*Second International Conference on Construction in the 21st Century (CITC-II)*
*"Sustainability and Innovation in Management and Technology"*
***10-12 December, 2003, Hong Kong***

# The Use of Self-compacting Concrete Technology in Sustainable Construction

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**Abstract**
Over the last decades there has been a tremendous growth of built environment to meet higher standards of living with growing industrialization and urbanization. The replacement and rehabilitation of aging and deteriorating existing infrastructures are the challenges of the $21^{st}$ century. Concrete is the most widely used of all building materials and the cement industry is one of the major contributors to the damaging emissions of large quantities of $CO_2$ into the atmosphere. In the $21^{st}$ century, there will be a tremendous growth in concrete construction as developing countries become developed and emission of $CO_2$ will be multifold. The 1997 World Earth summit in Kyoto, Japan made it clear that the unchecked increase in the emissions of greenhouse gases to the atmosphere is environmentally and socially no longer acceptable for sustainable development. Development of new environmentally friendly building materials like self-compacting concrete (SCC) incorporating high volumes of supplementary cementing materials (HVSCM) can be a solution.

The concept of SCC that can consolidate under its own weight without vibration was initially developed in 1988 in Japan. Since then remarkable progress had been made in the development and utilization of SCC. The development of SCC incorporating HVSCM is a diverse technology that can lead to lower green house gas emission, consumption of wastes, durable construction, sustainability in concrete industry and minimize worldwide infrastructure problems. This paper will discuss various aspects associated with SCC and sustainable development including environmental and economical issues. The development of new cost-effective HVSCM SCCs and their applications and performances in sustainable construction will also be described.

## 1. Introduction

Sustainable development can be defined as economic activity that is in harmony with the earth's ecosystem. The definition of sustainability, following the World Commission of Environment and Development, emphasizes the importance of ensuring the satisfaction of present need without compromising the ability of future generations to meet their own requirements. Sustainable development includes the issue of environmental impact, resource use and social effects. Sustainable development achieves social, economic and environmental objectives in parallel (Howard, 2000; Yates, 2001). For the construction industry sustainability means: progress that meets the needs of the society, economic development, preservation of environment and efficient use of resources. Sustainable development is also related to eco-efficiency. The World Business Council for Sustainable Development (WBCSD) identified elements to achieve eco-efficiency. These include the reduction of material and energy efficiency of products, reduction of toxic emissions, maximization of sustainable use of renewable resources and enhancement of material recyclability, product durability and service life. It is proved that normal concrete of the past does not satisfy the needs of structures in harsh and even mild climates. Deterioration due to poor durability is the main issue and it is imperative that the concrete industry use more sustainable materials in construction practice.

Worldwide construction industries contribute significantly to greenhouse gas (GHG) emissions. The manufacture of steel and cement, the two dominant construction materials, tops the list in terms of energy consumption, just after aluminium. With the turn of the century, global warming and other environmental considerations are of increasing critical importance in the selection of materials and construction practices (Mehta 1999).

A novel technology based on self-compacting concrete incorporating supplementary cementing materials (SCM) and wastes offers limitless advantages from the standpoint of energy and materials conservation, durability, cost efficiency, job site productivity, and overall sustainable development (Skarendahl 1999). One of the most effective ways to make the concrete industry sustainable is to promote and initiate the use of self-compacting concrete (SCC). SCC can be defined as a concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional concrete. This paper describes the elements associated with SCC and sustainable development.

## 2. Self-Compacting Concrete Technology and Sustainable Development

Self-Compacting Concrete (SCC) is one of the newest forms of high performance concrete available in the market today. SCC is a material that meets a unique combination of performance and uniformity requirements that cannot always be achieved using conventional constituents and usual construction practices. It can spread readily into place and self-consolidate under its own weight without exhibiting any significant separation of constituents. These characteristics translate into a substantial reduction in labour cost and construction time, and a better working environment by eliminating the impact of vibration.

The first generation of SCC, developed at the University of Tokyo, Japan, in the late 1980s, requires an excessive cement content and the use of costly chemical admixtures (Ozawa et al. 1989). Despite its high initial cost, this form of SCC has been used for different prestigious applications in Japan and Europe (Yurugi 1998; Petersson 1998). For instance, the Japanese Government supports a plan that by 2003, the use of SCC should exceed 50% of all concrete placed there. In Canada, the development of SCC is relatively new and its use has been limited to a few industrial and demonstration projects (Khayat et al. 1997, 2001). The development and use of SCC will be promising for years to come. But, the rapidity with which this material will be used depends on its acceptance by the market and efforts should be made by researchers to make SCC more affordable for the construction industry.

This novel SCC technology will allow the construction industry to optimise material use, generate economic benefits, and build structures that are sound economically and environmentally.

