APPLICATION OF RECYCLED AGGREGATES IN THE EUROPEAN CONCRETE INDUSTRY – ITS CURRENT STATUS AND FUTURE OUTLOOK -

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INTRODUCTION

CDW recycling and sustainable development

Mankind's universal mission for the next century could be summarised as to "feed double the number of people, provide them with energy and materials, let them live according to the requirements of a developed society and do not pollute the earth nor change the climate" [1]. In essence, this should be the clear objective for a "sustainable society". The concept of "sustainable development" was put on the international agenda with the UNO-report " Our Common Future", also known as the "Brundtland Report", which was published in 1987 [2]. This report stated – simply put - that problems which occur due to human actions should not be passed on to future generations. In the present paper the "problem" of waste recycling, and in particular the recycling of construction and demolition (C&D) waste, will be addressed. It is estimated that the amount of construction and demolition (C&D) waste produced in Europe ranges between 220-335 million tons annually, approximately 0.6-0.9 ton per capita. As a comparison, this is roughly twice the amount of municipal solid waste produced per inhabitant. It will be clear that C&D waste should be considered as a major waste stream. The progress achieved in Europe will highlighted and documented, including the progress obtained within the recently established European Thematic Network on "Use of Recycled Materials as Aggregates in the Construction Industry"[4]. The presentation will be concluded with a vision on how large-scale application of recycled aggregates in the (concrete) construction industry may gradually be obtained.

CURRENT STATUS OF CDW RECYCLING

EC Directive on waste

In Europe some ideas derived from the Brundtland report became part of the EC Directive 91/156/EEC on waste, formally adopted in March 1991. This directive intends to force EC Member States to stimulate, a/o:

- the prevention and reduction of waste through the development of clean technologies as well as products that can be re-used or recycled;
- the recycling and recovery of waste, and its conversion into secondary materials; and
- the recovery and disposal of waste without endangering human health or the environment.

Based on this directive, waste management plans are currently in the process of implementation on a European Community level, as well as on a Member States level. And because one of the major waste streams in the European Union consists of construction and demolition waste (C&D waste), the EU-construction industry is closely involved in setting up and implementing these management plans.

European CDW

Table 1 summarises EU official data on C&D waste on a European country by country basis [o.a. 3]. Presently, these data are not believed to be entirely correct [ongoing discussion in 4], mainly due to a lack of proper definitions for C&D waste fractions, and a lack of sound EU monitoring programs. However, from table 1 some trends may clearly be derived. It is clear that notably the more densely populated countries, such as Belgium, Denmark and the Netherlands are progressing relatively well with respect to CDW recycling. Running up are Finland, France, Germany and the UK. In the other countries CDW recycling still seems to be restricted to larger urban agglomerations.

Table 1. Generation of C&D waste in EU member countries [4]. Data between brackets were derived from reference [5].

EU Country	Population (Million)	C&D waste (Mton)	C&D waste (kg/capita/year)	Percentage Recycled [3]	Domestic waste (kg/capita/year)
Belgium	10	7,5-8 (7)	700-800	87	350
Denmark	5,2	2,3-5 (3)	460-1000	81	460
Finland	5	1,6 (1)	320	45	620
France	56	20-25 (24)	340-450	15	460
Greece	10	Unknown (2)	- (500)	<5	300
Netherlands	15	13-14 (11)	870-930	>90	500
Ireland	3,5	2,5 (1)	710	<5	310
Italy	58	35-40 (20)	600-690	9	350
Luxembourg	0,4	2,7 (0)	6670 (?)	(?)	450
Portugal	10	Unknown (3)	- (330)	<5	300
Spain	39	11-22 (13)	280-560	<5	320
United Kingdom	57	50-70 (30)	880-1220	45	350
Sweden	8,5	1,2 (2)	140	21	370
Germany	79	52-120 (59)	840-1900	17	360
Austria	7,7	22	2860 (?)	41	430
EU-total (est.)	*364*	*221-334 (180)*	*607-918*	*28*	*390*

Current applications of C&D waste

Most of the EU stony C&D waste is currently still applied for road foundations. Wood is recycled mainly for the wood-chip industry or use as energy source for e.g. power plants, metals are also recycled as raw material in the steelwork industry, and plastics are generally combusted, due to the current lack of economically interesting applications. What remains are asphalt granulates and stony aggregates. If the Netherlands are taken as an example, asphalt granulates may be reused relatively easily for new or renovated roads. It is a waste fraction, which also becomes available as a more or less uniform material, and it is not recommended to mix asphalt granulates with entirely stony aggregates; any future separation, for whatever reason, is bound to be much more difficult than the process of mixing it up.

