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AN ANALYSIS ON VARIOUS STRATEGIES TO REDUCE THE ENVIRONMENTAL EFFECT OF CONCRETE PRODUCTS

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An Analysis on Various Strategies to Reduce the Environmental Effect of Concrete Products

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***Abstract* – Nowadays concrete is the most common building material in the world. Buildings are responsible for more than 25 % of global carbon dioxide emissions in France. With the new regulations, the concrete industry must limit the emissions of greenhouse gases.**

Thermal conductivity and mechanical strength were tested on lightweight concrete samples. These measurements, in parallel with the study of environmental data led to the conclusion that wood aggregates present an interest for the environment and should be the object of deeper research. CERIB is currently considering the possibility of applying for a patent on some other innovative solutions examined in this research.

One strategy to make concrete 'greener' construction material is to utilize fly ash, either as partial or total substitute for Portland cement in concrete. This attempt results in twofold benefits, i.e. to provide a solution with regard to the concern on the carbon dioxide emission from Portland cement production, and to provide way to effectively use fly ash. Fly ash, the byproduct material from burning coal especially in power stations, is available abundantly worldwide. Its availability is increasing and yet its utilization to date is still very low.

Without proper plan, the management of fly ash may incur cost, and potentially harm the natural environment as well. This paper discusses the technology and the current progress of research on utilizing fly ash in concrete.

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INTRODUCTION

The protection of our environment is one of today's priorities for the industrial world. Buildings are responsible for more than 25 % of global carbon dioxide emissions in France, especially because of the energy consumption for heating. Cement production is also responsible for very significant greenhouse gas emissions.

Nowadays concrete is the most common building material in the world because of its very high mechanical strength and durability. It is used more and more with today's requirements concerning infrastructures, industry and housing. That is why it is necessary for the French precast concrete industry to work on reducing the impact of concrete on the environment. It's difficult to say if one of these factors is more important but we often consider that the climate change is a good indicator. It represents greenhouse gases emissions.

Carbon dioxide is the main greenhouse gas. Today building are responsible for 25 % of total $C0_2$ emissions. That's why reducing building's environmental impact is a major issue for sustainable development. The potential environmental benefit to society of being able to build with green concrete is huge. It is realistic to assume that technology can be developed which can halve the CO2 emission related to concrete production. With the large consumption of concrete this will potentially reduce Denmark's total CO2 emission by 0.5 %.

Portland cement is one of the most popular and major construction materials worldwide. In the foreseeable future, this tendency will remain so. The cement production is expected to rise from 1.7 billion tones in 2000 to 2 billion tones in 2010, whereby the major increase will take place in China and India.

However, Portland cement production raises environmental concern, not only due to highly energy intensive, but also due to high amount of carbon dioxide released to the atmosphere. Production of one ton Portland cement will release one ton of carbon dioxide into atmosphere. Moreover, there is also concern on the durability of the concrete structures, especially those built in aggressive environment.

On the other hand, fly ash, "the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system", is available abundantly worldwide. In 2001, the fly ash production in the USA was in the order of 68 million tons, but only 32 percent was used in various applications, such as in concrete, structural fills, waste stabilisation/solidification, etc.. Worldwide, the estimated production of coal ash in 1998 was more than 390 million tons. The main contributors for this amount were China and India. Only about 14 percent of this fly ash was utilized, while the rest was just disposed in landfills. By the year 2010, the amount of fly ash produced worldwide is estimated to be about 780 million tons annually.

The utilization of fly ash and other by-product materials, such as granulated blast furnace slag, rice husk ash, as a substitute or partially substitute of Portland cement in concrete has been studied intensively and extensively. Partial substitution of Portland cement by 20-30% fly ash has become a common practice. A more substantial development in this area were the development of high volume fly ash concrete with 50-60% Portland cement replacement by using fly ash, and the development of fly ash-based geopolymer concrete whereby the use of Portland cement is totally replaced by the geopolymer matrix using fly ash as the source material.

ENVIRONMENTAL EFFECT OF CONCRETE

The world's yearly cement production of 1.6 billion tons accounts for about 7% of the global loading of carbon dioxide into the atmosphere. Portland cement, the principal hydraulic cement in use today, is not only one of the most energy-intensive materials of construction but also is responsible for a large amount of greenhouse gases. Producing a ton of portland cement requires about 4 GJ energy, and portland cement clinker manufacture releases approximately 1 ton of carbon dioxide into the atmosphere.