## 3. SCC with Wastes & Sustainable Development

The development of a cost-effective SCC with desirable fresh and hardened properties is important for such concrete to be used in the construction industry in the future. Thanks to very recent research efforts, new types of SCC have been developed by replacing a high percentage of cement, in the mix, with recyclable industrial by-products. The SCC can be manufactured by incorporating either supplementary cementitious materials such as fly ash (FA) and ground granulated blast furnace slag (GGBFS) or viscosity-modifying agents (VMA) (Bouzoubaâ and Lachemi 2001; Lachemi et al. 2003a). Surprisingly, the use of fine industrial "waste" products such as fly ash (FA) and ground granulated blast furnace slag (GGBFS) can ensure high fluidity and good cohesiveness of the mix and enhance concrete durability at a much lower cost. Also, the use of these by-products improves rheological properties of the fresh concrete and reduces thermal cracking of the hardened concrete. Fly ash is the residue of the burning of pulverised coal in thermal power plants, and blast furnace slag is the by-product of the manufacture of molten iron. The energy required to produce GBFS is only 25-33% of the energy necessary to produce cement, which is 40% of the total production cost of concrete. Commercially available VMAs are expensive, it is therefore important to explore new cost effective VMAs to manufacture more economical SCC. Research is in progress to develop cost-effective VMA's from industrial wastes and other sources (Lachemi et al. 2003b) that can lead to sustainable development.

Researches are in progress to develop SCC with volcanic debris such as volcanic ash (VA) and finely ground volcanic (VP). In addition to economic impacts, volcanic disasters have social and environmental effects related to commerce, industry, wildlife, aesthetics and other environmental qualities, relocation and rehabilitation of people, disruption of social and cultural patterns. It is imperative that engineers, planners and builders should deeply consider the major social and environmental concerns. It has been seen that the debris of volcanic eruption are the major sources of devastation. Even the emission of volcanic ash (VA) and its subsequent down fall to the earth can destroy the social and environmental structure as seen in the past in Papua New Guinea and other parts of the world (Blong-Aislabe 1988; Hossain 1999).

Mount Pinatubo in the Philippines erupted in the early 1990's and a fertile beautiful valley was totally overrun by hot volcanic lava. Presently much of the valley is a wasteland and a source of volcanic pumice (VP). This VP was used as useful building materials for constructing affordable housing and also shipped to Vietnam where a 36-sq. meter model home was built. One interesting outcome of the work in Vietnam was the experimenting of a hybrid wall made of pumice-crete reinforced with bamboo- a material, which is plentiful in the area. The insulating properties of the pumice-crete were very beneficial in the hot climate of South Vietnam (Hossain 1999). The Caribbean Island of Monseratt has recently witnessed one of its volcanoes erupting and emitting large quantities of VA and VP in the lava flows. Of course these volcanic eruptions are very dangerous catastrophes but what they leave after the danger has passed is often a very useful material. The removal of the volcanic debris is a major cause of concern for the post disaster rehabilitation and development works. One way to get rid of the debris is to use them as construction materials in the development works (Hossain 1998).

The use of industrial wastes and volcanic debris in SCC will contribute to the sustainable development with:

- **Substantial reduction in greenhouse gas emissions:** The use of high volumes of industrial by-products and volcanic debris in SCC mixtures provides a net reduction of 50-70% in cement, which equates to 50-70% less carbon dioxide ($CO_2$) released to the atmosphere. It should be noted that the production of every tonne of cement contributes about 1 tonne of $CO_2$ into the atmosphere. Worldwide, the annual cement production is about 1.5 billion tonnes and it is expected to reach 2 billion tonnes by 2010 (Malhotra 2000, Lambros et al. 2003).
- **Substantial reduction in energy consumption:** As the manufacture of cement is highly energy intensive, the replacement of a large amount of cement by industrial by-products (usually dumped in landfills) is particularly beneficial. Another immediate environmental benefit of using these by-products in concrete, especially with the current situation in some Canadian provinces, is reduced pressure on landfills (Malhotra 2000, Lambros et al. 2003).
- **Substantial reduction in the construction time and labour cost:** In a project involving SCC for a liquefied natural gas tank in Japan, the number of concrete workers was dramatically reduced from 150 to 50, and the construction time was reduced from 22 months to 18 months (Li 1995). This is particularly important to Canada where there is a critical shortage of skilled workers in the field.
- **Substantial reduction in the exposure to compaction and vibration noise:** A study conducted at the University of Paisley, Scotland, has shown that the use of SCC could result in noise levels

that are approximately one tenth the noise levels produced when conventional concrete is used. This noise reduction is beneficial not only for workers at construction sites, but also when construction is in progress in urban areas. In certain countries, it is forbidden in urban areas to cast concrete after a certain time because of the noise generated. In France, for instance, pre-casters have to pay a premium to a national agency in charge of health and security that is proportional to the level of noise at the precast plant.

