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Construction and Demolition Waste Usage Possibilities

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Abstract
Construction and demolition waste with certain treatment procedures can be effectively used for different applications – as material for roads bearing layer as well as an addition for various concrete and asphalt mixtures. It is well known that this usage directly affects on environmental protection, saving the natural resources. In order to achieve necessary requirements for an appropriate disposal, recovery and storage of construction and demolition waste, certain methods and procedures should be specified.

In this paper, there will be presented requirements and recommendations for using raw material obtained from C&D waste, and in particular characteristics of recycled aggregate. Physical and mechanical properties of recycled aggregate depend on waste origin, separation procedures and material treatment. Possibilities of its usage mostly depend on user requirements and for that purpose, specific properties of recycled aggregate in comparison with aggregate from natural resources should be clearly defined. In general, the whole system of C&D waste management should be supported by legislation relating to the building design and issuance of location and building permits. It is necessary in order to increase use of environmentally friendly materials, to discourage generating of new construction waste, and to include construction waste management options in design documents.

Keywords
Construction and demolition waste, Recycled aggregate, Properties, Requirements, Recommendations

1. Introduction

In accordance to globalisation and industrialisation growing, demands for clear environment, energy sources protection and waste disposal are increasing world wide. Environmental protection and energy saving become crucial problems in all fields of technology. To save clear environment, it is essential to develop sustainable and environmentally friendly technologies. In the Earth Summit held 1992 in Rio de Janeiro, term sustainability was defined as economic activity in accordance with the earth ecosystem (Mehta, 1999). Basic principle of sustainable development is to use less natural resources and to decrease harmful waste. Nowadays, construction industry is the biggest consumer of natural resources and one of the largest producer of the waste. For all these reasons, it is necessary to take all the steps for making concrete technology sustainable.

Concrete was undoubtedly construction material of the 20th century and for all its advantages, mass production of concrete will be also unavoidable in the 21st century. Only in Europe is annualy produced over 750 mil. m^3 of concrete and that is 4 tonnes of concrete per capita. Although concrete itself as finished material does not have harmful effect on the environment, production of concrete components influences on the environment . Particularly, annual world consumption of portland cement is about 1,5 bil. tonnes and it is expected that this number increases in the future. Only in Asia, consumption of

cement was doubled in the period of 11 years (from 1994. 0,68 bil. tonnes to 2005. around 1 bil. tonnes). For production of 1 t of portland cement clinker, 1 t of CO_2 is emited in the environment. Studies shown that just cement industry is responsible for 7 % world emission of CO_2. It is well-known that CO_2 emission is the main reason for the basic ecological problem – global warming. Ordinary concrete consists of 12 % of cement, 8 % of water and 80 % of aggregate. Therefore, if for the production of concrete is used 1,5 bil. tonnes of cement per year, at the same time is used 900 mil. l of water and 9 bil t. of sand and stone. (Mehta, 2002). Besides energy consumption during production of cement and emission of CO_2 quantities, major problem of concrete structures is durability i.e. early damaging. This problem finally manifests as problem of construction and demolition waste disposal. Annually is produced more than 1 bil. tonnes of C&D waste which is disposed on the landfills all over the world.

Estimated value of C&D waste produced in the Republic of Croatia, based on the data collected in the frame of CONWAS project (2006-2008), is approximately 2.5 mil. tonnes per year. This leads to the number of approximately 550 kg of C&D waste per capita.

Basis for sustainability in concrete industry is in three primary approaches as demonstrated with Figure 1. Waste management is one of the priority for each society, because it can improve life quality. Basic principle of quality waste management is minimization of new mass production, forming of procedures for recycling and re-use of existing waste and safe and economically acceptable disposal of useless waste.

