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Short and long-term behavior of structural concrete with recycled concrete aggregate

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ABSTRACT

Recycling concrete construction waste is a promising way towards sustainable construction. Coarse recycled concrete aggregates have been widely studied in recent years, however only few data have been reported on the use of fine recycled aggregates. Moreover, a lack of reliable data on long-term properties of recycled aggregate concrete has to be pointed out.

In this paper the effects of both fine and coarse recycled concrete aggregates on short and long-term mechanical and physical properties of new structural concrete are investigated. The studied concrete mixes have been designed by adjusting and selecting the content and grain size distribution of concrete waste with the goal to obtain medium–high compressive strength with high content of recycled aggregates (ranging from 27% to 63.5% of total amount of aggregates).

Time-dependent properties, such as shrinkage and creep, combined with porosity measurements and mechanical investigations are reported as fundamental features to assess structural concrete behavior.

1. Introduction

It is well known that concrete industry largely contributes to the environment impoverishment. For this reason, the less natural aggregates are used in concrete production, the lower the impact of the concrete industry on the environment. Aggregates are the major components of concrete and have a significant effect on engineering properties of the final product [1]. Natural resources are remarkably affected by their extensive use due to the increasing demand of structures. Therefore, the use of construction and demolition waste (C&DW) as alternative aggregates for new concrete production gains importance to preserve natural resources and reduce the need for disposal. Indeed, the deposition of demolition waste has an environmental impact and it strongly contributes to landfill saturation.

Maximizing the amount of recycled materials among concrete components is a very effective and promising approach toward sustainable construction [2–9]. In fact, aggregates represent almost 80% of concrete, thus their replacement with recycled materials can really help to transform traditional concrete into a sustainable material.

Available experimental data concerning concrete made with recycled aggregate (recycled aggregate concrete, RAC) are highly variable since the quality of RAC mostly depends on the quality of original demolished concrete used for recycling. Even if some results are contradictory, some general conclusions can be drawn about the effects of coarse recycled aggregate. For example, RAC with low to medium compressive strength can be easily obtained irrespective of the specific quality of recycled aggregates [5,10–14]. Moreover, it is not uncommon to demolish relatively young structures (for instance 15 years old or less), because their functional features do not suit any longer the new technical and social needs [10]. This type of waste represents a very good choice for recycling high grade concrete in new concrete structures.

The physical properties of recycled aggregates strongly depend on the adhered mortar quality and amount [11,15]. Adhered mortar is a porous material and its porosity depends on the water/cement ratio (w/c) originally adopted. In general, the quantity of adhered mortar increases with the decrease of the recycled aggregates size [11,15,16]. The crushing procedure also has an influence on the amount of adhered mortar. Due to the adhered mortar, recycled concrete aggregates have a lower density and higher water absorption, compared to natural aggregates. The actual concrete compressive strength varies with the compressive strength of the original concrete used as recycled aggregates and the adopted w/c. Moreover, the presence of potentially un-hydrated cement on the surface of recycled concrete aggregate can further affect the concrete properties [17].

All the mentioned reasons explain why the quality of the recycled aggregates is a key point in the production of new concrete and how the comparison between RACs properties coming from literature data can be directly affected by this issue.

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So far, most of the research carried out focused on the use of coarse recycled aggregates in new structural concrete [5,10–14], whereas the use of fine recycled fraction [18,19] is still poorly investigated because it can significantly impair some concrete properties. The utilization of fine recycled aggregates in structural RAC is generally not recommended [5]. However, during the last decade the use of fine recycled aggregates has achieved great international interest, mainly because of economic implications related to the shortage of natural sands suitable for concrete production [19–21]. Indeed, the use of recycled aggregates of all grades is strongly recommended to increment the recycling process of C&DW.

The novelty of this paper is that the effects of both fine and coarse recycled concrete aggregates on short and long-term mechanical and physical properties of new structural concrete are investigated. The current study has been carried out with an integrated approach involving mechanical characterizations and porosimetric analysis.

Although in the past, several studies were focused on the relations between cement matrix pore size distribution and extent of shrinkage/creep in traditional concrete structures, less research in this direction has been carried out on recycled aggregate concretes [20,24–26]. RACs have been studied extensively from the point of view of environmental impacts [4,5], mix-design [11,20,26] and short-term mechanical performances [5,10–14], but a lack of widespread and reliable data on long-term properties is evident. Thus, time-dependent properties combined with porosity measurements can be considered as the original features of the present paper, besides the fact that all the types of recycled aggregates derive from the same demolished structures.

