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Properties of cement–lime mortars vs. cement mortars containing recycled concrete aggregates

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HIGHLIGHTS

- The replacement of natural aggregates with recycled aggregates in mortars was studied.
- Cement and cement–lime mortars were compared.
- Recycled aggregates worsen the properties of cement mortars.
- Cement–lime mortars characteristics improve by recycled aggregates addition.

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ABSTRACT

Cement based materials have a very special presence amongst building and construction materials, and therefore their recycling is of capital importance. In this research, concrete wastes were used as replacement of natural aggregates in cement and cement–lime mortars. The mortars were cured for 28-days with an increasing substitution of fine natural aggregates with recycled aggregates and have been prepared as well as characterized. The results show that, as expected, cement mortars always have better mechanical properties than the corresponding cement–lime mortars. A worsening of mechanical properties is observed upon increasing the amount of recycled aggregates in the cement mortars; on the contrary, cement–lime mortars show an improvement in mechanical properties of up to 60% when increasing the amount of recycled aggregates. The experimental results suggest that this improvement could arise from a synergic effect of lime hydraulicity and the filler effect due to the fine fraction of recycled aggregates within the mix, that lead to better densification of the lime mortars by blocking the capillary pores.

1. Introduction

Every year many construction and demolition works are done in the world, especially in developed countries such as Europe and North America. This causes the production of a large amount of Construction and Demolition Wastes (CDW), especially in cities. In the EU27, about 869 million tons of waste were produced in 2010 [1] from the economic activity 'Construction' according to NACE codes [2], corresponding to about 1.7 tons per capita per year. In the United States of America, the Environmental Protection Agency (EPA) reports that the total C&D waste generation in the Northeast (the six New England States, New York and New Jersey) in 2006 was approximately 12 million tons, corresponding to roughly 0.19–0.42 tons per person per year [3]. In California, overall disposed wastes of the class of 'Inerts and other' amount to 11.6 million tons (29.1% of the total) and the concrete fraction is about 0.5 million tons (1.2%) [4].

In most developed countries, CDW are still mainly disposed of in landfills – either dedicated landfills or municipal solid waste (MSW) sites. However, the increasing perception of a shortage amongst natural resources [5] would suggest different practices, such as recycling the CDW again in the construction industry. One of the most effective ways to recycle CDW is to crush them into aggregates that can be reused in the production of new concrete [6]. Of course, there are severe requirements on the mechanical properties of ordinary concrete, because it generally has a structural role in buildings; therefore recycled aggregates can be used to replace natural aggregates for fabrication of concrete in limited amounts, as recent literature suggests [7–13]. For example, Evangelista & de Brito [9,10] points out that using more than 20–30% of recycled aggregates in concrete leads to a large

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increase in water absorption, due to their higher porosity when being compared to natural aggregates. Furthermore, replacement of natural aggregates with recycled aggregates can also lead to unacceptably high sulfate content in the final concrete. For a comprehensive review on the use of recycled aggregates in concrete fabrication, the reader is referred to Evangelista & de Brito [14].

Mortar is considered a less noble construction material in respect to concrete [11]; therefore there is less attention given in literature when analyzing the properties of mortars containing recycled aggregates. However, there is an increasing interest in using CDW in mortars as a replacement of natural aggregates [7–9,15–29] or binder [30]; since mortars do not have structural roles, its mechanical requirements are less stringent, and a higher amount of recycled aggregates can be used in their preparation. As pointed out by Neno et al. [28], many characteristics of the mortars containing recycled aggregates strongly depend on the quality and source of recycled aggregates and on the specific mortar composition, therefore it is expected that different outcomes emerge from different studies. In addition, using different kinds of cement can in turn affect how the binder interacts with the recycled aggregates. For example, Corinaldesi and Moriconi [25] used Portland-limestone blended cement (CEM II/B-L 32.5 R) and replaced natural sand in mortars with recycled aggregates from different sources. They discovered that the prepared mortars always had poorer mechanical strength than the reference one, but gained better mortar–brick bond strength; among the recycled aggregates used, the aggregates coming from concrete wastes led to mortars with the best performances. Braga et al. [26] instead used the fine fraction (<0.150 mm) of recycled aggregates from concrete wastes as a replacement in the preparation of mortars. They demonstrated that replacement ratios up to 15% could improve mortar performances in terms of flexural and compressive strength (increasing) and water absorption (decreasing). Unfortunately, the authors do not report details about the kind of cement used in the study. Jimènez et al. [27] replaced up to 40% by volume of natural aggregates with fine recycled aggregates obtained from ceramic partition wall rubble; they found an improvement of compressive and flexural strength of mortars made with a pozzolanic cement (CEM IV/A (V) 32.5 N), and only a small decrease in bulk density and workability of the hardened mortars. Neno et al. [28] showed that their mortars containing recycled aggregates compared well with the reference one in terms of water absorption (decreasing for replacements up to 25%) and compressive and flexural strength (increasing with replacement), while only adhesive strength was slightly poorer; also in this study the mortars were prepared using a pozzolanic cement (CEM II/B-L 32.5 N). Vegas et al. [29] used wastes from concrete and ceramic debris crushed below 2 mm in size, and suggested that a 25% replacement of fine recycled aggregates led to mortars with no loss of compressive strength, workability and shrinkage in respect to the reference mortar, using CEM II/B-M 42.5 R as binder.