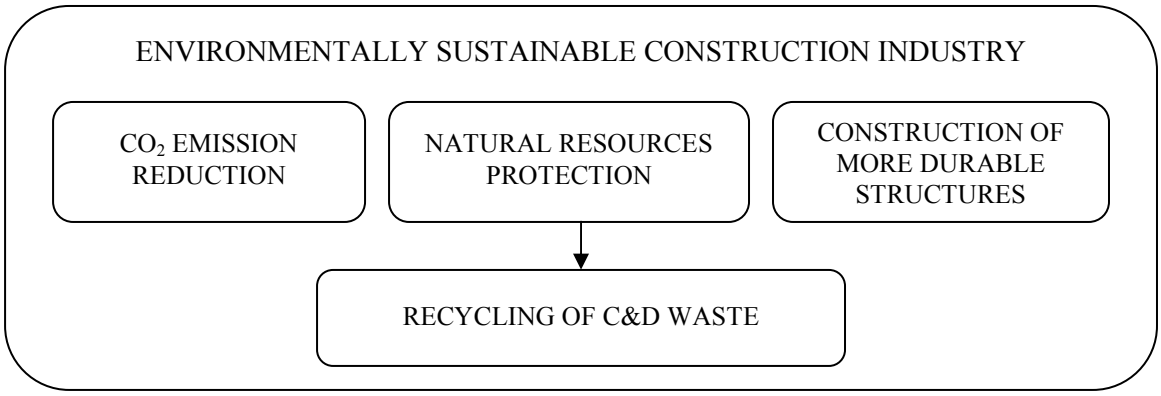

Figure 1: Environmentally Sustainable Construction Industry

2. Construction and Demolition Waste

Efficiency of waste management system depends on several factors: regulations, their enforcement and awareness of all stakeholders in waste management process. In the introductory part of the Waste management strategy for Croatia, it is stated that waste management is the major problem of environmental protection in Croatia. That is especially related to creation and enforcement of the legislation and emphasis is on the influence on groundwater as main Croatian natural resource. In the same document, it is also stated that waste management is the major individual problem of environmental protection according to the European Commission avis from the April, 20th, 2004 on the Croatian candidacy for European Union Membership. There is a need for harmonizing the regulations with EU requirements and standards and it is concluded that even the current regulations are not enforcing. For the purpose of supplying the framework to resolve that situation, Waste management strategy for Croatia, proposed by Ministry of environmental protection, physical planning and construction, was enacted by Croatian Parliament on the session held on October, 14th, 2005.

Construction and demolition waste is type of material produced from construction and demolition works, renovation or reconstruction, either on the surface or under ground. C&D waste has considerable financial value and technologies for separation and recycling are accepted, easy accessible and usually cheap. And

the most important, market for recycled aggregate which can be applied in different areas of civil engineering exist- as material for roads bearing layer as well as an addition for various concrete and asphalt mixtures.

The types of materials that can appear in construction and demolition waste depending on the type of construction work are shown in Table 1 (CONWAS).

Table 1: Types of Materials that can be Contained in Construction or Demolition Waste

Excavation	Structural engineering	Building construction	Mixed construction and demolition waste
Earth (peat) Sand, gravel Clay, loam Stone	Bitumen (asphalt) or concrete-bound material Sand, gravel, crushed stone	Concrete Brick Limestone Mortar Plaster Expanded clay Gas concrete Clinker Natural stone	Wood Plastics Paper, cardboard Metal Cables Paint, lacquer Rubble

EU member states produce 180 mil. tonnes of C&D waste per year following that for the EU population of 370 mil., annual production of C&D waste per capita is about 480 kg. As solution of this problem, it is recommended to recycle C&D waste and to apply it in different sectors of civil engineering.

EU member states encourage waste recovery through activities such as recycling. Disposal at landfills or incineration without energy return are at the lowest level of the scale.

When planning demolition of certain structure, it is necessary to take all measures related to collection, recycling and re-use of generated material in future construction works. Due to environmental impact, demolition and C&D waste recycling are nowadays interconnected terms.

C&D waste includes a broad range of materials and basic categories are:

- waste generated during completely or partially demolition work,
- waste generated during building construction
- soil excavation, i.e. is soil, sand, gravel, clay, stone
- waste generated during structural works.

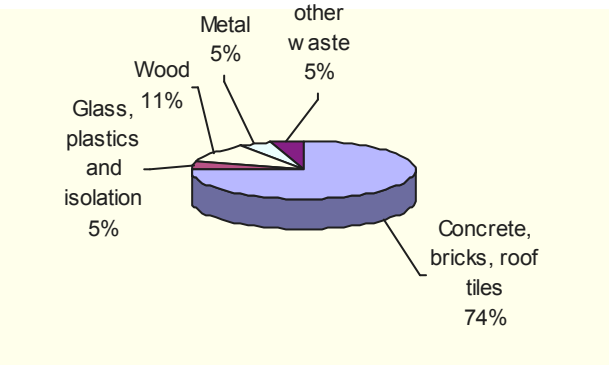

Figure 2: Content of C&D Waste

Demolition waste management consists of the following steps:

- preparing the structure for demolition
- demolition work
- waste recycling
- recycled waste usage

There are two basic approaches for C&D waste recycling:

- separate collection at waste origin and direct transport to treatment facilities or on the location where it will be used
- collection in joint containers and sorting at waste sorting facilities

3. C&D Waste Recycling

One possible method for waste reduction is to recycle demolition waste and to re-use it for new building construction. In order to reduce use of natural aggregates, application of recycled materials are increasing. Civil enginnering represents one of the main indicator of development and prosperity and thereby, C&D waste is recognized as priority problem in EU that has to be solved. It means that special attention should be devoted to promotion of the measures for C&D waste recycling. Considering that C&D waste makes a large volume, increasing its recycled percentage could save valuable space occupied by landfills. Furthermore, if this waste is not separated on its origin, it can contain small quantities of hazardous waste. Accordingly, by recycling and re-using of C&D waste, requirements for new exploitation decrease and also uncontrolled waste disposal are avoiding.