Concrete waste deriving from the demolition of concrete buildings located in Punta Perotti (Bari, Italy) was crushed and properly assorted to create grain size distributions suitable to produce high quality concrete for structural applications. Aggregates play a fundamental role in determining workability, strength, dimensional stability and durability of concrete. Exploiting previous studies in this field [22,23], the investigated concrete mixes have been designed adjusting and selecting the content and grain size distribution of concrete waste with the goal to obtain medium–high compressive strength with high content of recycled aggregates (fine and coarse).

Five concrete mixes with a large content of recycled concrete aggregates (ranging from 27% to 63.5% of total volume of aggregates) replacing natural ones (fine and/or coarse) have been designed and characterized at the fresh and hardened state by physical–mechanical tests in order to obtain a full description of their short and long-term behavior. The experimental results are discussed and correlated with the determined porosity data (total porosity and pore size distribution), in order to highlight their effects on the macroscopic behavior of new concrete mixes. A control concrete mix, prepared with natural aggregates and the same cement amount and *w*/*c* ratio as those prepared with recycled concrete aggregates, is reported for comparison.

Finally, this work attempts to strengthen the concept of sustainability in civil constructions combining the use of coarse and fine recycled concrete aggregates to produce structural concrete with a low environmental impact.

2. Experimental investigation

2.1. Materials

Cement type CEM II-A/LL 42.5 R, according to UNI EN 196-1 [27], was used as binder.

Sand (*S*, 0–6 mm), fine gravel (*FG*, 6–16 mm) and gravel (*G*, 16–25 mm) (Cave Pederzoli, Bologna, Italy) were used as natural aggregates (*N*) in concrete mixes. Two cumulative grain size distributions were prepared following Fuller distribution, with maximum diameter of 16 and 25 mm, respectively: *N 16* (*S* 60 vol% and *FG* 40 vol%) and *N 25* (*S* 48 vol%, *FG* 25 vol% and *G* 27 vol%) (Fig. 1).

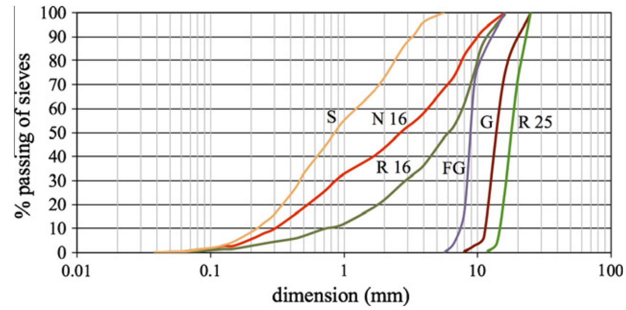

Fig. 1. Grain size distribution of natural (*S*, *FG*, *N 16*, *G*) and recycled (*R 16*, *R 25*) aggregates.

Concrete waste coming from the demolition of Punta Perotti building (2006, Bari, Italy) [22,23] was used as recycled aggregates. Punta Perotti building represents a typical Italian example of structures built in a natural protected area without planning permissions (Fig. 2). The construction started in 1995 and was stopped by the Italian court after 2 years, thus the building was never completed with interior partitions, technological apparatus, etc. It took 11 years of legal debates to reach the final decision of complete structures demolition. From the scientific point of view, the demolition waste of Punta Perotti building has been considered as very interesting as constituted by concrete and steel only. After demolition, steel was removed and recycled, whereas a large part of the concrete waste was disposed to landfill. Fortunately, a minor part of the demolished concrete was also collected by the University of Bologna and used for scientific purposes.

Compressive tests made on concrete cores of the original building showed medium–high compressive strength ($f_{cm} \approx 36$ MPa), thus making the relevant demolition waste very attractive for the production of new structural concrete. Indeed, concrete waste coming from Punta Perotti building has been considered completely stable at the moment of the demolition as the relevant concrete was cast 15 years before.

The demolished concrete underwent on-site crushing in two different stages. The first crushing treatment, used to separate concrete from steel, was made with clamp mechanical excavators and

Fig. 2. Punta Perotti structure (Bari, Italy) before demolition.