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Review

Alternative processing procedures for recycled aggregates in structural concrete

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HIGHLIGHTS

- Recycled concrete aggregates (RCAs) present higher porosity than natural ones.
- The higher porosity of RCAs results in a higher water absorption capacity.
- Autogenous cleaning process is considered to reduce water absorption.
- The influence of the process duration on the concrete properties is investigated.
- Both workability and strength are enhanced by the process under consideration.

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ABSTRACT

As sustainability is becoming a fundamental requirement for all modern industrial activities, upcoming environmental research efforts should be intended at both enhancing the efficiency in the use of raw materials and reducing the carbon footprint. The present research activity has been launched at the Federal University of Rio de Janeiro (UFRJ, Brazil) for demonstrating the feasibility of "ecological concrete" for structural use, characterised by a significant replacement of natural aggregates with recycled ones, which are produced from processing Construction Demolition Waste (CDW). Particularly, this work explores alternative processing procedures and investigates their influence on the relevant physical and mechanical properties of the resulting aggregates and concrete mixtures. Therefore, particle size distribution, bulk density attached mortar content as well as the associated water absorption capacity of recycled aggregates were monitored to scrutinise the effect of such processing procedures. Subsequently, a series of concrete batches was produced for evaluating the influence that alternative processing procedures for recycled aggregates have on the main mechanical performance in a fresh and hardened state. Results reported in this paper show the feasibility of "autogenous cleaning", which removes surface impurities and reduces particle heterogeneities, usually characterising the morphology of a recycled aggregate matrix. It shows that the considered cleaning procedure significantly reduces the gap between the performance of recycled aggregate concrete (RAC) and ordinary ones, both in terms of workability at the fresh state and strength at the hardened state of concrete mixtures.

Contents

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1. Introduction

Environmental issues are gaining increasing consideration in engineering and industrial applications and are more and more often the crucial point in decision-making procedures. In fact, starting from the second half of the last century, the world production of goods and services has increased exponentially as a results of several phenomena, such as huge expansions in industrial activities, vast developments of urban areas and strong demographic growth. Moreover, in more recent years, significant industrial growth of emerging economies such as in Brazil, Russia, India, China and South Africa (BRICS) suggests that the world demand for raw materials will even further increase in the near future [1]. Therefore, industrial processes and human activities should be intended at both increasing the efficiency in (re-)using raw materials and reducing greenhouse gas emissions. In fact, the current rate of consuming natural resources will result in an unsustainable pressure on the Earth's natural balances and resources [2]. In the end, the same processes and activities produce a significant amount of end products which will finally turn into "waste". Although no common definition is actually accepted for the word "waste" across all countries, the following classification is often adopted within the international scientific literature [3]: Municipal Waste (produced by individuals and economic activities), Industrial Waste (related to production processes), Construction and Demolition Waste (produced by construction sector), and Mining Waste (generated by oil and gas operations). According to this classification, construction and demolition waste (C&DW) is defined as all kinds of waste obtained from construction, renovation and demolition activities. In fact, it covers a very broad range of used materials like: concrete, bricks, tiles and ceramics, wood, glass and plastic, bituminous mixtures, coal tar and tarred products, metals, soil, etc.

In Europe, the contribution of each sector to the generation of waste is well described by the EEA (European Environment Agency), which monitors all available data from the first 15 Member States of the European Union. The percentages of produced waste varies considerably among the different sectors and waste categories, and reflects different socio-economic factors. It is interesting to mention that, according to the EEA data, the largest share of waste (31%) derives from construction and demolition activities, while, municipal waste, which is probably better related to the idea of waste in the common way of thinking, only represents about 12% of the total waste production [4].

In fact, about 850 million tons of C&DW are generated each year in Europe and approximately one third consists of concrete debris [5]. In order to compare the production of C&DW among European countries, it is useful to refer to values per capita. For instance, when considering data between 2004 and 2006, Luxembourg had the highest production per capita, with 15 tonnes, while any other country did not exceed one half of this value (ETC/SCP, 2009) [6]. Moreover, in 2004 France generated about 6 tons per capita, Finland 4 tons, while Germany showed a remarkable decrease of C&DW production from 1995 to 2005, as less than 2 tons per capita were recorded. Finally, the majority of European countries generate between 1 and 2 tons. However, as in many countries of the European Union, such as The Netherlands and Denmark, environmental restrictions do not allow for opening new landfills anymore, leading to a strong motivation for finding alternative solutions for handling the significant amount of C&DW, such as the production of recycled aggregates. Taking this point into account, it is interesting to analyse some available data about the current practices in recycling C&DW. For instance, it can be observed that, even though Italy, Denmark and The Netherlands generate almost the same amount of C&DW per capita, Italy recycles only 10% of its overall production, despite the remarkable results achieved by the other two aforementioned countries, where the percentage of recycling and reusing is more than 90% [7].

The ambition of reducing the use of natural materials in construction and the aim of reducing the environmental impact of the concrete industry has recently driven Europe to adopt a policy that strongly promotes the use of recycled aggregates in concrete production. The European Directive n.98 of 19/11/2008 [8] calls on member states to take "the necessary measures to promote the reuse of products and the preparing measures for re-use activities, particularly by promoting the establishment of economic tools and criteria about tenders, quantitative targets or other measures". Particularly, it specifies that preparations for re-use, recycling and other types of recovery of material, including construction and demolition waste, shall be increased up to at least 70% (by weight) by 2020.

Waste materials produced from either demolished concrete structures or from industrial precasting of concrete members, are the potential sources for Recycled Concrete Aggregates (RCAs), and can possibly be employed for producing new cement-based composites, such as ecological concretes or mortars [9]. The resulting physical and mechanical properties of these concretes, produced with recycled aggregates, were initially investigated from several papers recently published in the technical literature [10–15]. The focus of these papers is mostly on comparing the relevant performance aspects of Recycled Aggregate Concrete (RAC) with the ordinary ones, made with "natural" aggregates [16]. Several investigations point out that the physical and mechanical properties of RAC strongly depend on the quality (nature, size and grading) of the recycled aggregates [17]. In fact, RCAs are particularly characterised by a significantly higher water absorption capacity and lower mechanical properties with respect to "natural" gravel and sand [18]. The reason for this behaviour can be attributed to the higher porosity characterising the outer layers of the crushed concrete particles, called "attached mortar". Since this attached mortar structure of RCA clearly affects the relevant physical and mechanical properties of RAC, a certain attention should be paid to monitor these effects, or even better, take them into account in the mix design. This can be possibly done by measuring their water absorption capacity, its effect on the workability at the fresh state and, its consequence on the mechanical properties in terms of strength at the hardened state [19,20].

As a matter of fact, recycled concrete aggregates are mainly composed of two phases [21,22], namely old aggregates and old mortar paste. Consequently, the standard procedure generally adopted for the design and production of ordinary concrete (i.e., with natural aggregates), cannot be applied when Recycled