Applications of recycled aggregates into concrete currently remain restricted to pilot and demonstration projects. Results are definitely promising. A practical problem is logistics. For that reason, there are currently only few concrete(-products) manufacturers in Europe who supply (and apply) concrete with recycled aggregates on a regular basis into their products (e.g. are concrete street- and pavement blocks, pre-fabricated walls for housing projects).

Applications for recycled stony aggregates

Stony aggregates are, according to the recommendations of the CEN 154 “ad hoc group on recycled aggregates” [6] to be divided into three main classes. These classes also reflect the fact that in Europe houses and other constructions are made of concrete, clay bricks or natural stone. Gypsum plaster and gypsum blocks are also generally applied for indoor walls and indoor wall finishing or decoration. Relatively small quantities of lightweight concrete and sand-limestone bricks remain in certain EU countries. In table 2, an overview of the three above-mentioned recycled aggregate classes is provided.

Table 2. Classification criteria for recycled aggregates [6].

Requirement	**Type I**	**Type II**	**Type III**	**Test method**
Minimum dry particle density (kg/m^3)	1500	2000	2400	prEN 1097-6
Maximum wt.% with SSD < 2200 kg/m^3	-	10	10	prEN 1744-1 section 13.2
Maximum wt.% with SSD < 1800 kg/m^3	10	1	1	modified as ASTM C123
Maximum wt.% with SSD < 1000 kg/m^3	1	0.5	0.5	
Maximum wt.% of foreign materials (metals, glass, plastic, wood, paper, tar, crushed asphalt, etc.)	5	1	1	Test by visual separation as in prEN 933-7

Note 1: prEN 1744-1 section 13.2 as currently drafted separates materials only at a density of 2000 kg/m^3; prEN 933-7 is a sorting method, limited to the determination of shell content.

Type I aggregate are implicitly understood to originate primarily from masonry rubble, while type II aggregates are implicitly understood to originate from concrete rubble. Finally, type III aggregates are implicitly understood to consist of a blend of recycled aggregates (with a maximum of 20%) and natural aggregates, with a mandatory minimum of 80%. The maximum content of Type I aggregates in a blend is intended to be 10% (i.e. 50/50 masonry/concrete mixtures may be used for blending with natural aggregate). In some documents of CEN a type of recycled natural stone masonry is foreseen with almost the same specifications as for Type III. These categories may be related to an increased level of performance, Type III resulting in concrete with a performance essentially unchanged by the content of recycled material.

The properties of concrete with recycled aggregates may differ from concrete with only natural aggregates. Because of this preference is given to concrete in which only part of the aggregate consists of recycled material. RILEM [6;7] concluded that the property variations within concrete with up to 20% (m/m) recycled concrete aggregates or up to 10% (m/m) recycled masonry aggregate are negligible. Depending on a specific application, higher replacement levels may result in slight property deviations. As an example, ongoing studies at the TU-Delft [8;9;10] point out that recycled concrete and recycled mixed aggregates may be applied for concrete with a design strength of 35 MPa and an environmental class of 3 up to replacement levels of 100% for the course 4/22(32) fraction. According to the same study, recycled fine aggregates may be recycled up to replacement levels of 50% in concrete with the above specification, a result that has also been reported by Van der Wegen and Haverkort [11]. Recent large inventories carried out by the Dutch CUR organisation suggest that concrete with recycled mixed aggregates is very well applicable for concrete with 28-strengths up to 25-35 MPa, and environmental classes up to 2 (W/C ratio 0,55) [12].

Standardisation, quality control and legislation

As already mentioned, standardisation procedures are well developed in most EU countries [see 7], and discussion networks are steadily being extended. An example of the latter is the recently started European Thematic Network on Use of Recycled materials in Construction [see 4]. Quality control is a different issue, which should be addressed as soon as there is an agreement over draft standards. It should be realised that the construction industry will NEVER apply recycled materials if their quality can not be guaranteed. Finally, national and regional public bodies and governments, e.g. those responsible for regulation and legislation, play a crucial role. It is well established that in The Netherlands, application of recycled aggregates was stimulated greatly by a ban on the landfilling of recyclable C&D waste, effective from 1997 onwards. Currently, gate fees have to be paid "at the gate" of recycling plants, depending on the C&D quality (or recycling potential). Only if these three aspects are well covered, and in the proper order, the recycling industry should be expected to invest in the large scale processing of C&D waste.

