (Figure 1) which have been used in Europe to remove lightweight organic contaminant materials (Derks et al., 1997). However, the consumption of large amounts of water in jigs has certain environmental implications. Another strategy for producing high quality recycled aggregates is reducing porous phases, like cement paste attached to the gravel through diverse crushing stages (Nagataki et al., 2004), as well as thermal treatment and abrasion of particles (Shima et al., 2005). However, these techniques have only been proven in the removal of cement paste from pure concrete waste, and the efficiency for mixed C&D waste (with red ceramic) is unknown.

The removal of porous red ceramic, wood particles and plaster is possible by optical sorting (Mulder et al, 2007). A line scan colour camera (CCD) image processes in real time on a dedicated computer and identifies the colour of each particle. A computer controlled air injector removes the undesirable particles.

This paper discusses the influence of red ceramic content on the porosity of Brazilian mixed C&D recycled aggregates and how the removal of red ceramic from such aggregates by optical sorting lab test can upcycle its quality and improve concrete mechanical performance.

2 MATERIALS AND METHODS

2.1 Characterization assays of mixed CDW recycled aggregates

Three mixed CDW recycled aggregate samples were collected from two recycling plants owned by local authorities in São Paulo and Vinhedo, both located in the state of São Paulo. A 2-ton sample was taken from each recycling plant over a 20-day production period, then homogenized, crushed (< 25.4 mm) and reduced to near 60 kg for characterization assays. The samples represented the average composition of mixed CDW in the cities (Angulo et al., 2004). The main difference between the two recycling plants was the type of crusher, which were impact and jaw crusher, respectively. The samples were sieved at coarse size fractions of from 25.4 to 4.8 mm using 4 screens with nominal apertures: 19.1; 12.7; 9.5; 4.8 mm.

In order to investigate the density and porosity distributions of some phases (red ceramic, cement covered particles and rock particles) for each sample, 1-5 kg of each size fraction were taken for sequential sink-float separation (Figure 1). The heavy liquid separation was conducted in a zinc chloride ($ZnCl_2$) water solution with densities of 1.7 and 1.9 kg/dm^3, and then in a bromoform ($CHBr_3$) and ethylic alcohol solution of 2.2 and 2.5 kg/dm^3. Initial data analysis was presented in Angulo et al. (2004).

