Physical, Chemical and Mineralogical Characterization of Construction and Demolition Waste Produced in Greece

C. Alexandridou, G. N. Angelopoulos, F. A. Coutelieris

***Abstract*—**Construction industry in Greece consumes annually more than 25 million tons of natural aggregates originating mainly from quarries. At the same time, more than 2 million tons of construction and demolition waste are deposited every year, usually without control, therefore increasing the environmental impact of this sector. A potential alternative for saving natural resources and minimize landfilling, could be the recycling and re-use of Concrete and Demolition Waste (CDW) in concrete production. Moreover, in order to conform to the European legislation, Greece is obliged to recycle non-hazardous construction and demolition waste to a minimum of 70% by 2020. In this paper characterization of recycled materials - commercially and laboratory produced, coarse and fine, Recycled Concrete Aggregates (RCA) - has been performed. Namely, X-Ray Fluorescence and X-ray diffraction (XRD) analysis were used for chemical and mineralogical analysis respectively. Physical properties such as particle density, water absorption, sand equivalent and resistance to fragmentation were also determined. This study, first time made in Greece, aims at outlining the differences between RCA and natural aggregates and evaluating their possible influence in concrete performance. Results indicate that RCA's chemical composition is enriched in Si, Al, and alkali oxides compared to natural aggregates. X-ray diffraction (XRD) analyses results indicated the presence of calcite, quartz and minor peaks of mica and feldspars. From all the evaluated physical properties of coarse RCA, only water absorption and resistance to fragmentation seem to have a direct influence on the properties of concrete. Low Sand Equivalent and significantly high water absorption values indicate that fine fractions of RCA cannot be used for concrete production unless further processed. Chemical properties of RCA in terms of water soluble ions are similar to those of natural aggregates. Four different concrete mixtures were produced and examined, replacing natural coarse aggregates with RCA by a ratio of 0%, 25%, 50% and 75% respectively. Results indicate that concrete mixtures containing recycled concrete aggregates have a minor deterioration of their properties (3-9% lower compression strength at 28 days) compared to conventional concrete containing the same cement quantity.

***Keywords*—**Chemical and physical characterization, compressive strength, mineralogical analysis, recycled concrete aggregates, waste management.

C. Alexandridou is a Ph.D student Department of Environmental and Natural Resources Management, University of Patras, Greece (corresponding author to provide e-mail: chris@ plasmatech.gr).

G. N. Angelopoulos is Professor at Department of Chemical Engineering, University of Patras, Greece (e-mail: angel@chemeng.upatras.gr)

F.A. Coutelieris is Assistant Professor at Department of Environmental and Natural Resources Management, University of Patras, Greece Seferi 2, 30100, Agrinio, Greece, (Tel: +30 26410-74196; Fax: +30 26410-74176, e-mail: fcoutelieris@upatras.gr).

I. Introduction

The valorization of Construction and Demolition Waste (CDW) has been identified by the EC as a priority because of the large amounts that are generated and the high potential for re-use and recycling of these materials. The building activity in Greece, although severely hit by the economic crisis, is still one of the major productive sectors. It consumes annually more than 25 million tons of natural aggregates, originating mainly from quarries and producing 2 million tons of construction and demolition waste. The Waste Framework Directive (WFD) 2008/98/EC requires Member States to take any necessary measures to achieve a minimum target of 70% of CDW by 2020 for recycling [1]. Similar legislations are implemented in most developed countries and in general the interest for using recycled materials derived from CDW is growing all over the world. [1]-[6]. In some countries the CDW recycling system is well developed (Germany, Denmark, North America) achieving more than 70% recycling rates while in others (Italy, Portugal) this percentage may be below 5%. Greece belongs to the latter, although Greek legislation CDW recycling has been adopted since August 2010.

The main application of Recycled Concrete Aggregates (RCA) worldwide is as a landfill material in road construction and earth works. Their use in structural concrete is still very limited for different reasons. Namely, heterogeneity of original CDW, insufficient specifications with respect to quality control in the processing of RCA and the production of RCA concrete as well as the market suspiciousness for the suitability of those materials have been reported as the main limiting factors [2].

