EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Prospective Technological Studies (Seville)
Sustainability in Industry, Energy and Transport

End of Waste –Aggregates Case Study

Working document

5 MARCH 2007

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INTRODUCTION TO IPTS END OF WASTE PROJECT

In the preliminary communication regarding the Thematic Strategy on Waste, among others, the issue of when a waste ceases to be waste is highlighted as being ambiguous and whose clarification could be important and beneficial. It is proposed that in order to improve this situation, the revised Waste Framework Directive shall contain a provision that is designed to clarify “end of waste” status for those waste streams where the use of “end of waste” would be appropriate, on a stream-by-stream basis. The aim of the IPTS project is to support the development of such end of waste criteria under the revised Directive, through a scientific, thorough and transparent analysis.

On the request of the DG ENV, the IPTS project is to achieve the following three objectives:

- Propose candidate waste streams for the definition of end of waste criteria based on operational selection criteria according to the principles of the Thematic Strategy on the prevention and recycling of waste as well as the proposed revision of the Waste Framework Directive (WFD)

- Develop a methodology (including the frameworks for the technical analysis and impact assessment) for proposing end of waste criteria under the WFD

- Apply the methodology to propose and assess end of waste criteria (possibly alternative sets of such criteria) for a number of pilot cases

To achieve these objectives, a number of research activities have been initiated. A literature review and assessment has been carried out in identifying current practices within the EU and also the general views of the various stakeholders regarding the end of waste concept. As a result, some candidate waste streams / secondary material categories have been identified together with early indications of possible end of waste criteria.

An analysis of waste streams in the EU both in quantitative terms and in respect of the associated environmental issues (i.e. the upstream examination) is being launched. This work basically will result in a list of waste streams, categories for the recovered material, and the general steps involved from which specific ones can be selected for more detailed examination.

To develop a framework methodology as a guidance to define end of waste criteria, three pilot cases, i.e. aggregates, compost and metal scrap, are being carried out to provide feedbacks and refine the general framework methodology so that it can be applied consistently for detailed assessment for other waste stream categories. These parts of the project are closely linked and interactive. With applying the framework methodology, the pilot cases are expected to assess the feasibility of end of waste criteria on each of the studied waste stream and to propose the suitability of a general framework methodology for the development of the end of waste criteria. The case studies may also conclude that end of waste criteria are not appropriate for the studied waste stream.

CASE STUDY ON AGGREGATES

This case study looks at the use of substitute materials as natural aggregate replacement. It will serve to contribute to the development of a framework methodology for determining end of waste criteria. For any material stream studied, it is necessary to understand:

(a) the potential market situation for the material(s) studied;
(b) the environmental issues related to the production, handling and use of the material(s); and
(c) the possible impact of declassifying the material as waste and treating it as a non-waste product.

To assess secondary materials with the potential to be used as aggregates, a characterisation of the materials is required. To address the environmental and technical issues associated with the use of the secondary material as aggregate as well as the market context of the material.

Objectives of the workshop

As part of the planned approach for this project, two expert workshops are planned. The first workshop will serve to discuss and debate with experts some of the main issues related to the use of recycled and secondary materials as aggregates. More precisely, the objectives are:

- to discuss and validate the selected materials with the potential to be used as aggregate.
- to discuss the environment risks associated and the technical limitations of the materials
- to debate market issues related to the recycled/secondary aggregates vs primary aggregates
- to debate the processes and techniques used for producing secondary/recycled aggregates
- to get an initial impression how the experts see possible end of waste criteria and to discuss the impact of the criteria
- to identify technical information that could help to accomplish the objectives proposed.

1 INTRODUCTION

Aggregates are a basic input, necessary for most types of construction. According to the source material aggregates can be classified as,

Natural aggregates, produced from mineral sources. Sand and gravel are natural aggregates resulting from rock erosion. Natural aggregated can also be produced from crushed rock.
Secondary aggregates, by-products produced from industrial processes.
Recycled aggregates, produced from processing material previously used in construction

For producing secondary and recycled aggregates several materials streams can be used.

Construction and demolition waste
Ferrous and non-ferrous slags
Ashes from combustion or incineration processes
Fired clay broken products
Spent foundry sand
Mining waste
Tyres
Glass

The materials used for the production of secondary and recycled aggregates are waste materials or by products from industrial processes. With the utilisation of these types of materials as secondary or recycled aggregates, the amount of waste disposal and the consumption of natural aggregates can both be reduced.

Given the large range of materials which could be used as secondary or recycled aggregates, three are selected as good examples for the aggregate case study to contribute to the development of an end-of-waste methodology. These are construction and demolition waste; ferrous slags; and ashes from coal combustion.

In Europe the aggregate market accounts for 3000 million tonnes of aggregates produced, including natural, secondary and recycled aggregates. Recycled and secondary aggregates represent a small fraction, only 7 % of the total (UEPG 2006)

1.1 Type of applications

The field of application of aggregates can be divided in two main types; bound applications or unbound applications.

Bound applications: the mixture contains a binding agent, such as cement, bitumen or a substance that in contact with water has binding properties, similarly to cement.

Unbound applications: the aggregate is not bound

Concrete may be defined as a mixture of water, cement or binder and aggregate. The water and the cement/binder form the paste and the aggregate forms the filler, not intervening in the chemical reaction of the mixture. Concrete is used in many types of applications for the construction of buildings and structures. It is used in the production of pre-cast structures and masonry units.

Aggregates are used for producing mortars together with one or more binders and possibly additives and/or admixtures. There are many different types of mortar, and correspondingly many different types of applications, e.g. floor/screed mortar, surfacing of internal walls (plastering mortar), rendering external walls, masonry mortar to join ceramic tiles and masonry units, grout mortar to fill in cavities or empty junctions between materials.

The design of a road is strongly connected to the foreseen load, traffic and weather conditions. These factors will determine the type of road and the type of materials to be used. Additionally the raw material availability has an impact on the road design. The cost of transporting the material needed for road building increases the price of the material. Sometimes to use a local material even if the characteristics are not exactly the ones required can be an economical option, compensating the falling characteristics with other materials in other road layers.

1.2 European standards

The “Construction Products Directive” (89/106/EEC) defines the essential requirements for construction materials. These are the basis for the preparation of harmonized standards at European level in order to achieve the greatest possible advantage for a single internal market. The European Committee for Standardization (CEN) is the entity responsible to develop the standards according to a mandate given by the commission, Mandate 125.

The Europeans standards for aggregates were developed by the CEN 154 technical committee, specifying the properties of the aggregates per type of application, fitness for use. The aggregate material could be obtained from natural rock, manufactured materials such as by-products from industrial processes or recycled aggregates. Despite the type of the aggregate material all should comply with specifications described in these standards. Care should be taken when considering the use of manufactured materials or recycled aggregates. These materials could have other characteristics not included in the Mandate 125.

European Standards for recycled aggregates are expected to be issued in 2007 (UEPG 2006). This will occur by amending the EN 13242 (Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction) standard to incorporate clauses for recycled aggregates.
The revised standard will introduce a new 'classification of the constituents of coarse recycled aggregates' to be determined in accordance with the new prEN 933-11 (Tests for geometrical properties of aggregates – part 11: classification test for the constituents of coarse recycled aggregates). Also a new 'category for resistance to fragmentation of coarse aggregates' and four new categories for 'resistance to wear of coarse aggregate' are introduced. Concerning the chemical requirements for recycled aggregates, the 'water-soluble sulphate content of the recycled aggregates' shall be determined. Regarding the factory production control (annex C of the standard), for recycled

aggregates there should be a documented input control of raw material identifying, the date, the nature of the raw materials, the transporting company and the place of origin of the materials.

