

Characterization of three recycled materials for alternative use of mortars

F. Guadalupe Cabrera-Covarrubias, J. Manuel Gómez-Soberón, Jorge L. Almaral-Sánchez, Ramón Corral-Higuera, Antonia Navarro-Ezquerria, Marc Tous-Coll

Abstract— Because natural resources in construction are limited, it is advisable to look for new alternatives that meet comparable functions, and likewise, reduce consumption of non-renewable resources. The use of recycled materials is of benefit to the uncontrolled elimination of residues that cause the use of the public resources, such as landfills. In addition, this contributes to the reduction of the environmental impact caused by the industries in the process of obtaining the same ones. Therefore, recycled materials such as concrete or masonry demolished, glass and ceramics different, can be employed in different ways to be used in the construction industry. This work focuses on presenting the initial characterization of three recycled materials as an alternative to use in replacement of natural sand in mortars, this as a first step for further study in different percentages of replacement, as currently his understanding is unknown, or little known.

Keywords— recycled aggregates, recycled aggregate characterization, sustainable mortars.

I. Introduction

Currently, due to increased waste production and taking into account the environmental problems that these cause, as the case of the restriction of landfills; recycled materials can be utilized within the construction industry (1) in order to achieve sustainable growth in the economy and society (2), (3). This implies a new respectful approach to the environment (4) in actual construction.

As current alternative for replacing recycled aggregates for use as mortar, demolition materials, such as concrete or ceramic (bricks and tiles), masonry, or other minor representation as waste wood, plastic, etc. (5), should be included as a potential suitable for use.

F. Guadalupe Cabrera-Covarrubias, J. Manuel Gómez-Soberón, Antonia Navarro-Ezquerria, Marc Tous-Coll
Universidad Politécnica de Cataluña
Spain

Jorge L. Almaral-Sánchez, Ramón Corral-Higuera
Universidad Autónoma de Sinaloa
México

Alternatively other residue from other industry is the glass, which is a usual product that can be found in applications such as bottles, containers, windows, windshields, light bulbs, cathode ray tubes, etc. (6), (7), which have a limited time of use, and their re-use, storage or deposit is not feasible. It is therefore urgent to find

alternatives to the use of this waste glass to provide environmental solutions.

Finally, another possible origin of second generation materials is the brick coming from the tile manufacturing industry, in which large volumes of defective products are generated and also seems feasible in the application in the mortar and concrete, in improving the mechanical properties and durability (8), (9), (10).

In Spain, the new Instruction of Structural Concrete (EHE-08) regulates some application of recycled materials, allowing the use of the coarse fraction (≥ 4 mm), replacing up to 20% of natural aggregate by recycled aggregate in conventional concrete. Because of this, a large amount of recycled fines cannot be reused in concretes or roadbeds (11).

In this sense, the manufacture of mortars is a potential application for the use of the fine fraction of recycled concrete (12) or of others aggregates mentioned. Unlike the concrete, mortars do not follow a specific rule, which limits them to being governed to requirements of design and utilization of materials.

Therefore, the use of recycled materials in construction is an attractive option with good expectation for the high number of possible material to use, for their low quality requirement applied, and its simple constitution in its production (13). For all of the above, the present work aims to provide the initial studies required for the characterization of these (aggregates of demolished concrete, ceramic and glass), in order to verify the feasibility of its use in the manufacture of mortars.

II. Materials

To give as feasible a new application of a material by incorporating it within a cementitious matrix, is first necessary to know their basic physical and mechanical properties in accordance with the provisions in the rules of the product to create, then make a second verification of these, contained in the element as an integral part of it (mortar). The origin of the aggregates of residues of concrete, glass and ceramics used in this work, are present below.

A. Natural aggregate

The aggregate used for comparison of recycled aggregates (NA) was siliceous sand, acquired in a local company marketer of arid for the construction. This

aggregate is constituted by particles with grain size 0 to 4 mm (Figure 1a).

B. Recycled concrete aggregate

The aggregate used in this work (RCA) was facilitated by a local company with authorization of the waste Agency of Catalonia for the recycling of construction waste. The facilitated material included sizes of particles between 0 to 20 mm, by what it was needed sift the material for the mesh Not 4, with the purpose of to segregate the fractions thick and fine and thus collect only the fine fraction (Figure 1b).

C. Recycled glass aggregate

The glass aggregate (RGA) used is from a local industry, which processes laminate glass recycled (windows, doors and windshield). The samples are ranging in size from 0 to 1.8 mm and transparent color (Figure 1c).

D. Ceramic recycling aggregate

This aggregate (CRA) comes from the same company that the RCA before presented, was gathered the fraction from 0 a 5 mm whose origin was the manufacture of ceramic tiles rejected for failing to meet production standard. This material is sieved through mesh No. 4 to segregate the coarse fraction and use only the fine fraction (Figure 1d).

likewise of the natural sand used as element of reference and control appears in the TABLE I.

