

# Relationship between the c/a proportion and properties in fresh state of mortars containing recycled ceramic aggregate

F. Guadalupe Cabrera-Covarrubias, J. Manuel Gómez-Soberón, Jorge L. Almaral-Sánchez, Ramón Corral-Higuera, M. Consolación Gómez-Soberón, J. Miguel Mendivil-Escalante

**Abstract**—In the search for alternative solutions for the recycling of ceramic waste from both of the industry as the demolition and as contribution to the conservation of the environment, treatment of this waste is being implemented so that they can be incorporated back into the construction industry, both in mortars and concretes. In this work has made an assessment on the properties of mortars containing ceramic waste (as aggregate), focusing on those presented in its fresh State (consistency, density and air content), since these can influence the quality of the execution of the work and even contribute in the properties of hardened state; therefore, mixtures with different percentages of arid ceramic instead of the usual aggregate, as well as with different relationships c/a were performed. The results show that the effect of ceramic aggregate content has greater influence than the relation c/a in the fresh properties of recycled ceramic mortars.

**Keywords**—Sand-cement ratio in recycled mortars, recycled mortar consistency, recycled mortar density, air content in recycled mortars.

## I. Introduction

The promotion of recycling activity is one of the topics in which emphasis is done in the current society, which is raised by the own need to optimize the use of limited natural resources, to prevent the pollution produced by own waste, and for the preservation of the environment in general (1). The search for effective solutions for the treatment of waste, as a possible alternative sustainable, is currently being investigated as a solution, and in order to achieve sustainable growth in the economy and society (2).

In the sector of construction (important sector in the development of society), big quantities of residues are generated from the demolition; of which and by a suitable process of them, these are feasible of its transformation to be included again both in mortars and concretes (by reducing of its size can be used as aggregates), and therefore be able to achieve once again be incorporated in the construction industry (3).

As for the ceramic wastes obtained from both industry and the demolition (from preselected), you can find different types such as blocks, bricks, tiles, sanitary furniture, electrical insulation, etc.; of which some (recycled ceramic aggregates CA) are being investigated for incorporation in replacements total or partial of the usual aggregates (UA) in recycled ceramic mortars (RCM) (4) (5) (6) (7) (8) (3) (9) (10) (11).

In order to validate the application of RCM, it is necessary to evaluate the properties that they present, and thus able to establish their behavior and their possible feasibility of use. For the case of properties in fresh state, these tend to be related in the construction, in the work of placing the material, and which may even influence its performance, on the quality of the execution of the work, and even in the later decisive properties such as that of its strength and durability (12).

In previous work it has been reported that the consistency of RCM is reduced with the increase in the percentage of substitution of CA by UA (5), in this study is replaced 10-20% of the aggregate, resulting decrease in consistency, with values between 11 and 24% respectively. The above was explained by the fact that the CA (high absorption of water) inferred in the RCM. Same conclusion was validated by Silva et al. (2010) (8), who also indicated that the greater the incorporation of CA, more water will be needed for appropriate mixture.

With regard to the content of air included in the CRM in fresh condition, Jimenez et al. (2013) (10) determined that a RCM with different percentages of CA (5, 10, 20, and 40%) can reach similar values for this property (14.3, 14.7, 15 and 15% respectively), focusing in the range of the British standard BS 4721 (7-18%), so here we can say that the effect of the CA in a RCM does not carry any implication of limitation of its use.

Finally, the density in fresh state of the RCM, with replacements of up to 40%, reported reductions of 5% for the maximum replacement (10) (11). However, these results differ with other research (8) that indicated losses of up to double the previously referenced (50% replacement); even indicated that one gets to have losses of 17% when 100% of the aggregate is replaced (compared to reference). In this research, the density of the CA (less than the of the UA), was the cause that justifies the reported values.