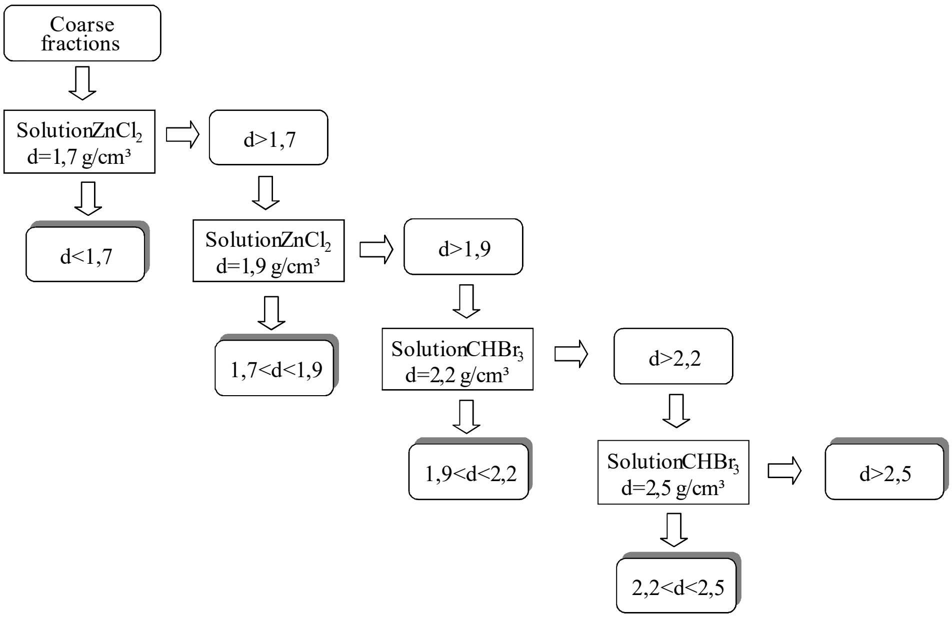


Figure 1 - Heavy-liquid sequential density separation

Oven-dry density (with internal pores) of coarse size fraction samples (> 4.8 mm) at each density interval was measured according to ASTM C 127 as well as water absorption. The method consists of mass sample determinations before and after 24 hours of particle immersion in SSD (saturated surface-dry) condition.

For each coarse size fraction, the phases' composition at each density interval was evaluated in 3-5 kg samples by hand sorting (ABNT, 2004). Particles were divided into: (a) cement covered particles; (b) rock; (c) red ceramic; (d) white ceramic; (e) asphalt; (f) cement asbestos; and (g) other (mixture of two phases). The oven-dry densities and water absorptions of phases were also determined in accordance with the presented methods to characterize the density and porosity distributions.

To validate some conclusions on paper, some unpublished data of additional mixed coarse CDW recycled aggregates from some Brazilian cities located in other states (Macaé, Maceio, etc) were added, as were data from the city of Santo Andre (state of São Paulo).

2.2 Lab optical sorting characterization assays

The RGB (red, green, blue) tiff extension images of hand-sorted phases (red ceramic, cement covered particles and rock) of coarse fractions of CDW recycled aggregates (-25.4+19.1 mm; -19.1+12.7mm; -12.7+9.5 mm) from Itaquera were acquired in 2005 using a 1,300 x 1,300 pixel CCD camera, Axiocam HR Zeiss, 12 bits per colour channel, 256 colour intensity/channel.

Three lamps (2 x 60 W and 1 x 100 W) were used to provide the artificial illumination system. The image resolution was 6.2 pixels/mm. The RGB colour intensities were extracted using Image-Pro Plus 4.0 software, Media Cybernetics, and separability according to these parameters was discussed.

An experiment using an optical automatic sorting machine was conducted at CommoDaS/Titech in Wedel, Germany. Coarse concrete and red ceramic aggregates (4-32 mm) were obtained at Bauhaus Universtät Weimar along with three mixes featuring different red ceramic content (17.1, 37.7 and 87.7 %).

The samples were humidified with water to improve the colour contrast before passing to the scanning level. The CCD camera detected the red ceramic colour differences and processed a command to separate this material. The free falling particles detected as red brick were removed by pulses of compressed air at the end of the belt and collected as rejects. The other particles compose the accepted material. The accepted and rejected materials were submitted to hand sorting in order to evaluate separability efficiency.

2.3 Concrete produced with mixed C&D aggregates

The influence of red ceramic content in mixed CDW recycled aggregates on the compressive strength of concrete was analyzed using the data from Passos (2009); Zordan (1997) and Bazuco (1999).

3 RESULTS AND DISCUSSIONS

3.1 The influence of red ceramic content on porosity of mixed CDW recycled aggregates

The composition of mixed coarse CDW recycled aggregates changed according to density intervals (Figure 2). The material with density lower than 1.7 kg/dm^3 was essentially wood, plastic and paper and its mass was lower than 1 %. It was not considered in the analysis.

The red ceramic represented the main phase at the lowest density interval (d< 1.9 kg/dm^3). The remarkable influence of red ceramic on the amount of material with density lower than 1.9 kg/dm^3 was confirmed with data from Brazilian cities located in other states (Macaé-RJ and Maceió-AL) (Figure 3). This material was mainly concentrated at densities lower than 2.3 kg/dm^3.

Rock represented the main phase at the highest density interval (d> 2.5 kg/dm^3). Cement covered particles were present at all density intervals. Others were composite, non liberated red ceramic-cement particles.