EN 13139	**Aggregates for mortar** masonry mortar, floor/screed mortar, surfacing of internal walls (plastering mortar), rendering of external walls, special bedding materials, repair mortar, grouts.
EN 13450	**Aggregates for railway ballast**
EN 13242	**Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction**
EN 12620	**Aggregates for concrete** This standard covers aggregates having an oven dried particle density greater than 2,00 Mg/m3 (2 000 kg/m3) for all concrete.
EN 13043	**Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas** This standard does not cover reclaimed bituminous mixtures.
EN 13055-1	**Lightweight aggregates – part 1: lightweight aggregates for concrete, mortar and grout** Lightweight aggregates from mineral origin having particle density not exceeding 2 000 kg/m^3 (2,00 Mg/m^3) or loose bulk densities not exceeding 1 200 kg/m^3 (1,20 Mg/m^3)
EN 13055-2	**Lightweight aggregates - Part 2: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications**
EN 13383-1	**Armourstone - Part 1: Specification**

The CPD Directive also refers to essential requirements related to ´Hygiene, health and the environment´. The construction work, must be designed and built in such a way that it will not be a threat to the soil, groundwater and to indoor air by the releasing dangerous substances. To cover this aspect several CEN committee's have developed or are developing approaches to assess the risk of building materials releasing dangerous substances into the environment.

A CEN/TC 292 "characterisation of wastes" is currently involved in developing standardised tests and procedures to evaluate and characterise wastes. The work developed by this TC could be also suitable for construction products and for secondary materials used as construction products.

CEN/TS 14429	Characterization of waste - Leaching behaviour tests - Influence of pH on leaching with initial acid/base addition (published) pH dependence leaching test
CEN/TS 14997	Characterization of waste - Leaching behaviour tests - Influence of pH on leaching with continuous pH-control (in publication) pH dependence leaching test
CEN/TS 14405	Characterization of waste - Leaching behaviour tests - Up-flow percolation test (under specified conditions) (published) Column leaching test
EN 12457	Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges

1.3 National regulations

Denmark

The Danish waste management policy is based on the "polluter pays principle". A voluntary agreement between the Danish Constructors Association and the Ministry of Environment and Energy was signed in 1996. It sets the standards for good practice. It obliges the contractors to perform the demolitions activities in a environmental friendly way. The selective demolition of modern buildings is planned alongside with its construction.

A "Statutory Order no. 655 of June 27, 2000, on Recycling of Residual Products and Soil in Building and Construction Work" defines 3 categories for soil and secondary materials according to leaching of contaminants. According to the type of material, it defines the parameters, sampling, frequency of analysis and methods to be used to analyse the material. The legislation also defines the type of applications on which the secondary materials can be used according.

	Category 1	Category 2	Category 3
	Solid content mg / kg dry matter TS		
Arsenic	0 - 20	> 20	> 20
Lead	0 - 40	> 40	> 40
Cadmium	0 – 0.5	> 0.5	> 0.5
Chromium, total	0 - 500	> 500	> 500
Chromium (VI)	0 - 20	> 20	> 20
Copper	0 - 500	> 500	> 500
Mercury	0 - 1	> 1	> 1
Nickel	0 - 30	> 30	> 30
Zinc	0 - 500	> 500	> 500
	Concentration in eluate µ g/l		
*Chlorides**	0 – 150,000	0 – 150,000	150,000 – 3,000,000
Sulphates	0 – 250,000	0 – 250,000	250,000 – 4,000,000
Sodium	0 – 100,000	0 – 100,000	100,000 – 1,500,000
Arsenic	0 - 8	0 – 8	8 – 50
Barium	0 - 300	0 – 300	300 – 4,000
Lead	0 - 10	0 – 10	10 – 100
Cadmium	0 - 2	0 – 2	2 – 40
Chromium, total	0 - 10	0 – 10	10 – 500
Copper	0 - 45	0 – 45	45 – 2,000
Mercury	0 – 0.1	0 – 0.1	0.1 – 1
Manganese	0 - 150	0 – 150	150 – 1,000
Nickel	0 - 10	0 – 10	10 – 70
Zinc	0 - 100	0 – 100	100 – 1,500

* The result should be corrected for $CaCl_2$ added in connection with leaching test for soil

Table 1– Danish limit values for recycling of residual products in building and construction work

Germany

There are requirements for the material recycling of mineral residues/waste, which were elaborated by the working group of the German Länder on waste issues LAGA. These technical rules have been introduced in various Länder where they are legally binding. An ordinance on federal level is being discussed, if approved the LAGA values would become binding in all Länder. The technical rules include requirements for recycling slag from iron, steel and casting foundries, slag from waste incinerators and foundry sand. To assure protection of the environment the leaching of heavy metals should be done on the original materials. Wastes are divided in seven categories depending on the composition and the leachability according to the DIN 38414-SA leaching protocol Z_0, $Z_{1,1}$, $Z_{1,2}$, Z_2, Z_3,Z_4 and Z_5.

Parameter	*Categories*	Z_0	$Z_{1,1}$	$Z_{1,2}$	Z_2
	Restrictions	*Unlimited use*	*Unfavourable hydrological conditions*	*Polluted areas with values larger than* $Z_{1,1}$	*Limited use with technical safeguarding measures*
pH		7 – 12,5	7 – 12,5	7 – 12,5	7 – 12,5
Conductivity	mS / cm	500	1500	2500	3000
Chloride	mg/l	10	20	40	150
Sulphate	mg/l	50	150	300	600
Arsenic	µg/l	10	10	40	50
Lead	µg/l	20	40	100	100
Cadmium	µg/l	2	2	5	5
Chromium$_{total}$	µg/l	15	30	75	100
Copper	µg/l	50	50	150	200
Nickel	µg/l	40	50	100	100
Mercury	µg/l	0,2	0,2	1	2
Zinc	µg/l	100	100	300	400
Phenol index	µg/l	< 10	10	50	100

Table 2– German Limit values for recycled aggregates in LAGA **(Weil 2006)**

France

France has a "Circulaire DPPR/SEI/BPSIED n° 94-IV-1 du 9 mai 1994 relative à l'élimination des mâchefers d'incinération des résidus urbains" which defines categories for ashes from municipal solid incinerators V, M and S.

		V	*M*	*S*
Loss on Ignition		< 5%	< 5%	< 5%
Mercury	mg/kg	< 0,2	< 0,4	> 0,4
Lead	mg/kg	< 10	< 50	> 50
Cadmium	mg/kg	< 1	< 2	> 2
Arsenic	mg/kg	< 2	< 4	> 4
Chromium VI	mg/kg	< 1,5	< 3	> 3
Sulphates	mg/kg	< 10000	< 15000	> 15000
TOC	mg/kg	< 1500	< 2000	> 2000
Total dissolved solids		< 5%	< 10%	> 10%

Table 3 – Categories of ashes from municipal solid incinerators according to leaching parameters, French standard X31-210(U. S. Department of transportation 2000).

Category V, ashes can be used in road construction
Category M, ashes must be treated before use either by stabilization or by maturation
Category S, ashes must be landfilled.

The Netherlands

A general ban of landfilling of recycled C&D waste was implemented in January 1997.
The Building Material Decree (BDM) sets the environment conditions from the point of view of soil and surface waters protection for the use of primary and secondary building materials used for outdoor constructions. The decree does not distinguish between waste materials and primary materials.
The risk approach is based on the assumption that the distinction between waste/secondary materials for building materials is no longer relevant provided that secondary materials do not present an environmental risk compares to the primary materials.

The BDM covers the release of inorganic substances on soil, based on risk assessment. The limits are defined as immission values. The decree classifies building materials into two main categories.
Category 1, building materials that do not exceed the values set in the BDM. The use of building materials is permitted without additional measures to protect the environment.
Category 2, includes the building materials whose composition do not exceed the values of the BDM, but whose imissions values would if additional measures were not taken.
There are two exceptions for some materials that do not fall into these categories, bottom ash from waste incineration plants, and tarry asphalt aggregate. In this case special isolation measures are needed.

