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Influence of recycled coarse aggregates on normal and high performance concrete subjected to elevated temperatures

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HIGHLIGHTS

- We studied RCA concretes after exposure to temperatures up to 750 °C.
- We considered both normal strength and high performance concretes.
- Residual tests on cracking, mass loss, porosity, thermal and mechanical properties.
- RCA concretes had comparable but slightly worse performance than reference concretes.
- RCA concretes were affected by impurities and cracking at mortar–aggregate interfaces.

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ABSTRACT

Recycled concrete aggregates (RCA) can be a promising solution for sustainable development. For buildings, the high temperature performance is critical to estimate fire resistance. Thus, this paper investigates RCA concretes after exposure to temperatures up to 750 °C by considering laboratory and industrial RCA, and normal and high performance concretes. Tests were conducted on cylindrical specimens to assess cracking, mass loss, porosity, and thermal and mechanical properties. The residual performances for the recycled concretes were generally similar to but slightly worse than those observed for the reference concretes. The presence of non-cementitious impurities accelerates the damage of concretes with temperature.

1. Introduction

In the past decade, construction activity in Europe in particular has been growing at an increasing rate, and aggregate production and importation are no longer sufficient to provide all the needed raw materials. In France, quarries are more and more frequently classified as protected sites, and aggregate producers cope with a lack of workable sites. On the other hand, demolition sites produce a huge amount of waste, which is too rarely reused and often recycling is generally limited to road construction. A promising alternative is to recycle the demolition waste as construction materials for structural concrete, provided their mechanical behaviour allows it.

The properties of recycled concrete have already been widely studied [1–4]. It is now accepted that the high water absorption coefficient and low density of recycled concrete aggregates (RCA) give recycled concrete lower mechanical properties and durability when compared to concretes formulated with natural aggregates. However, appropriate mix design of the RCA concrete can provide concrete with comparable mechanical properties to those of concrete with natural aggregates [5]. Despite reasonable performance at room temperature, only a few authors have considered the performance of RCA concretes when submitted to high temperatures [6]. When concrete is heated, several phenomena can occur such as expansion of aggregates, shrinkage of cement paste, increases

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in vapour pressure, and cracking or spalling. Thus, this paper aims to address this gap in knowledge by investigating the thermal and mechanical behaviour of both normal and high performance concrete containing RCA.

2. Background

Aggregates compose around 80% of the structure of concrete and therefore have a great influence on the thermal response of concrete. For example, [7] compared thermal deformation of several concretes formulated from different types of aggregates and showed that the coefficient of thermal expansion for concrete depends mainly on the type of aggregate. For instance, flints have higher coefficients of thermal expansion when compared to those of limestones, and therefore concretes made with flint aggregate have lower thermal stability than calcareous concretes [8,9].

In addition to potential differences in the mineralogy of the aggregates, RCA contain mortar and thus they have very different properties than natural aggregates: they are more porous, they have a higher water absorption coefficient, and they contain hydrates. Additionally, concretes with RCA have in general twice as many interfacial transition zones because the RCA have interfacial zones between the mortar and the original aggregate as well as between the RCA and the new cement paste. These interfacial transition zones are known as being weak areas in terms of mechanical properties [1,10].

A few studies have been led on the subject of recycled concrete submitted to high temperatures, and from them a few conclusions can be drawn [6,11–17]:

– Just like natural concrete, recycled concrete exposed to high temperatures shows a great decrease in its mechanical properties when compared to the properties before heating.
– No explosive spalling has ever been witnessed in the recycled mixes tested.
– Recycled concretes seem to show better residual mechanical properties when compared to reference natural concretes.
– Recycled concrete with low *w*/*c* ratios seem to have better properties than concretes with higher *w*/*c* ratios.
– Just as with natural aggregates, RCA from calcareous concrete show better thermal stability than RCA obtained from concrete made with flints.