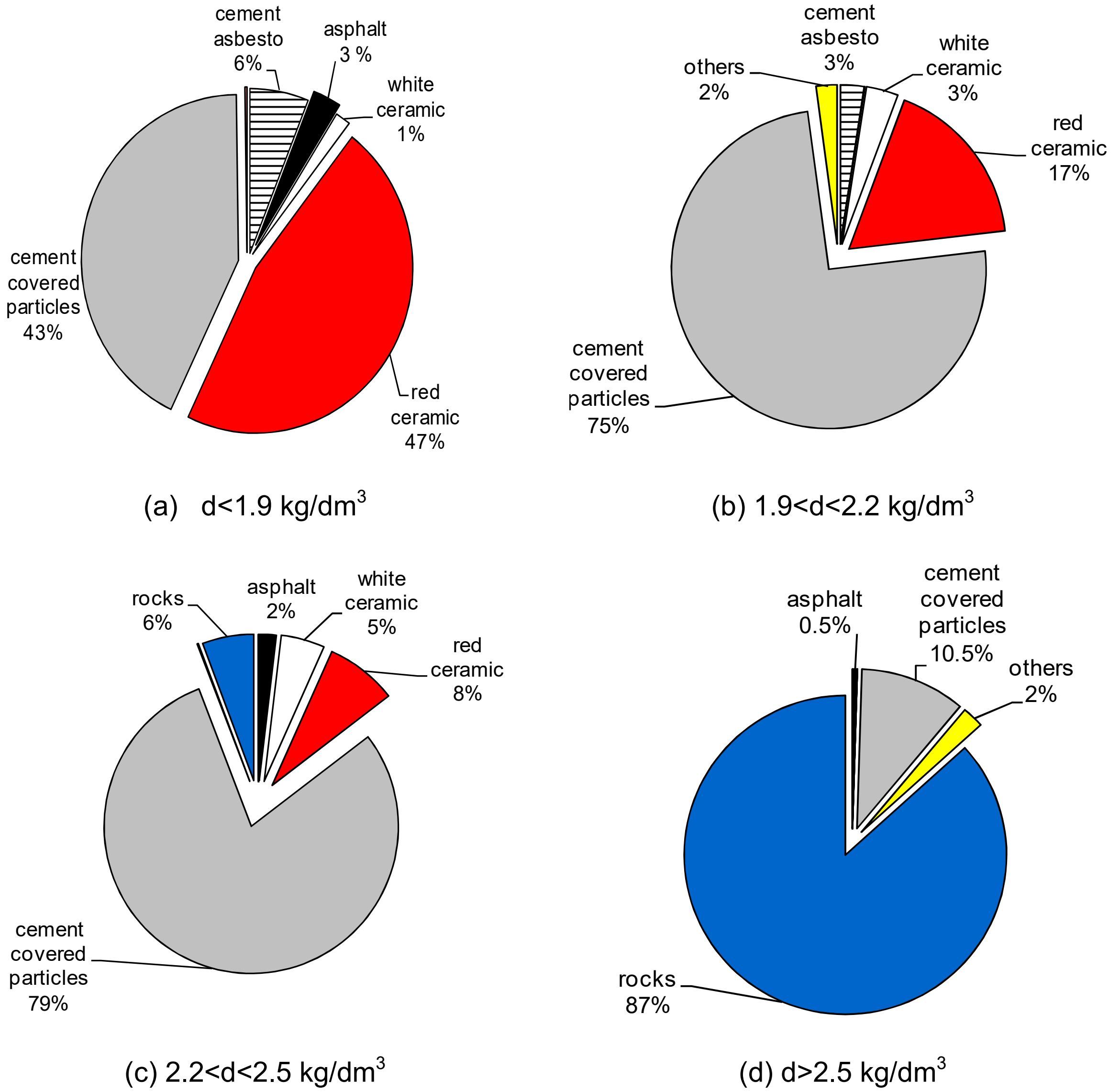


Figure 2 - The composition of mixed CDW recycled aggregates in function at density intervals (City of Vinhedo and São Paulo – state of Sao Paulo)

