Evaluation of the potential of the use of recycled aggregate for concrete production

V. Vytlačilová[1]

[1] Department of concrete and masonry structures, Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7166 29 Prague 6, Czech Republic

Presenting author email: vladimira.vytlacilova@fsv.cvut.cz

Abstract

This paper intends to provide a holistic view of the study of waste management in the field of construction and demolition waste and situation of the recycling of C&D waste in the Czech Republic (in comparison with other EU states) during the recent years. An effort has been made in this paper to present a summary of the use of recycled aggregates as a partial or full replacement of natural aggregate in the construction industry (concrete production) in Czech Republic. The study presented in this paper describes some properties of recycled aggregate (concrete or masonry rubble), especially in relation to strength and durability of recycled aggregate concrete and environmental risk (content of hazardous substances). Tests samples were obtained in the different recycling plants and results were compared with legislative requirements in Czech Republic.

Keywords: Recycled aggregate, Waste management, Recycling, Construction and demolition waste

1. Introduction

Building activity is requiring amounts of inert materials derived mainly from natural sources and together is generating high quantity of wastes. The increasing occurrence of landfills coupled with costs of their subsequent removal, the abusive exhaustion of sources of valuable natural aggregate or the growing environmental interest and sustainable building towards the use of recycling principles are highlighted at an international level. Recycled aggregate (RA) used for construction can relieve aggregate shortage problem and reduce both environmental pollution and ecological footprint. It is therefore necessary to promote recycling of construction and demolition (C&D) waste and increase the potential of recyclates for building practice. C&D waste constitutes a major portion of total solid waste production in the world, and most of it is still used in land fills. Reduced extraction of raw materials, reduced transportation cost, reduced environmental impact and fast-depleting reserves of conventional natural aggregates has necessitated the use of recycling, in order to be able to conserve conventional natural aggregate. The large volume of materials consumed in the construction industry has, on the other hand, a considerable potential for its use in the form of recycled materials (raw waste) in new structures, which is now a prerequisite for sustainable development.

Especially the end of the 20th century and early 21st century is marked by the rapid development of recycling technologies and processes in waste management in the context of the idea of sustainable development. Waste processing and its subsequent use in the construction is a subject related to special legislation. The final quality of recycled material is also influenced by the principles of recycling and technology in the recycling process. For example in [1] are presented equations for estimating aggregate quality with a reduced number of aggregate tests. The development of the simplified testing procedures under three groups not only saves time and resources in understanding the full properties of the recycled aggregate (RA) but also enables the classification of RA at the source locations within a short time after crushing, thereby realising the full potential of RA in high-grade concrete applications [1].

It has been recognized that concrete manufactured using recycled concrete aggregate could have mechanical properties equal to the natural aggregate concrete provided that the original concrete is of good quality. There are many studies focused on various physical and mechanical properties of recycled concrete aggregates. Recycled concrete aggregates are different from natural aggregates and concrete made from them has specific properties. In case of concrete with replacement of natural aggregate by recycled aggregate, the strength of recycled concrete can be 10–25% lower than that of conventional concrete made with natural coarse aggregate [2].

The paper is dealing with questions of C&D waste recycling, it also characterizes construction and demolition waste in general, furthermore it analyses production of construction waste and subsequent production and properties of recycled materials in Czech Republic.

2. Construction and Demolition Waste management in Czech Republic

The first Waste Act was adopted in the Czech Republic as recently as 1991. Since 2004 our legislation is influenced mainly by the European Union regulations. Waste management in the Czech Republic, as in other EU member states, is governed by the Framework Waste Directive 2008/98 /EC on Waste [3], which establishes, among other, the hierarchy of waste management The strategy of the Czech Republic in the field of waste management for the next ten-year period is reflected in the document "Waste management plan of the Czech Republic", that establishes in accordance with the principles of sustainable development the objectives, policies, and measures of waste management [4]. Legal rights and obligations are closely related to administrative tasks.

