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Mechanical and durability performance of sustainable structural concretes: An experimental study

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A B S T R A C T

This study reports the results of a wide experimental campaign intended at investigating the mechanical and durability performance of structural concretes made with Recycled Concrete Aggregates (RCAs) and coal Fly Ash (FA). To this end, twelve mixtures were designed by replacing part of the ordinary constituents (i.e. cement, sand and coarse aggregates) of a reference one with RCAs and FA. Samples of these mixtures were subjected to various tests aimed at assessing both their structural properties and durability performance. As for the former, time evolution of compressive strength was monitored at various curing times up to 365 days, and the splitting strength was determined at 28 days. Moreover, the expected durability performance of the aforementioned concrete mixtures was scrutinised by measuring some relevant physical quantities, such as water permeability, carbonation depth and chloride-ions ingress at various curing ages.

The results obtained from these tests are often not self-evident, as they unveil the synergistic effect of combining both RCAs and FA on the resulting physical and mechanical properties of "green" concrete. Moreover, they demonstrate that the current code restrictions on the use of both RCAs and FA for structural concrete might be significantly relaxed, especially if the delayed binder effect, induced by the latter, is duly taken into account and, hence, concrete properties are measured at curing times longer than the conventional 28 days.

1. Introduction

With a global production of around 10.000 million tons per year [1], concrete is certainly the most used construction material. Consequently, the concrete production requests huge amounts of energy and raw materials, resulting in a significant depletion of natural resources [2]; moreover, it is also responsible for a significant share of the global greenhouse gas emissions, mainly due to cement production processes [3].

Therefore, nowadays several organisations and, consequently, research groups are committed to formulating more sustainable materials and processes intended at "greening" the concrete industry [4]. A possible solution for achieving this objective is based on adopting alternative binders (often obtained from industrial by-products) as a partial replacement of Portland cement [5], with possible positive consequences, not only on sustainability, but also in terms of durability [6]. Furthermore, replacing ordinary aggregates with recycled ones is another viable solution [7]: in the literature, the concrete produced with recycled aggregates is often referred to as Recycled Aggregate Concrete (RAC) [8].

The huge amount of Construction and Demolition Waste (CDW) produced in Europe [8,9] is a potential source for producing recycled aggregates: in fact, despites the huge production of CDW (Fig. 1), its recycled percentage is often very low (Fig. 2). Moreover, the current regulations about structural concrete [10–14], with their restrictions to the use of recycled aggregates, represent a further hurdle for RAC to be more commonly employed in construction, at least when ordinary mechanical properties are requested and mild environmental exposure conditions are expected.

However, several recent researches demonstrated that a limited use of recycled aggregates derived from CDW has negligible consequences on the mechanical performance required in structural applications in terms of technological aspects [15], fundamental behaviour (i.e. in terms of cement reaction development) [16,17]

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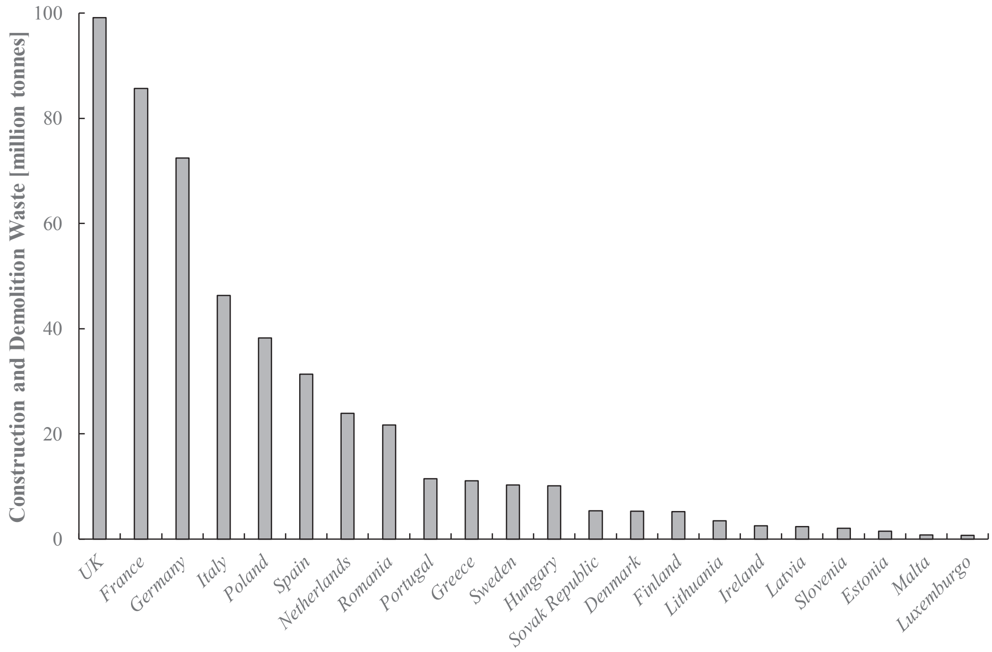