There have been a number of publications on the influence of replacing coarse and fine natural aggregates on mechanical properties of concrete. [7]-[11]. Results presented in these studies are often controversial, showing that the properties of RCA's depend on the specific location where they are produced thus enhancing the necessity of a thorough characterization of locally available RCA's in each case. The results on compressive strength of RCA concrete indicate variations, compared to concrete with normal aggregates, ranging from equivalent down to 30% inferior performance. On the other hand, drying shrinkage is generally accepted to increase as the percentage of RCA replacement increases. However, only a few studies including chemical and mineralogical characterization of RCA aggregates are available [12]-[15]. In these cases, chemical and mineralogical results were used to identify possible uses of different fraction sizes of RCA in building industry. The effect of RCA chemical composition on the chemical composition of RCA concrete has also been examined.

A limited number studies is available for the characterization and/or the potential use of Greek CDW for other uses besides backfilling operations [16], [17]. In [16], CDW was obtained by crushing concrete test cubes and the effect of the original concrete homogeneity on the splitting and compressive strength and the durability of RCA concretes have been examined. Moreover in [17], the effect of the RCA percentage on the mechanical and physical characteristics as well as durability to high temperatures of RCA concretes was examined. In both case no chemical or mineralogical evaluation was considered. However, according to EN12620:2013 [18], RCA's must comply with certain physical and chemical specifications and their mineralogical composition must be declared. This outlines the necessity of correlating the performance of concrete mixes to the properties of RCA's used.

In the present study an effort is made to characterize two types of recycled materials: commercially produced RCA from one Greek private recycling plant (hereafter referred as S(1) as well as laboratory produced RCA from crushing concrete cubes used for ready mix quality control (hereafter referred as LAB-RCA). These materials have undergone chemical physical and mineralogical characterization and they were consequently used to produce and test RCA concretes. Namely, X-Ray Fluorescence and X-Ray Diffraction analyses were used for chemical and mineralogical characterization, respectively. Physical properties such as particle density, water absorption, sand equivalent and resistance to fragmentation were determined. Finally, four RCA concrete mixes were produced using 0%, 25%, 50% and 75% of S(1) RCA's respectively and the compressive strength was measured at 28 days.

II. Experimental Procedure

The commercially produced RCA investigated in this study was delivered by a recycling plant located in Southern Greece, which designates the product as 3A (0/31.5mm) recycled concrete for use in civil engineering and road construction. The plant performs sorting, fragmentation and sieving. RCA collected originate from construction and demolition waste, namely old pavements, buildings etc.

Moreover aggregates were produced in the laboratory by crushing old concrete cubes of different strength classes (C16/20, C20/25 or C25/30). These concrete cubes had been previously tested for standard strength tests by the Laboratory of the Department of Materials Control and Public Works Quality of Patras, during a period of one month in the process of quality control of the production of different ready mix plants in the area of Peloponnese. Therefore, these aggregates are essentially recycled concrete of different ages, classes and composition presenting a lower degree of inhomogeneity compared to materials produced in a recycling plant, since their composition is restricted to concrete and aggregates. As these materials have never been used in construction, they must be characterized as reclaimed crushed concrete aggregates, following the definition used in EN 206 Concrete Part 1: Specification, performance, production and conformity [19].

In order to establish the differences between the two recycled materials and natural aggregates used in concrete production, samples of natural aggregates were also collected from a ready mix company located in the area of Peloponnese. Table I gives the code of each sample.

Lab-RCA was crushed in the lab crusher in order to produce a material of maximum grain size of 31.5mm. S(1) RCA were sieved in order to obtain two grain-size fractions: 0/4mm (fine fraction) and 4/31.5mm (coarse fraction).

TABLE I
Samples Code

Code	Description
Lab RCA:	Laboratory produced Reclaimed Concrete Aggregates
S(1) RCA:	Recycled Aggregate from Plant in Southern Greece
G -N	Coarse natural aggregate 11.2/22.4 (Gravel)
FG-N	Coarse natural aggregate 2/11.2 (Fine Gravel)
S -N	Fine natural aggregate 0/4 (Sand)

Natural aggregates were used as received. Chemical, physical and mineralogical evaluation of all samples was performed following the methods described in the next section.

III. Methods

A. Classification

Coarse fractions of S(1)-RCA recycled aggregates were examined in accordance with the procedure from EN 933-11:2009 [20] standard in order to identify and estimate the relative proportions of constituent materials.

