SUSTAINABILITY OF CONCRETE IN CONSTRUCTION

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ABSTRACT

The production of Portland cement, an essential constituent of concrete, leads to the release of a significant amount of CO₂ and other greenhouse gases. There is a need to develop effective approaches for life cycle design and management of constructions that will ensure their sustainability in terms of improved physical performance, cost-effectiveness, and environmental compatibility. Material choice should include anticipation of the extraction, processing, transport, construction, operation, disposal, reuse, recycling, and off gassing and volatile organic compounds (VOCs) associated with the material. There is a need for being concerned about sustainability of concrete and minimizing the CO₂ emission. By using non-potable water, a significant amount of money can be saved. Large-scale mechanization and production of concrete by engineered means can result in efficient cement utilization and hence would lead to sustainability. Use of six components namely, coarse aggregate, fine aggregate, water, OPC cement with mineral admixture/blended cement and plasticizer for production of engineered concrete, instead of non-engineered/semi-engineered concrete can make concrete sustainable.

Keywords: Sustainability, Life Cycle Management, Embodied CO₂.

INTRODUCTION

According to the World Commission on Environment and Development of the United Nations, sustainability means “meeting the needs of the present without compromising the ability of the future generations to meet their own needs”. Sustainability in a broad sense is the ability to preserve a certain process or state over a long period in future.

The sustainability of the cement and concrete industries is imperative to the well being of our planet and to human development. However, the production of Portland cement, an essential constituent of concrete, leads to the release of a significant amount of CO₂ and other greenhouse gases. The environmental issues associated with CO₂ will play a leading role in the sustainable
Development of the cement and concrete industry during this century. One of the biggest threats to the sustainability of the cement industry is the dwindling amount of limestone in some geographical regions. At present developed countries are more concerned about maintenance of existing structure and infrastructures. On the other hand in India, need for new constructions both for housing and for infrastructure sectors, necessitates large-scale use of engineered construction material. Hence, it is not surprising that India is second largest producer (consumer) of cement after China and this production is likely to increase significantly, as the per-capita consumption of cement in India is lower compared to world average per-capita consumption. Concrete production is a significant source of employment also. Therefore, not only to create sustainable societal development but also to sustain employment—such as batch plant operators, truck drivers, iron- workers, laborers, carpenters, finishers, equipment operators, and testing technicians, as well as professional engineers, architects, surveyors, and inspectors—the concrete industry must continue to evolve with the changing needs and expectations of society worldwide.

WHAT IS SUSTAINABILITY FOR CONCRETE INDUSTRY?

Sustainability requires those in the construction industry to consider the entire life cycle—including construction, maintenance, demolition, and recycling of buildings.

A sustainable concrete structure is one that is constructed so that the total societal impact during its entire life cycle is minimal. Designing with sustainability in mind includes accounting for the short-term and long-term consequences of the structure. To decrease the long-term impact of structures, the creation of durable structures is paramount.

Building in a sustainable manner and scheduling appropriate building maintenance are significant in the "new construction ideology" of this new century. In particular, to build in a sustainable manner means to focus attention on the effects on human health, energy conservation, and physical, environmental, and technological resources for new and existing buildings. It is also important to take into account the impact of construction technologies and methods when creating sustainable structures. An integrated sustainable design process can reduce project costs and operating costs of the building or the infrastructure construction.

SUSTAINABLE DESIGN AND LIFE CYCLE MANAGEMENT

To address the challenges faced, there is a need to develop effective approaches for life cycle design and management of constructions that will ensure their sustainability in terms of improved physical performance, cost-effectiveness, and environmental compatibility. These optimized designs and management systems should provide the owners with the solutions that achieve an optimal balance between three relevant and competing criteria.

1. Engineering performance (e.g. safety, serviceability and durability)
2. Economic performance (minimum life cycle costs and minimum user costs)
3. Environmental performance (minimum greenhouse gas emissions, reduced materials consumption, energy efficiency, etc.)

The first two criteria are not new to design professionals but the last criterion changes the entire thinking of design. Life cycle thinking expands the traditional focus on manufacturing processes to incorporate various aspects associated with a product over its entire life cycle. The producer becomes responsible for the products from 'cradle to grave' and has, for instance, to develop
products with improved performance in all phases of the product life cycle. Sustainable design has to consider three major aspects of sustainability, social, economic and environmental.