Since in some cases these properties have not been studied with respect to the ratio cement/sand (c/a), or that are not established adequately for all the percentages used of CA –even it seems to exist contradictions in occasions–; and since these are important to ensure a feasible commercial application of the RCM in the construction sector, it is

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F. Guadalupe Cabrera-Covarrubias, J. Manuel Gómez-Soberón  
Universidad Politécnica de Cataluña  
Spain

Jorge L. Almaral-Sánchez, Ramón Corral-Higuera, J. Miguel Mendivil-Escalante  
Universidad Autónoma de Sinaloa  
Mexico

M. Consolación Gómez-Soberón.  
Universidad Autónoma Metropolitana.  
Mexico.

proposed in this research its experimental evaluation and elucidation.

## II. Materials

As aggregate for this study, CA was used with a particle size of 0 - 5 mm from a local industry accredited for the processing of recycled aggregates, this was the residue of ceramic tiles which had defects in size or shape (breach of the technical specifications). In order to separate the fine fraction (to be used), the material was sieved through a sieve No 4 (4.75 mm). As aggregate of reference (mortar usual, UA), silica sand with particle size of 0-4 mm was used, and it was acquired in a local company that sells UA.

Composition of granulometric profiles for both aggregates were required to meet compliance with the limits of ASTM C144; for which, both aggregates were separated through sieve No. 30 (0.59 mm), in order to make their use in comparable replacement, different percentages were validated to find the maximum compactness (equivalent replacement among them) (13); which it was obtained with the following combination:

- 60% of CA with particles > to sieve No. 30, and 40% with particles < to sieve No. 30
- 50% of particles UA both above and below the sieve No. 30

The physical properties of the aggregates used were tested in accordance with ASTM standards (see TABLE I). For the case of density, CA is always less than that of UA (difference of 760.7 and 468.2 kg/m<sup>3</sup>), whereas for absorption, the CA achieved significant increases regarding UA (increase of 16.8 %).

TABLE I. Physical properties of aggregates.

Property	UA	CA
D <sub>OD</sub> (Kg/m <sup>3</sup> )	2581.6	1820.9
D <sub>SSD</sub> (Kg/m <sup>3</sup> )	2623.6	2155.4
Absorption coefficient (%)	1.6	18.4
Fineness modulus	2.4	2.8
Particles < 75-µm (%)	2.9	8.2

\*D<sub>OD</sub> = Density Oven-Dry, D<sub>SSD</sub> = Density Saturated Surface Dry.

Finally, cement Portland classified as CEM I 42.5 N/SR (UNE EN 197-1:2011) was used as a binder, for being of use, with properties and components common, and tap water.

## III. Methodology

The series of mixtures of RCM with replacements of CA by UA (10, 20, 30, 50, and 100%) and with three c/a (1:3.25, 1:4 and 1:4.75) for each of them, they were prepared for the study and evaluation of behavior in fresh state (consistency, density in fresh state and air content).

The samples have been identified as UM-3.25, UM-4.00 and UM-4.75 (usual mortars of reference: UM = 100% of UA and for each study of the c/a); and to identify the mortars with CA, the following agreement was established: where: d.dd = c/a (1:3.25, 1:4 and 1:4.75); and XX = % of CA that replaces UA in RCM, (10, 20, 30, 50 and 100). Mixtures were made with a ratio water-cement (w/c) = 0.5 initial. In the following Table II, they present the quantities of materials used for every variable of study.

TABLE II. Materials used in the dosage of the RCM.

Classification and proportions of the mixture	w/c initial	Cement (g)	UA*		CA*	
			< sieve No. 30	> sieve No. 30	< sieve No. 30	> sieve No. 30
UM-4.00	0.5	400	800	800	0	0
RCM-4.00-10			720	720	64	96
RCM-4.00-20			640	640	128	192
RCM-4.00-30			560	560	192	288
RCM-4.00-50			400	400	320	480
RCM-4.00-100			0	0	640	960
UM-3.25		480	781	781	0	0
RCM-3.25-10			702	702	62	94
RCM-3.25-20			624	624	125	187
RCM-3.25-30			546	546	187	281
RCM-3.25-50			390	390	312	468
RCM-3.25-100			0	0	624	937
UM-4.75		342	811	811	0	0
RCM-4.75-10			731	731	65	97
RCM-4.75-20			650	650	130	195
RCM-4.75-30			568	568	195	292
RCM-4.75-50			406	406	325	487
RCM-4.75-100			0	0	650	974

\*Dry condition, in g.