Substance	*Imission standards (mg/m^2 per 100 years)*
Sb	39
As	435
Ba	6300
Cd	12
Cr	1500
Co	300
Cu	540
Hg	4.5
Pb	1275
Mo	150
Ni	525
Se	15
Sn	300
V	2400
Zn	2100

Table 4 - BDM imission values

Austria
The "Ordinance on the separation of Waste Generated During construction" obliges the contractor to sort C&D waste into different material flows and specifies minimum quantities per materials stream, above which the contractor is obliged to send that stream to recovery. Sorting and recovery obligation applies only if there is a treatment centre in a perimeter of 50 km from the demolition site and if the cost of treatment does not exceed 125% of traditional disposal costs.
Austria has a voluntary agreement between Ministry of the economy and the construction industry federation. Based on this quality standards for recycled materials and waste exchange schemes were implemented.
The regulation "recycled building materials; regulation regarding the environmental compatibility, December 2002" defines a first set of parameters describing leaching behaviour of the recycled materials. If there are indicators, based on the source material or visual inspection, of a possible contamination then the material has to fulfil a more complete set of parameters.

Parameters	Unit	Grade A^{+}	Grade A	Grade B
Eluate with a L/S 10				
pH value		7.5 – 12.5	7.5 – 12.5	7.5 – 12.5
Conductivity	mS/m	150/200	150/200	150/200
Chromium total	mg/kg DM	0.3	0.5	0.5
Copper	mg/kg DM	0.5	1	2
Ammonia-N	mg/kg DM	1	4	8
Nitrite-N	mg/kg DM	0.5	1	2
Sulphate-SO4	mg/kg DM	1,5	2,5	5
Carbohydrate index	mg/kg DM	1	3	5
Total content				
Σ 16 PAH (EPA)	mg/kg DM	4	12	20

Table 5 – Austrian classification of recycled building materials according to environmental compatibility (Federal Ministry of Agriculture and Forestry 2006)

It also defines which field of application the recycled material is appropriated according to the environmental compatibility defined.

Field of application	*Hydro-geologically less delicate area*	*Hydro- geologically delicate area*
In bound form or unbound with covering layer	B	A
Unbound without covering layer	A	A^{+}
In bound form, used as aggregate	B	B

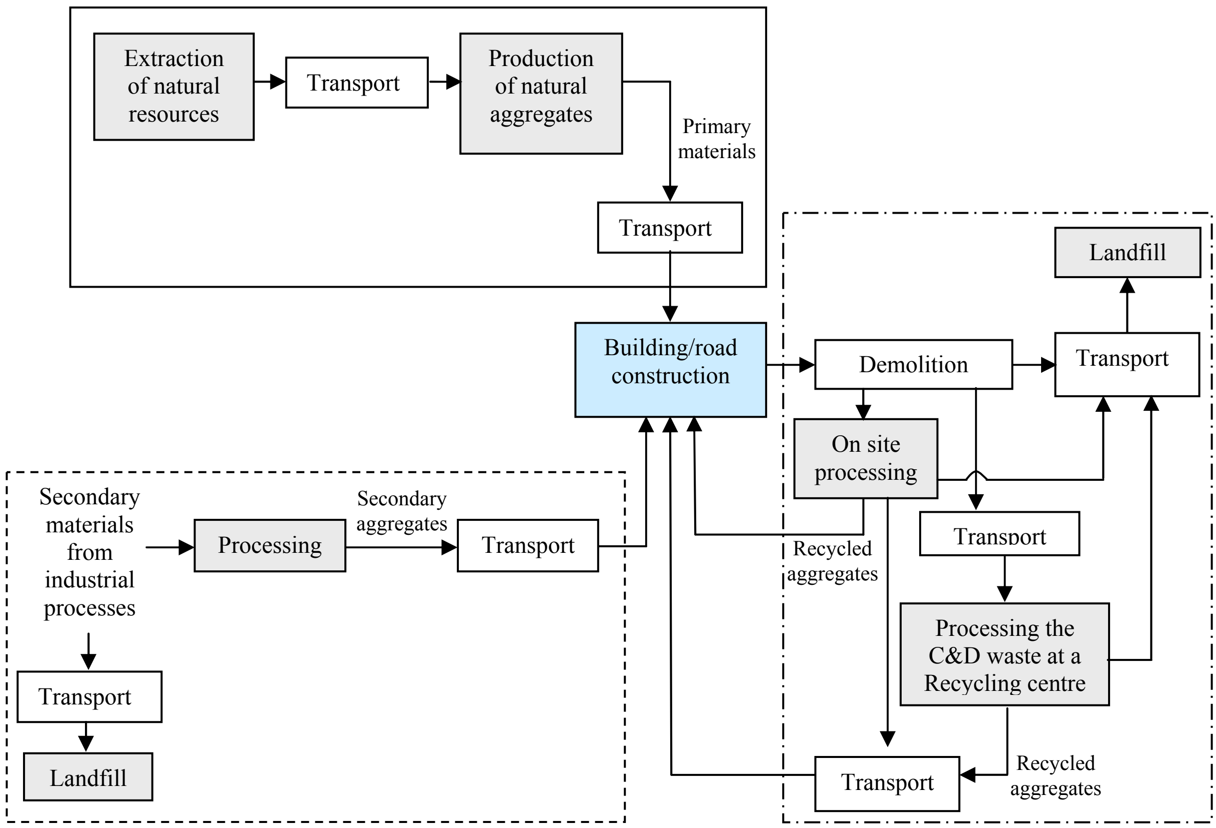
The guidelines define the engineering characteristics, grade and quality control of the product. The control is made internally and externally. The external control of the environmental compatibility is done once a year. Internal control is done twice a month, covering pH value, Σ 16 PAH, electric conductivity, chromium, and copper (Österreichischer Baustoff-Recycling Verband 2004).

1.4 Environmental impact

One of the barriers for a wide utilisation of secondary and recycled materials in the construction sector is the uncertainty related to the environmental impact of using these types of materials. In order to assess this issue it is important to identify all the positive and negative aspects of these materials at critical stages of its life cycle.
The comparison between different waste management options helps to estimate the impact of using recycled/secondary aggregates.
Concerning the secondary materials with potential to be used as recycled or secondary aggregates, depending on the source material two different cycles can be defined:

- The use of C&D waste for producing recycled aggregates

- The use of secondary materials arising from industrial processes for producing secondary aggregates



A life cycle approach helps to identify the environmental loads, inputs and outputs related to each stage of the life cycle of recycled and secondary aggregates. The main issues related to the recycled, secondary and primary aggregates are:

Raw material consumption/replacement

- The consumption of secondary materials used for producing the recycled or secondary aggregates: C&D waste and materials arising from industrial processes.
- The use of recycled and secondary aggregates has the potential to reduce the consumption of natural resources and disposal of waste.

Energy consumption

The fuel or electricity used for the waste management operations, (e.g. washing, crushing, sorting, classification) and for natural aggregate processing, needs to be considered when evaluating the overall impact of recycling, together with the GHG emissions associated.

Air emissions

The handling, transporting and processing of the secondary raw materials, recycled and primary aggregates, generates dust.

Water consumption

The recycling process and the natural aggregates production may use water and its estimation should be included as well effluent emissions.

Substances leaching into the soil

The use of recycled/secondary and primary aggregates has an environmental impact related to the leaching of substances to the environment. Leaching of metal or organic contaminants has been identified as key issues that need to be evaluated.

Noise

The recycling process, the production of primary aggregates, the transport and pre-handling of the secondary materials generates noise.

Waste disposal

The recycling process generates some waste that cannot be further recycled. This material needs to be disposed at landfill sites.

The recycling process uses C&D waste and secondary materials arising from industrial processes that if not recycled would have to be disposed of. The recycling reduces the use of landfill space.

1.5 Impact of end of waste

The impact of declassifying the material as waste and treating it as a non-waste product could have a social and economic impact.

