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Recycling Concrete—An Overview of Challenges and Opportunities

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Synopsis: This paper consists of an overview of the development of techniques for recycling concrete. Demolition, processing and the recycling of the resulting materials are often analyzed separately. "High quality" recycling of concrete waste does not always correspond to production/use of the product with the highest value, but rather the most feasible product in a specific project or region. It is by analyzing the whole disposal/supply-chain, including the substituted material, that the best effects of recycling can be achieved.

Overviews of methods for environmental evaluations as well as economic considerations are presented. Integrated demolition waste management in Kosovo and an analysis of the potential market in Hong Kong are presented as examples of the worldwide market for recycled materials. Issues regarding the handling of polluted materials will be discussed from a practical point of view. Moreover, some aspects to consider regarding future demolition when producing new concrete products are presented.

Keywords: concrete; construction and demolition waste; demolition; integrated waste management; recycling

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SUSTAINABILITY AND "GREEN" CONCRETE

Since Agenda 21, the Rio Declaration on Environment and Development, was launched in 1992 sustainable development has been one of the key issues of modern society. Some years ago, ACI realized that even if concrete is an environmentally friendly material, Portland cement is the critical component of modern-day concrete. To address this issue and the relationship between sustainable development and concrete technology, the ACI Board of Direction, in 2000, formed a Task Group on Sustainable development and concrete technology. Its mission was to encourage the development and application of environmentally friendly, sustainable concrete materials, design and construction. One of the most important issues of sustainability was the use of recycled aggregates (1).

Fortunately, some ACI members had been far-sighted enough in 1985 to organize Committee 555 – Concrete with Recycled Materials. In 2001 the committee submitted a report *"Removal and Reuse of Hardened Concrete"* (2), which has established a very good basis for the future work of ACI on the sustainability and recycling of concrete.

Parallel to the work of ACI in the USA, the recycling of Construction and Demolition waste (C&D waste) has emerged as a socio-economic priority within the European Union and a considerable amount of research and development has taken place in the frame of RILEM[1]. In 1981 European and Japanese members of RILEM took the initiative to complete the first RILEM technical committee on the demolition and recycling of concrete, including several material research projects in this field. The research of the RILEM technical committees on recycling has been published in proceedings from three international symposia held by RILEM in Antwerp, Belgium 1985 (3), in Tokyo, Japan, 1988 (4) and in Odense, Denmark, 1993 (5). In 2000 the state-of-the-art-report of RILEM Technical Committee 165-SRM on *Sustainable Raw Materials* was edited by C.F. Hendriks and H.S. Pietersen (6).

THE NEED FOR C&D WASTE MINIMIZATION

In all communities it has always been common practice to retrieve valuable materials from the arising waste, e.g. metals and building materials. After some decades in this century with an extensive "use-and-throw-away" philosophy it has been recognized that we cannot continue this uninhibited use of natural resources and pollution of the world

[1] **RILEM** : The international union of testing and research laboratories for materials and structures

with waste. It is necessary to change our habits and to revise former common practices within the building & construction industry, as well as within other industries, households etc.

In many countries, industrial as well as developing, C&D waste is considered as harmless, inert waste, which does not give rise to problems. However, C&D waste consists of huge amounts of materials that are often deposited without any consideration, causing many problems and encouraging the illegal dumping of other kinds of waste. Whether C&D waste originates from clearing operations after natural disasters or from human-controlled activities, the utilization of such waste by recycling can provide opportunities for saving energy, time, resources and money (7, 8, 9). Furthermore, recycling and the controlled management of C&D waste will mean that less land is used and better opportunities will be created for the handling of other kinds of waste.

C&D WASTE STREAMS IN THE EU AND USA

A large proportion of C&D waste derives from demolition, rehabilitation, and new construction following normal development, as well as from natural and technological disasters. For example, the production of building materials and goods involves surplus ready-mixed concrete, concrete elements, articles of wood etc., which can be classified as industrial waste.

In the European Union, whose population in 2000 was approximately 370 million, it is estimated that the annual generation of C&D waste is approximately 200- 300 million tonnes - equivalent to ½ - 1 tonne per capita per year in very rough figures (7, 10).

Clear figures regarding recycling do not exist in every EU member country. An EU study calculated that an average of 28 % of all C&D waste was recycled in the late 1990s (11). In the Netherlands 95 % of all C&D waste is recycled and in Denmark 90 % is recycled.

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 such as timber, steel and quarry materials. Recycled materials are generally less expensive than natural materials, and recycling in Germany, Holland and Denmark is less costly than disposal (7, 10, 11).

The C&D waste streams in the USA were assessed by Robert H. Brickner in 2002 (12). It is estimated that the amount of C&D waste is 250 – 300 million tonnes per year (2002 figures) and that 20 – 30 % is recovered for recycling (1996 figures).