The resultant water of the initial w/c was used to perform a prior saturation of one minute (to prevent mobility of water needed for the process of hydration) of aggregates; then the cement was incorporated into the mixer (Mod. E93, brand Matest), initiating the sequence of mixing at medium speed for 60 seconds. Then continued mixing at a high speed for 30 seconds more, subsequently they allowed to rest 90 seconds and finally 60 seconds at high speed.

Once finished the process of kneading of mixtures, we proceeded to carry out the tests required: the first of these (consistency), was governed by the standard ASTM C230, which used a flow table with a rigid top circular plate (Figure 1), sustained in the center by a support; the configuration of the equipment allows to make fall the circular plate so that this one receives a blow when reaching the end position, making that the prepared mix over the top of this extends horizontally freely in all directions. For this trial, it is intended that the mortar achieves a flow of 110 ± 5% (in accordance with the ASTM C109) after applying 25 falls to the sample on the table of flow over a period of 15 seconds. This "fluency" is determined by the average measure of two perpendicular diameters (d<sub>1</sub> and d<sub>2</sub> in Figure 1) when the mixture experienced his provoked extension. According to the diameter of the initial mold (Figure 1), the proper consistency was established to 21 ± 0.5 mm; therefore, if the mixture does not meet this requirement, one proceeds to increase the water content in small portions,

repeating itself this determination up to reaching the wished fluency.

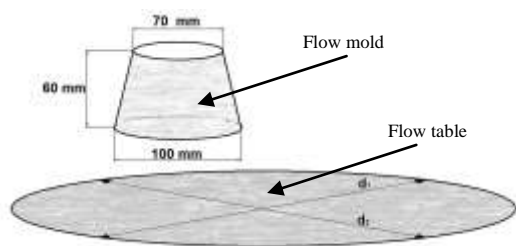


Figure 1. Table and mold flow.

Once obtained the normed consistency, determining the density of the mortars in the fresh state was performed. The test involves the use of a cylindrical vessel (standard with capacity of one liter) in which the mortar is available in three layers of equal thickness and the material is tamped 20 times each layer uniformly; once full the container is leveled and weighed. The value of the density of the fresh mortar is obtained by weighing the content of mortar in the container (Figure 2), so that both weight and volume are known, so are replaced in the formula (1).

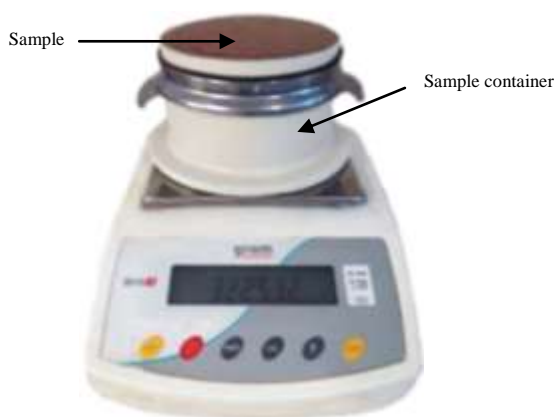


Figure 1. CRM density measurement.

$$\rho = \frac{M}{V}$$

(1)

Where:

$\rho$  = Density (g/cm<sup>3</sup>)

M = Mass (g)

V = Volume (cm<sup>3</sup>)

Finally, the obtaining of the content of included air, it was obtained using an aerometer normalized (Luftgehaltsprüfer, 1 Liter, brand TESTING), which uses the method of pressure (ASTM C231) helped with a container pre-regulated with a capacity of one liter (Figure 3). This rig has a pressure chamber where the pressure is generated. The opening of a discharge valve allows balancing the pressure between the pressurized Chamber and the vessel containing the sample; being understood that the fall of pressure is compared to the measure of the air content of the mortar in his fresh condition. The result of the air content is obtained by the reading on the manometer calibration.