- What will happen to C&D recycling rates?
- Will the number of recycling centres increase? Will this affect the employment rates?
- Recycled aggregates from C&D waste will compete against ashes and slags, how will the end of waste criteria for C&D affect the market?
- Will the end of waste criteria affect the trading of these materials?

The impact of declassifying the material as waste and treating it as a non-waste product could have an overall environmental impact.

- Will the declassification of the material as waste affect the consumption of primary aggregates?
- Will the declassification of the material as waste affect the quantity of waste going to landfill?
- How will the declassification of the material as waste affect the GHG emissions?

2 CONSTRUCTION AND DEMOLITION WASTE

C&D waste represents a high proportion by weight of all wastes produced. In general C&D waste has a broad meaning covering a wide range of materials such as concrete rubble, wood, asphalt rubble, metals, glass, masonry waste, gypsum, soil, paper or cardboard, insulation materials, garden wastes, dangerous wastes, asbestos, plastics wastes. These materials can be classified according to their origin and site type:

> ***Demolition waste:*** residues resulting from the demolition of structures or buildings and/or from the refurbishment of existing buildings.
>
> ***Construction waste:*** residues produced from the construction of buildings or infrastructures.
>
> ***Road construction and maintenance wastes***: residues from the construction of new roads, and from the maintenance of existing roads.

Demolition waste composition varies according to the type of building or structure and also with the age of the building. The material reflects the construction techniques and materials used at the time they were built. Some of the materials used decades ago e.g. asbestos, are now banned and classified as hazardous substances. This is an important issue because it poses a specific threat source of contamination and could jeopardize the use of recycled materials. Furthermore, C&D waste varies according to the country where is generated. The construction techniques and materials differ from country to country and consequently the type of residues produced.

Construction waste composition should be more or less known. Mainly it consists of damaged materials, excess materials left over at the end of the job, intermediate residues and packaging waste used for conditioning the construction materials.

Road maintenance generates a significant amount of residues. It mainly consists of excavating existing materials (asphalt, aggregates) and the replacing by new. This requires significant amounts of new materials and the transport and disposal of the existing materials. The recycling of reclaimed asphalt into new asphalt can result in both cost savings and the reduced environmental impacts. The reclaimed materials that cannot be recycled directly into the new asphalt is processed at recycling centres similarly to C&D wastes.

The EWC (European Waste Catalogue) classifies C&D waste in eight main categories. The most relevant ones for producing recycled aggregates are 17 01, 17 03 and eventually 17 09.

17	CONSTRUCTION AND DEMOLITION WASTES (INCLUDING EXCAVATED SOIL FROM CONTAMINATED SITES)
17 01	**concrete, bricks, tiles and ceramics**
17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
17 01 07	mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 02	**wood, glass and plastic**
17 02 01	wood
17 02 02	glass
17 02 03	plastic
17 03	**bituminous mixtures, coal tar and tarred products**
17 03 02	bituminous mixtures other than those mentioned in 17 03 01
17 04	**metals (including their alloys)**
17 04 01	copper, bronze, brass
17 04 02	aluminium
17 04 03	lead
17 04 04	zinc
17 04 05	iron and steel
17 04 06	tin
17 04 07	mixed metals
17 04 11	cables other than those mentioned in 17 04 10
17 05	**soil (including excavated soil from contaminated sites), stones and dredging spoil**
17 05 04	soil and stones other than those mentioned in 17 05 03
17 05 06	dredging spoil other than those mentioned in 17 05 05
17 05 08	track ballast other than those mentioned in 17 05 07
17 06	**insulation materials and asbestos-containing construction materials**
17 06 04	insulation materials other than those mentioned in 17 06 01 and 17 06 03
17 08	**gypsum-based construction material**
17 08 02	gypsum-based construction materials other than those mentioned in 17 08 01
17 09	**other construction and demolition wastes**
17 09 04	mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03

Table 6 – Adapted from the European Waste Catalogue, 2000/532/EC

Despite the existence of these categories, Member States interpret these categories in slightly different ways which makes comparison difficult.

There are uncertainties over how soil is dealt within the statistics. Large volumes of contaminated soil are moved around with or without some form of treatment, if recorded these amounts can easily distort the C&D statistics.

There is a lack of information related to the use of materials processed on the demolition site. The amounts involved could be significant and some processed material may leave the site as non-waste whilst other material doesn't leave the demolition/construction site at all.

2.1 Construction and demolition waste management options

Around 180 million tonnes of C&D waste are generated in Europe every year. Traditionally it has been landfilled, and only 25% is re-used or recycled (Symonds 1999).

2.1.1 Re-using and recycling (other than aggregates)

By carrying out selective demolition, it is possible to separate and re-use directly some materials, such as fireplaces, wood panels, windows, doors. Additionally many materials such as wood, plastics, metals and gypsum can be recovered for further use.

2.1.2 Landfill

The objective of the landfill Directive 99/31/EC is to reduce and to reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfills. The total cost of establishing maintaining and closing of the landfill site is considered when establishing the landfill cost. The directive defines three classes of landfills for hazardous waste, for non-hazardous waste and for inert waste depending on the characteristics of the C&D waste.

In December 2002 the council decision establishing criteria and procedures for the acceptance of wastes at landfills pursuant to Article 16 of the landfill directive was published. It took effect on 16 July 2004. In particular, it lists the wastes that can be accepted at a landfill site for inert wastes without testing. C&D waste free of dangerous substances is considered inert waste can be admitted at a landfill site without further testing.

Some countries the Netherlands, Belgium, and Denmark have specific legislation and regulations for managing this type of material, restricting or banning the landfill, resulting in recycling rates bigger than 80 % (data from mid 1998). Other countries Spain, Portugal and Greece have less than 5 %.
The low recycling rates from the south european countries can be explained by the existing natural resources available for producing primary aggregates (Symonds 1999).

With the implementation of landfill directive, other waste management options for C&D needed to be considered, to divert the C&D waste from landfills.

2.1.3 Recycling C&D waste as aggregates

Inert C&D waste has a high potential to replace primary aggregate. The recycling process can take place on site where the demolition or the construction project is taking place or off site in a recycling plant.

The on site recycling depends on the nature of the project. If a substantial amount of waste is going to be produced the setting up of a mobile equipment on site could be viable. Ideally the demolition waste being treated on site could be used on site as secondary aggregates for the new construction avoiding the transport of the primary or secondary aggregates. However on site recycling can create noise and dust to the surroundings. More space is needed for the machinery and for all the recycling operations and this type of operations on site also bring less flexibility about where and when the materials can be used or sold. Additionally if the recycled materials are going to be used on site, space is needed for stockpiling.

Off site recycling plant has the advantage to be more flexible in terms of holding stocks, making positive marketing of recycled materials easier and facilitate the quality control of the recycled materials. This type of plants enables the implementation of techniques to reduce or mitigate adverse environmental impacts on surroundings areas. However the cost of transporting the materials to the site and the less control on the demolition process, essential to avoid the arrival of unknown quality material are two important issues influencing the quality and the price of the recycled materials. Large off site recycling plants operate in a similar way to conventional aggregates quarries, building up different stocks according to the specifications of the materials enabling a rapid answer to the market demand.

The composition of the construction waste produced on site should be known by the contractor. As mentioned before it is essential that separation of residues is kept, to know exactly what type of residues is produced and to find the suitable treatment for them.

The processes involved in the production of recycled aggregates from C&D waste are typically:

Visual inspection	The material is visual inspected and weighed at the gate. According to what was declared by the owner of the residue, the waste is tipped and stored according to its composition, and again visual inspected.
Sorting	Depending on the quality of the materials arriving at the recycling centre, hand sorting sometimes is unavoidable. The material is feed to a picking station through a conveyor belt. The workers separate the unwanted materials to different bins by hand sorting.
Magnetic separation	Magnetic separation is used to remove ferrous material, after its separation the metal can be recovered.
Crushing	The size of the material is reduced by means of crushers.
Classification	The aggregate size is a paramount factor for determining the use of the material.
Washing	For more demanding type of applications, the material has to be free of fines and clay. To remove them from the surface of the aggregate the material is washed.

