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Evaluation of the concrete prisms test method for assessing the potential alkali-aggregate reactivity of recycled concrete aggregates

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ABSTRACT

The concrete prism test (CPT) is a widely used method for assessing the potential alkali-aggregate reactivity of any given natural aggregate. This paper presents the evaluation of the current method and its applicability to assess the alkali-silica reactivity of recycled concrete aggregates (RCA). The testing was carried out on two different types of RCA: manufactured from > 15 years old blocks disposed outdoors and from a demolished overpass infrastructure. Following the analysis of the different parameters that make RCA different than original aggregates, it has been found that the residual mortar content of the RCA particles and their absorption condition prior to their addition to mixtures are considerably important. The CPT is reliable to access RCA reactivity, however it is therefore recommended to use saturated RCA as higher expansion is obtained under these conditions. It is also recommended to use the aggregate dry rodded bulk density to determine the coarse aggregate-to-sand ratio, instead of using a fixed 60 to 40 ratio. Moreover, no pessimum effect was observed using RCA; in fact, the expansion of the test prisms was increasing with increasing RCA content. The extent of damaged suffered by the concrete from which the RCA are manufactured and the geology of the original virgin aggregates incorporated in the RCA are also important parameters to consider while using the CPT to assess correctly each RCA reactivity.

1. Introduction

Concrete is currently the most widely used construction material in the world. In fact, an average of about one (1) cubic meter of concrete per capita is produced annually. However, the environmental impacts resulting from this production make it one of the most "costly" [1]. Actually, the 2013 worldwide cement production (3.7 billion tons), an essential component of concrete, represented 7.4% of the annual carbon dioxide (CO_2) emission in the atmosphere [2]. The sustained demand for concrete construction could also lead to the premature shortage of aggregate resources in the vicinity of urban areas, the potential destruction of natural habitats and the increase in greenhouse gas (GHG) emissions due to the mining process and the continuously increasing distances for transportation of these materials [1].

On the other hand, since the majority of concrete infrastructures in the world have been built after the 1950′s, it is almost inevitable that they will require repairs or reconstruction in a near future to meet modern standards and serviceability requirements [3]. About 510 million tonnes of construction and demolition waste are produced each year in Europe, while the United States and Japan produce respectively about 325 and 77 million tonnes of such materials annually [4]. Given that China and India are now producing and using over 50% of the world's concrete, their waste generation will likely keep increasing as development continues [4]. The abundance of concrete demolition material and the emerging concepts/approaches regarding sustainable development have contributed to an increased interest in research and potential use of recycled concrete aggregates (RCA) in the construction sector. Although RCA are largely used in geotechnical projects (e.g. road foundations), there is a growing interest in the use RCA in concrete construction, which requires that RCA meet stringent requirements commonly applied for such type of application.

2. Recycled concrete aggregates

One of RCA's special feature, is the presence of residual mortar (RM) surrounding the original virgin coarse aggregate particles (OVA) (Fig. 1). This residual mortar carries a significant porosity that results in a fairly high absorption potential of RCA (can reach more than 5%); it has also been pointed out by many authors as the main reason why compressive or tensile strengths are lower for recycled aggregates

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Fig. 1. Example of a RCA particles and its component (RM: residual mortar; OVA: Original virgin aggregate).

concrete (RAC) than for conventional concrete of equivalent mix proportions [5–10]. However, Fathifazl et al. [6] proposed a new design method for concrete incorporating RCA that takes into account the RM content in the RCA, which actually results in the production of RAC with mechanical and structural properties that are equal or superior to companion concretes incorporating only original concrete aggregates (OVA).

So, in addition to the porous nature and high absorption capacity of RCA, such material imposes an added challenge in regards to the durability of recycled aggregate concrete (RAC) since it may have been produced from concrete structures/elements that were affected by deleterious pathologies, such as freezing and thawing in the presence or not of deicing chemicals, internal/external sulfate attack, and alkali-aggregate reactions. This makes the parent concrete from which the RCA are manufactured even more decisive of the quality of the latter. In fact, according to Akbarnezhad et al. [11] the compressive strength at the time of demolition, the size of the OVA and the crushing methods strongly affect the RCA properties. Unfortunately, it is fairly rare to demolish infrastructures that are in good condition. It is then required to produce aggregates incorporating significant deficiencies.