Fig. 1. Annual production of construction and demolition waste in Europe [9].

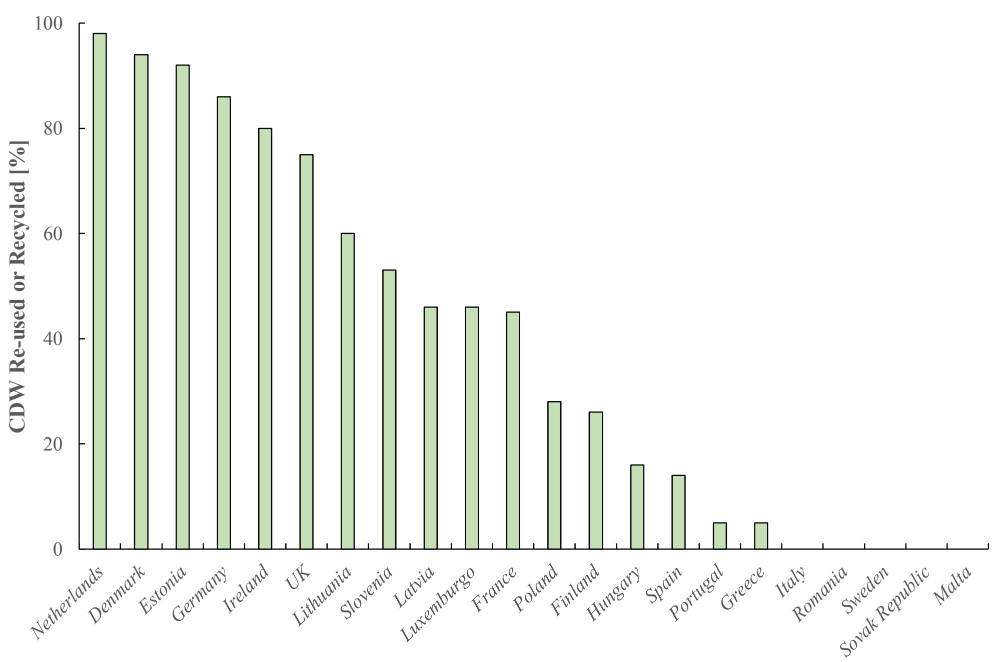

Fig. 2. Re-use and recycling of construction and demolition waste in Europe [9].

and resulting stress-strain response [18].

The present study focuses on the combined use of recycled aggregates derived from demolished concrete members ("Recycled Concrete Aggregates", RCAs) and coal Fly Ash (FA), which places several concerns about the resulting mechanical and durability performance of concrete.

In fact, since RCAs can be seen as the combination of two main phases, such as original natural aggregates and paste attached to them (usually referred to as Attached Mortar, AM [19]), they are generally characterised by higher porosity and, hence, water absorption capacity, with respect to the "ordinary" natural aggregates. This is the key motivation for developing a dedicated mix-design procedure capable of predicting the effects of RCAs on the resulting compressive strength of RAC [20]. Moreover, the presence of RCAs can seriously affect both workability at the fresh state [21] and durability performance of RAC [22].

However, the use of FA in partial substitution of Portland cement and fine aggregate can also be considered, in order to mitigate the drawbacks induced by using RCAs in structural concrete and, at same time, promoting a further greening practice in the concrete industry [23]. As widely demonstrated in the literature, a limited use of FA, either as a filler or as a possible cement replacement, can