2.1.3.1 Technical characteristics

The physical and technical properties of the recycled material strongly depend on the secondary material used and the process techniques applied. Recycled aggregates cannot substitute all type of applications when comparing to natural aggregates.

The use of recycled aggregates in concrete is the highest level application for secondary aggregates. Concrete made with recycled aggregates replacing 100% of the gravel, presents up to 20 % less strength when using gravel, however there are ways various ways to address this (Ch. F. Hendriks 2000).

Recycled aggregates are less dense, resulting in a higher porosity. More water is needed to ensure a full saturation of the aggregate.

Comparing to natural aggregates gravel, recycled aggregates have an angular grain shape and a rough surface that adversely affects the workability of the fresh concrete. This may be compensated by an increased amount of matrix materials (binding agent) and/or by reducing the shear resistance of the matrix during processing. A suitable workability can be achieved by an increased use of cement or fly-ash (with cementing agent properties) and a corresponding amount of water and/or increased use of concrete plasticizers. Consequently concrete with natural aggregates and concrete with recycled aggregates usually have different cementing agent compositions (Weil 2006).

The recycled aggregates need to be free from impurities as they can affect the technical behaviour of the material. The material has to be clean of plaster and anhydrite, because they can expand due to water absorption. Porous insulating bricks or aerated concrete should also not be present as these materials are too soft and adversely affect the strength in certain application. Additionally soil (clay agglomerates), products containing tar, glass, chloride and plastics and all materials leading to alkali-aggregate reactions (Ch. F. Hendriks 2000).

2.2 Environmental impact

	C&D waste
Recycling	Dust Emission to water Consumption of energy Noise
Use of the material	Leaching of the material - High alkalinity - Chromium - Chloride - Sulphate - Hydrocarbons
Raw material	Reduces the consumption of natural resources
Waste disposal	Reduction of landfill space

The type of recycling operations will influence the quality of the recycled product. The recycling process for producing "high quality" aggregates has a higher environmental impact than "low grade" aggregates.

The environmental risks associated with the use of recycled aggregate strongly depend on the type of application. If the material is bound, the risk of leaching is smaller than if the material is unbound and in contact with water.

2.3 Market

The decision to produce recycled aggregates strongly depends on the existing conditions at a demolition or construction site. Hardly a demolition/construction contractor starts to separate waste at source and to bring it to a recycling plant just to prevent the use of natural resources and avoid waste generation. The evolving conditions at the site dictate the practices of the contractors.

The decision made by the demolition contractors takes into account the costs of handling, transporting, processing and the disposal of all the separated fractions, not just the inert fraction which can be used to produce recycled aggregates.

The existence of landfill restrictions to divert inert recoverable C&D wastes from landfills is an important factor. The landfill taxes charged and the landfill gate fee cost (based on the composition of the waste) force the demolition / construction contractor to look for other waste management options. Costs for landfilling vary between 5 – 40 EUR/tonne (FIR 2005).

If the contractor decides to carry the C&D waste to a recycling centre, there is also a gate price depending on the composition of the waste. The cost of treatment varies 1-6 EUR a tonne. The sales price of recycled aggregate varies between 1 – 6 EUR/tonne (FIR 2005).

The availability of recycling installations within a reasonable distance of a demolition/construction site, is a determinant factor for recycling. The distance between the recycling centre and the site strongly influence the cost of transporting and consequently the final price of the treatment.

The contractor's decision to go for recycling or to go for waste disposal will be based on the final cost of treatment option.

The aggregate levy was introduced in 2002 in the UK to ensure that the environmental impact of extracting primary aggregate is more fully reflected in the price, encouraging a reduction on primary aggregates, shifting the demand to the use of alternative materials. This measure influenced the recycling rates in the UK. Currently the aggregate levy is set at £1,60 per tonne of primary aggregate(WRAP 2006).

Also the price of natural aggregates has a strong impact on the marketing of recycled materials. In some countries the availability and the quality of natural aggregates is not a constraint. In other countries the pressure on natural resources is significant.

It is important for the recycled aggregates market to have specifications and standards that can assure to the user a safe use of the materials. The development of isolated national standards could create barriers for cross-border trading.

For a good market acceptance of the recycled material, the user should be aware of the advantages of using the recycled material. The user tends to see the recycled product as a waste and not as a construction product.

The market is typically organized according to the following scheme,

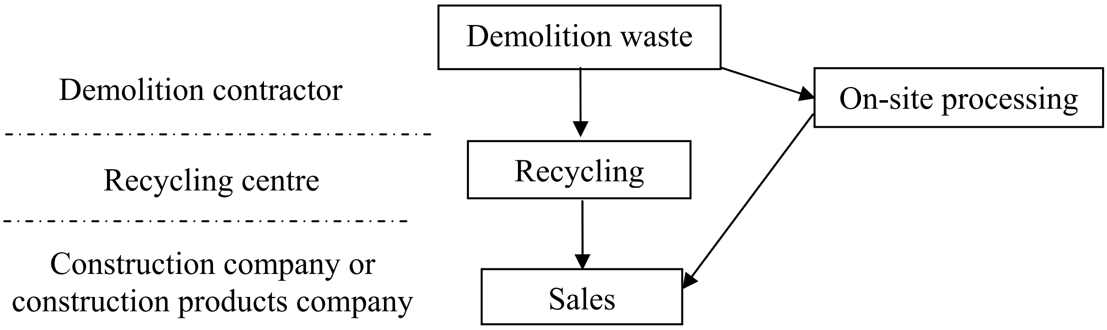


Figure 2.1 – Typical market chain of recycled aggregates

The demolition waste processed on site can be used on site, in this case the material does not enter in the market, or it can be sold to a construction company or construction products company. In this case is not waste anymore and the waste authorities do not have jurisdiction over this type of material.

2.4 End of waste criteria

End of waste criteria has to assure the fulfilment of two main principles:

- There is no overall disadvantage for the environment associated with the declassification of the material as waste and treating it as a non-waste product
- There is a market for the recycled material.

To follow the above principles, operational principles have to be defined.

- The product must fulfil the engineering requirements set in the European standards for aggregates.

- A selective demolition helps the separation at source of the materials with potential to be reused or recycled. This procedure helps the identification and removal of hazardous substances than can contaminate the inert material jeopardizing its recycling.

- The production process of recycled aggregates requires a controlled process. This will enable not only the elimination of impurities but also the production of a product that fulfils the requirements of a quality category

- The product must fulfil the regulations applicable to aggregates.

How to ensure a quality of recycled aggregates which minimise the environmental risks?

- Source selection, decontamination prior to demolition
- Selective deconstruction, removal of other materials
- Inspection and testing prior to processing
- Processing techniques
- Inspection and testing after processing
- Short term vs long term environmental impact

3 SLAGS FROM IRON AND STEEL INDUSTRY

The production of iron and steel involves various different process steps using different furnace types. Each furnace produces a liquid metal product and a slag. Iron ore is first smelted to produce pig iron which is further refined in subsequent furnaces to produce a metal product of the desired quality. Scrap metal is added to the process in the later stages.
The production of pig iron from ore takes place in a blast furnace and generates a blast furnace slag. The raw material, iron ore contains a large content of hematite (Fe_2O_3) and sometimes small amounts of magnetite (Fe_3O_4) (European Commission 2000). It is treated before entering the furnace to improve the performance of the blast furnace. This preparation involves the agglomeration of the furnace charge either by sintering or pelletisation, mixing the iron ore with other additives such as lime, dolomite, collected dusts, and recycled sinter to lower the melting point of the gangue, to improve sulphur uptake by slag, to provide the required liquid pig iron quality and to allow for further processing of the slag. The blast furnace is fed with sintered/pelletised iron ore and with coke, the reducing agent. The iron ore is reduced and slag is formed combining the aluminates and the silicates of the ore and coke. Both pig iron and blast furnace slags emerge from the furnace at a temperature at aprox. 1500°C. The slag which has a lower density floats on the pig iron. For producing one tonne of pig iron 210-310 kg of blast furnace slags are generated.