Furthermore, mining large quantities of raw materials such as limestone and clay, and fuel such as coal, ften results in extensive deforestation and top-soil loss. Ordinary concrete typically contains about 12% cement and 80% aggregate by mass. This means that globally, for concrete making, we are consuming sand, gravel, and crushed rock at the rate of 10 to 11 billion tons every year. The mining, processing, and transport operations involving such large quantities of aggregate consume considerable amounts of energy, and adversely affect the ecology of forested areas and riverbeds. The concrete industry also uses large amounts of fresh water; the mixing water requirement alone is approximately 1 trillion L every year.

Reliable estimates aren't available, but large quantities of fresh water are being used as wash-water by the ready mixed concrete industry and for curing concrete. Besides the three primary components, that is, cement, aggregates, and water, numerous chemical and mineral admixtures are incorporated into concrete mixtures. They too represent huge inputs of energy and materials into the final product. What about batching, mixing, transport, placement, consolidation, and finishing of concrete? All these operations are energy-intensive. Fossil fuels are the primary source of energy today, and the public is seriously debating the environmental costs associated with the use of fossil fuels.

Finally, the lack of durable materials also has serious environmental consequences. Increasing the service life of products is a long-term and easy solution for preserving the earth's natural resources. Concrete structures are generally designed for a service life of 50 years, but experience shows that in urban and coastal environments many structures begin to deteriorate in 20 to 30 years or even less time.4 In the April 1998 issue of *ASCE News*, the American Society of Civil Engineers gave the nation's infrastructure an average grade of D and estimated that it would take $1.3 trillion to fix the problems. The cost to repair or replace several hundred thousand concrete bridge decks alone would be $80 billion, whereas the present annual federal funding for this purpose is about $5 to $6 billion. Considering the funding constraints, Freyermuth5 has suggested that in the future structures be designed and built for a minimum service life of 100 to 120 years, and major bridges in urban environments should have at least 150 years of useful life. The trend toward designing infrastructure based on life-cycle cost will not only maximize the return on the available capital but also on the available natural resources.

The need for reducing the environmental impact of concrete is recognized in a recent report of the Strategic Development Council. An abbreviated version of the report, "Vision 2030: A Vision for the U.S. Concrete Industry," was published in *Concrete International,* March, 2001.

According to this report, concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases.

STATE OF AFFAIRS OF CONCRETE WITH REDUCED ENVIRONMENTAL EFFECT

There is considerable knowledge in Denmark about how to produce concrete with lower environmental impact, so-called green concrete. The concrete industry in Denmark has considerable experience in dealing with environmental aspects. The concrete industry realized at an early stage that it is a good idea to be in front with regard to documenting the actual environmental aspects and working on improving the environment, rather than being forced to deal with environmental aspects due to demands from authorities, customers and economic effects such as imposed taxes, etc.

Furthermore, some companies in the Danish concrete industry have recognized that reduction in production costs often go hand in hand with reduction in environmental impacts. A Danish concrete element manufacturer has achieved significant economic savings by dividing the waste into different fractions and thereby increasing the recyclability. Thus, environmental aspects are not only interesting from an ideological point of view, but also from an economic aspect.

The knowledge and experience in Denmark, about how to produce concrete with lower environmental impacts can be divided into two groups, concrete mix design and cement and concrete production: Concrete mix design:

- using cement with reduced environmental impacts
- minimizing cement content
- substituting cement with pozzolanic materials such as fly ash and micro silica
- recycling of aggregate
- recycling of water

Concrete mix design : The type and amount of cement has a major influence on the environmental properties of a concrete. An example of this is shown in figure 1, where the energy consumption in MJ/kg of a concrete edge beam through all the life cycle phases is illustrated. The energy consumption of cement production make up more than 90 % of the total energy consumption of all constituent materials and approximately 1/3 of the total life cycle energy consumption.

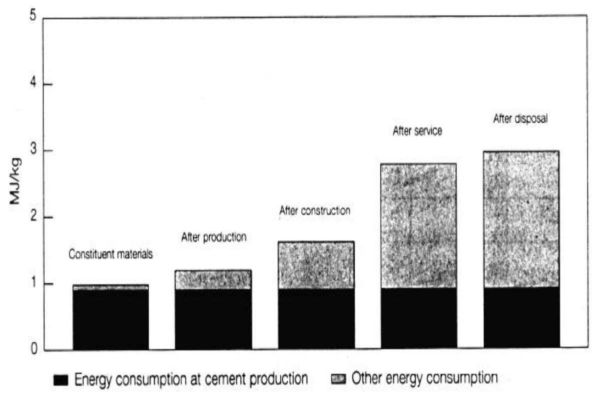

Figure 1. Edge beam: Total energy consumption through all the life cycle phases.

By selecting a cement type with reduced environmental impacts, and by minimizing the amount of cement the concrete's environmental properties are drastically changed. This must, however, be done whilst still taking account of the technical requirements of the concrete for the type and amount of cement. Denmark's cement manufacturer, Aalborg Portland, priorities development of cements with reduced environmental impacts.