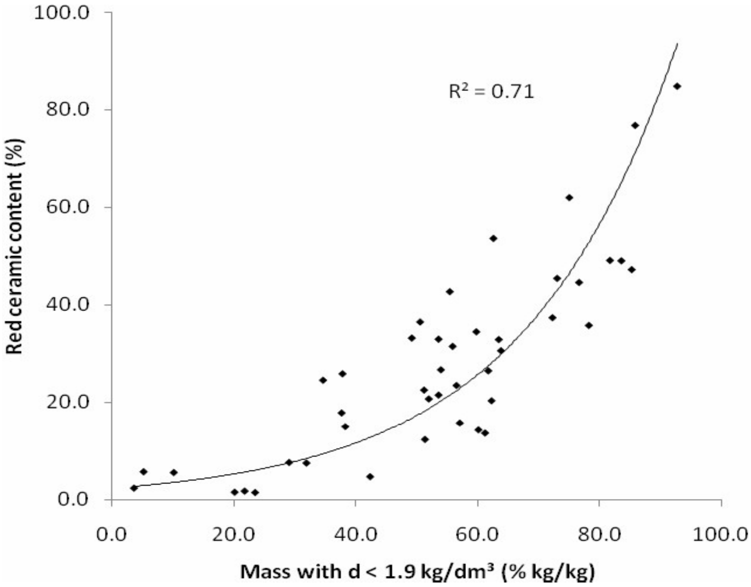
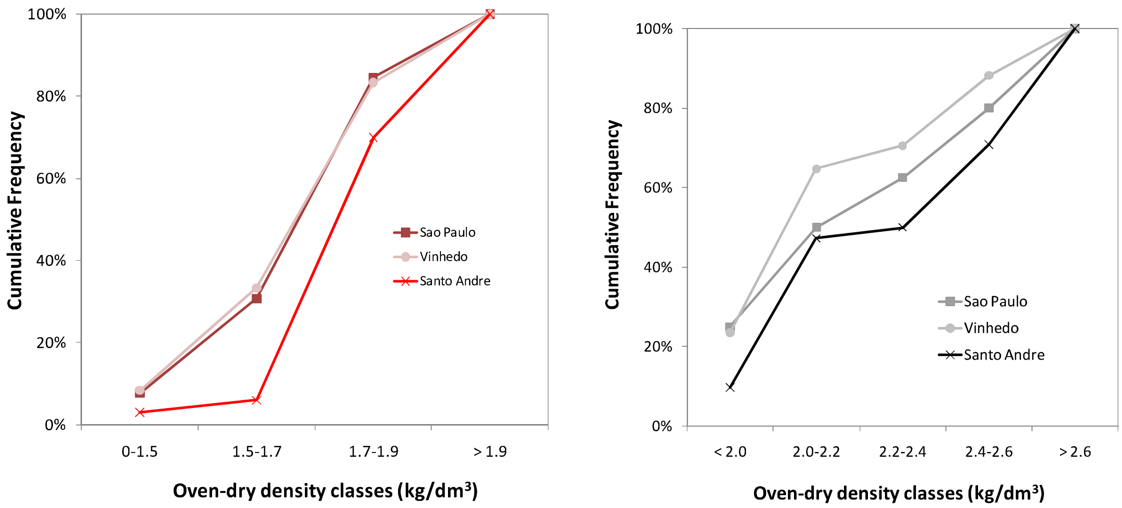
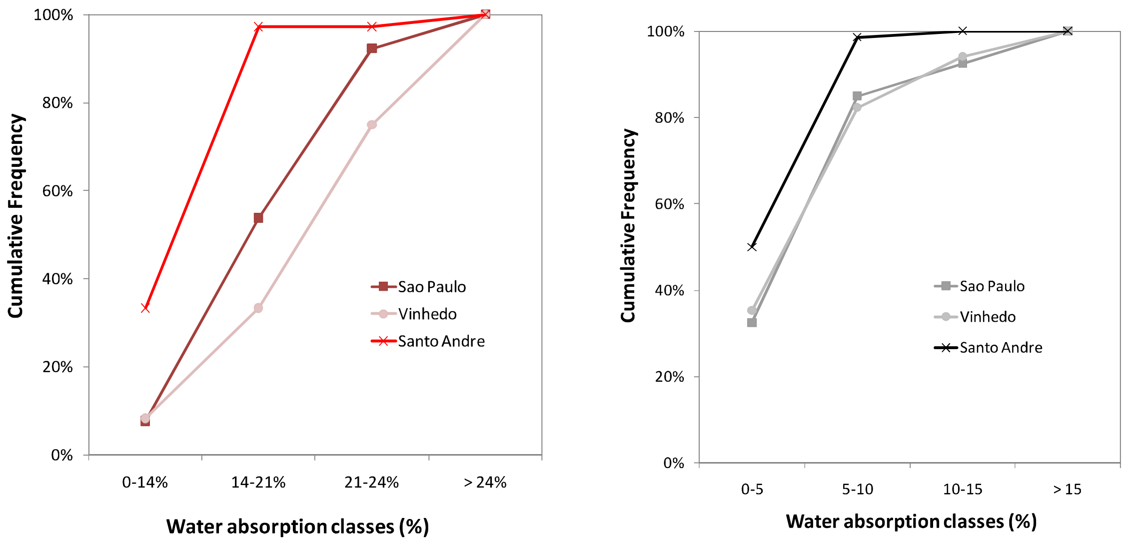