Overall, as recently reviewed by Neno et al. [28] some of the effects of replacement of natural aggregates in mortars have been already understood: water absorption, density, and shrinkage characteristics. Varying results are available regarding the mechanical properties of mortars containing recycled aggregates; it seems that usually using cements with fine fillers maintains good mechanical properties in the mortars even when a high proportion of recycled aggregates are used. From the point of view of substrate adhesion, the use of concrete wastes is more advantageous in respect to other kind of wastes [25,31].

In this work, a direct comparison of cement and cement–lime mortars containing recycled aggregates was studied. Mortars prepared with high quality concrete wastes were prepared and characterized: water absorption characteristics and mechanical properties were measured, and chemical and microstructural features of mortars have been assessed with respect to the substitution of natural with recycled aggregates and of cement with lime in the binder.

2. Materials and methods

2.1. Materials

Blended cement Type II/B-P 32.5 produced by Buzzi Unicem and hydraulic lime were used as binders. The reference natural aggregates (NA) are standard river sand aggregates with size <4 mm; the recycled aggregates (RA) have been prepared from high quality concrete wastes (Fig. 1) via a double crushing process. Sieve analyses have been done according to EN 933-1 [34] for both natural and recycled aggregates, and the results are reported in Fig. 2. The two aggregates have very different size distributions: NA particle size lies mainly around 500 μm, with neither fraction of particles below 125 μm nor above 6.25 mm. RA shows a completely different size distribution, with a large amount of coarse particles (about 70% above 5 mm) and nearly 1% of ultrafines (size <125 μm). This wide size distribution is expected to affect the mortars properties [23]; in particular, a higher filler effect is expected when using recycled aggregates, since they contain a fraction of ultrafines [35]. Sulfate acid content of the recycled aggregates was measured according to EN 1744-1 [32] and is 0.797 wt% SO_4^{2-} (less than 1% acid sulfate is recognized as an acceptable level). Water absorption of recycled aggregates is 4.5% g/g (EN 1097-6 [18]) and their apparent density is 2.67 g/cm^3 (EN 1097-6 [33]), while apparent density of natural aggregates is 2.62 g/cm^3.

2.2. Mix design

Eight mix batches were prepared: in four the binder was only cement (CM samples) while in the other four it was a 50:50 wt% mixture of cement and lime (CML samples).

The mix design was selected according to EN 13914-1 [36]: for CM samples, Cement:Aggregate weight ratio was 1:3 and for CLM ones the Cement:Lime: Aggregate weight ratio was 1:1:6 (see Table 1).

Fig. 1. Concrete wastes before crushing process.

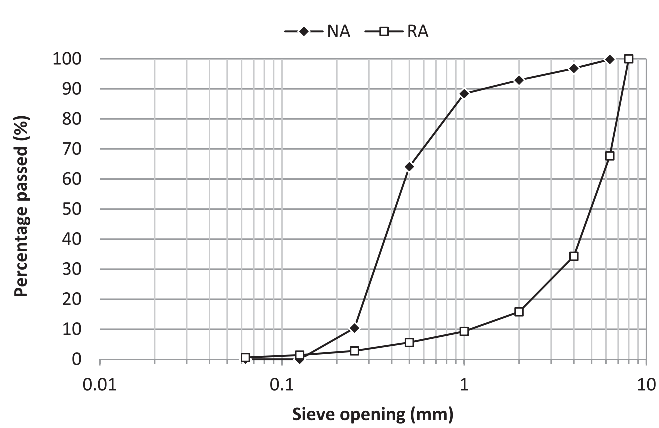

Fig. 2. Sieve size distributions of natural (filled marker, NA) and recycled (hollow marker, RA) aggregates.