One method of minimizing the cement content in a concrete mix is by using packing calculations to determine the optimum composition of the aggregate. A high level of aggregate packing reduces the cavities between the aggregates, and thereby the need for cement puste. This results in better concrete properties and a better environmental profile, due to a smaller amount of cement. When having experimentally determined the packing, the density, and the grain size distribution of each aggregate material, it is possible to calculate the packing of any combination of aggregates using DTI Concrete Centre's computer program.

Another way of minimizing the cement content in a concrete is to substitute parts of the cement with other pozzolanic materials. In Denmark, it is common to produce concrete with fly ash and/or micro silica. Both of these materials are residual products (from production of electricity and production of silicon, respectively) and both have a pozzolanic effect. Thus, a material with large environmental impact, i.e. the cement, is substituted with materials with reduced environmental impacts.

Cement and concrete production : It is also possible to reduce a concrete's environmental impact by reducing the environmental impacts in cement and concrete production. The Danish cement manufacturer has many activities concerned with the reduction of environmental impacts.

As regards concrete production, experience with reductions of primarily water consumption, energy consumption and waste production is available. Even though the contribution of concrete production to a concrete type's environmental profile is minor, it does give a contribution, and it is important – environmentally and economically - to the single concrete producer.

In a large Danish project, "Environmental management in the building and construction industry", a guide to environmental reading, environmental management based on the ISO 14001 standard, and a "get-started" guide are under preparation. The guide can help the concrete producers reduce environmental impacts from their production.

HIGH-PERFORMANCE CONCRETE

What is high-performance concrete? According to a recent paper by Aitcin, *what was known as high-strength concrete in the late 1970s is now referred to as high performance concrete (HPC) because it has been found to be much more than simply stronger*. ACI defines HPC as a specially engineered concrete, one or more specific characteristics of which have been enhanced through the selection of component materials and mix proportions. Note that this definition does not cover a single product but a family of high-tech concrete products whose properties have been tailored to meet specific engineering needs, such as high workability, very-high early strength (e.g. 30-40 MPa compressive strength in 24 hours), high toughness, and high durability to exposure conditions.

A major criticism against the ACI definition of HPC is that durability of concrete is not mandatory; it is one of the options. The misconception that high-strength will automatically lead to high-durability has probably resulted in many cases of cracking and premature deterioration of HPC structures, as reported in the published literature (6, 7). The reason lies in the mix proportions used to achieve very high-strength; for example, commercial high-strength concrete mixtures are often designed to obtain 50-80 MPa compressive strength at 28-day and at times high early-strength values on the order of 25-40 MPa at 1-day, together with 150-200mm slump for ease of constructability if the structure is heavily reinforced. Typically, these mixtures are composed of a high cement content, viz 450-500 kg/m3 portland or blended portland cement containing a relatively small amount of silica fume and fly ash or slag, a low water/cement on the order of 0.3 (with the help of a super plasticizing admixture), and an air-entraining agent when it is necessary to protect the concrete from cycles of freezing and thawing. Field experience shows that the foregoing high strength concrete mixtures are prone to suffer early cracking from a variety of causes, such as a large thermal contraction due to the high portland cement content, a large autogenous shrinkage due to the low water-cementitious ratio, and a high drying shrinkage due to the high cement paste-aggregate ratio.

Aitcin prefers to define HPC as a low water/binder concrete with an optimized aggregate-to-binder ratio to control its dimensional stability (i.e. drying shrinkage), and which receives an adequate water-curing (to control autogenous shrinkage). This definition adequately addresses the potential for lack of durability of HPC concrete except with massive structural members that may be subject to thermal cracking. In this regard, an earlier definition proposed by Mehta and Aitcin stated that the term HPC should be applied to concrete mixtures possessing the following three characteristics: high workability, high strength, and high durability.

The above critical examination of the commercial practice and the perceived meaning of the term, *high-performance concrete*, is essential to answer the question whether or not HPC is a sustainable product. Most of the conventional HPC products will not qualify to be classified as “sustainable” because they are not likely to be highly durable and may contain a high content of portland cement and a relatively small amount of pozzalanic and cementitious by-products for cement replacement. However, the high-volume fly ash (HVFA) system, discussed next, represents an emerging technology for producing *sustainable HPC mixtures.*

SUGGESTIONS FOR REDUCING ENVIRONMENTAL IMPACT

The environmental impact of the concrete industry can be reduced through resource productivity by conserving materials and energy for concrete-making and by improving the durability of concrete products. The task is most challenging but can be accomplished if pursued diligently.

