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Mechanical and durability performance of concrete produced with recycled aggregates from Greek construction and demolition waste plants

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ABSTRACT

Greece has to recycle 70% of Construction and Demolition Waste (CDW) by 2020, in the context of the enforcement of Waste Framework Directive (WFD) 2008/98/EC. CDW recycling has started only recently to a small extent and is restricted to road works. The reuse of CDW in new concrete production could contribute to the construction sector sustainability through minimizing landfill and the need for new raw materials. Literature data are found regarding the performance of recycled concrete, but limited knowledge is available regarding the chemical and mineralogical properties of recycled aggregates (RA) and how these affect concrete. Moreover, Greek aggregates are not siliceous aggregates as are most of the aggregates investigated in literature. Against this background, this study aims to evaluate for the first time mechanical and durability performance of concrete made with RA from different Greek recycling plants. All recycled materials used were characterized in terms of chemical and mineralogical composition and certain chemical and physical properties have been determined. It was found that all RA are enriched in Si, Al, and alkali oxides, which was mineralogically verified by the identification of quartz and minor quantities of mica and feldspars. They proved though innocuous to alkali aggregate reaction. Higher water absorption of coarse RA is their most negative physical characteristic. Fine fractions of RA have low Sand Equivalent and significantly high water absorption values, which make them unsuitable to replace natural sand. Water soluble ions are at the same level to that of natural aggregates.

Furthermore, concrete mixtures were prepared using an RA percentage ranging from 0% to 75%. Results indicate that the compressive strength of recycled concrete ranges from significantly lower (37% reduction) to equal, compared to conventional concrete, depending on the composition of RA. The majority of literature data relate the inferior quality of RA to their high water absorption, the findings of the present research though indicate that the presence of clay minerals has a more pronounced adverse effect to concrete's strength. As for the durability properties examined, i.e. water absorption, sorptivity, frost and carbonation resistance, the recycled concrete mixtures exhibited somewhat lower performance than reference concrete.

1. Introduction

The recycling of Construction and Demolition Waste (CDW) has been recognized by the EC as an important step towards the sustainability of the construction sector. This is stated in the Waste Framework Directive (WFD) 2008/98/EC, according to which the target of 70% recycling has to be achieved by 2020. As it is reported in RILEM TC 217-PRE Report (2013) as well as by Poon (2007), Li (2008, 2009) and Hadjieva-Zaharieva et al. (2003) the need for recycling CDW's has been identified in most developed countries and generally the interest for using recycled materials is increasing worldwide, especially where the availability of landfill places is low. Although the construction sector is the largest waste stream in EU, as it was also the case in Greece before 2010 when the economic crisis started, recycling percentages vary significantly among the member states from 90% (Germany, Netherlands) down to 5% (Greece, Cyprus).

Recycled Aggregates (RA) are mainly used in road sub base and earth works. Their restricted use in structural concrete is mainly

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attributed by the lack of confidence in the performance of these materials as it is presented in various cases in RILEM TC 217-PRE Report (2013).

Important research has been published concerning the effect of using RA on the mechanical performance of concrete. Etxeberria et al. (2007) used recycled coarse aggregates in wet condition from a waste recycling area in Spain and studied the influence on compressive strength, tensile strength and modulus of elasticity by preparing concrete mixtures of medium strength (25–35 MPa). According to their results, use of 100% recycled coarse aggregates results in 20–25% less compression strength, 2–10% less tensile strength and 16–17% lower modulus of elasticity than conventional concrete at all ages with the same effective w/c ratio.

Tabsh and Abdelfatahl (2009) used laboratory crushed aggregates from old 30 and 50 MPa concrete as well as commercially available RA from a dump site and made 30 and 50 MPa concrete mixtures with 100% coarse RA. Their results showed that the strength of the old concrete favors the strength of the new recycled concrete since the use of coarse aggregates made from 50 MPa old concrete produced a concrete with compressive and tensile strength comparable to that of conventional concrete. On the other hand the percentage loss of compressive strength of concrete made with commercial RA was 35% for 30 MPa concrete class and 15% for 50Pa concrete class. In addition, the percentage loss of tensile strength was 30% and 20% respectively.

On the other hand, Rahal (2007) prepared in the laboratory coarse aggregates by crushing waste concrete beams of two old buildings in Kuwait and found that concrete mixtures with target cube strength between 20 and 50 MPa, prepared with 100% coarse RA in saturated surface dry (SSD) condition exhibited only a 10% decrease in strength.

Moreover, according to the test results of Sagoe-Crentsil et al., 2001, there is no significant difference in compressive and tensile strength between recycled and conventional concrete. The authors evaluated the performance of 25 MPa grade concrete containing 100% crushed and graded coarse RA from a recycling plant in Australia. The recycled aggregates were used in presaturated condition.