Blast furnace slags

The blast furnace slag coming out of the bottom of the blast furnace is cooled down following different techniques; as a result different materials with different characteristics are produced determining the future use of the material.

Granulated blast furnace slag
Granulation in the most common process used in the EU 15. The slag is rapidly cooled through a high-pressure water spray in a granulation head. The granulated material is transported to a drainage system. The cooling water is reused. The rapid cooling makes the slag vitreous, turning it into a solid whose molecules have not had the time to position in a crystalline organisation due to fast cooling process. The material has latent hydraulic properties due to its structure and SiO_2, CaO, MgO, Al_2O_3 content, which allow the generation, in contact with water of a series of hydrated products that crystalise causing a stables solid body. However the reaction is much slower than in cement. To speed up the reaction, chemical activators are used, such as lime. The specific surface area of the material is also important, the smaller the size particle the faster it reacts. This characteristic enables the use in cement mixtures replacing ordinary portland cement and in concrete mixtures as a cementituous constituent.

Air cooled blast furnace slag
The blast furnace slag is poured in thin layers of molten slag directly into slag pits adjacent to the furnace. Sometimes water is used for reducing the cooling time; in this case the water is totally consumed by evaporation. The slag pits are then excavated and the material is ground and screened similarly to natural aggregate processing from crushed rock.

Pelletisation

According to EUROSLAG, in Europe only one plant in Germany uses this type of cooling method.

2004	Aprox. Million tonnes	%
Air cooled Blast furnace slag	5,7	23
Pelletized Blast furnace slag	0,5	2
Granulated Blast furnace slag	18,5	75
Total	**24,6**	

Table 7 – Production of blast furnace slags (EUROSLAG 2006)

The production of steel involves the removal the excess of carbon and silicon by oxidation. There are two main processes for producing steel, and consequently two main categories for slags.

Steel slags

Basic oxygen furnace slags

Associated with integrated steelworks, the pig iron produced in the blast furnace is treated in basic oxygen furnaces. Pressurised oxygen is injected in the furnace along with limestone eliminating carbon, silica and phosphorus from the pig iron. Metal scrap is also added to control the temperature as it is an exothermic reaction. The slags are formed on top and transferred to a tipping lagoon and allowed to cool slowly solidifying. There are other types of furnaces used for the basic oxygen steel making process, such as LD converter (Linz-Donawitz) or BOP (Bottom-blown Oxygen Process).

The slag is crushed and classified similarly to the production of natural aggregates from crushed rock. Sometimes the slags are treated to recover metallic iron by magnetic separation.

BOF slags are normally used in civil and hydraulic engineering, road construction and cement industry. In particular LD slags have a high abrasion resistance.

Electric arc furnaces slags

Associated with the melting and recovery of scrap iron and steel is the production of steel using electric arc furnace. The scrap is melted by electrical and oxyfuel energy. Oxygen, coal and slag formers such as lime and dolomite are blown into the melt. By tilting the furnace the slag is separated from the steel. The slag is tipped to an outdoor site where is cooled down. Metal could be recovered. The material is processed, crushed and classified. One tonne of liquid steel produces 100 – 150 Kg of EAF slags(European Commission 2000).

Secondary slags

After the oxidizing process the steel could be further processed, usually classified as secondary steelmaking. This further processing is the response to market demand for specific quality requirements. Typically it is carried out in ladle stations. One example of secondary steelmaking is the production of stainless steel. The production of stainless steel produces Argon Oxygen Decarbonisation slags.

2004	Aprox. Million tonnes	%
Electric arc furnace slags	4,408	29
Basic oxygen furnace slags	9,424	62
Secondary slags	1,368	9
Total	**15,2**	**100**

Table 8 - Production of steel slags
(EUROSLAG 2006)

3.1 Iron and steel slags waste management options

The generation of slags from the iron and steel production is unavoidable with the current technology. The production processes have reached a mature development and there is little scope to reduce the amount of slags generated per tonne of iron and steel produced.

3.1.1 Landfill

According to the Council decision of December 2002, slags to be disposed of at inert landfill have to be tested for acceptance.
The material has to be fully characterised to enable a safe disposal of the material in the long term. Basic information is gathered, source, origin, production process, characterization of the raw materials, waste treatment applied. The composition and the leaching behaviour of the material must be known. These requirements oblige the generator of the waste to test the material. The council decision establishes limit values according to three types of test. Batch tests with a liquid solid ratio of L/S = 2 or L/S = 10 or a percolation test. There are standardised tests EN 12457 for the batch test and the pr EN 14405 for the percolation test.

	L/S = 2 L/kg mg/kg dry substance	*L/S = 10 L/kg mg/kg dry substance*	*C_o mg/L*
As	0,1	0,5	0,06
Ba	7	20	4
Cd	0,03	0,04	0,02
Cr total	0,2	0,5	0,1
Cu	0,9	2	0,6
Hg	0,003	0,01	0,002
Mo	0,3	0,5	0,2
Ni	0,2	0,4	0,12
Pb	0,2	0,5	0,15
Sb	0,02	0,06	0,1
Se	0,06	0,1	0,04
Zn	2	4	1,2
Chloride	550	800	460
Fluoride	4	10	2,5
Sulphate	560	1 000	1 500
Phenol index	0,5	1	0,3
DOC*	240	500	160
TDS**	2 500	4 000	-

*Dissolved organic carbon
Total value of dissolved solids

Table 9 – Limit values for waste acceptable at landfills for inert waste, council decision 19 December 2002.

3.1.2 Recycling

According to EUROSLAG, 17,6 Million tonnes of slags are used for cement production. The cementitious properties of the granulated blast furnace slags make it the high market value for the material.

2004	Aprox. Million tonnes
Cement production	17,6
Road construction	15,6
Hydraulic engineering	0,5
Fertiliser	0,5
Internal recycling	2,2
Interim storage	3,0
Final deposit	1,7
Others	1,2
Total	**42,2**

Table 10 – Applications of iron and steel slags (EUROSLAG 2006)

3.2 Technical characteristics

Blast furnace slags

Granulated blast furnace slag
It is a granulated material with low density with a high angle of internal fraction. Additionally it has low resistance and self binding properties.

Air cooled blast furnace slag
It is a material with a high bearing capacity and a high abrasion resistance. Its low bulk density, together with self binding properties is an added value for certain applications It has low thermal conductivity, resulting in insulation properties.
There is a risk of swelling for air cooled blast furnaces slags with a high free lime content (SAMARIS 2006).

Steel slags
Steel slags have a greater absolute density than conventional natural stones and sand. This is considered in calculation mix designs, because of differences between volumetric and mass compositions.

Basic oxygen system slags
It is a hard, dense, clean and abrasion resistant material. It has good polished stone value. The volume stability of the material is influenced by the free CaO and MgO.

Electric arc furnaces slags
It is a material with a very good resistance to abrasion and fragmentation. It has a high angular shape and rough surface texture. It has a good adhesion to the bitumen.