The following are the design considerations for a sustainable building design:

1. Resources should be used only at the speed at which they naturally regenerate and discarded only at the speed at which local ecosystems can absorb them.
2. Site planning should incorporate resources naturally available on the site such as solar and wind energy, natural shading and drainage.
3. Resource efficient materials should be used in the construction of buildings and in furnishings to lessen local and global impact.
4. Energy and material waste should be minimized throughout the building's life cycle through reuse.
5. The building shell should be designed for energy efficiency considering factors such as day lighting, passive ventilation, building envelope, internal load, local climate, etc.
6. Material and design strategies should produce excellent indoor environmental quality.
7. The design should maximize occupant health and productivity.
8. Operation and maintenance systems should support waste reduction and recycling.
9. Water should be managed as a limited resource.
10. Location and systems should optimize employee commuting and customer transportation options and minimize the use of single-occupancy vehicles. These include using alternative work modes such as telecommuting and teleconferencing.

The above design considerations show that there should be efficient interactions among all the persons involved in the project (client, architect structural engineer, electrical and mechanical engineer, landscape architect, and others) at all stages of project.

**HOW SUSTAINABILITY IS TO BE ACHIEVED?**

Material choice should include anticipation of the extraction, processing, transport, construction, operation, disposal, reuse, recycling, and off gassing and volatile organic compounds (VOCs) associated with the material. Recycling is essential. Make allowance for disassembly and reuse. The life cycle cost analysis process must evaluate energy use and environmental impact during the life of the product, process, or activity. Demolished concrete must be recycled so that it can be readily used in new concrete for aggregates.

Control of this greenhouse gas emission is a major issue for sustainable concrete. Judicious use of cement in optimal fashion thus is a prerequisite for sustainability of concrete. Supplementary cementitious material, especially other industrial byproduct such as blast furnace slag and fly ash in concrete to reduce OPC clinker consumption is currently being considered as a major step towards achieving sustainability of concrete. Mechanized engineered production of aggregate or manufactured aggregate on the other hand, ensures optimal use of parent (rock) resources for aggregate production and also reduces the variability of concrete due to poor aggregate quality. Crusher dust can be suitably used as fine aggregate instead of sand in concrete. For the sustainability of the cement and concrete industries, use less water and Portland cement in concrete production, and use more blended cements and tailor-made organic chemical admixtures.

Furthermore, mixtures with less water should be developed with new technologies to create mortar and concrete containing a minimal amount of water. By using non-potable water, a significant amount of money can be saved. To be as cost-effective as possible, non-potable water for
construction and building uses should be identified early in the planning and designing process. Four ways to use and recycle water are to reuse water on-site for repeated cycles of the same task, treat and reuse water on-site for multiple purposes, use graywater after solids have been eliminated, and collect non portable water from such sources as rainwater, lakes, rivers, and ponds for use in construction.

Energy efficiency, providing the same or more services for less energy, helps to protect the environment. When less energy is used, less energy needs to be generated by power plants, thus reducing energy consumption and production. This in turn reduces GHGs and improves the quality of the air. Energy efficiency also helps the economy by saving costs for consumers and businesses. According to McDonough:

1. Use the thermal inertia of buildings e.g. concrete mass of a building allows it to retain heat
2. Use day lighting and natural ventilation
3. Use wind power and solar power
4. Recycle waste energy
5. Judiciously use colored materials on surfaces
6. Reduce heat islands in buildings
7. Manage and moderate microclimates of buildings

Unlike most of the developed countries, majority of the concrete in India is produced through non-engineered or at best, semi-engineered construction practices. This is obvious from a survey conducted in 2004 that only about 10-11% of cement in India is routed through Ready-Mixed Concrete (RMC) process. For the sake of comparison, USA uses 75 percentage of their total cement through RMC, for Japan this percentage is 70 percent. Non-engineered and semi-engineered construction practice leads to wastage of cement besides resulting in poor quality concrete. Thus large-scale mechanization and production of concrete by engineered means can result in efficient cement utilization and hence would lead to sustainability.

Plasticizing chemical admixtures or Water reducing agent or high range water reducing agent (WRA/HRWRA) can be effectively used in mechanized production of fresh concrete and with 10-30% reduction in water demand, the cement consumption can be reduced by an equal amount in concrete. Modern day second or higher generation plasticizer can reduce the water content by 25-30%. Thus, 12-15% additional saving in total cement consumption can be expected when these materials are used in concrete production in a large scale.