To examine how the concrete industry will have to restructure when the business paradigm shifts its emphasis from a culture of acceleration to a culture of resource productivity, I have subdivided the environmental impacts of modern concrete construction practice into several categories that are discussed separately as follows.

Cement conservation: Cement conservation is the first step in reducing the energy consumption and greenhouse-gas emissions. Resource productivity consideration will require us to minimize portland cement use while meeting the future demands for more concrete. This must be the top priority for a viable concrete industry. Except for blended port- land cements containing mineral additions, no other hydraulic cements seem to satisfy the setting, hardening, and durability characteristics of portland cement-based products. Although there is steady growth in the use of portland cement blends containing cementitious or pozzolanic by-products, such as ground granulated blast-furnace slag and fly ash, vast quantities of these by-products still end up either in low-value applications such as landfills and road subbases, or are simply disposed by ponding and stockpiling. The world cement consumption rate is expected to reach about 2 billion tons by the year 2010, and there are adequate supplies of pozzolanic and cementitious by-products that can be used as cement substitutes, thus eliminating the need for the production of more portland cement clinker.

Aggregate conservation: In North America, Europe, and Japan, about two-thirds of the construction and demolition waste consists of masonry and old concrete rubble. This presents a great opportunity for the concrete industry to improve its resource productivity by using *coarse aggregate* derived from construction and demolition wastes. In many parts of the world, dredged sands and mining wastes can be processed for use as *Fine aggregate.* Recycling these wastes in spite of some processing cost is becoming economical, particularly in countries where land is scarce and waste disposal costs are very high. In addition, virgin aggregate deposits have already been depleted in many areas, and hauling aggregates over long distances can be much more expensive than using a free or a low-cost source of local recycled aggregate. Recycled concrete, in some cases, is being used as a roadfill, which is better than landfill but it is "down-cycling" in the sense that virgin aggregate continues to be used for making new concrete.

Water conservation: So far, fresh water is abundantly available almost everywhere, and is being freely used for all purposes by the concrete industry. In fact, construction practice codes routinely recommend the use of potable water for concrete mixing and curing. But now, the situation has changed.

Concrete durability: In addition to the *steps* outlined above, improving concrete durability presents a long-range solution and a major breakthrough for improving the resource productivity of the concrete industry. For example, the resource productivity of the concrete industry will jump by a factor of 10 if most structural concrete elements are built to last for 500 years instead of 50.

Why do modern reinforced concrete structures sometimes begin to deteriorate in 20 years or less, whereas there are buildings and seawalls made of unreinforced Roman concrete that continue to be in good condition after almost 2000 years? Primarily because our portland-cement concrete mixtures are highly crack-prone and therefore become permeable

during service. The embedded steel reinforcement in permeable concrete corrodes easily, causing progressive deterioration of the structure. Today s construction practice, driven by a culture of ever-accelerating construction speeds, uses concrete containing a relatively large amount of high-early strength portland cement. As a result, the extensibility or crack-resistance of modern concretes is poor because of the high- tensile stress induced by too much thermal contraction and drying shrinkage, and too little creep relaxation.

CONCLUSION

The overview of the present state of affairs in Denmark of concrete types with reduced environmental impact has shown that there is considerable knowledge and experience on the subject. The Danish and European environmental policies have motivated the concrete industry to react, and will probably also motivate further development of the production and use of concrete with reduced environmental impact.

The somewhat vague environmental requirements that exist have resulted in a need for more specific technical requirements, and this is the focus of a recently started, large, Danish research project, where the most important goal is to develop the technology necessary to produce and use resource saving concrete structures, i.e. green concrete. This applies to structure design, specification, manufacturing, performance, operation, and maintenance.

The potential environmental benefit to society of being able to build with green concrete is huge. It is realistic to assume that the technology can be developed, which can halve the CO_2 emission related to concrete production, and with the large energy consumption of concrete and the following large emission of CO_2 this will mean a potential reduction of Denmark’s total CO_2 emission by ½ -1%.

Throughout the world, the waste disposal costs have escalated greatly. At the same time, the concrete construction industry has realized that coal fly ash is relatively inexpensive and widely available by-product that can be used for partial cement replacement to achieve excellent workability in fresh concrete mixtures. Consequently, in the modern construction practice 15%-20% of fly ash by mass of the cementations material is now commonly used in North America. Higher amounts of fly ash on the order of 25%-30% are recommended when there is a concern for thermal cracking, alkali-silica expansion, or sulfate attack. Such high proportions of fly ash are not readily accepted by the construction industry due to a slower rate of strength development at early age.

One most possible way to make concrete ‘greener’ construction material is to reduce the use of Portland cement. With the abundant availability of fly ash worldwide, it has potential to substantially replace the amount of Portland cement needed for making concrete.

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