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Durability of recycled concrete made with recycled ceramic sanitary ware aggregate. Inter-indicator relationships

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HIGHLIGHTS

- The relationships between the durability indicators are not modified in the new concretes.
- The chloride penetration was slightly deeper in recycled concretes.
- The electrical resistivity was higher in the recycled concretes than reference concrete.
- The recycled concrete would exhibit satisfactory durability throughout their service life.

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ABSTRACT

Effective industrial waste management is one of the challenges facing modern society. One possible solution, the inclusion of different proportions of waste of varying nature in concrete, calls for a thorough study of the durability of the resulting materials. Direct and indirect durability indices can be used to ensure that such concrete is able to withstand the actions to which it will be exposed throughout its service life to design safety, functionality and aesthetics and with no unexpected maintenance costs. In the present study, 20% and 25% of the natural coarse aggregate in concrete was replaced with recycled aggregate from the sanitary ware industry to explore the effect on chloride penetration and electrical resistivity, as well as the relationship among the durability indicators that predict concrete performance during its service life. The findings showed that chloride penetration was slightly deeper in recycled concretes, while no alterations were observed in the relationship among durability indicators. Electrical resistivity, in turn, was observed to rise with the use of recycled aggregate due to the intrinsic characteristics of this material. The new concretes proved to be as durable as the conventional material, performing satisfactorily throughout their service life.

1. Introduction

Industrial waste management is a major problem worldwide and one of the most daunting challenges facing modern societies, particularly as regards long-lasting non-biodegradable waste such as clay-based materials and construction and demolition waste (C&DW) [1,2]. In Spain as in other countries, machinery is in the pipeline to reduce the volume of such waste for direct shipment to landfills as a way of lowering the economic and environmental impact of poor management.

The reuse of such non-biodegradable waste as a raw material in the manufacture of new construction materials is an economically and technically feasible solution. Improving the circular economy across all value chains could yield a 17–24% reduction in raw material inputs by 2030, with potential overall savings for European industry of €630 billion per year [3]. At this time, re-usage rates in European Union member countries range from 5% to 85% [4]. These values are directly related to: (a) location and availability of natural resources; (b) distance to the source of natural aggregate; and (c) governmental pressure in the form of legislative and administrative tools that encourage some manner of valorisation.

Over the last 10 years, the scientific community has intensified its efforts to determine the feasibility of using ceramic industry waste (roof tiles, electrical insulation, ceramic sanitary ware...) in the manufacture of new and more environmentally sustainable materials. Some authors [5–7] have found that due to the

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pozzolanic nature of such waste, when finely ground and added in small percentages (<40 wt%), it enhances the physical and mechanical properties of the resulting cements and mortars. Other studies [8] have shown that recycled aggregate replacement ratios of up to 30% in both the fine (0–4 mm) and coarse (4–11 mm) fractions of new hot mix asphalt (HMA) yield materials compliant with the mechanical and surface requirements set out in the Spanish general technical specifications for roads and bridges (PG-3). Another line of research [1,9–12] has explored the use of ceramic waste as coarse or fine aggregate in concrete manufacture. The ceiling replacement rate and the structural or non-structural applicability of these new concretes have been found to vary depending on waste typology (roof tile, electrical insulation, sanitary ware), due primarily to intrinsic characteristics such as density, absorption, flakiness index and Los Angeles coefficient. In prior studies along those lines [13–17], the present authors used recycled ceramic sanitary ware waste as aggregate in structural concrete and observed no adverse effects on concrete mechanical strength, permeability or liability to leaching.

Like conventional concretes, such eco-efficient materials must meet strength and durability requirements throughout their service life, which according to Eurocode 2 [18] is "*the period of time during which the material withstands the actions to which it is exposed to design safety, functionality and aesthetics, with no unexpected maintenance costs*". For that reason, new concretes need to be studied in greater depth, particularly where they are exposed to attack by aggressive, deterioration-inducing physical, chemical or biological agents.

