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Comparative study of three types of fine recycled aggregates from construction and demolition waste (CDW), and their use in masonry mortar fabrication

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ABSTRACT

This research aims to study feasibility of incorporation of fine fraction of recycled aggregates coming from construction and demolition waste in cement-based masonry mortar fabrication. Initially, three types of recycled aggregates: concrete, mixed and ceramic recycled aggregates, were characterized in terms of physical, mechanical and chemical properties. There were used 1:3 and 1:4 cement-to-aggregate proportions and replacement percentages of 50%, 75% and 100% respectfully for three types of studied recycled aggregates.

Physical characterization of recycled aggregates shows a continuous size distribution curve, lower density and higher absorption, what makes the usage of additive necessary to obtain appropriate consistency. Main crystalline phases shown in the X-ray diffraction analysis were: calcite, quartz and gypsum. According to the results of the dosages study, recycled mortars present poorer behaviour than mortars fabricated using natural stand, however, complying with the limits established by the standards and manufacturers. Therefore, the results of this study suggest the possibility to replace 100% of natural sand with analyzed recycled aggregates.

1. Introduction

Massive exploitation of natural resources in the construction and building sector has been a continuing process through the times, causing gradual environmental degradation. Under the existing regulatory framework, it is vital to incorporate recycling policies which would enable effective sustainable development of construction sector.

Construction and demolition waste (CDW) is produced mainly during building rehabilitation and demolition phase. The construction industry generates in European Union around 900 million tons per year of wastes, what represents 30% of all wastes produced (Eurostat, 2010). There can be obtained three types of recycled aggregates (RA) classifying them according to the compounds they are formed of: concrete RA, mixed RA and ceramic RA (Gear Project, 2012).

The average recycling rate in Europe is 50%, and there are even some countries such as Denmark, Estonia and the Netherlands that recycle more than 90% of their CDW (Villoria et al., 2011). However, in Spain these rates are much lower and do not reach the objective established by the Integrated Waste Management Plan (2008).

Recycling rate is Spain is about 15% of the total production of CDW, which is used mainly as filler in road construction that is also typical for other countries (Vegas et al., 2008). The Code on Structural Concrete (EHE-08:2008) permits the usage of coarse fraction of RA in mortar fabrication, recommending substitution of up to 20% of natural sand by RA. However, the fine RA has not been considered by most standards until now because of its poorer properties. Lots of studies showed that the properties of concrete decrease as the replacement percentage of fine RA increased

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(Khatig, 2005; Shi-Cong and Chi-Sun, 2009). Therefore, the incorporation of this material in masonry mortar production implies a new alternative for recycling of CDW in the building and construction sector.

1.1. Literature review

Various scientific researches have studied the feasibility of incorporating fine fraction of RA in masonry mortars production. The bibliography consulted shows varying permitted replacement percentages, partly due to the heterogeneity of RA. Vegas et al. (2009) concluded that mortars can contain up to 25% of fine RA without their mechanical properties, workability and shrinkage being affected, requiring no additives.

Jiménez et al. (2013) concluded that the incorporation of up to 40% of ceramic waste in mortars production does not affect significantly the properties of cement mortar in fresh and hardened state, with exception of its density and workability.

Corinaldesi and Moriconi (2009) evaluated mechanical and rheological behaviour of cement mortars manufactured using three types of RA: rejected prefabricated concrete material, recycled bricks waste and plant recycling rubble. In three cases, 100% of RA has been used, determining poorer mechanical behaviour and higher mortar-brick bond strength of recycled mortars comparing to traditional mortars.

Corinaldesi (2012) replaced quartz sand in the production of cement and hydraulic lime mortars using ceramic aggregates coming from crushed red brick. The aggregates were incorporated in saturated-dried condition without admixtures use. It was concluded that fine crushed brick aggregates present poorer mechanical properties than coarse crushed brick aggregates due to the greater angularity of the coarse fraction. However, fine crushed brick aggregates present the best mortar-brick bond strength.