Figure 3 - Red ceramic content x mass amount of particles at density lower than 1.9 kg/dm^3 in mixed C&D recycled aggregates (Macaé, RJ and Maceió, AL)

Figure 4 presents oven-dry density and water absorption cumulative frequency distributions for red ceramic particles and cement+rock particles. The samples are not only from Sao Paulo and Vinhedo but also Santo Andre.





(a) red ceramic particles (b) cement-rock particles

Figure 4 - Oven-dry density and water absorption cumulative frequency distributions for red ceramic particles (a) and cement-rock particles (b) of mixed CDW recycled aggregates from Vinhedo, Sao Paulo, and Santo Andre (state of Sao Paulo)

Red ceramic is the phase responsible for the lower fractions of CDW recycled aggregates with oven-dry densities lower than 1.9 kg/dm^3. Only 20% of cement+gravel particles have oven-dry densities lower than 2.0 kg/dm^3. Around 90% of red ceramic particles present water absorption higher than 14%. Almost 100% of cement+gravel particles present water absorption lower than 15%, which is the reason the amount of red ceramic can directly influence the water absorption of CDW recycled aggregates in spite of high dispersion due to intrinsic variability (Figure 5).

It is also possible to note in the data some peculiarities of density distribution related to the local building materials market as well as the waste source. CDW recycled aggregates from Santo Andre are slightly denser than other Brazilian cities because the recycling plant owned by the city council received an unusually high fraction of concrete from public projects. Vinhedo, on the other hand, is a low-rise town where most of the waste came from single homes built with masonry and little reinforced concrete. These particularities will affect operation profitability and must be evaluated when planning the design of a processing plant. However, crushing reduces particle porosity (Nagataki et al. 2004) and can at least partially compensate for this.