According to Metha (13) the global concrete industry uses approximately 10 billion tonnes of sand and rock each year and more than 1 billion tonnes of C&D waste are generated every year.

CHALLENGES OF RECYCLING

According to the EU Waste Directive on Prevention and reduction of Waste the key issues are:

- Cleaner technologies
- Recycling, reuse & recovery (R3) of waste
- Management and planning of CDW handling
- Polluter pay principle

This presentation will focus on recycling. C&D waste has a high recycling potential because the majority of it consists of masonry, concrete, and steel. In Europe up to around 90 % of C&D waste consists of concrete and masonry. Buildings erected before the middle of the last century were mainly constructed with masonry, and buildings in the second half of the century were mainly constructed with concrete. The situation in the USA is probably the same.

Based on a global overview (13) it is estimated that the potential of recycling is approximately 50 %, which is equal to approximately 500 million tonnes, which is equal to 5 % of the global consumption of sand and rock.

At present, only very limited amounts of C&D waste are recycled as high-value materials, such as recycled aggregates in new concrete. The majority of such waste is disposed of or used as fill. Since the amounts of C&D waste are constantly increasing, there are many reasons for focusing on methods that promote an increase in the recycling of C&D waste (dumping fees in Europe and the USA are typically from US$ 20-50 per tonne). Present results in Europe show very favorable recycling possibilities in this field.

From a purely economic point of view the recycling of building waste is only attractive when the recycled product is competitive with natural resources in relation to cost and quality. Recycled materials will normally be competitive where there is a shortage of both raw materials and suitable deposit sites.

With the use of recycled materials, economic savings in the transportation of building waste and raw materials can be achieved. In larger recycling projects, such as urban development, renovation of motorways, or clearing of war/disaster-related damages, the total project cost will be dominated by transportation costs. These transportation costs involve the removal of demolition products and the supply of new building materials. In these cases the use of recycled materials is very attractive.

The prospects of systematic recycling of C&D rubble in various parts of the world have been analyzed (7, 14). In order of importance, the three main factors affecting the prospects of recycling C&D waste are

- population size and density,
- occurrence of and access to natural raw materials, and
- level of industrialization.

OPPORTUNITIES FOR RECYCLING

In order to meet the challenges of recycling, it is necessary that all opportunities, barriers and obstacles are detected and considered. The opportunities must be exploited, which can for example involve the recycling of concrete and masonry into aggregate, substituting natural materials:

- Aggregate bound in concrete
- Unbound sub-base and base materials

The opportunities for the production of concrete from recycled concrete are generally described in the ACI 555 report (2), and the recycling of concrete waste in a global perspective is described by Torben C. Hansen and Erik K. Lauritzen (7), Mats Torring (15) and Mats Torring and Erik K. Lauritzen (16).

The overcoming of these barriers and obstacles must be planned and carried out through a long-term action plan combined with adequate research and development. Implementation of the necessary legal, economic and technical instruments requires that initiatives involving legislation and regulations be taken.

Economy

With a condition of market economy, the choice between recycled and natural materials depends on price and quality. The quality of concrete with recycled aggregates can be the same as that of concrete with natural aggregates, but recycled concrete aggregates are regarded with suspicion. Hence, recycled concrete materials will only be preferred where the price of such aggregates is considerably lower than that of the natural materials, even when the recycled aggregates meet given specifications.

Introducing economic instruments, which encourage recycling and the use of recycled materials, can overcome the economic barriers. As an example it should be mentioned that several countries have introduced special taxes and fees in favor of recycling. For example, in 1986 the Danish government introduced a tax on waste that is not recycled but disposed of at landfill sites. Today the tax is DKK 375 (approx. EURO 50) per tonne of waste disposed of at landfill sites.

The major issue of the cost-benefit to society is:

- willingness to pay for the impact on the environment
- willingness to accept the impact on the environment

Policies & Strategies

C&D waste must be considered as a specific individual type of waste associated with the building and construction industry. It is important that the management and handling of waste is carried out by the industry itself. Generally, the building and construction industry is relatively conservative, and changes in normal procedures often take time and need long-term policies and strategies.

One of the most important barriers is the many different interests in building waste.

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Usually it is the environmental politicians, departments and public offices who prepare the policies and issues concerning waste recycling and reduction, whereas the building and construction industry is controlled by laws, departments and offices concerned with housing, construction and public works. To co-ordinate the interests of all parties, particularly with respect to the implementation of cleaner technologies in industry, it is necessary that long-term policies and strategies should first have been prepared and implemented.

Danish experience in this field has led to the recommendation that long-term strategies, e.g. for 10 years with respect to achieving goals for the recycling of C&D waste, should be adopted. These must then be continuously revised in accordance with the political situation, and followed up by adequate legislation and regulation at all levels - national, regional and local.