However, these studies often show opposing results. In all of them, concrete samples were submitted to rather fast heating rates, between 4.5 °C/min and that of the ISO-834 fire. In their study, [12] assumed that, after maintaining the target temperature for two hours after ISO fire test, the temperature would be homogeneous within the sample. This assumption was contradicted by Zega and Di Maio [11] who showed that, even after 4.5 °C/min heating and 4 h at a steady temperature of 500 °C, there was still a 50 °C difference between the temperature of the oven and the centre of the concrete sample.

Moreover, the variability of origins and nature of the studied aggregates make it difficult to compare the results.

The thermal instabilities observed in these studies are limited to the appearance of cracks on cubical samples from 800 °C [12] and from 600 °C on prismatic samples. No explosive spalling has been witnessed in recycled concrete during fast heating [12,13].

To this day, no study was found on the thermal behaviour of recycled aggregates or recycled concrete in terms of conductivity, diffusivity, specific heat. Additionally, no studies at high temperature were found on high performance concrete made with RCA.

Thus, the current paper addresses these research gaps by investigating the thermal and residual mechanical performance of both normal and high performance concretes made with RCA. In order to make meaningful comparisons, all the concretes of the study are composed of the same original aggregate and a homogeneous temperature is ensured in samples of concrete. Such an improved understanding of physical, thermal, and mechanical properties is an important step towards implementing RCA more widely as structural concrete in buildings.

3. Objectives and significance of the research

The main objectives of the research were:

(1) To investigate the influence of the *w*/*c* ratio on high temperature behaviour.
This is an important parameter to study because the *w*/*c* ratio of the new paste has an influence of strength of bonds between aggregate and paste. If the strength of interface increases, then the failure mode changes. For example, the old mortar composing the recycled aggregate may become the weaker than the interface between the new paste and the RCA and thus cracks may occur in the old mortar rather than at the interfaces. Since cracking is an important phenomenon at high temperature, changes in interfacial bond strength may have an influence on the high temperature behaviour of concrete made with RCA. Moreover, the differences of permeability between old and new paste can be important in a case of high performance concretes with lower *w*/*c* ratios for the new paste. The high performance concrete could prevent water vapour from escaping from the old paste thus leading to increased pore pressure and the potential for more cracking or even spalling. Alternatively, the more porous RCA may mitigate any tendencies for spalling in the high performance concretes. Understanding these mechanisms of performance at high temperature is important for fire performance of RCA concretes.

(2) To compare the performance of concretes made from RCA from real demolition waste against those sourced from concrete made in the laboratory.
Such comparisons are critical to understand of the influence of the age of the paste and the effects of contaminants.

The research is significant because investigating high performance concretes can help demonstrate how internal failure modes may be modified, and how mix designs for RCA can be modified to enhance thermal and mechanical performance at high temperature. Additionally, the research has practical applications in that a comparison is made between the different sources of RCA. The RCA sourced from the laboratory is comparable to that obtained from excess concrete returned to a concrete plant while the industrial RCA is representative of demolition waste. This research will help producers understand any differences in high temperature performance that occur as the result of the type of RCA. Finally, quantifying the high temperature behaviour of RCA concretes is critical for understanding the fire performance of buildings built with such concretes.

4. Materials and methods

The main parameters in the study were the type of aggregate and the class of concrete (i.e., either normal or high performance). Table 1 provides an overview of the investigation. Three types of coarse aggregates were used: one was a natural crushed silico-calcareous coarse aggregate (SCCA), used as a reference, one was RCA from concrete made in the laboratory (i.e., LRCA) while the third was RCA from an industrial source (IRCA). Half of the specimens were made from normal strength concrete with a water to cement (*w*/*c*) ratio of 0.6 while the remaining specimens were made from high performance concrete with a *w*/*c* ratio of 0.3. Each type of concrete was exposed to six different temperatures ranging from room temperature (20 °C) to 750 °C as shown in Table 1.