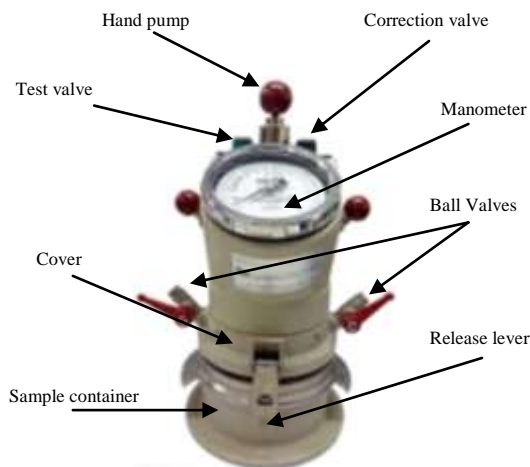


Figure 3. Meter of air content.

## IV. Results and discussion

Below are present the obtained results corresponding to the consistency (quantities of water required) reported by the RCM in study (see Figure 4). The two main relationships established in the study can apply in the following way:

1. A higher proportion in the ratio c/a of the RCM, it will involve direct increases in the water necessary for his kneading. Being the c/a of 1:4.75 the one that sensitively is major.
2. The increase in the content of CA in the RCM causes greater need for incorporation of water to achieve the necessary condition of consistency established in standard; being the replacement of 100% of CA which reports the maximum significant value.

The previous postulates, can be explained in the following way: with regard to the increase in c/a and with the AC content in RCM (and as reported in TABLE 1), the CA are aggregates with greater absorption (more porous) than UA; it is therefore a direct result that the increase in the RCM translates directly into higher requirements of water of mixture. Similar behavior in terms of the content of CA has also been reported in previous studies (5) (8); however, to the effect of the ratio c/a little has been established as a prior precedent (4).

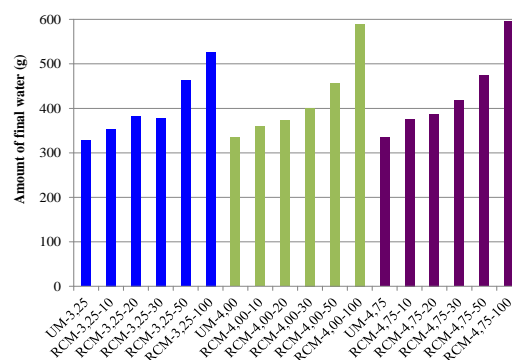


Figure 4. Amount of water required (ASTM C109) of the RCM.

As a direct result of this behavior, it is predictable the need of higher quantity of water in the RCM (induced by the relation  $c/a$  and the content of CA); which may result in making mortars with more porosity, and consequently, a foreseeable loss of compressive strength. However, it will be necessary to validate with a research of their behavior.

The results of density for the RCM studied can be seen in Figure 5, in this you can see also two clearly established trends –although in this case the relationships are reverse–:

1. The change or increase of  $c/a$  will cause subtle variations in its density –the higher the ratio of  $c/a$ , the density is reduced–.
2. The density of the CRM decreases of subtle form, inverse and proportional with the increase of CA.

The previous behaviors are related to the own density of CA; for the case of the relation  $c/a$ , the CA are less dense than the cement (usually  $3160 \text{ kg/m}^3$ ) (14), and for the case of the replacement content, the CA are less dense than UA (to see TABLE I). Regarding this last relationship, previous research are coincident (8) (10) (11); on the other hand, in terms of the ratio  $w/c$  other work presents the same trend (7).

It is expected that the effect of increase in  $c/a$  or CA content in the RCM, could produce adverse effects in the hardened state thereof; since the direct relationship is established between the increases in density vs. the increase in resistance.

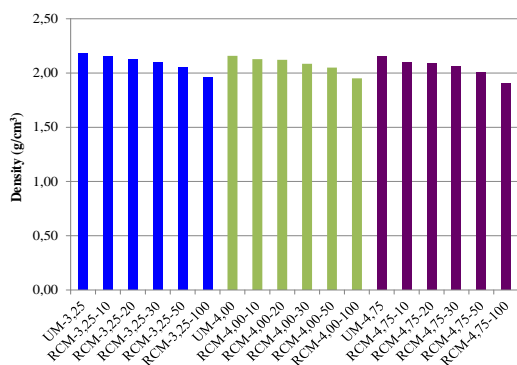


Figure 5. Density of the different RCM in study.

