

## Recycled aggregate in civil works and building construction

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### Abstract

The sustainable development policies presently in place, along with the Paris Agreement on climate change, are clear indications that economic growth must be made environmentally sustainable to ensure the transition from a linear to a circular economy.

Given the large volumes of construction and demolition waste (C&DW) generated, which account for 30-35 % of the total in the European Union, this type of waste has come under particular scrutiny in today's socio-economic context.

This paper provides an overview of the types of recycled aggregate obtained in waste management plants sited in the Spanish region of Extremadura. The end products were characterized chemically, physically and mechanically to determine their compliance with the existing legal requirements on materials used in civil and building construction. The findings will serve as grounds for raising public awareness of the quality of these new aggregates, their potential use in construction and their contribution to sustainable development.

**Keywords:** Construction and demolition waste, legal requirements, civil works, building construction.

### Introduction

If the United Nations Framework Convention on Climate Change commitments laid down in the Kyoto Protocol and the Paris Agreement are to be met and the economy rendered truly circular in today's economic, social and energy scenario, earnest attempts will be needed to valorize industrial waste and reduce natural resource consumption and GHG emissions.

Against that international backdrop, construction and demolition waste (C&DW), which accounts for 30-35 % of the total generated in the European Union, is the object of particular concern. To reach a 70 % reuse target by 2020, a regulatory framework has been developed for C&DW management on the European (Directive 2008/98/EEC on waste management), national (Nationwide Waste Management Plan, PEMAR, 2016-2022) and regional (Comprehensive Waste Plan of Extremadura, PIEEX 2016/2022) scales.

The construction industry is characterized by a huge demand for natural resources, in particular large volumes of natural aggregate. According to European Aggregates Association (UEPG) data, in 2013 the EU-28 produced 2.3 billion and Spain 92 million tons of these materials [1]. Approximately 45 % of that production is used to manufacture cement-based materials such as ready-mix, precast and architectural concrete products.

In recent years many authors have analyzed the viability of using different fractions of C&DW as recycled aggregate in the design of new concretes [2-4] or fillers (fines fraction) or additions in new cement design [5-7]. Further to their findings, such waste has huge potential for use in the cement-based materials industry.

This overview discusses the recycled aggregates produced in waste management plants sited in the Spanish region of Extremadura. Several types of recycled aggregate were characterized chemically, physically and mechanically to determine their compliance with the legal requirements on materials apt for use in civil and building construction.

## Experimental

### 1. Materials

The aggregates studied were sourced from a number of C&DW management plants located in the Spanish region of Extremadura. They were initially selected based on two criteria: particle size distribution (<4 mm) and appearance. A total of four types were selected and conditioned for subsequent characterization.

### 2. Methods

Chemical compositions were studied on a Bruker S8 TIGER wavelength dispersive X-ray fluorescent spectrometer, using QUANT EXPRESS standardless calibration (SEPECTRAPlus package) software. The physical and mechanical properties analyzed and standard test methods used for each are given in Table 1.

**Table 1.** Physical and mechanical properties

<i>Property</i>	<i>Standard</i>
Composition	EN 933-11
Fines content	EN 933-2
Density and water absorption	EN 1097-6
Flakiness index	EN 933-3
Los Angeles coefficient	EN 1097-2

## Results and Discussions

### 1. Composition

Figure 1 shows the weight percentage of the materials comprising the recycled aggregates studied (M1-M4). All contained primarily stony materials ( $R_c > R_u > R_b$ ) and smaller proportions of bituminous matter ( $R_a$ ) and minority substances such as glass, metal or wood.

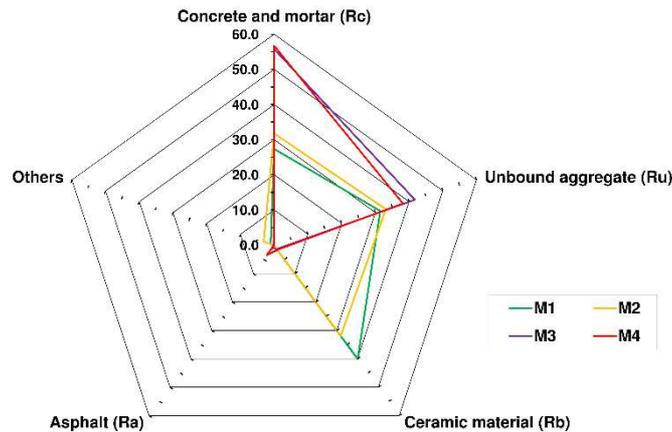


Figure 1. Recycled aggregate constituents

Further to international specifications for recycled aggregate (RILEM and LNEC 471), the end products were classified [8] into two categories depending on their fired clay-based and concrete contents, as follows: M1 and M2, fired clay-based recycled aggregate (fired clay > 30 %, concrete < 70 %) or M3 and M4, concrete recycled aggregate (fired clay ≤ 10 %, concrete ≥ 90 %).