	BOF Slags	EAF Slags	Granite	Flint gravel
Bulk density (g/cm^3)	3,3	3,5	2,5	2,6
Shape – thin and elongated pieces (%)	< 10	< 10	< 10	< 10
Impact value (%)/wt.)	22	18	12	21
Crushing value (%/wt.)	15	13	17	21
10% fines (KN)	320	350	260	250
Polishing (PSV)	58	61	48	45
Water absorption (%/wt.)	1,0	0,7	< 0,5	< 0,5
Resistance to freeze-thaw (%/wt.)	< 0,5	< 0,5	< 0,5	< 1
Binder adhesion (%)	> 90	> 90	> 90	>85

Table 11 – Technical properties of steel slags and natural aggregates (Motz H. 2001)

Volume expansion
Some free CaO and MgO exists in steel slags. In contact with moisture the CaO and MgO hydrates and the volume increases. The free lime hydrates rapidly and can cause large volume changes over a relatively short period of time (weeks), while magnesia hydrates much more slowly and contributes to long-term expansion that may take years to develop. There are several techniques used to overcome this problem.

- Adding silica sand into the liquid steel slag, combined with oxygen blowing.
- Ageing the slag by steam. The slag is covered with tent sheets and steam is injected for 48 hours.
- Ageing the slag by steam under pressure. The steel slag is placed into the autoclave, where steam is injected under pressure and the slag is kept for about three hours at 0.5 Mpa of pressure.
- Ageing the slag by spraying with water, in controlled heaps.

Chemical composition % by weight	**Granulated blast furnace slag [1]**	**Basic oxygen slag [2]**	**Electric Arc Furnace [3]**
SiO_2	30,5 – 40,8	15,26	10 - 18
Al_2O_3	5,9 – 17,6	4,35	3 - 8
CaO_{Total}	30,9 – 46,1	41,44	25 - 45
CaO_{Free}	-	4,09	≤ 4
MgO	1,66 – 17,31	8,06	4 - 13
FeO	0,12 – 4,72	13,95	-
Fe_2O_3	-	9,24	-
TiO_2	0,07 – 3,70	0,72	0,3
P_2O_5	-	1,15	0,01 – 0,6
MnO	0,07 – 3,12	5,2	4 - 12
Na_2O	0,09 – 1,73	<0,05	0,46 *
Na_2O-equivalent *Na_2O + 0,658 K_2O*	0,19 – 2,61	-	-
K_2O	0,08 – 1,51	0,42	0,11 *
SO_3^{2-}	0 – 0,86	-	-
S^{2-}	0,42 – 2,29	-	-
Cr_2O_3	-	-	1 - 2
V_2O_5	-	-	0,11 – 0,25
ZnO	-	-	0,02 *
CuO	-	-	0,03 *
NiO	-	-	0,01 – 0,4
C	-	-	0,33 *

Table 12 – Chemical composition of Iron and Steel slags [1](EUROSLAG), [2] (H. Y. Poh 2005)[3] (European Commission 2000)*data available from one plant only

3.3 Standards

Slags are produced to meet the requirements expressed in the European standards for cement and concrete. The raw materials selection is made not only with regard to iron and steel production, but also regarding the final chemical composition of the slag. Aluminates are added to increase the alkalinity of the blast furnace slag and its value in cement manufacture. The final product is labelled and CE marked.

The standards for aggregates mentioned before chapter 1.2, refer to special requirements for slags used as aggregate material. These special requirements address the following:

Constituents, which affect the volume stability of blastfurnace and steel slags
Dicalcium silicate disintegration of air-cooled blastfurnace slags, EN 1744-1
Iron disintegration of air-cooled blastfurnace slags, EN 1744-1
Volume stability of steel slag aggregate, EN 1744-1
Loss on ignition of air-cooled blastfurnace slags, EN 1744-1

3.4 Environmental impact

	Blast furnace Slags	*Steel slags*
Recycling	Dust Emission to water Consumption of energy Noise	Dust Emission to water Consumption of energy Noise
Use of the material	Leaching of the material - pH >11 - boron (B) - Vanadium (V). - Barium (Ba)	Leaching of the material - pH >11 - boron (B) - Chromium (Cr) - Molybdenum (Mo) (in EAF slags) - Vanadium (V) - Sulphates
Resources	Reduces the consumption of natural resources	Reduces the consumption of natural resources
Waste disposal	Reduction of landfill space	Reduction of landfill space

The environmental risks associated with the use of secondary aggregates strongly depend on the type of application. If the material is bound, the risk of leaching is smaller than if the material is unbound and in contact with water.

3.5 Market

The market for slags exists and it is well organised according to EUROSLAG, there is a demand for slags. The slag market follows the cycles of the construction industry. Years ago slags were stock piled because there was no demand for it. At the present the construction industry is growing in some countries and the demand for slags is high, more than the production. There are no heaps of slags waiting to be used. However in other countries this scenario could be different. The competition with primary aggregates is strong, and is more difficult to sell the slag.

The trading/importing of slags between two countries is not frequent due to the cost of transporting the material, yet near borders it could happen. The distance range between the steelworks and the customer is about 100-150 km.

3.6 Legislation

- The European Waste Catalogue, slags are referred as "10 02 01 wastes from the processing of slag" and "10 02 02 unprocessed slag."
- The European Waste Shipment Regulation, "GC 070 slags arising from the manufacture of iron and carbon steel (including low alloy steel) excluding those slags which have been specifically produced to meet both national and relevant international requirements standards".

3.7 End of waste criteria

End of waste criteria has to assure the fulfilment of two main principles:

- There is no overall disadvantage for the environment associated with the declassification of the material as waste and treating it as a non-waste product.
- There is a market for the recycled material.

To follow the above principles, operational principles have to be defined.

- The product must fulfil the engineering requirements set in the European standards for aggregates.

- The environmental behaviour of the product should be assessed and evaluated according to limit values defined in regulations (e.g landfill directive).

How to ensure a quality of secondary aggregates from slags which minimise the environmental risks?

- certain slags prohibited
- specific slag treatment
- inspection and testing prior to processing
- processing techniques
- inspection and testing after processing
- short term vs long term environmental impact

4 ASHES FROM COAL COMBUSTION PROCESSES

The combustion process is associated with the generation of ashes. Solid fuels produce much more ash than liquid or gaseous fuels. Coal is one of the most frequent used fuels for electricity production. Before being combusted it is finely ground and is mixed with other types of fuels, in order to optimize and control the combustion conditions.
One of the driving forces for operating a coal power plant besides the production of electricity is the ash production. Depending on the quality and composition there could be a market for the ash avoiding the problems and costs of disposal.
The combustion residues produced are roughly 15% to 10% of the fuel combusted depending on the fuel composition. In the Europe 25 is estimated that 95 million tonnes of residues are produced (Berg 2005). There are different types of ashes produced. The composition of the ashes not only depends on the furnace temperature but also the type of coal, the size of the milled particles and the exposure time in the interior of the furnace.

Fly ash or pulverised fuel ash
It is a fine powdery spherical material (0.2 to 200 micron of diameter, average) transported with the exhaust gas from the furnace. It is separated by means of electrostatic precipitator or mechanical separation. Depending on the type of coal used and boiler, fly ash can be classified as silica-aluminium (CaO content inferior to 10%), sulphur-calcium (CaO content over 20%) and silica –calcareous, see **Table 13**. The type of boiler used also influences the quantity of fly ash produced. Sulphur calcium ash has more hydraulic binder properties than silica-aluminium ash. Fly ash can account for 80 % of the total ash produced in the case of dry boiler and 50% in wet-bottom boilers. Power plants using lignite as a fuel produce ashes with high lime content.

Compound	*High content lime ash [1]*	*Low content lime ash [1]*	*Bottom ash [2]*
	Content (%)		
SiO_2	34.1	42.6 – 59.8	50.46
Al_2O_3	14.2	21.8 – 34.5	28.35
Fe_2O_3	7.2	6.3 – 18.1	10.69
CaO	38.0	2.8 – 7.0	2.07
SO_3	4.2	0.19 – 1.9	0.34
MgO	1.5	1.2 – 2.6	-
K_2O	1.4	0.38 – 6.0	3.81
Na_2O	0.44	0.15 – 0.94	-
Reactive Silica	30.9	0.94	-
Lime	17.1	Insignificant – 0.74	-
Total carbon dioxide	0.34	0.27 – 3.9	-
TiO_2	-	-	1.57
ZrO_2	-	-	0.18
V_2O_5	-	-	0.09
MnO	-	-	0.07
ZnO	-	-	0.03

Table 13 – Composition of fly and bottom ash [1](SAMARIS 2006), [2] (Andrade L. B. 2007)

Fly ash with a high lime content (sulphur-calcium), presents hydraulic properties, capacity to harden in presence of water or moisture.