In relation to the results of air content determined for the RCM (see Figure 6), it is possible to observe that it is not achieved to establish a trend or exact relation between the  $c/a$  or the CA content concerning him; the range in which the results are established was between 3.5 and 5.1% (relatively small). However, when compared between each group of  $c/a$  is obtained that RCM-4.75-XX showed the highest content of air (average 4.49%), while the RCM-4.00-XX obtained 3.86%, and the RCM-3.25-XX 3.73%.

This behavior could have relationship with low bulk density and the highest percentage of voids in CA with respect to UA, as reported in previous work (13). In other previous work, were reported ranges of similar proportions between the studied variables (substitutions of 5, 10, 20 and 40% CA); however comparing to this research, the study values are high (14.2 to 14.9%) (10). This could be because of air-entrainment, which was used to improve workability of mortar.

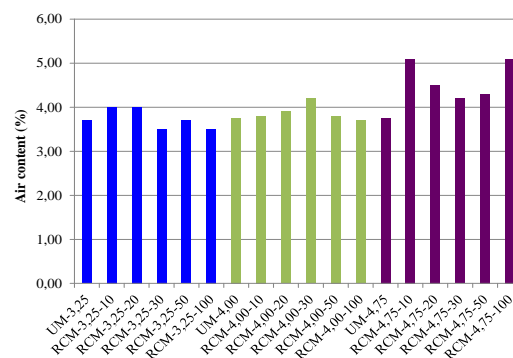


Figure 6. Air content for different RCM.

The Figure 7 presents the results of the relation  $w/c$  final, which is established as the necessary used to achieve the proper consistency of the mixture. Relations in terms of the effect of  $c/a$  and the content of CA, are a direct consequence of the hypothesis and relations established previously (Figure 4).

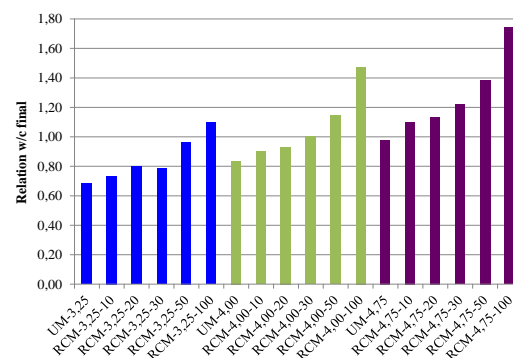


Figure 7. Relation  $w/c$  of RCM.

## v. Conclusions

From the presented results, it is possible to mention the following reached conclusions:

- It is established that the increase of the ratio  $w/c$  in the RCM will cause greater needs (incremental direct proportion) of the amount of water needed for the ASTM C109 test condition (the  $c/a = 1:4.75$  was the one that needed more water); this also happens with the increase in the percentage of replacement of CA (although in more noticeable way, and reaching maximum values for replacements of 100%).
- The density of the RCM decreases with higher ratios of  $c/a$ ; as well as also with the increase of CA. In this case, the variations between the different samples studied are less distant each other.
- High relations of  $c/a$  will provoke increases in the air content of the RCM; however; when CA replaces UA, the contents are not significant.
- Variations of the relation  $c/a$  in the RCM, as well as the contents of CA in these, will affect in the properties in fresh state of the RCM; being more

outstanding by the effect of the content of CA that by the relationship c/a.

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**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-Queretaro, 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.



**M. C. Gómez-Soberón.**

**Title:** PhD in Structural Dynamics (Technical University of Catalonia).

**Research areas:** Vulnerability of structures and bridges



**J. M. Mendivil-Escalante.**

**Title:** Civil engineer and PhD candidate at the Universidad Autónoma de Sinaloa, Mexico.

**Research areas:** Concrete technology, sustainable concretes characterization techniques applied to pastes, use of recycled aggregates and recycled PET in polymer modified concrete.

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