The primary data source of waste management information is the comprehensive database Waste Management Information System (hereinafter "WMIS"), which collects primary data on waste production and methods of waste management in the Czech Republic, reported under the legal obligation to keep waste records. The WMIS database is managed for MoE by CENIA, Czech Environmental Information Agency (hereinafter "CENIA"). Development of the overall waste production and selected methods of waste management in the Czech Republic in the period 2009 – 2014 is shown in Table 1. Is show that the total production of waste oscillates around the value of 30 million tons. This amount is influenced primarily by construction activity because 50-60% of total waste generated in construction.

Table 1: Production of waste in Czech Republic in the period 2009 – 2014

Year	Total waste production	Share of waste	Share of materially	Share of energy	Share of waste disposed of by
	[kt]	[%]	[%]	[%]	[%]
2009	32267	74,5	72,5	2,0	15,0
2010	31811	73,5	71,0	2,5	13,5
2011	30672	78,0	75,0	3,0	13,0
2012	30023	79,0	75,5	3,5	13,0
2013	30620	79,5	76,0	3,5	11,0
2014	32028	83,0	79,5	3,5	10,0

Source: WMIS, Since 2009 is so called "Recalculated database".

The current Act no. 185/2001 Coll. "On Waste and Amendment of Some Other Acts" [5] emphasizes waste prevention, defines the hierarchy of waste handling, and promotes the fundamental principles of environmental and health protection in waste handling. Ministry of Environment (MoE) is the central government administration authority in the field of waste management. A 70% recycling target was introduced in the new "EU Waste Framework Directive 2008/98/EC" to be achieved by 2020. It executes supreme state supervision in waste management, prepares and proposes legislative standards in waste management.

In terms of the recovery of waste, no significant changes are apparent in the past few years and the use waste for landscaping still belongs among the most common ways of waste recovery (mainly construction and demolition waste is used in this way), together with recycling and reclamation of other inorganic materials. Large volumes of C&D waste also end on illegal landfills which have became a big issue in the Czech Republic, although the illegal disposal of waste can be fined here up to 1900 EUR.

Construction and demolition waste definition from Waste Act no. 185/2001 complies with Waste Catalogue (code 17) used in the Czech Republic and with Waste Framework Directive 2008/98/EC. After their transposition it is possible to classify part of the waste stream as by-products, not subject to the Waste Act. C&D wastes are usually defined as the residues from the operations of construction, reconstruction, extension, alteration, maintenance and demolition of buildings and other infrastructures. These wastes consist of distinct types of materials, and are a heterogeneous residue that can contain any material that is part of a building or infrastructure as well as any other materials used during construction work. According to the European Waste Catalogue, C&D wastes can be composed of: concrete, bricks, tiles, ceramics, wood, glass, plastic, bituminous mixtures, coal, metals, soil and stones, insulation materials or gypsum-based material. Waste Catalogue in the Czech Republic harmonizes separation of the waste material with the European Waste Catalogue. Construction waste is given as a separate group (code) of 17 00 00 - Construction and demolition waste and is divided into the following subgroups:

- 17 01 00 – concrete, masonry, ceramics
- 17 02 00 – wood, glass, plastic,
- 17 03 00 – asphalt, tar product,
- 17 04 00 – metals and metal alloys,
- 17 05 00 – mined soil,
- 17 06 00 – insulating materials,
- 17 08 00 – gypsum product,
- 17 09 00 – other construction and demolition waste.