According to Wilmot and Vorobieff (1997), recycled aggregate from bricks is was applying for road construction in Australia in last hundred years. Also, Detroit News published one article in 1980´s on the development of recycling aggregate industry in the region of Michigan, USA. (Nelson, Shing C., 2004).

Recycled aggregate use percentage in Europe differs from country to country as it is shown in the Table 2.

Table 2: Use of Recycled Aggregate
(Project CONWAS- source - ***Study on socio-economic dimension, requirements and justification of natural resources exploitation in the area of Zagreb County*****)**

Country	C&D waste recycling (%)	Production of recycled aggregate (mil. t)	Production of aggregate as raw material (mil. t)
Belgium	75	3.1	55
Czech Republic	n/a	5	62
Denmark	85	n/a	44
France	n/a	18	390
Netherlands	85	0.5	22
Germany	70	90	463
Spain	n/a	8.2	420
Switzerland	n/a	62.5	50
Croatia	7	-	28

n/a – data not available

Reasons for increasing use of C&D waste are:

- awareness on limited natural resources and necessity of its rational use
- more rigorous regulations on C&D waste
- difficulties at finding locations for new landfills.

As traditional methods costs would increase, commercial aspect of recycling would also increase and intention is that each commercial benefit should be used in the frame of local economy.

4. Recycled Aggregate Properties

Recycled aggregate needs to satisfy the same requirements as ordinary aggregate from natural resources. Likewise, recycled aggregate concrete can be mixed, transported and placed in the same way as ordinary concrete. Properties of recycled aggregate that are different from ordinary aggregate are certain types of impurities, density and water absorption.

4.1 Impurities

4.1.1 Clay lumps and lightweight particles

According to experimental study of Gutiérrez and Sánchez de Juan, it is shown that clay lumps and lightweight particles are the most common type of impurity that can appear in recycled aggregate. Density of lightweight particles is lower than 2000 kg/m^3.

Spanish specifications defines criteria for clay lumps content as ≤0.25 % and to comply with this limit, it is recommended that clay lumps content in recycled and natural aggregate should be limited to 0.6 % and 0.16 %, respectively, in blends with 20 % recycled aggregate. Also, Spanish specifications gives criteria for lightweight particles ≤1.00 % (the European standard does not include this property). Authors recommend that in the case when the percentage of used recycled aggregate is 20%, it would be necessary to limit the content in lightweight material to 0.97% for natural aggregate and 1.12% for recycled aggregate, to obtain a blended aggregate that complies with the specification of 1%.

4.1.2 Other impurities

Standard BS 8500-2:05 allows up to 5 % of ceramic material, up to 5 % of asphalt and up to 1 % of other impurities (glass, plastics etc.). According to Australian recommendations (CSIRO), limit for all kind of impurities is 2 % and according to RILEM recommendations the content of impurities should be lower than 1 %.

4.2 Chemical Properties

Authors Gutiérrez and Sánchez de Juan show that recycled aggregate could contain a certain quantities of chloride and sulphate ions. (Table 3) Large content of chloride ions could be found in C&D waste generated from structures that was located in marine environment.

Table 3: Spanish Specifications for Chemical Properties of Recycled Aggregate (Gutierrez *et al.*)

Property	Test method	Spanish specification (EHE)
Cl^- soluble in water (%)	UNE–EN 1744–1:99	≤ 0.05
Cl^- total (%)	UNE 80–217:91	≤ 0.05
Acid sulphate content as $SO_3^=$ (%)	UNE–EN 1744–1:99	≤ 0.8
Total sulphur content as SO_3 (%)	UNE–EN 1744–1:99	≤ 1.0

Classification shown in the Table 4 is included in European Standard specifications for aggregate (CEN Technical Committee TC 154 'Aggregates'). It has been stated that impurity control is necessary to provide satisfying quality of final product.

Table 4: Recycled Aggregates Types (RILEM)

Type of aggregate	Composition	Impurities	
		Foreign material*	Total organic material
I	Mainly derived from masonry (brick)	≤ 5 %	≤ 1 %
II	Mainly derived from concrete	≤ 1 %	≤ 0.5 %
III	Mixture with not less than 80% natural aggregate, not more than 10 % Type I, and up to 20 % Type II	≤ 1 %	≤ 0.5 %

*glass, bitumen, soft materials etc.