Silica-aluminium fly ashes with a low lime content, has pozzolanic properties. The pozzolanic activity of a material is defined as the capacity to fix calcium hydroxide at an ordinary temperature in presence of water, generating solid materials with a high resistance. This is why fly ashes are used in blended cements. The ashes react with the calcium hydroxide liberated by the portland cement.

Bottom ash
During the combustion some of the mineral content of the fuel agglomerates becoming sintered. This material is too heavy to leave the boiler with the exhaust gas, remaining in the bottom of the boiler. It is directly removed or it is removed by jets of water. Bottom slag may need to be further processed, dewatered, ground and graded before being stored. Additionally, metal could be removed by magnetic separation. Its composition is variable.

Boiler slag
Boiler slag is produced when the fuel is burned in slag-type furnaces at 1500 to 1700 ºC. The slag is removed from the furnace in a molten stage and is cooled with water solidifying resulting in glassy granules. Boiler slag may need further treatment grinding and sieving and are classified according to the granules size.

Fluidized bed combustion ash
Fluidized bed combustion ashes are produced in fluidized bed combustion boilers, at temperatures of 800 to 900 ºC. With this type of technology it is possible to achieve high desulphurisation rates within the boiler itself by addition of limestone to the fluidised bed where such desulphurisation is performed. The remaining ash is rich in S and CaO.

4.1 Waste management options

4.1.1 Landfill

According to the Council decision of December 2002, ashes from combustion processes to be disposed of at inert landfill have to be tested for acceptance. The material has to be fully characterised to enable a safe disposal of the material in the long term. Basic information is gathered, source, origin, production process, characterization of the raw materials, waste treatment applied, see **Table 9**.

4.1.2 Recycling

As mentioned previously, ashes can have pozzolanic properties meaning that in the presence of certain compounds they show cementious properties. Additionally ashes can show cementitious properties only by reacting with water, hydraulic properties.

The focus of this case study is the use of materials as aggregates. Consequently the pozzolanic and hydraulic properties of ashes will not be studied in any detailed.

For fly ash to be used as a lightweight aggregate is has to pass through two main processes: agglomeration and hardening. Agglomeration is done by shaking, granulation or compactation. Hardening is done by sinterization (temperatures over 900°C), by hydro-thermic method (temperatures between 100 and 200°C in the presence of wate), or in cold temp below 100°C) (SAMARIS 2006).

2004 [kilo tonnes]				Fly Ash	Bottom Ash	Boiler Slag	FBC-Ash	Other**
Cement raw material				5 675	192			
Blended cement				2 480	118		22	
Concrete addition				5 871	77	177		
Aerated concrete blocks				929	28			
Aggregates	Bound mixtures	Concrete	Grouting	594		109	111	
		Other	Non-aerated concrete blocks	627	919			25
			Lightweight aggregate	141	0			
			Bricks + ceramics	97	21			13
		Asphalt	Asphalt filler	131				
	Unbound	Filler	General engineering fill	1 729	362			11
			Structural fill	1 972	132			
			Infill	891	60		297	
			Subgrade stabilisation	162	96		37	
			Pavement base course	348	182	1 013	46	
			Blasting grit		12	356		
	Sub total aggregates			**6 692**	**1 784**	**1 478**	**491**	**49**
Other uses				347	76	295	20	
Reclamation, Restoration				18 411	2 862	0	306	
Temporary stockpile				3 158	199	0	145	15
Disposal				665	577	0	40	
Total used				24 888	3 023	1 950	718	64
CCP Production				43 476	5 840	1 950	983	59

* Reuse of stockpiled ashes
** fly ash and slag from coal gasification

Table 14 – Production and utilisation of ashes in 2004 EU 15 **(ECOBA)**

4.2 Technical characteristics

Fly ash

It is a fine powder, in concrete mixtures it can contribute to increase the plasticity and the mechanical strength of mixes with a lower quality Portland cement. It also contributes to a reduction of the concrete permeability.

When used as mineral filler in asphalt mixtures, fly ash is expected to provide excellent resistance to asphalt stripping.

Fly ash used as structural fill or embankments, offers several advantages over natural soil or rock. Its low unit weight makes it suitable for low bearing strength soils. It is easily compacted.

For Ca rich coal fly ash its pozzolanic reactivity is a positive characteristic for certain applications.

However because it is a powder material, dust control measures may be needed and erosion can be a problem.

Bottom ash

Due to its porosity, bottom ash combines low weight with good soil mechanics. However, its particle size may vary as it depends on the fineness of the pulverized coal and the combustions conditions.

The variability of the coal bottom ashes characteristics/properties makes it classification difficult. Bottom ash might contain pyrites (iron sulphide), which is volumetrically unstable, expansive and produce a reddish stain when exposed to water over an extended period. It is not used for asphalt surface applications.

Boiler slag
The glassy material, similar to natural sand, presents a low bulk density, high angle of friction, and an excellent frost resistance.
Due to its regular surface, in asphalt applications, bottom slag aggregates should be mixed with natural aggregates to help the adhesion of the binder. Its black colour aids in the melting of snow from the road surface during winter.

4.3 Standards

The use of fly ash in concrete has a high market value, justifies the constant monitoring of the ash quality and the investment that some companies have made in the construction of silos to keep the fly ash dry. The non compliance with the EN 450 standards 'fly ash for concrete', takes the fly ash to the next market step, the production of blended cement. In this market the fly ash has to compete with blastfurnace slags which make the penetration in the market more difficult. To be accepted in the production of blended cement, the fly ash has to meet the requirements EN 197-1 Production of fly ash cement.

Using fly ash as aggregate has a low market value comparing with concrete and blended cement use. The fly ash that does not meet the EN standards for concrete and blended cement is used as aggregate in bound and unbound applications.

The European standards mentioned before chapter 1.2 are applicable for ashes used as aggregate. They refer to special tests for ashes in bitumen mixtures, mortar, and lightweight aggregates - loss on ignition of coal fly ash (EN 1744-1)

4.4 Environmental impact

	Fly ash	*Boiler slag*	*Bottom ash*
Recycling	Dust Emission to water Consumption of energy Noise	Dust Emission to water Consumption of energy Noise	Dust Emission to water Consumption of energy Noise
Use of the material	pH Leaching of the material - Cr - As - Mo - Se - V Radioactivity Dust	pH Leaching of the material - Cr - Sulphates Radioactivity	pH Leaching of the material - Cr - Sulphates Radioactivity
Resources	Reduces the consumption of natural resources	Reduction the consumption of natural resources	Reduces the consumption of natural resources
Waste disposal	Reduction of landfill space	Reduction of landfill space	Reduction of landfill space

4.5 End of waste criteria

End of waste criteria has to assure the fulfilment of two main principles:

- There is no overall disadvantage for the environment associated with the declassification of the material as waste and treating it as a non-waste product
- There is a market for the recycled material.

To follow the above principles, operational principles have to be defined.

- The product must fulfil the engineering requirements set in the European standards for aggregates.

- The environmental behaviour of the product should be assessed and evaluated according to limit values defined in regulations/standards (e.g landfill directive).

How to ensure a quality of secondary aggregates from ashes which minimise the environmental risks?

- Certain fuels
- Specific ash treatment
- Inspection and testing prior to processing
- Processing techniques
- Inspection and testing after processing
- Short term vs long term environmental impact

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