FUTURE OUTLOOK OF CDW RECYCLING

From "waste management" towards "chain management"

Currently, in some European countries (notably The Netherlands), a trend has started to investigate the possibilities to recycle stony building materials into the materials where they were originally derived from. The driving force is the producer's responsibility to provide for "sustainable" as well as "durable" building materials, potentially lasting centuries. The implication is that concrete should preferentially recycled back into new concrete, and e.g. sand-limestone bricks into sand-limestone bricks. For concrete this seems to be relatively easy, for clay-bricks it will be far more complicated. Even reuse at the construction element level is looked at. The latter aspect requires new solutions in the fields of construction (mounting and demounting of elements), quality control and logistics, and does not seem that easy. Realistic quality control procedures, and the willingness to work accordingly, are essential for an unreserved application of recycled aggregates in the building industry [see e.g.13].

Economical aspects

From an economical point of view, recycling of building materials is only attractive when the recycled product is competitive with natural resources in relation to cost, quality and quantity [3]. Mainly due to several additional procedures and possibly slightly more complicated processing, necessary for the manufacturing of good quality concrete with recycled aggregates, the costs to produce the recycled aggregates for concrete will be at a higher level than in road construction. Even in the Netherlands, where there is a ban on landfilling building- and demolition waste, applications in concrete have not started on a really large scale yet. The main reason here is also that road-construction still has sufficient capacity. However, the general expectation is that in future the application in concrete will increase, especially since the bulk of demolished concrete is growing rapidly. Other solutions, such as those mentioned earlier on in the text, have to be ready by that time [13].

REFERENCES

1. Personal communication, Okkerse and van Bekkum, 1997
2. Our common future, World Commission on Environment and Development, Oxford University Press, 1987.
3. Lauritzen, E.K. (1998) sited from: The Global Challenge of Recycled Concrete, in "Use of Recycled Concrete Aggregate", Ed. R.K. Dhir, N.A. Henderson and M.C. Limbachiya, Thomas Telfort, London
4. Personal communication within the Brite Euram Thematic Network on Use of Recycled Materials as Aggregates in the Construction Industry (BBRT-CT98-5064), 1999. See also: the ETN Recycling in Construction website at http://www.etnrecy.net

5. Construction and Demolition Waste Management Practices, and their Economic Impacts (1999)
6. Hanson, T.C., Recycling of Demolished Concrete and Masonry: A State-of-the-Art Report 1945-1989. RILEM report No. 6, E.Fn. Spon, London.
7. Report of the ad-hoc group on recycled aggregates of CEN TC 154, aggregates, March 1998.
8. Fraaij, A.L.A., Pietersen, H.S., Janssen, J. and Wardenier, P. (1999) Potential Application of Recycled Aggregates for the "Zandkreekdam" project, Stevinreport 22.1-99.12, TU-Delft, Faculty CiTG-CT, (in Dutch).
9. Pietersen, H.S. and Fraay, A.L.A., Performance of Concrete with Recycled Aggregates, CIB congress 1998, 7-12 June, Gavle, Sweden.
10. Pietersen, H.S., Fraay, A.L.A. and Hendriks, Ch.F. Application of Recycled aggregates in Concrete – Experiences from the Netherlands, CANMET Symposium on Sustainable Development of the Cement and Concrete Industry, October 21-23, 1998, Ottawa, Canada.
11. Van der Wegen, G. and Haverkort, R. (1998) Recycled Construction and Demolition Waste as Fine Aggregate for Concrete, in "Use of Recycled Concrete Aggregate", Ed. R.K. Dhir, N.A. Henderson and M.C. Limbachiya, Thomas Telfort, London. See also: CUR report 98-6 "Breaker- and Sieve Sand in concrete – potential as fine filler material".
12. Breker- en Zeefzand van Bouw- en Sloop Afval, Report of CUR B-69, CUR report 95-5 (1995) (in Dutch).
13. RILEM report 22. Sustainable Raw Materials – Construction and Demolition Waste, a State-of-the-Art Report of RILEM technical Committee 165-SRM (Sustainable Application of Mineral Raw Materials in Construction, eds. Ch.F. Hendriks and H.S. Pietersen, 2000, RILEM Publications.