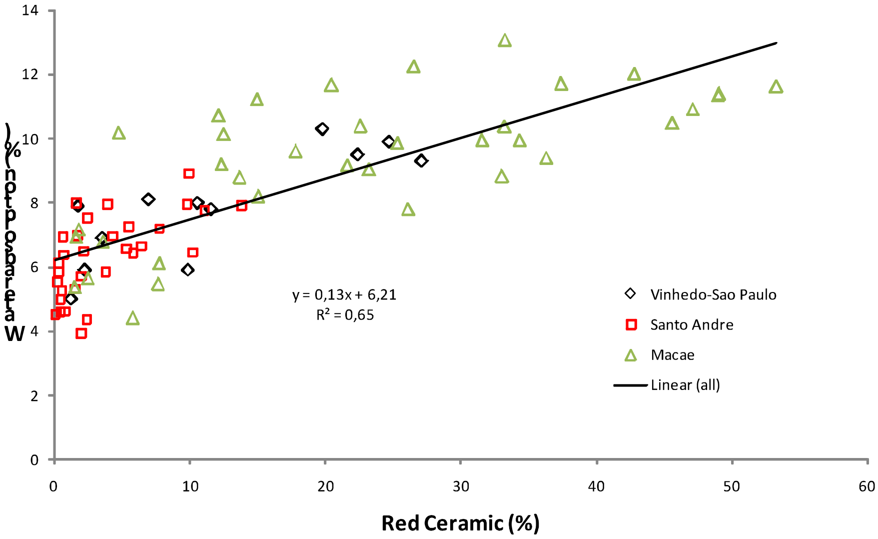


Figure 5 - Correlation between red ceramic contents and water absorptions of mixed CDW recycled aggregates

3.2 The removal of red ceramic to up-cycle C&D coarse aggregate quality for concrete

Figure 6 shows the lab scale experiment of red ceramic distinction of the other phases (cement covered particles, rocks and white ceramic) when analyzed with the green and red RGB signal intensities of a CCD camera. Such parameters were adjusted for optical sorting experiments where separability of red ceramic was investigated.