B. Chemical, Mineralogical Composition

Chemical composition was examined using X-ray Fluorescence (Oxford Instruments) on glass beads. Volatiles were determined as loss on ignition (LOI) at 1000°C. Mineralogical composition was studied using X-Ray diffraction (Bruker D8 Advance, equipped with a LynxEye® detector, using CuKa radiation (1.54Å)). The scanning area covered the 2θ interval 5–60°, with a scanning angle step size of 0.015° and a time step of 0.1 s. Semi-quantitative analysis was performed by a simple linear regression analysis based on the chemical composition of the minerals identified as it is available in the published mineral atlas.

C. Chemical Properties

The chemical tests were carried out according to the methods specified in EN 12620:2013 [18] standard. The water soluble ions (chloride and sulfate) content of recycled aggregates was determined in accordance with EN 1744-1:2009 standard [21]. The acid-soluble chloride ion was determined in accordance with EN 1744-5:2009 [22] standard. Water-soluble materials originating from coarse fractions of RCA used for the preparation of concrete mixtures were assessed for their influence on the initial setting time of cement paste in accordance with EN 1744-6:2006 [23] and EN 196.3:2011 standard [24].

D. Physical Properties

Size distribution was evaluated in accordance with the procedure from EN 933-1:2012 [25]. The EN 1097-6:2013 standard [26] was used to determine density and water absorption. Sand Equivalent for fine fractions was measured as specified in EN 933-8:2012 standard [27]. Resistance to fragmentation was measure as per EN 1097-2:2010 [28] standard.

E. Concrete Performance

For the evaluation of concrete performance, four concrete mixtures were prepared under laboratory conditions: one reference concrete made with natural coarse and fine aggregates and three with the S-1 RCA direct replacing the natural coarse aggregates (G-N) by 25%, 50% and 75%, respectively. The concrete mixtures were proportioned following a mix design for S3 (10-15mm) nominal slump and 25MPa compressive cube strength at 28 days. This mix design is used by the ready mix company which provided the natural aggregates for general concrete applications. The effective water/cement ratio was kept constant at 0.58. Portland cement (CEM IV) with a 28d compressive strength of 32.5 MPa was used. The sand, cement and coarse aggregates were placed and dry-mixed for about 2 min before water was added. After 3 min of mixing, specimens were cast from each mixture to assess compressive strength at 28 days. They were demoulded one day after casting and were cured at 20°C in a water filled tank for 28 days. Compressive strength tests were carried out on 150x150 mm cubes, according to EN 12390-3:2009 [29].

IV. Results and Discussion

A. Classification

By visual inspection S(1) RCA material was almost white and dry similar to natural aggregates. The proportions of different constituents present are given in Table II.

TABLE II
RCA Classification

Constituent	Description	S(1)-RCA
	Proportions % Test sample (4/31.5mm Proportions Test sample (4/31	
Rc	Concrete, mortar masonry	Rc_{50}
Ru	Unbound aggregate, natural stone Hydraulically bound aggregate.	Ru_{20}
Rb	Bricks and tiles	Rb_{10-}
Ra	Bituminous Materials	Ra_{10-}
Rg	Glass	Rg_{2-}
X	Other (soil and clays)	X_{1-}
FL	Floating Material cm^3/kg	$FL_{0.2-}$

The characterization of the different constituents follows the terms specified in EN 12620:2013 [18]. It seems that 70% of the material originates from old concrete structures.

B. Chemical, Mineralogical Composition

Table III presents the XRF chemical results of the different sizes of the natural as well as the recycled concrete aggregates investigated. Coarse and fine natural aggregates reveal an almost pure CaO composition as expected since the majority of aggregates in Greece are calcareous. S(1) RCA is enriched in SiO_2, Al_2O3, Fe_2O_3 and alkali oxides and so does Lab-RCA but to a much lower extent. Increased SO_3 content is found in all- RCA samples, but generally the SO_3 content is low (<0.5%) for both samples.