To the contrary, the use of fine RA from crushed concrete has been found detrimental by Khatib (2005). The reduction of 28d compressive strength at 25–75% replacement was found to be 25% but at a 100% replacement with RA it reached 36%. On the other hand no significant reduction was observed when fine aggregates from crushed brick replaced natural sand. With up to 50% replacement, the long-term strength is similar to that of the control, whereas at 100% replacement, only less than 10% reduction is observed.

Durability performance is reported to be inferior by Bravo et al. (2015a) but acceptable by Abbas et al. (2009, 2009) studied freezing and thawing resistance, chloride penetration and carbonation of mixtures made with two types of coarse RA from old concrete, specifically limestone and granitic aggregates. The relative dynamic modulus was found to range from 90% to 100% demonstrating that all mixtures had a good performance against freezing and thawing. Carbonation depths up to 7 mm were measured at all specimens throughout the 140 days of exposure in an accelerated carbonation chamber with 3% CO_2. Carbonation coefficients ranged from 0.51 mm/day for reference concrete to 0.63 $mm/\sqrt{day}$ for recycled concrete with recycled limestone aggregates. Respective values for specimens containing granitic RA were 0.54 $mm/\sqrt{day}$ to 0.51 $mm/\sqrt{day}$. The increased carbonation coefficients observed in the case of mixtures with recycled limestone aggregates were attributed by the authors to the lower cement content of the new concrete. On the other hand despite the fact that the mixtures with recycled granitic aggregates also contained lower content of cement, they exhibited carbonation coefficients similar to the reference concrete. The authors attributed this difference to the presence of fly ash in the old aggregates that compensates for the lower alkalinity of the new mixtures.

Bravo et al. (2015b) evaluated the durability performance of recycled concrete made with RA from different waste recycling plants in Portugal. For that purpose, absorption by immersion and capillarity, carbonation resistance and chloride ion penetration resistance were measured. The replacement percentages examined were 10%, 25%, 50% and 100% of coarse as well as fine aggregates. The composition of these RA was visually analyzed and found to consist of 68–86% concrete, mortar and natural sand and 1%–29% masonry-clay materials. Water absorption by immersion was found not to be affected up to 25% replacement of coarse aggregates and up to 10% replacement of fine ones. Beyond these percentages the increase of water absorption of the mixtures with coarse aggregates ranges from 0.9% to 20.6% for 50% replacement and from 16.5% to 52.9% for 100% replacement. The authors justified these significant variations by the additional water needed to keep the slump constant, the greater water absorption of the recycled aggregates and the higher content of ceramic materials in the recycled aggregates from certain recycling plants. Water absorption by capillarity (g/mm^2) generally increased with the aggregates replacement ratio. Beyond 10% the results of the mixtures with coarse aggregates showed wide scatter ranging from −6.3% to +22.2% at 25% replacement, −3.9%–28.2% at 50% replacement and 11.8%–44.6% at full replacement. These differences were attributed to the differences in the composition of these recycled aggregates, mainly to the ceramic materials content that varied between 4.2% and 28.6%. Carbonation resistance measurements showed lower carbonation resistance of the recycled concrete depending on the type of RA used. Carbonation depths up to 12 mm were measured in all specimens with coarse RA throughout the 91 days of exposure in an accelerated carbonation chamber with 5% CO_2. Higher carbonation depths were measured in mixtures with coarse RA with high ceramic content. The phenomenon is more intense in mixtures with replacement ratio greater or equal to 25%. At 25% replacement the percentage difference ranged from - 8% to 85.6% at 56d and from −15.8% to 55.2 at 91d. The respective ranges for 50% replacement are, 25.6%–93.3% and 26.8%–93.7%. The lowest carbonation resistance was measured in mixtures with RA with ceramics content around 30%.

These controversies in the available results regarding the suitability of RA, the specificities of various properties affecting their behavior and the performance of the recycled concrete indicate that research has to be conducted on a country or even on a regional basis.

Moreover, although old concrete and RA composition seem to play an important role on the recycled concrete's performance, limited chemical and mineralogical characterization of RA is available. Relative experimental studies tried to identify possible uses of various sizes of RA in the production of different building materials (Bianchini et al., 2005; Angulo et al., 2009; Rodrigues et al., 2013). Limbachiya (2007) studied the influence of RA's chemical composition on the chemical composition of the resulting concrete.

In Greece organized production of RA has started only recently. There is very little to almost no data available regarding their characteristics and their influence in concrete. Savva (2010) produced CDW in the laboratory from concrete test cubes to study the effect of the old concrete homogeneity on the splitting and compressive strength and the durability of recycled concretes. Moreover, Mavridou (2009) investigated the effect of the RA percentage on the mechanical and physical characteristics as well the behavior of RA concretes when exposed to high temperatures. In