The Association for development in recycling of building materials (ARSM) summarizes the yearly output of C&D waste in the CR from 1999 to 2008. Between 2002 and 2006, the data were administered by the T. G. Masaryk Water Research Institute, a public research institution – the Waste Management Centre. Since 2007 the Czech Environmental Information Agency (CENIA) summarizes the yearly data of waste inclusive construction and demolition waste. This agency records the information of waste management in database WMIS. Data on waste production also collects the Czech Statistical Office (CSO), which are presented in European database EUROSTAT. Unfortunately the obtained data in database WMIS are probably incomplete. Based on the analysis of ARSM around 50% of the waste is not accounted in the database [6]. The reason is a difficult material flow analysis of construction and demolition waste. Due to the current trends in recycling, where many construction companies have their own recycling facilities (crushers and screens), is the determination of the actual state very difficult. Construction companies use the obtained recycled material for their own needs and therefore it is not legally recorded in the database. WMIS and CSO databases have different methodology data acquisition and processing methods of waste and therefore can not be compared. The real volume of production and waste management better reflects WMIP database. Obtaining relevant information is not easy.

As in the past ten years has shown the correct analysis of material flows in this area almost impossible. Table 2 shows the production of selected construction and demolition waste in 2010-2014 according WMIS. This volume of waste goes through recycling centers. Generation of mineral construction and demolition waste in the latest available year 2014 according CSU database is shows in Table 3.

Tab. 2 Production of selected construction and demolition waste in 2010-2014

Code	Waste	2010	2011	2012	2013	2014
		[kt]				
17 01	Concrete, bricks, tiles and ceramics	3167	3033	3445	3249	3688
170101	Concrete	1163	1127	1385	1292	1422
17 01 02	Bricks	834	776	735	757	745
17 01 03	Tiles and ceramics	18	11	14	12	16
17 01 07	Mixtures other than those mentioned in 17 01 06	1130	1092	1250	1172	1473
17 03	Bituminous mixtures	466	443	531	510	573
17 05	Soil and stones	10845	9053	8908	9966	11128
17 06	Insulation materials	111	71	59	61	66
17 08	Building gypsum-based materials	7	8	7	9	11
17 09	Other construction and demolition waste	614	630	496	609	451
	Total	**15210**	**13239**	**13447**	**14404**	**15916**

Source: Database WMIS

Tab. 3 Generation of selected mineral construction and demolition waste in 2014

Waste		Total	In: Hazardous	In: Non-hazardous
		[kt]	[kt]	[kt]
17 00	Total	12 667	314	12 353
17 01	Concrete, bricks, tiles and ceramics	2 083	22	2 061
17 03	Bituminous mixtures, coal tar and tarred products	455	2	452
17 05	Soil (including excavated soil from contaminated sites), stones and	8 279	230	8 048
17 09	Other construction and demolition wastes	226	5	221

Source: Database CSO

Given the current construction activities, there is expected to be an increase in C&D waste including excavated soil from contaminated sites. Experts are currently estimating and monitoring the development of C&D waste production and expect an increase of around 10% by 2020. Currently there are about 93 recycling centers in the Czech Republic which process C&D waste and 172 landfills of C&D waste. The total yearly capacity of all the recycling centers in the Czech Republic is about 15 million tons (assuming a yearly period of the use 1500 hours and an hourly capacity of 9700 tons/hour). However the amount of recycled C&D waste used as building materials in the Czech Republic is estimated to be around 10% compared to raw materials used in the built environment, although the total use is indicated up to 90% depending on the database. Production of waste from construction (code 17) is variable, depending on the developments in the construction industry, in relation to the developments in the economy. Actually utilisation of C&D waste is about 6-7% of production of natural aggregates [6].

In table 4 is shown production and selected waste management methods of C&D waste in Czech Republic in 2009-2014. It is evident, that use of waste for landscaping (N1) is dominant. It ranges generally between 40-50% of total waste. Ministry of Environment presents information about production and waste management method in Environmental Statistical Yearbook [7] and [8].

