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Review

Assessment of properties of recycled concrete by means of a highly fractioned factorial design of experiment

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ABSTRACT

The study presented in this paper has been carried out using a highly fractional factorial experimental design. This design allows the analysis of a greater number of factors and levels with a reduced number of mixes. In the state of art of recycled concrete the studies have been carried out varying the level of one factor while the rest remained fixed. However an excessive number of factors or levels are not considered. This highly simplified test program was designed in order to make the number of tests viable whilst guaranteeing the reliability of the conclusions. The concrete has been produced by substituting the natural coarse aggregates for recycled aggregates from construction and demolition waste, which is mainly composed of concrete. In this research some factors that have not been analyzed in previous studies, such as the granular structure of the concrete or the replacement criteria, have been studied. The properties of recycled concrete analyzed were: density, absorption, compressive strength, elastic modulus and penetration of water under pressure. The concrete was made with dry recycled aggregate. The percentage of replacement of the recycled aggregate did not affect the compressive strength since the water/cement rate remained constant. However the elastic modulus is affected by the percentage of replacement when it exceeds 50%.

Contents

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1. Introduction

Currently, the environmental politics of most industrialized countries have as their main issues the valorization and recycling of the generated waste in any activity. In the field of construction a huge amount of waste is generated and the use of waste from construction and demolition to make concrete is becoming more wide spread. Following this path, under the First and the Second National Plan of C&DW [1] drawn up in Spain, different studies are being carried out with the purpose of being able to reuse concrete construction waste in the production of new concrete for different uses, being called recycled concrete [2–9]. This paper has been written as part of a wider research that aims to establish how some fundamental parameters of concrete making affect the properties of the more common structural concrete, i.e. that one with a characteristic compressive strength of 25 MPa or 35 MPa.

The most important aspect of the research carried out is to study the influence of some parameters that were not assessed in previous studies, such as the content of declassified material and the kind of granulometry.

Another very important aspect of this research is that it was carried out by means of a highly fractioned factorial experiment which obtains satisfactory results with a reduced number of tests. The levels of the factors were varied simultaneously since the high number of variables made it impossible to consider the variation of all of them individually. It would not be feasible to develop the test program fully taking into account all the factors and all their possible combinations. The reduction in the number of combinations to be tested was based on solid statistical foundations [10,11], used by Taguchi in later studies [12] and did not imply any decrease in the scientific rigor of the proposal.

2. Objectives

The main aims of this study are the following:

- Detection of factors linked with the selection of materials, dosage and quality objectives of the recycled concrete that have an influence on the properties of the recycled concrete obtained, and to highlight those that are not influential.
- To analyze potentially influential parameters including some that have not been frequently discussed.
- To apply robust statistical methods, by means of the testing program, that provide conclusive results.

3. Experimental program

Experimental research using concrete produced by substituting part of the natural coarse aggregates for recycled ones from concrete demolition was carried out.

3.1. Materials

The cement used was type III/A 42.5 N/SR. This type of cement is widely used in the area in which the study was carried out because the steelmaking industry located in the region generates a large amount of slag and is near a cement plant that usually supplies the concrete plants that funded this research. Its physical and chemical properties are summarized in Table 1.

In Fig. 1, granulometric curves for the three parts of the aggregate are shown: crushed stone (8/20 mm), gravel (4/14 mm) and sand (0/4 mm). They came from the calcareous natural aggregate that was used. Likewise, the granulometry of a silica rolled sand, commonly used for normal concrete can be observed. If it is added in a proportion between 12% and 18% it allows to correct the granulometric curve of the calcareous sand to be corrected and, since it is rounded, it improves workability of the concrete considerably.

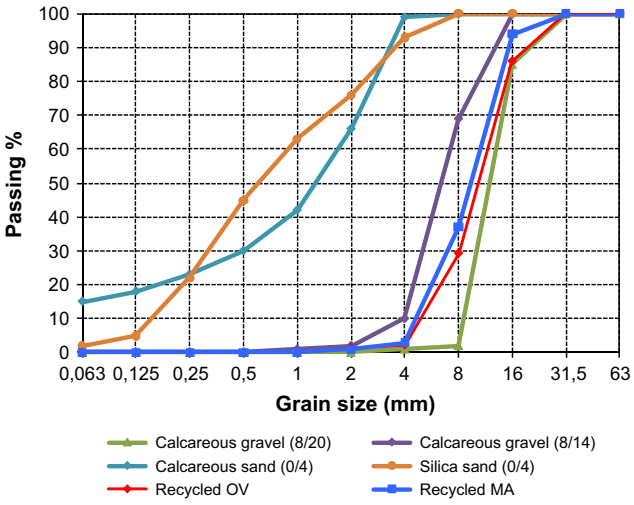

Fig. 1. Aggregates sieve distribution.

Two different additives were used to reach the targeted workability:

- 0.86 kg/m^3 of water reducer Pozzolith 370 N.
- A variable proportion of high range water reducer Glenium Sky 511 for each mixture.

3.2. Factors and levels analyzed

In this research, the influence of the following parameters on some properties of the recycled concrete was assessed: the quality of recycled aggregates (two types of recycled aggregates), the percentage of replacement of natural aggregate for recycled aggregate, the type of sieve curve, the declassified content, the target quality of the recycled concrete (compressive strength and workability) and the replacement criteria.

(a) The quality of the recycled aggregate was analyzed using two types of recycled aggregates from different sources (OV, MD) mainly from concrete waste. Their most relevant properties are shown in Table 2. The most important property that differentiates natural aggregates from recycled ones is the percentage of adhered mortar [13] which results in a greater wear rate in the Los Angeles machine and higher absorption. The amount of adhered mortar present in recycled aggregates used in concrete production leads to concretes which are more porous than those produced using natural aggregates. This results in a decrease in their mechanical properties and durability. The greater degree of water absorption of recycled aggregates implies a lower degree of workability for the same water–cement ratio when these concretes are compared to those produced with natural aggregates or, alternatively, the need for a greater amount of additives in order to make up for the loss of workability.

(b) The percentage of replacement of natural aggregate for recycled aggregate is studied using four rates of substitution of coarse aggregate: 0%, 20%, 50% and 100%.

(c) The influence of the granular structure of the concrete was analyzed by adjusting the mixture of solids (cement and aggregates) to three reference curves (Fig. 2). These three types of granulometric curves, coarse continuous ($a = 11$), fine continuous ($a = 16$) and discontinuous ($a = 12$), are based on the Bolomey parabola. This curve is a reference curve taken for mixing the coarse aggregate and fine aggregate on the concrete proportioning. Our aim was to analyze how the choice of granulometric curve when mixing the aggregates affects the properties of the concrete. The aggregate mixture obtained using continuous granulometric curves produces concretes which are more workable whilst discontinuous curves produce concretes which are more compact but at the same time show a greater tendency to segregate. The three curves are based on the Bolomey parabola [14]

Table 1
Physical and chemical properties of the cement.

Type of cement	Initial set	Final set	Expansión Le Chatelier	Chloride content	Ignition loss	Insoluble residue	Sulfate content
CEM III/A 42.5 N/SR	173 m	217 m	0.3 mm	0.01%	1.57%	0.28%	1.86%