Martínez et al. (2013) compared the properties of mortars made using three types of natural sand and three types of recycled aggregates from concrete, ceramic and masonry waste. 1:6 cement-aggregate proportion and 100% substitution of natural sand by recycled aggregates rate were used. It was concluded that mortars fabricated with recycled aggregates present poorer mechanical strength properties, except natural sand from Cuba, because of low quality of this sand. Higher water absorption and shrinkage were obtained in recycled mortars.

Fernández et al. (2015) evaluated the possibility to incorporate fine fraction of RA in masonry mortars using CEM II/BL 32.5 N. Obtained results show that replacement ratio of 50% can be achieved in mortar for indoor use.

The main aim of this work is the evaluation of recycled mortars properties both in fresh and hardened state using different replacement percentages of natural sand with three types of RA coming from collaborating recycling plant. This study results present a contribution regarding the published works, and could help to increase CDW recycling rates, reducing in such a way consumption of natural recourses in the construction sector.

2. Materials and methods

2.1. Materials

The following materials were used in this research: cement, sand, additive and water.

2.1.1. Cement

The binders used in the study were CEM II/B – L 32.5 N and CEM IV/B (V) 32.5 N, suitable for mortar fabrication and masonry in general. Spanish and European standard UNE-EN 197-1:2011 and the Instruction for the cement placing (RC-08) specify the properties of these cements. Their main characteristics and chemical composition are shown in Table 1.

2.1.2. Aggregates

Aggregates employed to prepare reference mortars were provided by the Cemex Company. Recycled sand was provided by an integrated CDW Treatment Plants of Madrid Region. Three samples of RA were employed: fine recycled aggregates RA-1, RA-2 and RA-3 originated from ceramic recycling process, mixed recycling process and concrete recycling process respectively. RA passed through the pre-screening, trommel separation of fines, crushing and grinding, and final screening obtaining fine RA of 0/6 mm size. The fine fraction was sieved in the laboratory to remove particles lager than 4 mm and shorter than 0.063 mm.

2.1.3. Additive

Recycled mortars were prepared using the superplasticizer additive Glenium Sky 604 by BASF Company. This is a high-activity water reducing/superplasticising additive based on polycarboxylates. Glenium SKY 604 was prescribed by BASF Company technical department to improve consistency of recycled mortars.

2.2. Characterization

Characterization of fine RA samples was based on the technical requirements regulated by the standard UNE-EN-13139:2002: “Aggregates for mortar”. Three types of fine RA comply with the upper and lower size limits and the maximum percentage of fines established by the standard for masonry mortars. The results of physical and chemical characterization of RA and natural aggregates (NA) are presented in Table 2.

Fig. 1 shows graphical representation of RA used in this study according to the requirements established by the UNE-EN-933-2:1995 and the UNE-EN-933-1:2012 standards, in particular Part 1: Determination of particle size distribution “Sieving method”.

As pointed by other authors, size distribution is one of the most important properties of aggregates (Etxeberria et al., 2007; Tam et al., 2008). Analyzed RA present continuous size distribution curve (Fig. 1) situated within the limits established by the reference standard.

To complete the characterization of RA the following tests were carried out: X-ray diffraction analysis and X-ray fluorescence method. Obtained results are presented in Tables 3 and 4.

Crystal structures and purity of samples were tested by X-ray diffraction (XRD) analysis, where the X-ray diffraction pattern was

Table 1
Characteristics of CEMII/B-L 32.5 N and CEMIV/B(V) 32.5 N.

	CEM II/B – L 32.5 N	CEM IV/B (V) 32.5 N
Physical characteristics		
Density (g/cm^3)	3.05	2.85
Blaine specif. area (cm^2/g)	4000	4400
Initial set (min)	175	230
Final set (min)	275	285
Chemical characteristics		
Al_2O3	3.25	13.40
CaO	60.10	35.55
Fe_2O3	2.56	3.50
K_2O	0.26	1.80
MgO	1.75	2.60
SiO_2	18.13	31.90
TiO_2	0.14	0.60
MnO	0.02	0.05
P_2O5	0.16	0.33
NaO_2	0.22	0.02
Loss on ignition	11.85	8.60