Certification of recycled materials

Demolition and crushing techniques for the production of recycled materials are well known and based on existing technologies. However, some changes in the demolition process, compared with traditional demolition, are required as described below. Even when recycled materials fulfil current standards for natural materials, and even when the prices can compete with the prices of natural materials, certain barriers still exist.

Owing to tradition and psychological barriers the general attitude towards recycling in the building and construction industry is largely prohibitive towards the utilization of recycled materials. Therefore, it is of great importance that recycled materials are officially certified and accepted by all parties in the building and construction industry. For example, in June 1994 RILEM published recommendations for concrete with recycled aggregates (17). A review of international classification and certification of use of recycled C&D waste is presented by Henrichsen (10).

It is recommended that considerable emphasis be placed on specifying the areas of utilization and quality standards for recycled materials. These must be in accordance with the local demand in order to improve confidence in the recycled materials and solve problems regarding the responsibility of using such materials.

Planning demolition projects

A necessary condition for the recycling of building waste is careful sorting of the waste. Waste from new constructions and rehabilitation is sorted either at the production site or at a special treatment site. This separation into materials categories is fairly simple.

The sorting of waste from demolition is, however, a more complicated process. Demolition has until recently been regarded as a low technological process. Rapid demolition and disposal of structures were the main aims of the contractor. Special measures to separate the different types of materials were not possible, owing to the time factor, nor were they desired.

Optimal handling and recycling of C&D waste depends on the materials being sorted in-situ and in co-ordination with the demolition process using demolition technologies and methods as described in the ACI 555 report (2). It is therefore necessary to alter the traditional methods of demolition and introduce selective demolition. This requires that before and during the demolition process an effective sorting of the different materials categories is carried out, thereby preventing any mix of materials leading to pollution of, for instance, recyclable concrete/masonry rubble by wood, paper, cardboard, plastics etc. Since selective demolition takes more time than traditional demolition, detailed planning is considered as mandatory.

It is recommended that demolition projects should be planned and controlled in detail, in the same way as all other building and construction projects, to ensure selective demolition and correct handling of the demolition waste.

Education and information

The most important means to identify and exploit the opportunities and overcome the barriers and obstacles is education and information. It is necessary that the message and understanding of recycling be discussed at technical universities, among private enterprises and public servants.

INTEGRATED RESOURCE MANAGEMENT

In order to achieve the maximum benefit of recycling a management system must be established on a project basis in relation to a specific construction project, e.g. urban development master plan, or on a permanent basis in relation to long-term municipal and C&D waste management system.

The Integrated Resource Management System comprising environmentally and economically balanced management of the following elements:

- Demolition (selective demolition)
- Recycling, reuse recovery
- Handling of hazardous C&D waste materials and non-recyclable materials
- Transportation
- Substituting (saving) natural resources

A presumption of the success of the Integrated Resource Management System is that an effective co-operation between all stakeholders/decision makers has been established in order to avoid a conflict of interests. Conflicts between recycling companies and raw materials companies, for example, could prevent all initiatives towards recycling in general.

The Integrated Resource Management can be implemented according to normal routines of project management in the construction industry, e.g.:

- National policies (legal and fiscal instruments)

- Regional strategies (control of C&D streams, stationary or mobile recycling plants)
- Concepts (high versus low value recycling)
- Feasibility studies (specific proposals for recycling)
- Computer optimization (e.g. waste-resource streams and economic models)
- Master planning
- Design
- Supervision
- Quality & environmental management

GLOBAL VISIONS

The construction industry must aim at durability and sustainability as described by Metha (13). A holistic life cycle based approach is recommended in order to reduce the environmental impact. Further it is mentioned that the resource efficiency of the concrete industry will increase by a factor of five if the service life of most structures built today were 250 years instead of the conventional 50.

Looking at recycling, it is estimated - based on a global C&D waste production of 1 billion tonnes per year - that potentially 50 % should be recycled and could substitute approximately 5 % of the global consumption of sand and rocks.

However, the truth is that there is a long way to go before this level of recycling can be attained in developing countries, and many other environmental problems must be prioritized. But there is no excuse for the industrialized nations not to start the implementation of Integrated Resource Management Systems, aiming of 90 % recycling and maximum substitution of natural resources. There is no doubt that results and experience from European research and development can be transferred to other parts of the world and enable natural (primary) raw materials to be replaced by recycled materials, especially in urban renewal and rehabilitation projects.

CONCLUSION

The development of technologies for the recycling of concrete and the market for various types of recycled concrete materials has proved the viability and sustainability of recycling concrete. The challenges of recycling are dominated by a very high potential of concrete waste all over the world and a demand for recycled materials in order to substitute natural resources. The opportunities for recycling are based on economics, policies & strategies, certification of recycled materials, planning of demolition projects, and education and information.

The success of recycling concrete today in some European countries is based on integrated resource management. The success of recycling in the future is based on global visions for the implementation of recycling concrete worldwide in order to save natural resources and protect the environment.

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