Tab. 4 Production and selected waste management methods of C&D waste

	Year	2009	2010	2011	2012	2013	2014
Generation of C&D waste	[kt]	14883	15210	13239	13447	14004	15916
Recycling R5	[kt]	2503	2475	2647	3300	3797	4110
Use of wastes for landscaping N1	[kt]	8225	5555	5221	5300	5686	7654
Use of wastes for landfill reclamation N11	[kt]	566	480	1007	987	1031	752
Technical layers of landfills N12	[kt]	572	697	750	619	552	637
Generally N1+N11+N12	[kt]	9363	6732	6978	9606	7269	9080
Landfilling D1	[kt]	690	565	413	487	361	362

Source: Database WMIS

As is known, the target of the directive is increase by the year 2020, to at least 70% by weight, the rate of preparing for re-use and the rate of recycling of C&D waste and other types of their material recovery, including backfilling. Basic principles of [4] are:

- To regulate the production of C&D waste management with regard to the protection of human health and the environment.
- Implement maximum recovery of processed C&D waste and recycled materials from construction and demolition waste.

Basic measures for meet this principles are:

- Legislative support in related areas.
- Ensure mandatory use of recycled materials meeting the respective construction standards, as a substitute for natural resources in construction activities financed from public funds, if technically and economically possible.
- Prevent the use of unprocessed construction and demolition waste, with the exception of excavated soil and spoil material without dangerous properties.

The input (buyback) price of recycling companies depends on the individual companies and on the categories of waste, i.e. on the recycled C&D waste characteristics, degree of pollution and possibilities of use. In Table 5 the price for waste recycling (buyback of C&D waste) in the Czech Republic is shown. It is proven that the price of the processing of one tone of sorted waste is around 3 EUR (includes crushing, screening at 3 fractions, manipulation and necessary tests). The most important step for recycling of construction waste is on-site separation. The buyout of unsorted waste is expensive because of its recycling is very difficult or impossible. Table 6 shows the sale price of recycled aggregate (rubble). Price of natural aggregate is 10-18 EUR per tonne depending on the fraction of the aggregate. The price range is based on 16 recycling centres from CR.

Tab. 5 Receiving of C&D waste for recycling in recycling centers

C&D Waste	Code	EUR/t
Concrete	17 01 01	3,70-6,00
Reinforced concrete	17 01 01	7,40-12,00
Masonry	17 01 02	5,00 - 7,20
Ceramic products	17 01 03	5,50 - 7,00
Soil and stones	17 01 04	5,50-8,30
Mix waste	17 01 07	10,50-18,00

Tab. 6 Sale of recycled materials in recycling centers

Recyclates	Fraction	EUR/t
Concrete rubble	0/16 mm	1,90-5,10
Concrete rubble	16/63 mm	5,90-11,20
Concrete rubble	63/120 mm	3,70-5,50
Masonry (mix) rubble	0/8 mm	1,20-3,30
Masonry (mix) rubble	16/63 mm	1,20-2,50

3. Construction and Demolition Waste management in Europien Union

According to the final report of Service contract on management of construction and demolition waste – SR1, the amount of SDO in the EU-27 ranges from 310 to 700 million tones per year [7]. Though clear figures about recycling are not available for individual countries in EU, an EU study calculated that more then 180 million tons of C&D waste is generated in European Countries per year. Only 28% is recycled and reused; rest of it is sent to landfills. The construction industry is responsible for 50% of the consumption of natural resources. Most EU member countries have established goals for recycling that range from 50% to 90% of their C&D waste production, in order to substitute natural resources. Netherlands, Denmark and Belgium are the most accomplished EU countries on waste management via recycling generated wastes 90%, 81% and 87%, respectively [9]. Recycled materials are generally less expensive than natural materials, and recycling in Germany, Holland and Denmark is less costly than disposal. However, due to the fact that people are not able to abandon customary methods, aggregate being a cheap structural material and lack of recycling consciousness; RCA does not have a wide-spread use for example in Turkey as well as many countries. [10]. Recycled concrete aggregate is mostly used as a filling material for building construction, road foundations and hydraulics work spaces [11].