Finally, the method used to manufacture the RCA was also pointed out by Exteberria et al. [12] and several other authors as the determining factor of the shape of the RCA. Of course, the workability of the concrete is linked to this parameter, but the amount of RM attached to the OVA is also bound to the crushing methods. As the RM absorption is significantly higher than OVA particles, a particular attention should be paid to this matter. This topic will be further discussed later in this paper.

2.1. The potential alkali-silica reactivity of RCA

Alkali-silica reaction (ASR) is one of the main causes of deterioration of concrete infrastructures worldwide. Also reported as the *concrete cancer*, ASR is a reaction that occurs between the alkali hydroxides (Na, K – OH) included in the concrete pore solution of the hydrated cement paste and certain siliceous mineral phases of aggregates [13]. Shehata et al. [14] carried out a research program to determine the performance of ASR-affected RCA for new concrete manufacturing. The destruction of concrete blocks from an outdoor exposure site used during another study on ASR [15] allowed the production of RCA, which were used in the fabrication of RAC. The original concrete had been produced using a reactive siliceous limestone aggregate (Spratt) and a general use (GU) Portland cement and had reached about 0.2% after 12 years of outdoor exposure. Concrete prisms (following CSA A23.2-14A) [16] and mortar bars (in accordance with ASTM C 1260 standards) [17] were manufactured to determine the efficacy of the accelerated mortar bar test (AMBT) for evaluating the potential alkali-reactivity of RCA, as well as the effectiveness of supplementary cementing materials (SCM) to control expansion due to ASR with such aggregate materials.

According to this study, three major conclusions emerged:

- ASR related cracking is as intense in RAC concrete than in the original concrete used to manufacture the RCA;
- A larger amount of SCM is necessary to prevent ASR in RAC than that necessary to control the potential alkali-reactivity of the original virgin aggregate;
- Concrete prism test (CPT is effective in assessing the ASR potential of RCA and to determine the proportion of SCM needed in the mix to prevent ASR expansion with such aggregate materials.

The data reported by Shehata et al. [14] were most interesting; however, all the testing had been carried out on only one type of RCA and requires further support with a larger variety of recycled aggregate materials. Such additional information is essential to develop guidelines that would allow the safe use of RCA in the construction of concrete infrastructures.

2.2. Important parameters to consider when using RCA

2.2.1. Water absoprtion

As previously indicated, the RM surrounding the OVA is the main factor regarding the high absorbency of RCA. A recent study carried by Delobel et al. [18] mentioned that in the case of absorbing aggregates like RCA, absorption water cannot be neglected. The effective water-to-cement ratio could be significantly changed, and so influence the measured expansion. It was found that the absorption water greatly influenced the expansion of the specimens made with RCA, and should be considered in the composition of the mixes. The initial state of saturation, on the other hand, is less influential.

2.2.2. Leaching of alkalies

Johnson and Shehata [19], tried to evaluate the efficacy of accelerated test methods to evaluate alkali silika reactivity of RCA. The expansion reached by the specimens cast with RCA which had not been washed prior to their incorporation to mixes was significantly higher that those using washed RCA. In fact, the expansion difference between those two specimens was higher than the established test variation. However, it is highly probable that washing fine RCA has a bigger impact on the leaching of the alkalies than when coarse RCA are washed before their use in concrete.

3. Scope of work

The particular subject of this paper is the use of the *Concrete Prism Test (CPT)* for assessing the ASR potential of RCA. In order to achieve our objective, extensive testing was performed on RAC specimens incorporating RCA obtained from two different sources: 1) the crushing of four sets of concrete blocks made with a variety of reactive coarse aggregates from Canada and that have been previously subjected to natural environmental conditions on the CANMET outdoor exposure site located in Ottawa (ON, Canada) for a period of about 15 years [14–15], and 2) an ASR-affected concrete overpass from the Quebec City area that was demolished in 2010 (Du Vallon – Charest).

In this study, two important RCA properties were evaluated through concrete prism testing, i.e. the saturation condition of the aggregates (coarse RCA and fine natural sand) prior to their use in fresh concrete, and the influence of the residual mortar (RM) content on expansion due to ASR. The evaluation of both parameters has been made to provide recommendations regarding the use of the above method for evaluating the potential alkali-reactivity of RCA.