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Recycled concrete aggregates

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Abstract

The subject of concrete recycling is regarded as very important in the general attempt for sustainable development in our times. In a parallel manner, it is directly connected with (a) increase of demolition structures past out of performance time, (b) demand for new structures and (c) results—especially in Greece—of destruction by natural phenomena (earthquakes, etc.). The present paper refers to the concrete recycling subject and, more specifically, to a proposal for Greek specifications of recycled concrete aggregates (RCA) with reference to international experience and practice. The existence of Greek specifications of RCA—the European ones will come much later—will help Olympic Games 2004 to be as "green" as possible.

Keywords: Recycled concrete; Recycled aggregates; Specifications; Sustainable development

1. Introduction

The protection of the environment is a basic factor, which is directly connected with the survival of the human race. Parameters like environmental consciousness, protection of natural recourses, sustainable development play an important role in modern requirements for construction works.

Construction materials are very significant in our lives, because we spend 90% of our time in buildings or infrastructures (roads, highways, bridges, etc.). The section of construction materials corresponds to 3–4% of the total product in Europe, and the construction industry, as well as construction works, occupy millions of people. However [1], in a parallel manner the construction section is responsible because it:

- takes 50% of raw materials from nature;
- consumes 40% of total energy;
- creates 50% of total waste.

In general, in the European Union, 500 kg of construction rubble and demolition waste correspond annually to each citizen [2].

Regarding concrete, which is the construction material of our era, the protection of the environment concerns three basic axes:

- Use of high amounts of raw materials (aggregates for the production of cement and concrete) which result in the decrease of available natural resources which is continuously sub-graded.
- Consumption of high amounts of energy for the production, transport, use of raw materials and final ones, as cement and concrete.
- Creation of big volumes of old concrete from old construction works (demolition wastes).

The main reasons for the increase of this volume of demolition concrete waste are:

- many old buildings and other structures have overcome their limit of use and need to be demolished;
- structures, even adequate to use, are under demolition, because there are new requirements and necessities;
- creation of building wastes which result from natural destructive phenomena (earthquakes, storms...). The approximate percentage of various construction materials in demolition waste (DW) is presented in Fig. 1 where values were estimated by us.

The recycled concrete aggregates (RCA) are the main components of old concrete and for many reasons there is a need to re-use them.

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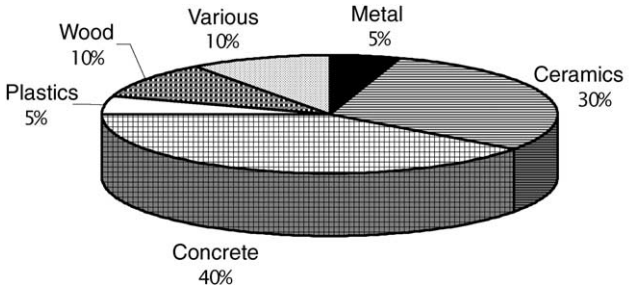

Fig. 1. Basic composition of demolition wastes (approx.).

2. Necessity for the re-use of RCA

The need for the production and use of RCA [3–8] is nowadays very urgent. This subject is considered very important especially for Greece, because there are now suitable conditions for construction of big infrastructures. By the production and use of RCA:

- There is an establishment of presuppositions for substantial protection of natural sources of country, which are neither endless nor inexpensive.
- There is a decrease of high volumes of fresh concrete wastes, which illegally ends up in uncontrolled areas of deposition.
- The aim of sustainable development is followed and, consequently, the basis for a friendly co-existence of man and nature is set.

A basic presupposition for the use of RCA in Greece is also the existence of a national and local policy for the treatment of building and demolition waste (BDW), which should contain answers to main questions as:

- control system of deposit of BDW with guidances, penalties, etc.;
- definition of deposition areas, for pre-selection, treatment, transport of RCA, especially close to big urban centers;
- support of public and private teams/organizations which have the intention of realising treatment programs of RCA;
- encouragement of studies concerning technical works, introducing the use of RCA following sustainable development;
- setting principal specifications for RCA covering their quality requirements.

In the fragments of the last paragraph, the treatment of BDW policy, land protection and treatment of natural resources, the present paper contributes with a relative proposal until the final approval of corresponding specifications by the official committee of CEN.

3. International experience on RCA

The use of RCA in construction works is a subject of high priority in building industry throughout the world [9].

Indicatively, 10% of used aggregates in Great Britain [10] are RCA, 78,000 tons of RCA were used in Holland [9] in 1994 as the corresponding national organization admitted that the use of 20% of coarse RCA result in no differentiation of the properties of fresh or hardened concrete. Additionally, the recycling of BDW at 40% has been set as an aim in Germany [11] since 1991. A recent report [8] of the Federal Highway Administration refers to the relative experience from European data on the subject of concrete and asphalt pavement recycling (Table 1).

The rapid development in research on the use of RCA for the production of new concrete has also led to the production of concrete of high strength performance [12]. It should be noted, of course, that the use of coarse RCA (up to 30%) is normally recommended but the addition of superplasticisers [13,14] is often considered necessary for achieving the required workability of new concrete.