TABLE III
XRF Chemical Composition of Natural and Recycled Concrete Aggregates Expressed in %

	G-N	FG-N	S -N	Lab RCA	S(1) RCA 0/4	S(1) RCA 4/31.5
SiO_2	0.18	0.24	0.46	8.55	10.85	8.33
Al_2O_3	0.05	0.08	0.13	1.34	2.03	1.65
Fe_2O_3	0.04	0.06	0.08	0.72	1.13	0.98
CaO	55.09	54.93	54.59	41.13	45.17	47.61
MgO	0.34	0.37	0.38	7.13	0.83	0.73
K_2O	0.02	0.02	0.02	0.19	0.24	0.17
Na_2O	0.00	0.00	0.00	0.12	0.13	0.08
SO_3	0.02	0.02	0.02	0.5	0.37	0.33
TiO_2	0.01	0.01	0.01	0.07	0.11	0.09
P_2O_5	0.03	0.04	0.05	0.03	0.02	0.02
Cr_2O_3	0.00	0.00	0.00	0.01	0.02	0.02
MnO	0.01	0.01	0.01	0.04	0.02	0.02
SrO	0.03	0.04	0.03	0.04	0.02	0.02
LOI	43.72	43.89	43.85	40.08	38.76	39.66
TOTAL	99.54	99.71	99.63	99.95	99.70	99.71

Loss On Ignition (LOI) follows the variations of CaO indicating that its major source is CO_2, as the result of the original aggregates used in concrete production, the carbonation of cement paste and much less the limestone filler used in cement's composition. Analogous investigation of recycled aggregates in other European countries and in Brazil has not come to similar observations because of the siliceous nature of the natural aggregates used in these countries [12]–[14]. According to those results, RCA chemical composition is richer in Ca and Al oxides when compared to their own natural aggregates.

The unusually high MgO content of LAB-RCA may be attributed to dolomite in the aggregates used for the production of the old concrete cubes. Additionally compositional variations are observed in relation to size fractions. The material below 4 mm contains higher percentages of SiO_2, Al_2O_3, Fe_2O_3 and alkali oxides and less CaO.

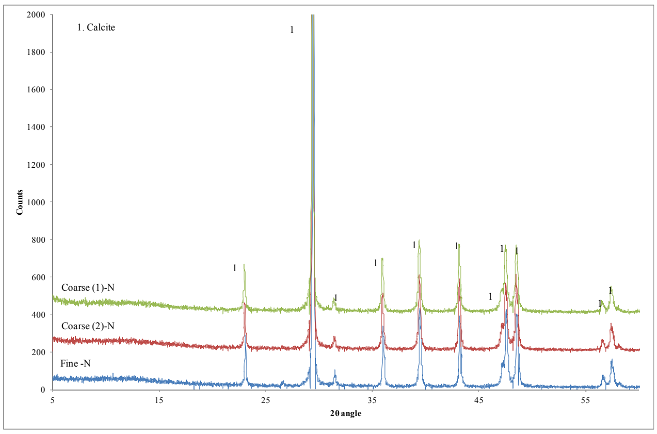

Fig. 1 XRD patterns of natural aggregates samples

Mineralogical analysis of natural aggregates has verified that natural aggregates in Greece are almost pure limestone (Fig. 1). No aluminosilicate or dolomitic minerals were identified. XRD analysis of the data obtained for RCA patterns (Fig. 2) shows a predominance of calcite peaks, followed by minor peaks of quartz, alkali feldspars, mica (muscovite), and dolomite. Traces of portlandite, which had not yet been converted to carbonate phase and calcite, were identified in Lab-RCA.

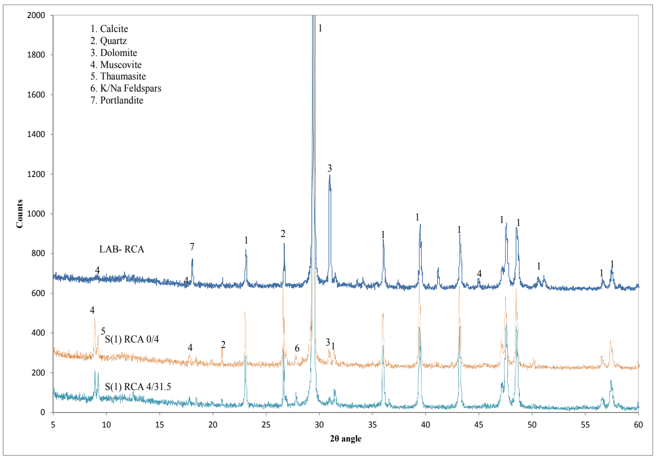

Fig. 2 XRD patterns of RCA samples: S(1)RCA, LAB RCA

TABLE IV
XRD MINERALOGICAL SEMI-QUANTITATIVE ANALYSIS OF NATURAL AND RECYCLED CONCRETE AGGREGATES

Description	G-N	FG-N	S -N	Lab RCA	S(1) RCA 0/4	S(1) RCA 4/31.5
Mineralogical phases						
Calcite	97%	97%	96%	54%	75%	81%
Dolomite			3%	36%	5%	4%
Quartz			1%	8%	7%	5%
Portlandtite				1%	-	-
K/Na Feldspars					3%	3%
Muscovite				1%	4%	3%
Thaumasite				-	6%	4%