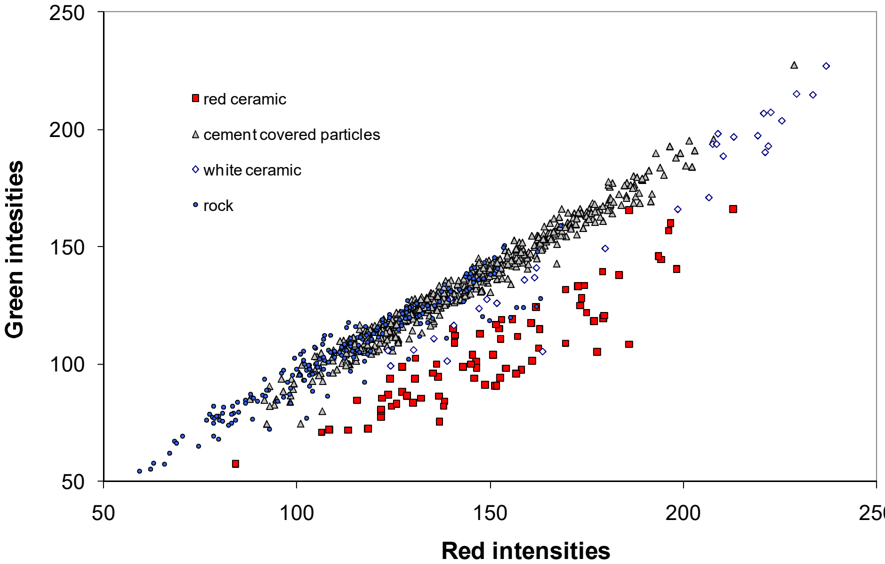


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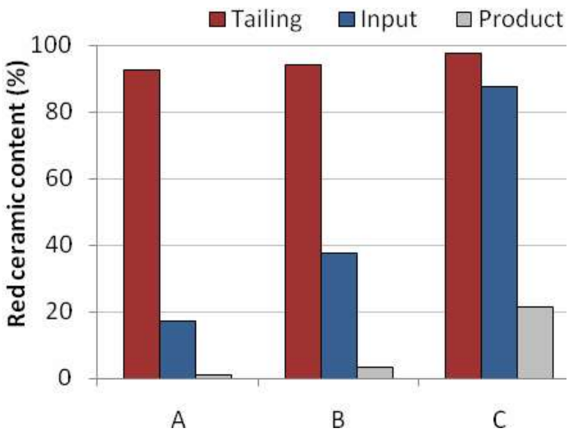
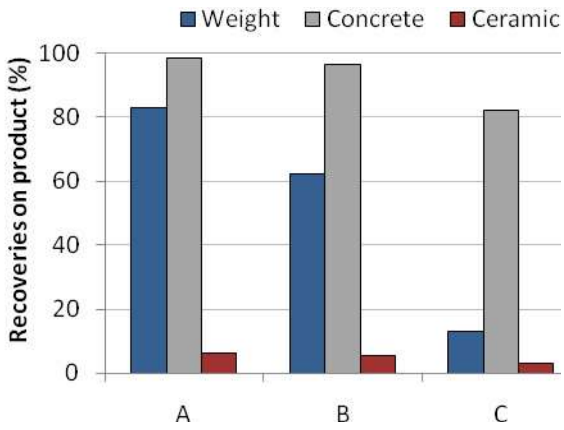
Figure 6 - Correlation between green and red intensities using the Axiocam HR Zeiss for the coarse phases of CDW recycled aggregates (São Paulo)

The colour sorting technology efficiency was reduced depending on the amount of red ceramic in mixed CDW recycled aggregates (Figure 7a). This was probably due to the availability of air injectors and relative positions of particles. In CDW recycling plants, the content of red ceramic mixed into CDW recycled aggregates used to be lower than 50% in mass (Figure 5). One stage colour cleaning is enough to reduce the content of red ceramic to a level lower than 10% with very high selectivity and recovery – from 82 to 98% for non-ceramic materials.



(a)



(b)

Figure 7 - Content of red ceramic in the input and output products from optical sorting (a); distribution of weight, concrete and red ceramic in attained products (b)

Figure 8 shows how the compressive strength of concrete can improve through the removal of porous red ceramic in mixed CDW recycled aggregates. This analysis was constructed with experimental Brazilian data from Passos (2009); Zordan (1997) and Bazuco (1999). The authors investigated the concrete mechanical performance of different red ceramic content inside CDW recycled aggregates. With total removal of red ceramic, concrete aggregates will remain, which is why water absorption of the resulting CDW aggregate would drop to approximately 7% from the original 14% after total red ceramic removal (Figure 5).

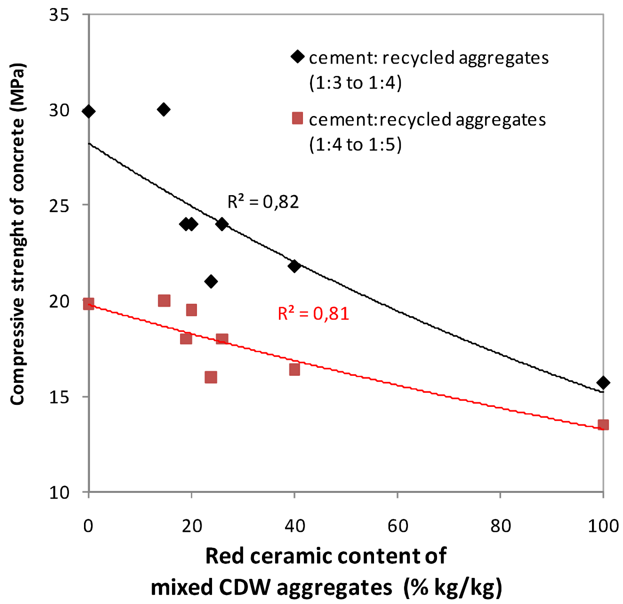


Figure 8 - The influence of red brick content of mixed CDW recycled aggregates on concrete compressive strength

Color sorting has the advantage of not using water. The optical sorting equipment is not capable of detecting high-porosity and low strength cement-based particles such as mortar and cement asbestos; however, fractions of these particles cannot be separated by jigs either because water absorption will increase the oven-dry density particles, which includes the volume of pores, thereby reducing separation efficiency (Mueller; Wienke, 2004). In many cases, like the São Paulo sample, the removal of the ceramic fraction is enough to achieve good performance for conventional strength structural concrete. In other samples, like Vinhedo, a gravity separation of all porous fractions seems to be more suitable.