Table 1
European data of concrete and asphalt pavement recycling [8]

Country	Data year	Material	Million metric tones	
			Produced	Used
Sweden	1999	Old asphalt pavement	0.8	0.76
Denmark	1997	Demolition waste	1.5–2.0	Small quantities
		Old concrete	1.06	0.90
		Old asphalt pavement	0.82	0.82
		Old ceramic materials (bricks...)	0.48	0.33
Germany	1999	Old asphalt pavement	12.0	6.0
		Other road materials	20.0	11.0
		Demolition waste	23.0	4.0
		Old asphalt pavement	10.7	10.7
		BDW	9.2	9.2

4. Specifications of RCA for new concrete

Three types of RCA are specified by RILEM [14]:

- Type I which consists primarily from masonry rubble.
- Type II which consists primarily from concrete rubble.
- Type III which consists of a blend of recycled aggregates (max. 20%) and natural aggregates (min. 80%).

An alternative way of classifying the composition of recycling aggregates is by density RILEM proposed the use of dense medium separation (ASTM C 123) to exclude too many of the lighter weight materials e.g. not more than 10% with SSD density less than 2.200 kg/m^3.

BRE Digest 433 [15] takes as its basis the above RILEM specification and specifies the following classes:

- RCA (I), origin: brickwork, brick content (by weight): 0–100%.
- RCA (II), origin: concrete, brick content (by weight): 0–10%.
- RCA (III), origin: concrete and brickwork, brick content (by weight): 0–50%.

Regarding that the quality data of old concrete is often unknown (w/c ratio, kind and amount of admixtures, aggregates origin and gradation, etc.), as well as the differentiation of its properties during its performance time, the knowledge and tests of RCA should refer to four categories:

(a) *Historical data of RCA* referring to the composition of old concrete, masonry etc., petrography characteristics, data of old structures.
(b) *Physical characteristics*, especially in water absorption, specific gravity, amount of chlorides and sulphates, amount of contained foreign ingredients, possibility of creation of alkali–silica reaction.
(c) *Mechanical characteristics*, testing resistance to abrasion/degradation by the use of L.A. machine, percentage of soft granules.
(d) *Environmental characteristics*, especially in cases where RCA seem to create "leachates".

RCA deposits for using concrete are generally available in Greece and it seems very useful to be checked by specifications. They contain lumps of unwanted material and have higher values of water absorption and lower values of mechanical properties comparing with natural aggregates. In our opinion it will be very helpful for Greek specifiers to have as a tool for their designs, Greek specifications for control of RCA although RILEM focuses on the suitability of RCA as a product for the proposed end use.

Table 2
Proposed basic tests and limits of RCA

Tests	Limits
Specific gravity, kg/m^3, min	2.20
Water absorption, %, m/m, max	3.0[a]
Foreign ingredients, %, m/m, max	1.0
Organic ingredients, %, m/m, max	0.5
Sulphate ingredients, %, m/m, max (as SO_3)	1.0
Granulometric gradation	GSCT limits
Amount of sand, %, m/m, max (<4 mm)	5
Amount of filler, %, m/m, max (<0.063 mm)	2
Resistance to abrasion/degradation by the use of L.A. machine, %, max	40
Soft granules, %, m/m, max	3
Soundness,[b] loss, %, max	10
Sand equivalent,[c] %, min	80

[a] This limit can be increased up to 5% in specific cases if the other requirements are OK. The maximum amount which is accepted by the corresponding German specification [17] is 15% for the sand.

[b] The method testing the aggregates soundness using sulphate salts is considered to be unsuitable for checking the suitability of RCA for the production of new concrete [18], because of the reaction of sulphates with hydrated cement. For this reason, the relative method of CEN [19] is proposed, by which soundness can be defined through washing, sieving, drying and finally submission of them in 10 cycles (24 h) of freezing–thawing (+25 °C ↔ −20 °C) in deionised water bath.

[c] The methylene blue test according to EN 933-9 is similarly proposed.

Thus, according to the local laboratory research and experience [16] the main test methods of suitability of recycled concrete aggregates (RCA) for the production of new concrete can be proposed in principle for Greece based on the coordination of requirements of Greek Specification of Concrete Technology (GSCT) and of the European one (ENV 206). Table 2 shows these proposed test methods and limits.

An important note should also refer to the presence of chlorides and the possibility of creation of the alkali–silica reaction of RCA. The total amount of chlorides which can be dissolved in acid should be determined according to ASTM C 1152-90 or BS 1881: Part 124: 1988 or EN 1744-1 so that the amount of chlorides which has bonded with the hardened cement paste of RCA should also be estimated.

Regarding the possibility of creation of the alkali–silica reaction, the quick chemical test according to ASTM C 289-94 describing the decrease of alkalinity of a normal solution of NaOH in the presence of a ground aggregate at 80 °C is considered as indicative.