TABLE I. Tests and standards used in experimental campaign.

TEST	NORM
Granulometry	ASTM C144-99, ASTM C136, ASTM C702-98
Materials Finer than 75-µm (No. 200) Sieve	ASTM C117-95
Fineness modulus (MF)	ASTM C136-06
Bulk density (“unit weight”) compacted/ loose, and voids	ASTM C29/C29M-97
Density	ASTM C128-04a
Absorption	ASTM C128-04a

The previous compendium of essays include the basic properties that are applicable to the design and dosage of mortars, providing the necessary data are established to guarantee its use, and therefore the possibility of replacement of fine aggregate.

iv. Results

The obtained results allow doing a qualitative and quantitative analysis of the studied aggregates facilitating the interpretation, correlation and implication in his possible replacement to constitute a recycled mortar.

A. Granulometric properties

The granulometric profile of an attached is a property that they allow to determine the fulfillment of the ideal distribution of the size of his particles, guaranteeing a solid, dense and efficient structure of the mortar that contains it. In Figure 2 presents the distribution of sizes of particles, as well as the limits set by the standard ASTM C144.

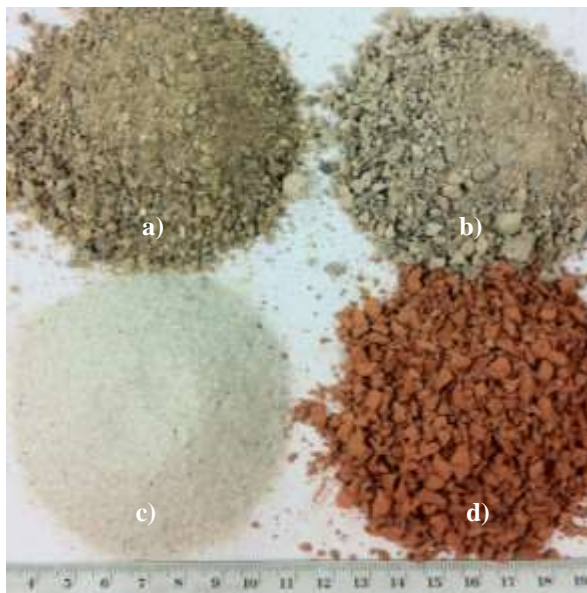


Figure 1. Recycled aggregates: a) NA, b) RCA, c) RGA y d) CRA.

iii. Methodology

The procedures of test were performed according to the ASTM International standards. The type and designation of specification of the tests realized to obtain the characterization of the recycled materials used in this study,

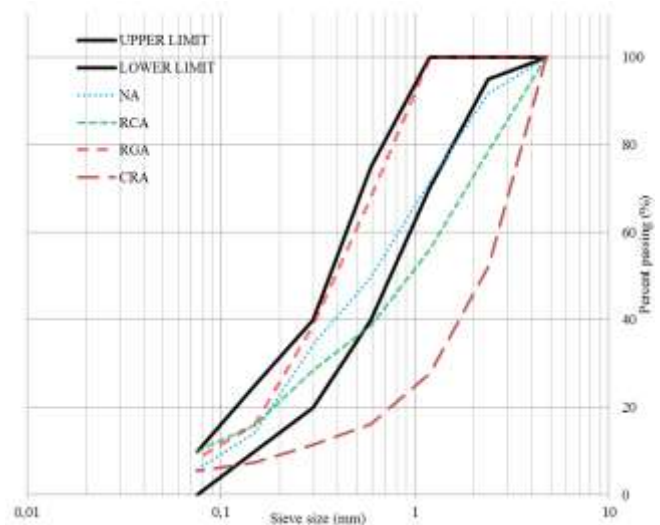


Figure 2. Granulometric graph of the aggregate ones in study.

As shown, the AN is included in the limits of the norm, except in the sieve No. 8 (2.38 mm). For the RCA, the granulometric profile is below the lower limit in the area of the particles from the sieve No. 30 which shows that more than half of the sample is thicker than the lower limit. This possibly would imply that when used in a mortar, its porous structure would be greater, and therefore require more cement to fill the gaps caused by the lack of smaller particles.

For the case of RGA its curve lies within established the limits, which could ensure appropriate properties in the mortar that integrate it (at least regarding his distribution, not to his reactivity).

The CRA contains higher amount of aggregates in the coarse fraction in practically the entire route of its curvature, just a 4.19% (No. 200 sieve) of the sample enters the standard limits. The use of these aggregates would entail a lot of voids, resulting in a weak structure due to the low compactness between the particles.

