Chemical and mineralogical properties of recycled aggregates

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Keywords: construction and demolition waste, recycled aggregates, chemical properties, mineralogical analysis
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The exploitation of natural resources, in particular non-renewable resources, for construction purposes leads to millions of tones of construction and demolition (C&D) waste every year (Silva *et al*, 2014). As construction wastes are classified wastes from the construction, remodeling and repairing of individual residences, commercial buildings and other civil engineering structures while as demolition wastes those from razed buildings. C&D wastes may be also produced significantly from environmental disasters, such as earthquakes, hurricanes, tornadoes, and floodwater (Wen-Ling *et al.*, 2002).

Since most countries have no specific processing plan for these materials, they are sent to landfill instead of being reused and recycled in new construction (Silva *et al*, 2014). Discarding waste without any pre-treatment provokes a considerable burden to the environment, which apart from soil and water contamination as well as air pollution, includes also aesthetic degradation, reduced property values and landscape destruction. One way of disposing this waste stream is to utilize it in construction industry where after suitable treatment, would be recycled and reused as recycled aggregate (RA) for producing environmentally friendly concrete. Waste recycling and reuse responds to current trends in technological development, that focus mainly on sustainable development, natural resources safeguarding and efficient waste management (Oikonomou *et al.*, 2003)

The construction industry is now putting greater emphasis than ever before, on increasing recycling and promoting more sustainable waste management practices. In keeping up with this approach, several studies have been conducted for years. However, while studies on the properties of laboratory – crushed concrete aggregate or demolished concrete aggregates are abound, only limited data are available on commercial – grade recycled aggregate. Moreover, the existing studies, that are based on commercial – grade recycled aggregate, focus mainly on recycled aggregates' geometrical – physical properties. Therefore research on chemical and mineralogical properties of recycled aggregates is almost nonexistent. Thus, this paper estimates the aforementioned properties emphasizing to those ones, that affect the properties of fresh and hardened concrete.

The recycled aggregates, used in this research, were derived from C&D waste, which had been processed by mechanized crushing and sieving at a C&D waste recycling plant. The origins of the C&D waste were unknown; therefore, the composition was evidently heterogeneous, depending on the type, age, use and size of the structure it came from. The sample of C&D waste used as recycled aggregates contained: pieces of concrete, bricks, ceramic tiles, marble, asphalt and natural aggregates as well as a small percentage of other materials. Four size fractions of RA were used, having nominal size of: <5mm, 6–11mm, 12–25mm and 26–55mm.

Due to the variability in the RA's composition, a statistical analysis of the percentage of each material's presence was considered necessary. The rate of participation of each material is expected to affect the properties of the RA and, in particular, their strength and chemical composition. Subsequently, the chemical properties of the RA were determined. In particular, the following chemical properties were determined in accordance with the European standard EN 1744-1: chloride content and sulfate content (total sulfur content and acid soluble sulfates) and in accordance with the European standard EN 196-21 carbon content. All experimental measurements are presented in Table 1.

Thereafter, whether the RA are suitable for use in the production of concrete was determined by comparing the tests' results with the requirements of the Greek standard ELOT 401 - the Greek regulation of concrete technology (1997) and the European standard EN12620. It was observed that total sulfur content is within limits for all fractions of RA, whereas on the basis of acid-soluble sulfates all fractions were classified as AS0,8 (sulphate <0.8%) with the exception of RA with nominal size larger than 12mm that were classified as AS0.2 (sulphate <0.2%). In addition, chlorides were estimated at less than 1% for all fractions and therefore are not expected to have a negative impact on the properties of recycled concrete. In conclusion, it was observed that the carbon content varies between 22 - 28%. Based on literature, high carbon content is expected to aggregates with higher water absorption and lower specific gravity (Wang, 2015), also confirmed by previous research (Tsoumani *et al*, 2015).

Table 1. Chemical properties of recycled aggregates.

Property (content rate %)	Aggregate fraction			
	0-5mm	6-11mm	12-25mm	26-55mm
chloride content	0.95	0.78	0.67	0.51
total sulfur content	0.15	0.12	0.07	0.12
acid soluble sulfates	0.36	0.29	0.18	0.28
carbon content	20.25	27.43	28.45	23.98

Afterwards, the X-ray Fluorescence (XRF) method was used to determine the mineralogical analysis of the RA. This procedure was performed for all aggregates' fractions and focused on those elements that are expected to affect setting, hardening, strength and volume stability of concrete, as well as protection against corrosion of reinforcement. The oxides identified were silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O) and sodium oxide (Na_2O).

Results showed an increased presence of silicon dioxide and calcium oxide in all fractions of RA. In this case, problems are expected by the presence of silicon dioxide that is not inert in concrete's high pH environment causing the alkali-silica reaction, resulting in loss of concrete strength and finally leading to its failure. In addition, iron oxide is likely to have a negative impact on the produced concrete, causing expansion and spotting, however it appeared in low ratio. Finally, the high content of calcium oxide leaded to the conclusion that RA are of limestone origin. Calcium oxide is expected to affect concrete's properties only in the form of filler, as it reduces the adhesion between aggregate and cement paste, diminishing the strength of hardened concrete.

The tests' results, led us to the conclusion that the use of recycled aggregate in concrete for structural use is generally not excluded. However, their chemical and mineralogical properties and their heterogeneity may affect in a negative way the produced concrete's properties. Further experimental investigation is required in order to reassure that their use in concrete production is possible. Probably, RA could be used in lower end applications of concrete. Either way the use of recycled aggregates in concrete provides a promising solution to the problem of C&D waste management. Greater efforts are needed in the direction of creating awareness, and relevant specifications to clearly demarcate areas where RA can be safely used.

Acknowledgements

The authors would like to thank "Anakiklosi Adranon Macedonias" (Macedonia's aggregates recycling company) for providing the samples of recycled aggregates and especially Mr. Christoglou for his useful advice. The authors also wish to acknowledge TITAN Group and Mr. Leptokaridis in particular for their advice and experimental assistance.

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