Finally, the maximum limits of harmful elements–substances should be defined for the completion of RCA tests from an environmental point of view and these limits can be determined by elution (DIN 38406). For example, the corresponding limits of the German Committee [17] (Table 3) can be followed completing proposal for Greek specifications of RCA.

Table 3
Proposal of maximum limits of harmful elements of RCA

Element–substance	Limit (μg/l)
As	50
Pb	100
Cd	5
Cr	100
Cu	200
Ni	100
I	2
Zn	400

5. Final remarks

Aggregates from recycled aggregate (RCA) are already used in all countries in various applications of civil engineering works, as road pavement materials, subbasements, soil stabilization, improvement of subground, production of concrete of many categories, etc. The existence of temporary Greek specifications for testing the suitability of RCA is a basic factor of their use, especially for the production of new concrete.

The new European specifications for the aggregates, which are made by CEN TC 154 Committee which must become official by the end of year 2003, do not substantially refer to the RCA subject. This gap which will possible continue to exist until the end of the year 2010 is possible to be solved with the help of the national organization of standardization [18]. A relative example exists in the United Kingdom [20], where a protocol is in power for the production of new concrete, where the substitution with up to 20% of RCA coming from production waste is permitted.

Finally, it is very important for the Games to prove to be not only an athletic and touristic action but also a success in environmental field. Sydney [21] has already set the example.

6. Conclusions

In the present work a guidance of tests and limits of RCA is proposed in order to be used as a basis for pilot and long scale works where the use of RCA can be estimated as more economic and friendlier to the environment.

In practical terms, for Greece an experimental use of RCA for a pilot structure is proposed during a first phase, with the addition of only coarse aggregate (>4.75 mm) up to 30% which should comply with the proposed specifications.

The subject of RCA use in works in Greece is considered especially urgent, because of the big projects for the Olympic Games of 2004 in Athens.

References

[1] Anik D, Boonstra C, Mak J. Handbook of sustainable building. James & James; 1996.
[2] Symonds Group Ltd 46967. Construction and demolition waste management practices, and their economic impacts. Final Report to DGXI, European Commission, February 1996.
[3] Dhir R, Henderson N, Limbachiya M. editors. Proceedings of International Symposium: Sustainable Construction: Use of Recycled Concrete Aggregate. Thomas Telford, 1998.
[4] BRITE/EURAM 3. Use of recycled materials as aggregates in the construction industry. Project Ref: BRRT 985004, 1998–2002.
[5] BRITE/EURAM 3. European concrete pavement for recycling. Project Ref: BRST 985334, 1999–2000.
[6] RILEM. Recycling of demolished concrete and masonry. E&FN SPON, 1996.
[7] US Department of the Interior. Crushed cement concrete substitution for construction. Aggregates—a materials flow analysis. US Geological Survey Circular 1997.
[8] US Department of Transportation. Recycled materials in European highway environment. Uses, technologies and policies. International Technology Exchange Program, 2000.
[9] de Vries, P. Concrete recycled: crushed concrete aggregate. In: Proc. of the International Conference: Concrete in the Service of Mankind. I. Concrete for Environment Enhancement and Protection, Dundee, Scotland; 1996. p. 121–30.
[10] Collins RJ. Increasing the use of recycled aggregates in construction. In: Proc. of the International Conference: Concrete in the Service of Mankind. I. Concrete for Environment Enhancement and Protection, Dundee, Scotland; 1996. p. 130–9.
[11] Acker Av. Recycling of concrete at a precast concrete plant. Betonwerk + Fertigteil-Tech 1996;6:91–101.
[12] Limbachiya MC, Leelawat T, Dhir RK. Use of recycled concrete aggregate in high-strength concrete. Mater Struct 2000;33:574–80.
[13] Zankler G. Recycled materials in concrete construction: fields of application, development tendencies and quality assurance. Betonwerk + Fertigteil-Tech 1999;4:38–43.
[14] RILEM TC 121-DRG. Specifications for concrete with recycled aggregates. Mater. Struct. 1994;27:557–9.
[15] Building Research Establishment. Digest 433. Recycled Aggregates, 1998.
[16] Oikonomou N, Selevos S. Recycled concrete. In: Proceedings 13th Greek Conference of Concrete, Rethymne; 1999. p. 235–241.
[17] P. Grübl, M. Rühl, Use of Recycled Concrete Aggregate, German Committee for Reinforced Concrete (DafStb)-Code (in Ref. [3]).
[18] Collins RJ. Recycling—are standards impeding it? Bitpave Seminar 99: A Greener Way Ahead, Hinckley, 19 October 1999.
[19] pr EN 1367-1. Tests for thermal and weathering properties of aggregates. Part 1: Determination of resistance to freezing and thawing, Final draft, December 1998. p. 11.
[20] Collins RJ. Use of Recycled materials as aggregates in the construction industry. Strategy Report on Standardization (Draft): European Thematic Network (ETN recy.net), April 2001.
[21] Dumitru I, Munn R, Smorchevsky G. Progress towards achieving ecologically sustainable concrete and road pavements in Australia, WASCON 2000, North Yorkshire, 2000.