Today's scientific community uses durability indicators [19–21] to predict and assess concrete performance throughout its service life. These indicators are based on properties or characteristics whose quantification provides information on concrete's capacity to last for its established useful life. Nonetheless, the scientific and technical knowledge gaps about the effect of new recycled aggregates on such indicators and the relationships among them calls for an intensified research effort.

Durability indicators are regarded as direct when they measure the type of attack involved (chlorides and carbonation) and indirect when they measure transport-related parameters (water absorption, permeability to water and air, porosity and electrical resistivity). Both types are directly related to concrete pore structure.

The present study explored the effect of the partial replacement of natural aggregate with ceramic sanitary ware waste on strength and chloride penetration in the resulting recycled concretes. The relationships among the durability indicators used to predict performance throughout the material's service life were also analysed. To that end, compressive strength, chloride penetration, porosity, water penetration depth under pressure, capillary absorption, permeability to oxygen and electrical resistivity were studied.

2. Experimental

The procedure used in the present study is outlined in Fig. 1.

2.1. Materials

Natural aggregate is divided into two fractions: coarse (gravel), with a maximum particle size of 4/20 mm, and fine (sand), with a particle size of under 4 mm. The majority component of these aggregates, SiO_2 (>97 wt%), is found together with other (primarily aluminium and iron) oxides. Mineralogically, quartz predominates, with a minority presence of aluminosilicates such as mica and feldspar.

The recycled ceramic aggregate consisted of jaw-crushed sanitary ware industry discards. After crushing, the material was sieved to obtain a fraction measuring 4/12.5 mm. The end product was characterised by sharp edges, irregular shapes, a more or less flat surface and two clearly distinguishable parts: a rough inner area and a polished vitreous coating typical of sanitary ware, comprising less than 2 % of the total waste (See Fig. 2).

As regards chemical composition, this waste was strongly acidic in nature, with a predominance of silica (66.57%) and aluminium (21.60%) and lesser quantities of other oxides. The main mineral component was likewise quartz, although here the minority components were hematite and zircon.

Table 1 gives the physical and mechanical properties of the coarse aggregates studied, along with the characteristics of other coarse recycled aggregate (clay-based waste such as blocks, roof tiles, insulator... and construction and demolition waste) used by other authors [22]. In the final column it lists the requisites for concrete aggregates laid down in European standard EN 12620 [23].

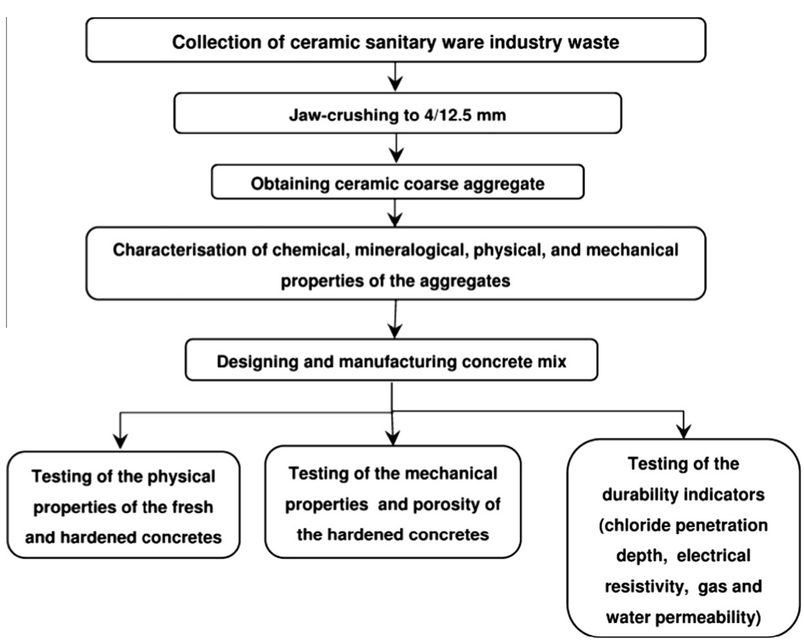

Fig. 1. Flowchart for the manufacture and study of mixed recycled aggregates.