4.3 Density

Density of recycled aggregate is usually lower than density of natural aggregate, especially density of sand due to higher content of cement paste and mortar on grain surface.

4.4 Grading

In the process of concrete recycling, two or three crushing machines can be used. First crushing machine is primary and other two are secondary crushing machines. The best grading of recycled aggregate is obtained by using all three crushing machines, but for market competitiveness, producers usually use only primary and one secondary crushing machine. Number of crushing machines also depends on C&D waste type i.e. waste composition. If C&D waste mostly consists of bricks, the use of primary crushing machine can be sufficient to reach satisfactory grading.

4.5 Water Absorption

Increased water absorption of recycled aggregate is the result of higher absorption of cement mortar that was remained on aggregate grains. Spanish standard for structural concrete restricts the maximum value to 5 %. Gutiérrez and Sánchez de Juan stated in their study that this requirement can be fulfilled in substitution of a natural aggregate percentage with reduced water absorption. It means that for combination of 20 % recycled aggregate and 80 % natural aggregate, the recycled aggregate water absorption should be limited to 7 %, and natural aggregate absorption should be maximum 4.5 %. On the other hand, RILEM recommendations limited the blend water absorption to 3 %, but at the same time they allow recycled aggregate absorption up to 10 %. It implies that the natural aggregate used in this case should be with very low value of absorption. According to British recommendations, recycled aggregate absorption is in the range between 3 and 10 %.

Gutiérrez and Sánchez de Juan also showed correlation between absorption and density of recycled aggregate. For the value of 7 % of absorption, density is higher than 2215 kg/m^3.

4.6 Abrasion

There is small number of investigations regarding recycled aggregate abrasion. According to Spanish study, Los Angeles testing results showed range from 35.1 to 41.7 %, with a variation coefficient of 5.1 %.

5. Use of Recycled Aggregate

5.1 Advantages

- *Ecological contribution – sustainability*

By C&D waste recycling, exploitation of limited natural resources decreases as well as quantities of permanently disposed waste.

- *Energy saving*

According to Kaima Tehnical Research Institute (2002), recycling process can be done on the site by using mobile crushing machines. This procedure can save energy needed for transport of material to recycling facilities which also affects on CO_2 emission reduction (Nelson, Shing Chai CGO).

- *Costs*

In the case of well organized recycling process, recycled aggregate is economically more acceptable than natural aggregate. Also, it is very important that the financing system stimulate collection and recycling of C&D waste. The practice of the EU member states ensures that a waste producer has either to dispose it or pay for its disposal in a such way that the lowest charge is for sorted waste (when it is delivered for recycling), a higher charge for unsorted waste, more for contaminated or hazardous waste, and the highest charge for permanent disposal of waste that does not undergo recovery system.

- *Job opportunities*

There is a need for opening new working places in the recycling facilities as well as in scientific institutions. By higher use of recycled aggregate, it is necessary to increase knowledge level of all the participants of C&D waste management process.

- *Market*

Recycled aggregate can be used as material for roads bearing layer, as an addition for various concrete and asphalt mixtures and in production of prefabricated concrete elements.

5.2 Limitations

- *Lack of specifications and guidelines*

Considerable financial resources are invested in research of recycled aggregate properties. Nevertheless, there are no clearly defined specifications, standards and specifications to ensure constant and safe use of recycled aggregate.

- *Water pollution*

Water used in the recycling process can have high alkalinity level. This water can be dangerous for aquatic eco-system and special care should be dedicated to this environmental impact.

- *Lack of facilities for C&D waste collecting and recycling*

Collecting and recycling facilities should be located depending on local conditions and expected quantities in accordance to C&D waste management system.

6. Study of Recycled Aggregate Properties in the Republic of Croatia

For the purpose of experimental study, waste generated from demolished concrete structure was recycled and used as aggregate for concrete mixtures. (Kovac, 2008). Relevant properties of concrete in fresh and hardened state were tested. Research was focussed on influence of recycled aggregate different proportions in the total aggregate amount. Properties of recycled aggregate concrete were tested on 5 different mixtures for recycled aggregate proportions of 0, 30, 50, 70 and 100%. One additional concrete mixture was created for the purpose of improving concrete properties. Total amount of 90 concrete specimens were prepared and following concrete properties were tested in fresh state: consistency, density, air content; and in hardened state: density, compressive strength, elasticity modulus, gas permeability, shrinkage and water permeability. Considering obtained results, it was recommended to use maximum of 30 % recycled aggregate in concrete mixtures, because up to this amount, properties of concrete regarding shrinkage and water permeability would be satisfactory. In the case of higher amount of recycled aggregate in concrete and additional durability requirements, admixtures should be used to satisfy necessary specifications.

7. Acknowledgements

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