Extensive use fly ash, ground granulated blast furnace slag (ggbfs) either through direct use in RMC or through use of Portland Pozzolana (PPC) and Portland Slag Cements can reduce OPC clinker consumption to a significant extent. This has multi fold benefits, namely reduction in OPC consumption resulting in reduction in environmental hazard and also, reduction in production of green house gas CO₂, besides ensuring better durability for concrete. Assuming on an average 30% [F/(C+F)] fly ash in total cementitious materials, it can be shown that, these results in a saving of at least 20% clinker. High volume fly ash concrete, concrete with activated blast furnace slag, geopolymer concretes are the other developments in recent times that can lead to better sustainability of concrete.

**CONCRETE**

For more than 200 years, concrete has been accepted for its long-lasting and dependable nature. In addition to durability and dependability, concrete also has superior energy performance, is flexible in design and is affordable. It can be expected that concrete will be needed to increase
industrialization and urbanization while protecting the environment. Sustainable concrete must be durable. Service life allows for quantification of durability. To do this, the concrete industry should consider recycling and reusing industrial by-products such as fly ash safely and economically without any waste left for disposal. Use of fly ash and ground granulated blast furnace slag (ggbfs) also enhances the service life largely by making the concrete impervious and by increasing the electrical resistivity of concrete. When industrial by-products replace cement, even up to 70%, in concrete, the environmental impact improves along with the energy efficiency and durability of concrete.

Acceptable limit of the degradation is defined in terms of suitable serviceability limits. At the end of the service life an element would demand repair and rehabilitation or replacement. Repairs or replacement implies additional effort, energy and disruption of primary activity for which the structure was constructed. Inspection is also a part of maintenance and repair. Durable design of concrete structure, based on service life, is still in its infancy because of lack of adequate understanding of the degradation phenomena. Mechanization and adoption of stringent quality adherence scheme can increase the service life of elements and ensure better sustainability. One example of the advantage of sustainable concrete is buildings constructed with concrete that have reduced maintenance and energy costs. Another is a concrete highway, which reduce the fuel needed for heavily loaded trucks.

Volumetric thermal capacity and thermal diffusivity of concrete is relatively but Concrete produced amounted to 1 m\(^3\) per person. Thus, even though concrete has low embodied energy per unit mass, yet it contributes to maximum embodied energy. The cement and concrete industries could contribute to meeting the goals and objectives of the 1997 Kyoto Protocol. Among other things, the Kyoto Protocol requires meeting a target of reduction in GHGs to the 1990 level. It is estimated that about 28 billion t of CO\(_2\) were emitted worldwide in 2004, with significant portions emitted by the United States \(\star\) 22%, China \(\star\) 18%, E.U. \(\star\) 11%, Russia \(\star\) 6%, India \(\star\) 5%, and Japan \(\star\) 5%. Those involved with the manufacture of portland cement would have a huge impact on the sustainable development of the concrete industry as a whole, because in 2004 cement production contributed about 7% of worldwide GHGs primarily CO\(_2\); or about 2 billion t of GHGs. Concrete producers are creating sustainable solutions for many market sectors, including agriculture and construction.

**PORTLAND CEMENT**

Portland cement is not an environmentally friendly material, because its manufacture creates greenhouse gas emissions; it also reduces the supply of good quality limestone and clay. The manufacture of Portland cement is the third most energy-intensive process, after aluminum and steel manufacture. In fact, for each metric ton of Portland cement, about 5-1/2 million BTU of energy are needed. Higher the energy used in making of a material, the more its contribution to anthropogenic CO\(_2\). Embodied energy is defined as the available energy that was used in the work of making a product, higher embodied energy thus contributes to global warming and hence acts against preservation of environment and ecological balance. A sustainable material therefore shall have low embodied energy. Cement production additionally contributes to CO\(_2\) emission because of calcinations of limestone during production of cement. CaCO\(_3\) is calcined to CaO and CO\(_2\) is released. Both embodied energy and direct emission contribute to total CO\(_2\) emissions. Total amount CO emitted per ton of cement production reported by various researchers vary from one another, and ranges from 0.74 ton to 1.24 ton.
One of the most significant changes to reduce the embodied energy is the replacement of wet production facilities with dry processing plants. In addition, the cement industry has also moved away from petroleum-based fuel use.