Minor peaks of thaumasite ($CaSiO_3$ $CaCO_3$ $CaSO_4$ $15H_2O$) were present in S(1) RCA probably coming from damaged old concrete structures in the CDW processed. No amorphous cement hydrated phases were observed. The presence of calcite may be attributed mainly to original aggregates used in concrete production and to carbonation of cement hydrated phases during service life of the original concrete. The minor peaks of feldspars, and mica may be related to bricks/tiles which contain such minerals. The mineralogical semi quantitative analysis data are given in Table IV.

Material below 4mm contains increased percentages of feldspars and micas. Finally almost none of the RCA samples tested have a similar to natural aggregates mineralogical composition, except for the coarse fraction of S(1) RCA. These findings are in good agreement with relative literature data, as far as the aluminosilicate minerals are concerned [11]-[14].

C. Chemical Properties

Table V shows the test results for the aggregates chemical properties. Water soluble chloride ions measured for RCA samples are in the same level with those of natural aggregates. According to EN 12620:2013 [18] standard, chlorides in recycled aggregates may be combined in the calcium aluminate and other phases. The combined chlorides are unlikely to be extracted using water in the procedures described in Clause 7 of EN 1744-1:2009 even if the sample is ground to a fine powder before extraction. In order to provide an additional margin of safety the standard requires a determination of acid-soluble chloride content, although it will probably overestimate the availability of chlorides, but this value should be used in the calculation of the chloride ion content of the concrete. Test results indicate that the acid soluble chloride in S(1) RCA exceeds 0.01%, which is the limit value for water soluble chlorides.

TABLE V
RESULTS OF THE CHEMICAL TESTS

	G-N	FG-N	S –N	Lab RCA	S(1) RCA 0/4	S(1) RCA 4/31.5
Water soluble Cl %	<0.001	<0.001	0.002	<0.001	0.0011	0.009
%Acid soluble Cl	<0.01	<0.01	<0.01	<0.01	0.03	0.02
%Water soluble SO_3	-	-	-	<0.001	<0.001	<0.001
Change in initial setting time (min)	-	-	-	<10	-	<10

Water-soluble sulfates in recycled aggregates determined in accordance with EN 1744-1 [21] are potentially reactive sulfates (e.g. gypsum plaster) and may also give rise to expansive disruption of concrete. Test results indicate that all RCA samples contain very low percentages of water soluble sulfates far below the limit of max $SS_{0.7}$ set in EN 206-1 standard [19] or even the lowest limit $SS_{0.2}$ specified in EN12620:2013 [18]. Higher water soluble sulfate contents were determined in recycled aggregates from Portuguese recycling plants [15]. Test results for the change in initial setting time of cement confirm that neither Lab RCA nor S(1) RCA contain any water-soluble materials which may influence the initial setting time of cement paste.

D. Physical Properties

Size distribution of aggregates is important as it influences concrete's compacity and strength [30]. Table VI displays the results of the sieving analysis performed in all samples. Results indicate that coarse fraction of S(1) RCA, which is separated in the lab from the whole sample collected, proved to be coarser than FG-N but finer than G-N. Lab RCA produced in the lab can be considered as all-in aggregate. Fine fraction of S(1) –RCA has a significantly lower fines content compared to the natural aggregates.

TABLE VI
SIEVING ANALYSIS

Sieve size (mm)	G-N	FG-N	S -N	Lab RCA	S(1) RCA 0/4	S(1) RCA 4/31.5
	Passing by weight (%)					
31.5	100	100	100	100	100	100
16	59	100	100	81.6	100	95
8	3	80	100	54.7	100	57
4	1	16	100	35.9	100	5
2	1	2	84	22.4	60	1
1	1	1	59	13.6	33	1
0.50	1	1	40	8.8	19	1
0.25	1	1	23	6.3	11	0
0.125	1	1	18	4.9	7	0
0.063	1.1	1.2	14.5	4.2	4.8	0.4

Apart from water absorption, which must be taken into account for the calculation of water content of concrete, no other characteristic presented in Table VII has a direct influence on concrete production. Particle densities of RCA's are lower than in natural aggregates due to porous cement paste adhered to the aggregates. The lowest particle density is observed for the fine fraction of S(1) RCA. Resistance to fragmentation, as measured through LA coefficient, is inferior to natural aggregates but within the specification of $LA_{\leq 50}$ of EN 206 standard or $LA_{\leq 40}$ of national regulations.