Therefore, in regard to the comparison of all the aggregates analyzed, the AN and the RGA are compliant with the granulometric profile (ASTM C144). Nevertheless the RCA and the CRA not (though the first one yes partially). Because of this, these aggregates require an adjustment of distribution of particles in order to correct its natural profile and conform to ASTM standard, thus making them suitable for the manufacture of mortars. The above, it will allow guaranteeing that all the aggregates could be used in comparable conditions (between them and between the aggregate of reference).

On the other hand, other habitual properties linked to the distribution of the particles it is the so called modulus of fineness (MF) and the percentage of fines content (sieve No. 200, 0.075 mm); both properties allow to have an approximate notion and global of the same ones. The values reached for the MF were: 2.38, 2.82, 3.85, 1.77, and fines content of: 5.80, 9.93, 5.44, and 8.16; for AN RCA, RGA, and CRA, respectively. This information classifies RGA as thin sand, to AN and RCA as average sand and to CRA as coarse sand.

From these results we can say with respect to the MF, that the values of the AN and the RCA are inside the limits of the norm ASTM C33 (value between 2.3 to 3.1), while the CRA and RGA exceeded it, this means that the CRA is a "coarse aggregate", whereas the RGA material is considered to be "fine aggregate". To this, we must say that this parameter is usually considered as an average value representative and valid only for quick reference and without significant consequences for their behavior.

In terms of the fines content in materials, all of them are below a coefficient of finesse $<$ 10; This value is the reference to the amount of fines passing the No. 200 sieve, and in this study, the percentages obtained by the recycled aggregates, such as the AN are among the limits (ASTM C144), in this case, is of highlighting the compliance with this criterion important for the sands, since the possible

applications of the fine fraction (usually maximum in recycled aggregates by his origin of the crushed one) is comparable to the of a AN.

B. Physical properties

1) Density

The results of density in dry (OD), density in saturated surface-dry (SSD), and the apparent density (SSD) saturated surface-dry of the aggregates used in this research, are presented in the following Figure 3 for easy comparison.

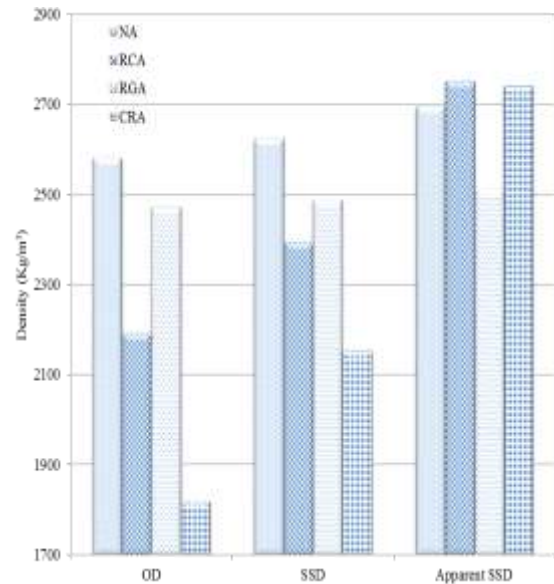


Figure 3. Densities of recycled aggregates and natural.

Emphasizing the RCA (Figure 3), shows that the density (OD) presents the less of the different studied densities, in principle attributable to their high volume of pores. Density (SSD) is 9.24% higher than the density (OD) (this refers to the amount of water within the pores of the aggregates particles). Finally, apparent density (SSD) is 25.47% higher than the density (OD) (this density, believes that the material has no pores and is therefore completely solid).

With respect to the RGA, minor differences were observed in terms of the different densities studied, which are justified by the compact matrix structure.

In the case of the CRA, SSD density is 18.37% greater than the density OD (difference caused by absorption and the high porosity). On the other hand, the apparent density SSD is 50.46% higher than the OD density.

If the three materials are analyzed as a whole, we can say the natural aggregate is more dense material of the three, which implies that the possible substitution of other aggregates should take into account the effects that this can cause; even to the extreme case of the ceramic, with values of up to 1.5 times less than natural.

This implies that some usual empirical correlations of mortars that relate: the density with the resistance, the density with the amount of water and the cement, or density with durability, in recycled mortars can be modified or require specific assessment.

Therefore, in terms of variations in density, dry density (OD) report lower, followed by SSD values, and finally the apparent density (SSD) is the one with highest values. These differences of density are related to the different quantities of present pores in these materials, and thus the porosity factor, becomes determinant in the feasibility of application of these aggregates. This is necessary to consider, as in other reports is this property of the recycled materials which can cause variations in the mechanical resistance level (12).

2) Absorption

The absorption results obtained by the aggregates studied are presented in the Figure 4. It can be observed that there is a big difference between the materials studied, from 0.6% for the minimum case of RGA, up 18.37% for the case of CRA (30 times).