Despite these advances, some shortcomings still exist when energy use is evaluated for the concrete industry. Dry process cement plants use preheaters, which increase the alkali content of cement. Thus, cement producers need to continue to develop ways to control the alkali content without increasing the energy consumption levels of the cement.

We must use more blended cements to reduce the need for portland cement clinker per metric ton of blended cement produced by blending with the clinker other PMs, such as coal or wood fly ash, slag, silica fume, finely ground waste glass. As a cement production feed material, instead of clay, industrial by-products such as used foundry sand or coal combustion products CCPs such as fly ash should be used in the optimum possible quantity.

The most energy-intensive stage of Portland cement production is during clinker production. It accounts for all but about 10% of the energy use and nearly all of the GHGs produced by cement production. Kiln systems evaporate inherent water from the raw meal and calcinate the carbonate constituents during clinker preprocessing.

Sources of CO\textsubscript{2} and GHG emissions in the manufacturing of Portland cement are as follows:

1. From calcinations of limestone * 50–55%.
2. From fuel combustion * 40–50%.
3. From use of electric power * 0–10%.

To produce 1 t of Portland cement, 1.6 t of raw materials are needed. These materials include good quality limestone and clay. Therefore, to manufacture the current worldwide production of 2.5 billion t of cement annually, at least 4 billion t of raw materials are needed.

INNOVATIVE CEMENT PRODUCTS

A number of characteristics apply to innovative concrete products. First, they are produced with precast or cast-in-place reinforced concrete elements that are made with Portland cement and pozzolanic materials that include renewable and recycled components. Second, innovative concrete products are constructed to enhance the performance of concrete elements, which may also contain recycled concrete as aggregates. High-performance materials are intended to reduce cross sections and the volume of concrete produced. They are also intended to increase the durability of concrete structures to minimize the maintenance needs of the concrete construction and limit the amount of nonrenewable special repair materials that need to be used in maintaining the concrete.

Although the embodied energy linked to concrete production is low, PMs, especially coal fly ash, have been used by the concrete industry for more than 70 years. Their use can contribute to a further reduction of concrete’s embodied energy.

One of the processes that is even more environmental friendly and productive, is the use of blended cements. Blended cements are made when various amounts of clinker are blended or inter ground with one or more additives, including fly ash, natural pozzolans, slag, silica fume, and other PMs. Blended cements allow for a reduction in the energy used and reduce GHG emissions. The advantages of blended cements include increased production capacity, reduced GHG emissions, reduced fuel consumption in the final cement production, and recycling of PMs.

We must employ environmentally friendly materials to reduce the use of Portland cement by replacing a major part of portland cement with PMs for use in concrete. In the United States, such
materials, primarily fly ash, slag, silica fume, natural pozzolans, rice-husk ash, wood ash, and agricultural products ash are available for up to 70% replacement. All these materials can be used to supplement the use of cement in concrete mixtures while improving the concrete product durability. With replacement of cement with other recyclable resources, worldwide CO₂ emissions would be reduced. A replacement of 50% of cement worldwide by other cementitious materials would reduce CO₂ emissions by more than 1 billion t. This is equivalent to removing approximately one-quarter of all automobiles in the world.

WASTE MATERIALS

Engineers should reuse industrial by-products and postconsumer wastes in concrete and other cement-based construction materials. Postconsumer wastes in concrete include glass, plastics, tires, demolished concrete, and clay bricks. To do this successfully, designers must watch for harmful hydration reactions of Portland cement and changes in the volume of concrete. The recycling of industrial by-products has been well established in the cement and concrete industries over the past several decades. The use of coal fly ash in concrete began in the 1930s, but volcanic ash has been used in mortar and primitive concrete for several millennia in Egypt, Italy, Mexico, and India.

CONCLUSION

The discussions presented above leads to the conclusion that there is a need for being concerned about sustainability of concrete and minimizing the CO₂ emission. There is also a need to minimize wastage of precious natural resources by making their efficient and judicious use. This is possible by large-scale mechanization of concrete construction in the country through extensive use of batching plant, RMC practices and prefabrication wherever possible. Further use of six components namely, coarse aggregate, fine aggregate, water, OPC cement with mineral admixture/blended cement and plasticizer for production of engineered concrete, can make concrete sustainable in India.

REFERENCES

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