TABLE VII
RESULTS OF PHYSICAL TESTS

Description	G-N	FG-N	S -N	Lab RCA	S(1) RCA 0/4	S(1) RCA 4/31.5
Apparent particle density (Mg/m^3)	2.74	2.73	2.74	2.74	2.57	2.66
Oven dry particle density(Mg/m^3)	2.70	2.69	2.69	2.32	1.93	2.30
Saturated surface dried particle density(Mg/m^3)	2.71	2.71	2.71	2.48	2.18	2.43
Water Absorption (24h)%	0.54	0.52	0.67	6.17	12.8	5.8
Sand Equivalent			75	83	74	
LA coefficient	25	25	-	39		35

The inferior resistance of RCA against mechanical wear may be attributed to the old cement mortar attached to RCA and poor bonding between old mortar and RCA [32]. Low Sand Equivalent and significantly high water absorption values indicate that fine fractions of RCA cannot be used to concrete production unless further processed. High water absorption values and lower particle densities for RCA are in agreement with the results of other researchers [15], [16], [31].

E. Concrete Performance

The compressive strength results obtained for the three prepared concrete mixtures are shown in Table VIII. Each presented value is the average of six measurements. Values in parenthesis represent standard deviations of the measurements. The compressive strength reduction is not analogous to the replacement percentage, having its maximum at 50% and not at 75%. The compressive strength of S(1) RCA is up to 9% inferior to that of reference concrete at 50% replacement and not at 75% replacement. This reduction was not observed in [16], where admixtures have been added in the mix design. According to these results, the lower compression strength of the concrete mixes produced using the RCA's examined is probably attributed to the higher water absorption capacity, which results in porous interfacial transition zone microstructure in the RCA [33]. The inferior resistance of RCA against mechanical wear may play also an important role.

TABLE VIII
COMPRESSIVE STRENGTH RESULTS (MPa)

%Replacement	S(1) RCA	% Reduction
0%	29.9(±0.40)	
25%	28.9(±0.92)	3%
50%	27.1(±0.75)	9%
75%	27.8(±0.64)	7%

V. CONCLUSION

In the present study an effort is made to characterize two types of recycled materials and to examine the influence of their properties on the mechanical performance of concrete produced using various coarse natural aggregates replacement percentages. These materials have been chemically, physically and mineralogically characterized and used to produce and test RCA concretes. The RCA's used are enriched in SiO_2, Al_2O_3, Fe_2O_3 and alkali oxides. Increased SO_3 content was found, compared to the natural aggregates, but generally the SO_3 content is low (<0.5%) for both samples. Analogous investigations of recycled aggregates in other countries have not come to similar observations because of the siliceous nature of the natural aggregates used in these countries. According to those results, RCA chemical composition is richer in Ca and Al oxides when compared to their own natural aggregates. In our study, XRD analysis shows a predominance of calcite, followed by small quantities of quartz, alkali feldspars, mica (muscovite), and dolomite.

The RCA's used in this study do not contain any water-soluble ions that may influence the initial setting time of cement paste. Water absorption is higher and particle densities are lower than in natural aggregates due to porous cement paste adhered to the aggregates. Resistance to fragmentation is inferior to natural aggregates but within the specification of $LA_{\leq 50}$ of EN 206 standard or $LA_{\leq 40}$ of national regulations. Finally, results indicate that concrete mixtures containing recycled concrete aggregates up to 50% have 3-9% lower compression strength than conventional concrete. The lower compression strength of the concrete mixes produced using the RCA's examined is probably attributed to the higher water absorption capacity. The inferior resistance of RCA against mechanical wear may play also an important role. Although the results are within a range of acceptable values, remedies such as presaturation of the RCA's or the use of admixtures maybe implemented to compensate for the somewhat lower performance. Nevertheless, further examination of larger sets of samples coming from a larger variety of sources is necessary for drawing safer conclusions.

Acknowledgment

Authors wish to thank Dr. J. Karayannis (Hellenic Cement Research Center) for performing the chemical analyses.