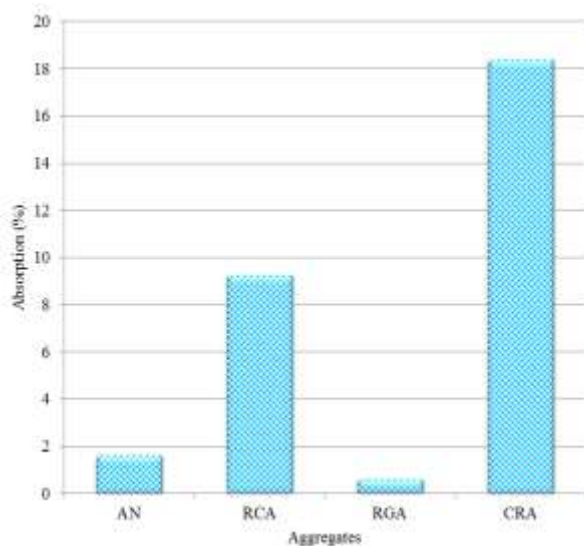


Figure 4. Percentage of fine aggregate absorption.

For what it concerns to the similarity with respect to the AN, we can say that RCA and the CRA are superior and could therefore have important implications in the replacement for purposes of durability, in its mixing and mobility of water of hydration (required to form the gel matrix); whereas for the case of the AN with regard to the RGA, the latter is fairly minor and probably will improve the strength of the resulting array, not necessarily the durability.

3) Bulk density and percent of voids

The results of bulk density and percent of voids in each studied material are presented in TABLE II. In this, it can be seen that the OD condition are very similar for the RCA and RGA, whilst for the CRA is lower, in any of the three cases, it remains below the AN.

With regard to the SSD condition, NA continues reporting the highest value, for what it is possible to say that the criterion is kept, subsequently followed by the RCA, whereas in this occasion the RGA and the CRA (ultimately) are similar.

Finally, the void content (linked with the structure, form of the particles and his distribution), reports that the RGA is material with maximum quantity of voids, while the rest of materials studied are relatively equal; being the difference between the maximum and the average of the others, from 9%. These data allow us to do the transformations of weights to volumes and vice versa, of the aggregates to the time of the calculation of the dosage of the mortar.

TABLE II. Bulk density and percentage of voids of the aggregates in the study.

Aggregate	Bulk density (M) in Kg/m ³		Voids (%)
	Condition OD	Condition SSD	
NA	1735.13	1860.76	32.87
RCA	1472.54	1608.60	32.93
RGA	1415.03	1423.52	42.83
CRA	1182.00	1402.44	35.28

v. Conclusions

Based on the study and in order to validate the use of recycled aggregates in mortars, the following considerations are necessary:

An adjustment in the grain sizes of aggregates (RCA and CRA) would be the guarantor of improvements in mechanical performance of its acceptance as an alternative material and certain environmental benefits associated with their use.

As for the low density obtained recycled aggregates (RCA and CRA) compared to NA, they present (based on the absorption) major number of pores, so that more water will be needed when the mixture of these materials are made in dry state condition. This could also lead to an increased permeability of the mortar itself, due to the porous structure of the aggregates.

With regard to the high void content submitted by the RGA compared to NA, we must consider that when this aggregate is used in the mortar mix, it should include an extra amount of cement to fill the voids spaces that will be generated in the resulting matrix, attributed this to the shape of its particles.

Based on the results obtained in this study for these materials in specific, the RGA presented greater similarities to the NA, in terms of granulometry, density and absorption; and therefore could present a good performance in mortar in which it is used.

Finally, to consider all the implications of this study of the recycled aggregates, is suitable investigate the chemical properties of the same ones; as well as the study of the matrix of the mortar overall, providing physical properties and of durability of these.

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About Author (s):



F. G. Cabrera-Covarrubias.
Title: Civil engineer and PhD candidate at the Polytechnic University of Catalonia.
Research areas: Use of recycled aggregates in cement mortars



J. M. Gómez-Soberón.
Title: PhD from the Technical University of Catalonia.
Research areas: Concrete recycled, porous structure of concrete, sustainable construction, minimization, reuse and recycling in construction, ICT in teaching, virtual campus teachers.



J. L. Almaral-Sánchez.
Title: PhD in Science (Materials), CINVESTAV-Querétaro, Mexico.
Research areas: Properties and modification of materials, inorganic-organic hybrid materials, zeolites, nanotechnology, sustainable materials and steel corrosion.



R. Corral-Higuera.
Title: PhD in Science (Materials), CIMAV-Chihuahua, Mexico.
Research areas: Concrete Technology, sustainable concretes characterization techniques applied to pastes, mortars and concretes, and sustainability in construction.



Antonia Navarro-Ezquerria.
Title: PhD in Geology from the University of Barcelona.
Research areas: Pathology of materials and building materials.



Marc Tous-Coll.
Research areas: Technician of the laboratory of materials.