EU waste management policies aim to reduce the environmental and health impacts of waste and improve Europe's resource efficiency. The long-term goal is to turn Europe into a recycling society, avoiding waste and using unavoidable waste as a resource wherever possible. The aim is to achieve much higher levels of recycling and to minimise the extraction of additional natural resources. Proper waste management is a key element in ensuring resource efficiency and the sustainable growth of European economies [12]. Furthermore, the waste management is the second most important contributor to employment growth in the environmental. C&D waste management was financial incentives – landfill tax and reduce of Value Added Tax for certain recycled materials and new management legislation with the criteria and conditions [13].

Main obstacles to use of recycled materials:

- Lack of information regarding the supply and demand in the build market.
- Availability of recycling facilities in rural locations.
- Classification of originated waste after its modification after legal provision (according to provisions of the Regulations).
- Unauthorised terrain alterations by means of soil. Waste producers often incorrectly assume that soil is a by-product or a non-waste and use it for backfilling or surface alterations without permission.

To prevent waste from building and construction sector the main instruments in the area of C&D waste are follows:

- Fostering the re-use of building materials.
- Information and awareness raising campaigns for all areas involved (designer, producer, builder, citizen).
- Producing a self-contained guidance document aimed at the prevention of C&D waste.
- Identifying hazardous substances contained in the building materials.
- Instruments for the registration and presentation of safe building materials.

4. Properties of recycled aggregate made from C&D waste

Recycled aggregate arises by crushing of C&D waste and then is divided by the coarseness into different fractions, usually 0-8, 8-16, 16-32, 32-63, 63-120, 0-63 mm. Recycled rubble products of recycling centers can be graded according to the customer's requirements at the most strict grading. Manufacturing problems encountered limit their industrial use mainly attributed to the laborious obtaining of quality recycled aggregates (such as gravel and sand) and its storage in a dump concrete plant. Another problem is the heterogeneity of recycled aggregates and dispersion its required characteristics depending on the origin of construction and demolition waste. Based on experiences coming from testing of properties of recycled aggregate also follows, that one of the most problematic properties of recycled aggregate is its high porosity, which affects negatively further properties, such as its bulk density, high water absorption, frost resistance etc. Table 7 shows the basic properties of recycled aggregate for different factions. Values are obtained from the sample collection within one year within the experimental program. Samples were taken from various recycling centres in CR.

Tab. 7 Properties of recycled aggregate

Aggregate	Fraction	Unit Weight	Tapped Apparent Density	Loose Apparent Density	Water Absorption
		[kg/m^3]	[kg/m^3]	[kg/m^3]	[%]
Masonry Rubble	0/8 mm	1650-1860	1180 - 1390	1034-1298	4,3-16,3
	0/16 mm	1706-1987	1190-1405	1020-1260	4,2-15,4
	0/32 mm	1774-2068	1256-1368	1056-1258	3,8-15,6
Concrete Rubble	0/8 mm	2098-2342	1413-1659	1236-1499	4,2-11,3
	0/16 mm	2112-2399	1388-1731	1248-1430	3,9-11,0
	0/32 mm	2114-2498	1436-1617	1257-1428	3,2-9,8

(The range of measured values for ca 20 samples for each fraction derived from different sources)

All the Standards dealing with the utilization of recycled aggregate for structural concrete require bulk density at least 2 000 kg/m^3 and absorbability less than 10%. Recycled aggregates as a component for production of new concrete is used mainly within the experimental testing, its utilization in actual construction is sporadic. Occasionally the natural aggregate is partly replaced by the recycled one, generally in 30 – 40% amount. This amount has been established by several researches – it has been proven that 30% replacement of natural aggregate by recycled aggregate does not influence significantly the mechanical-physical properties of the concrete [14-15]. Paper [16] presents the effect of recycled aggregate quality on the physical and mechanical properties of concrete while the presented results confirm the potential use of developed recycling concrete made with local recycled aggregate in some applications in building construction.