References

[1] WFD Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives
[2] RILEM TC 217-PRE report pp. 34-223.
[3] Chi-Sun Poon, "The use of recycled aggregate in concrete in Hong Kong, Resources, Conservation and Recycling 50 (2007) 293–305.
[4] Xuping Li "Recycling and reuse of waste concrete in ChinaPart I. Material behavior of recycled aggregate concrete", Resources, Conservation and Recycling 53 (2008) 36–44.
[5] Xuping Li, "Recycling and reuse of waste concrete in China Part II. Structural behavior of recycled aggregate concrete and engineering applications," Resources, Conservation and Recycling 53 (2009) 107–112.
[6] R. Hadjieva-Zaharieva, "Building waste management in Bulgaria: challenges and opportunities" Waste Management 23 (2003) 749–761.
[7] Khaldoun Rahal, "Mechanical properties of concrete with recycled coarse aggregate", Building and Environment 42 (2007) 407–415)
[8] Sami W. Tabsh et al., "Influence of recycled concrete aggregates on strength properties of concrete", Construction and Building Materials 23 (2009) 1163–1167).
[9] Etxeberria E. et al., "Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete", Cement and Concrete Research, Volume 37, Issue 5, May 2007, Pages 735-742.
[10] Khatib J.M., "Properties of concrete incorporating fine recycled aggregates", Cement and Concrete Research 35 (2005), 763-769.
[11] K. K. Sagoe-Crentsil, "Performance of concrete made with commercially produced aggregates", Cement and Concrete Research, 31 (2009), 707-712.
[12] M.C. Limbachiya, "Chemical–mineralogical characterisation of coarse recycled concrete aggregate",Waste Management 27 (2007) 201–208.
[13] G. Bianchini, "Recycling of construction and demolition waste materials: a chemical–mineralogical appraisal", Waste Management 25 (2005) 149–159.
[14] S.C. Angulo, "Chemical–mineralogical characterization of C&D waste recycled aggregates from São Paulo, Brazil", Waste Management 29 (2009) 721–730.
[15] Fernando Rodrigues, "Physical chemical and mineralogical characterization of fine aggregates from construction and demolition waste recycling plants" Journal of Cleaner Production 52 (2013), 438-445.
[16] A.E. SAVVA, "Experimental approach of the use of industrially recycled aggregates in the production of new concrete", Tech. Chron. Sci. J. TCG, No 2, 45-57.
[17] S. Mavridou, Part II, 16th Concrete Congress, TEE, ETEK, 21-23/10/ 2009, Paphos, Cyprus.
[18] EN 206-1: 2013Concrete - Specification, performance, production and conformity.
[19] EN 933-11:2009: Tests for geometrical properties of aggregates - Part 11: Classification test for the constituents of coarse recycled aggregate.
[20] EN 12620:2013 Aggregates for concrete.
[21] EN 1744-1:2009 Tests for chemical properties of aggregates - Part 1: Chemical analysis.
[22] EN 1744-5:2009 Tests for chemical properties of aggregates - Part 5: Determination of acid soluble chloride salts.
[23] EN 1744-6:2006 Tests for chemical properties of aggregates - Part 6: Determination of the influence of recycled aggregate extract on the initial setting time of cement.
[24] EN 196.3:2011 Methods of testing cement - Part 3: Determination of setting times and soundness.
[25] EN 933-1:2012 Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method.
[26] EN 1097-6:2013 Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption.
[27] EN 933-8:2012 Tests for geometrical properties of aggregates - Part 8: Assessment of fines - Sand equivalent test.
[28] EN 1097-2:2010 Tests for mechanical and physical properties of aggregates - Part 2: Methods for the determination of resistance to fragmentation.
[29] EN 12390-3:2009 Testing hardened concrete - Part 3: Compressive strength of test specimens.
[30] Neville, A. 1996, Properties of Concrete, 4th ed., Wiley, London, UK, 844p.
[31] Amnon Katz, "Properties of concrete made with recycled aggregatefrom partially hydrated old concrete", Cement and Concrete Research 33 (2003) 703– 711.
[32] M. Chakradhara Rao, "Influence of field recycled coarse aggregate on properties of concrete", Materials and Structures (2011) 44:205-220
[33] C.S. Poon et al., "Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates", Construction and Building Materials 18 (2004) 461–468.