- **Elimination of vibration health-related problems:** Many studies have concluded that casting SCC contributes to a less strenuous work environment compared with casting conventional concrete, and it is highly recommended from an ergonomic point of view (Bouzoubaâ and Lachemi 2001; Lachemi et al. 2003a). Also, operating a vibrating poker creates a disturbance in the blood circulation causing what is known as "white fingers". Today, health is not valued in terms of money. It is therefore difficult to use the better working environment as an economic reason to persuade the engineers and contractors to use SCC. But this will certainly change in the future given that priorities of our current industrial societies are directed towards sustainable development.
- **Proper distribution of concrete in restricted access areas:** This eliminates voids and insufficient bonding of concrete to the reinforcement, which increases the durability of the structure and reduces future rehabilitation costs. SCC can also result in superior surface quality and finishing (Bouzoubaâ and Lachemi 2001; Lachemi et al. 2003a).
- **Superior durability to aggressive chemicals:** The incorporation of supplementary cementing materials in concrete results in finer pores leading to a decrease in permeability, which decrease the transportation of aggressive chemicals into concrete. Design life cost analysis has shown that the increased use of durable concrete for infrastructure and building construction not only contributes to saving millions of Dollars but reduces the depletion of natural resources that would be required for the rehabilitation of concrete structures suffering premature deterioration due to poor materials and concrete mixtures characteristics (Malhotra 2000, Lambros et al. 2003).

## 4. Research and Comparative Performances of Various SCCs

Research to produce an economical SCC with desired properties was conducted over the last few years with the use of mineral admixtures or use and development of a cost effective VMA (Bouzoubaâ and Lachemi 2001; Lachemi et al. 2003a,b). Comparative performance of SCCs manufactured with FA, GGBFS and various VMA based on fresh and mechanical properties and also on cost were studied. FA SCC mixtures had cement replacement of 40%, 50% and 60% while GGBFS SCC mixtures had 50%, 60% and 70% replacement. The water-to-cementitious material ratios (w/cm) ranged from 0.35 to 0.45. Three different VMA including Welan gum, a commercial one named as "COM" and a new saccharide based VMA named as "A" were used in VMA SCC mixtures. Tests were carried out on all mixtures to obtain fresh properties such as viscosity and stability as well as mechanical properties such as compressive strength. The influence of percentages of FA or GGBFS, w/cm, dosage of superplasticizer, dosages of air-entraining agent and types of VMA on the properties of SCC was critically reviewed. The results showed that an economical SCC with desired properties could be successfully developed by incorporating FA, GGBFS or VMA.

Three different economical mixtures were identified from FA, GGBFS and VMA based SCC satisfying the targeted strength of 35 MPa (Table 1). These mixtures included FA with 50% replacement, GGBFS with 60% replacement and mix with new VMA "A" having a w/cm of 0.45. It was found that these SCC could replace the control concrete and could be more economical (30-40% in case of FA and GGBFS).

Table 1: Comparative study of strength and cost of Different SCCs

| SCC Types | w/cm | % VMA | Compressive strength (MPa) | | | Cost per $m^3$ ($) |
|---|---|---|---|---|---|---|
| | | | 1 day | 7 day | 28 day | |
| Control | 0.45 | 0.078 | 19 | 30 | 36 | 76.2 |
| VMA-A | 0.45 | 0.062 | 21.5 | 31 | 36.5 | 59.0 |
| GGBFS | 0.45 | 0 | 6 | 26 | 34 | 51.6 |
| FA | 0.45 | 0 | 6 | 17 | 33 | 44.7 |

The new VMA "A" was found to develop a SCC with better fresh and hardened properties and at significantly lower cost compared to its commercial counter parts "COM" and Welan gum (Table 1). Although the VMA SCC with new A-VMA was slightly costlier than those with FA and GGBFS, it was more resistant to segregation and had higher early strength development.

The cost analysis presented in this paper is based on Canadian conditions where FA and GGBFS are locally available. For the places, where FA and GGBFS are not found locally and are to be imported, the cost of FA and GGBFS SCCs may increase significantly. In this circumstance, the use of a SCC with VMA will be highly desirable, as it will need little amount of VMA that can be easily imported if not locally available.

SCC is useful in wide variety of applications using varied mix design. The selection of a mix based only on cost and strength is not suggested. The selection of the mix proportions needs to be made on SCC performance and actual in-place cost. The user should perform durability studies to justify the suitability of the selected SCC mixture for the intended project.

## 5. Conclusions

The challenges associated with the concept of sustainable development can be overcome with the promotion and implementation of new technologies. The concrete industry must become more aware of our diversified and demanding world if it wants to maintain its prosperity in a world market. In addition to consuming a lot of natural resources, the cement industry is very energy consuming. Our infrastructure is deteriorating due to poor quality concrete and new technologies have been hindered due to reductionisms and quick profits. Fortunately, environmental consciousness has infiltrated the concrete industries and many researchers have developed new and exciting technologies including SCC. SCC has become very diversified and effective in developing a program for sustainable development. SCC technology can dramatically reduce harmful $CO_2$ emissions by reducing the production of Portland cement with the increased use of SCM and low w/cm. Natural resources are conserved with SCC structures by incorporating by-products of other industries as well volcanic debris. The use of SCC can increase the durability and increase the life cycle of the structure. The use of concrete will increase in developing countries where environmental consciousness is not so conscious. Developed countries must embrace the concept of sustainable development, implement it and teach the developing countries the advantages of using it.

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