5. Ecological suitability of recycled aggregate

The utilization of inert recycled materials obtained from the construction and demolition waste has to be assessed, among others, in terms of their potential influence on the environment and human health. The ecological suitability for consequent application is proved based on their chemical composition, content of harmful substances and their possible leakage to surrounding environment. The ecological criterions are always determined according to requirements of legislation in force and according to requirement for specific type of waste and its utilization. Within the experimental programme, which has been focused on the possible utilization of recycled building material, the analysis of ecological risks evaluation has been carried out. The attention has been focused mainly on the content of hazardous substances in the dry matter and in the extract, on the radionuclides activity and ecotoxicity. A characterization of hazardous substances of 40 samples (studied in this experimental work is presented in Table 8 [17].

Tab. 8 Dispersion of values of hazardous substance in the dry matter of recycled aggregate

Hazardous substance	Limits [18]	Recycled Aggregate		
	[mg/kg]	Concrete 17 01 01	Masonry 17 01 02	Soil and Aggregate 17 05
As	10	3,17 - 54,7	5,38 - 21,5	8,0 - 48,4
Cd	1	< 0,4 - 2,08	< 0,4 - 0,8	< 0,4 - 0,41
Cr	200	23,3 - 362	13,8 - 73,5	27,3 -101
Pb	100	5,1 -182	9,1 - 107	8,5 - 301
Hg	0,8	< 0,2-0,78	< 0,2 - 0,81	< 0,2 - 1,05
Ni	80	12,4 - 33,8	9,1 - 87,2	17,2 -55,6
V	180	23,8 - 70,0	20,2 - 83,3	45,2 - 139
Σ 7 PCB	0,2	< 0,14	< 0,14 - 3,75	< 0,4 - 2,08
EOX	1	< 1,0	< 1,0	< 1,0
Σ BTEX	0,4	< 0,17 - 0,98	< 0,17	< 0,17
C10 - C40	300	20 - 928	20 - 355	25 - 3270
Σ 12 PAU	6	0,3 - 121,0	0,1 - 50,0	0,5 - 27,5

Source: Experimental program of CTU in Prague, Faculty of Civil Engineering [17].

To determination of hazardous substances in construction waste in the dry matter and in the extract are used limits given by the Decree 294/2005 Coll. (in Decree tab. no. 10.1) [18]. It has been proven based on measured resulting values that the most risky substances for recycled building materials are arsenic, petroleum hydrocarbons C10-C40 and the sum of extractable aromatic hydrocarbons – the sum 12 PAH. From all the tested samples only 30% of them met the legislative limits of the amount of arsenic for the waste utilization on the surface of the ground. The limit value for PAH has been exceeded for 57,5% of all the tested samples. Content of Petroleum hydrocarbons C10-C40 was exceeded in 8 cases from 40 samples, it means, this means that 80% of the samples satisfy. From 40 samples tested on ecotoxicity only 2 samples did not met the legislative limits, which means that 5% of tested samples failed the criteria. The results of analyses of recycled materials samples obtained from recycling facilities show, that in practice is utilizable only approximately 20% of all recycled materials, which fulfill the conditions of set limits of hazardous substances in the dry matter. Selected results of this experimental programme have been published in [17].

6. Conclusion

Waste management in Czech Republic has undergone considerable changes in the past 20 years to reach the current level, i.e. when a system that generally corresponds to the current requirements of European legislation is in place. In terms of further development, it is necessary to adjust and complete some waste management areas, in accordance with the principle of strengthening the shift to higher levels of the hierarchy of waste management (particularly the area of waste prevention, recycling and recovery, including energy recovery from waste). Substantial changes in legislation are currently being implemented, mainly reflecting the development of EU waste management legislation. Reducing and recycling C&D materials conserves landfill space, reduces the environmental impact of producing new materials, creates jobs, and can reduce overall building project expenses through avoided purchase/disposal costs. Changing how we think about these materials will create a more sustainable future.

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