## 2. Chemical composition

The chemical composition of the recycled aggregate depicted in Figure 2 shows that all comprised primarily silicon (>58 wt%), aluminum (>8.0 wt%), calcium (>7.5 %) and iron (>2 %) oxides, with minority magnesium, sulfate, equivalent sodium and other oxides. All these components exhibited loss on ignition (LoI) of over 6.8 wt%.

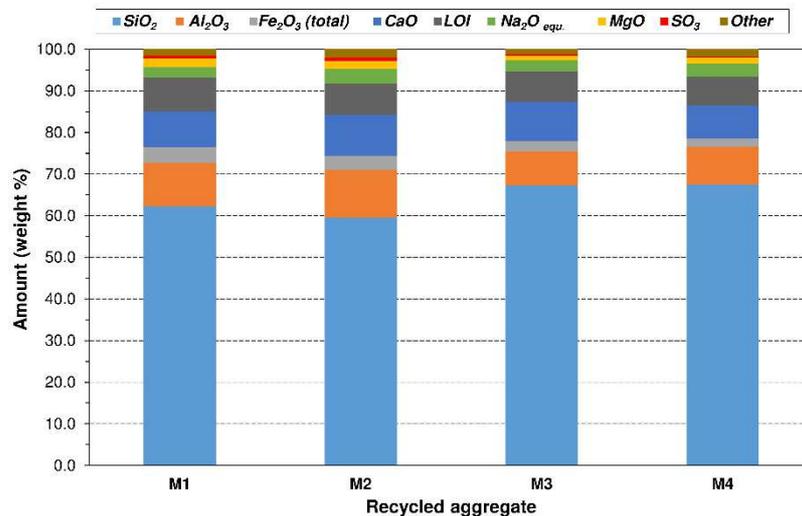


Figure 2. Chemical composition

These values were consistent with the chemical composition findings reported by earlier authors [9, 10]. The total sulfur and soluble sulfate and chloride contents were under the ceilings (1.0 wt%, 0.8 wt% and 0.05 wt%, respectively) laid down in Spain's structural concrete code, EHE-08 [11].

### 3. Physical and mechanical properties

The physical and mechanical properties of the aggregates analyzed and the requirements for coarse aggregate used in structural concrete manufacture are listed in Table 2. The crushed concrete recycled aggregates (M3 -M4) were denser than the mixed recycled materials (M1-M2). Aggregates M1 and M2 exhibited lower water absorption than aggregates M3 and M4 due to the higher percentage of mortar and concrete waste in the latter [10]. The values for the mixed aggregate were under, and absorption in crushed concrete aggregate was slightly over, the EHE-08 maximum.

**Table 2.** Physical and mechanical properties and requirements

<b>Recycled aggregate</b>	<b>M1</b>	<b>M2</b>	<b>M3</b>	<b>M4</b>	<b>EHE-08</b>
Dry sample real density (kg/dm <sup>3</sup> )	2.48	2.52	2.43	2.42	-
Water absorption (wt%)	3.12	2.80	6.19	5.59	< 5.00
Flakiness index (wt%)	26.32	16.33	7.89	6.16	< 35.0
Los Angeles coefficient (wt%)	45.5	50.1	36.0	40.0	< 40 40 -50
Fines (wt%)	0.69	1.63	3.12	2.28	< 1.50

Coarse aggregate shape, defined by the flakiness index, plays an important role in concrete workability. As Table 2 shows, all the recycled aggregates were EHE-08-compliant in this regard. In addition, aggregates M1 and M2, with a higher fired clay material content, had a higher percentage of flakey particles than majority concrete aggregates M3 and M4. A similar finding was reported by Medina et al. [12] who, comparing the flakiness index in sanitary ware waste-based and natural aggregates, observed that the initial shape of the former induced higher flakiness.

Crushed concrete aggregates M3 and M4 had a lower LA coefficient than the maximum allowed in EHE-08, with values higher than the mean (28 wt%) previously reported for this type of aggregates [13]. The value for the mixed aggregates fell within the range (40-50 wt%) allowed by EHE-08 to manufacture concretes with a strength <30 MPa. Their lower performance was closely related to their higher proportion of weaker fired clay-based, than stronger stone-based, material [14].

The fines requirement was met by all the aggregates except M1, non-compliance for which may be corrected by eliminating the <0.063 mm fraction.

### Conclusions

The following conclusions can be drawn from this study.

- The absorption coefficient is lower in mixed recycled than in crushed concrete aggregates.
- Mixed recycled aggregates exhibit slightly higher flakiness indices and Los Angeles coefficients than crushed concrete materials.
- Recycled aggregates are apt for use as partial natural coarse aggregate replacements in new structural concrete design.

### Acknowledgements

This study was funded by the Spanish Ministry of Science and Innovation under projects BIA 2013-48876-C3-1-R, BIA 2013-48876-C3-2-R and BIA2016-76643-C3-1-R, as well as by the Government of Extremadura and the European Regional Development Fund (ERDF)

under grant GR 15064 awarded to the MATERIA research group and by the SOSMAT University of Extremadura- (Spanish) National Research Council Associated Research Unit.

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