4 CONCLUSIONS

The available data shows it is possible to improve the quality of mixed CDW recycled aggregates for production of conventional strength structural concrete by removing low-density, high-porous particles, which are predominantly ceramic in most Brazilian sources. Quality control of this industrial process can be mostly based on water absorption and the maximum amount of particles with low oven-dry density.

Colour sorting does not use water and the process is not influenced by water absorption of the particles as is gravity concentration. The separation is very efficient and non-ceramic recovery is very high – 82 to 98% for samples with red ceramic feed content ranging from 17 to 88%. Pure concrete aggregates will result in clean colour sorted product, therefore the best process for quality improvement of mixed CDW recycled aggregates (automatic sorting or gravity concentration) must be based on the actual composition of the local CDW stream and environmental issues.

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REFERENCES

Angulo, S.C.; Ulsen, C.; Carrijo, P.M.; John, V.M.; Kahn, H. (2004). “Characterization of Brazilian construction and demolition coarse recycled aggregate”. In: International Rilem conference on the use of recycled materials in building and structures. Barcelona.

Angulo, S.C. et al (2010). "On the classification of mixed construction and demolition waste aggregate by porosity and its impact on the mechanical performance of concrete ". *Materials and Structures*, 43, 519-528.

Bazuco, R. S. (1999). “Concrete waste recycled aggregates for new concretes”. Master Dissertation Thesis (Federal University of Santa Catarina). 123 p. In Portuguese.

Brazilian Association of Technical Standards ABNT (2004). “NBR 15116: aggregates from construction and demolition waste: requisites for use in pavements and concrete”. Brazil. 12p.

Deutsche Institut fur Normung DIN (2002). “Aggregates for mortar and concrete—part 100: recycled aggregates”. Germany.

Derks, J. W. et al. (1997). “Wet processing of demolition rubble with Pulsator Jigs”. *Aufbereitungs-technik*, 38 p.139-143.

Hendriks, C. F. (2000). The building cycle. Aeneas, Netherlands.

Mueller, A. (2003). “Recycling von Mauerwerkbruch: stand und neue verwertungswege (teil 1)”. *Ziegelindustrie International*, 56, 17-25.

Mueller, A.; Wienke, L. (2004). “Measurements and models for the gravity concentration of C&D waste through jigging”. In: International Rilem Conference on the use of recycled materials in building and structures, Elsevier, France, v.1, p. 115-122.

Mulder, E. et al. (2007).” Closed Cycle Construction: an integrated process for the separation and reuse of C&D waste”. *Waste Management*, 27, 1408–1415

Nagataki, S., Gokce, A., Saeki, T. and Hisada, M. (2004). “Assessment of recycling process induced damage sensitivity of recycled concrete aggregates”, *Cement and Concrete Research*, 34, 965-971.

Passos, L. Pinto Jr., N. O.; Ramos, M. F. (2009). “Mix experimental design of Red Ceramic Waste”. In: 51 Congresso Brasileiro do Concreto, Brazil. CD-ROM. (In Portuguese).

Shima, H.; Tateyashiki, H.; Matsuhashi, R; Yoshida, Y. (2005). “An advanced concrete recycling technology and its applicability assessment through input-output analysis”, *Journal of Advanced Concrete Technology*, 3, 53-67.

Tam, V. W. Y.; Tam, C. M. (2007). “Crushed aggregate production from centralized combined and individual waste sources in Hong Kong”. *Construction and Building Materials*, 21. p. 879–886.

Zordan, S. E. (1997). “Use of contruction and demolition waste as aggregates to concrete production”. Master Disseration Thesis (University of Campinas). 156 p.