

*These columns of ICJ offer an opportunity to the engineering fraternity to express their views on the current practices in design, construction and management being followed in the industry.*

*To share your opinion with our readers, you may send in your inputs in about 1500 words via e-mail to editor@icjonline.com*

## What is Green Concrete?

Karthik H. Obla

Engineers and architects have choices of the material and products they use to design projects – when it comes to a building frame the choice is typically between concrete, steel and wood; for paving applications the choice is generally between concrete and asphalt. Material choice depends on several factors including first cost, life cycle cost and performance for a specific application. Due to growing interest in sustainable development engineers and architects are motivated more than ever before to choose materials that are more sustainable. However this is not as straight forward as selecting an energy star rated appliance or a vehicle providing high gas mileage.<sup>1</sup> On what “measurement” basis can engineers and architects compare materials and choose one that is more sustainable or specify a material in such a way as to minimize environmental impact?

Life Cycle Assessment (LCA) seems to offer a solution. LCA considers materials over the course of their entire life cycle including material extraction, manufacturing, construction, operations, and finally reuse/recycling. LCA takes into account a full range of environmental impact indicators – including embodied energy, air and water pollution (including greenhouse gases), potable water consumption, solid waste and recycled content. just to name a few. Building rating systems such as LEED and Green Globes, are in various stages of incorporating LCA so that they can help engineers and architects select materials based on their environmental performance or specify materials in such a way as to minimize environmental impact.<sup>2,3</sup>

One potential drawback of LCA however is that the person conducting the analysis often has discretion to set

which environmental impact indicator is most important. And often times conducting a full LCA is so complex that only a partial LCA is conducted with a focus on one or two phases of the life cycle. Recent focus on climate change and the impact of greenhouse gas emissions on our environment has caused many to focus on CO<sub>2</sub> emissions as the most critical environmental impact indicator. The problem with this approach is that it forces engineers, architects and product manufacturers to focus their efforts on reducing greenhouse gas emissions without regard to other sustainable practices.

### Concrete and CO<sub>2</sub>

Every 1 ton of cement produced leads to about 0.9 tons of CO<sub>2</sub> emissions and a typical cubic yard (0.7643 m<sup>3</sup>) of concrete contains about 10% by weight of cement.<sup>4</sup> There have been a number of articles written about reducing the CO<sub>2</sub> emissions from concrete primarily through the use of lower amounts of cement and higher amounts of supplementary cementitious material (SCM) such as fly ash and slag. Table 1 has been developed based on data presented by Marceau *et al.*<sup>5</sup>

The following observations can be made:

Since a cubic yard of concrete weighs about 2 tons, CO<sub>2</sub> emissions from 1 ton of concrete varies between 0.05 to 0.13 tons.

Approximately 95% of all CO<sub>2</sub> emissions from a cubic yard of concrete is from cement manufacturing and so it is no wonder that much attention is paid to using greater amounts of SCM.

**Table 1. Total CO<sub>2</sub> emissions for 1 cubic yard (yd<sup>3</sup>)<sup>+</sup> of concrete for different strength classes and mixture proportions<sup>5</sup>**

Ready mix Id	Strength class, psi (kgf/cm <sup>2</sup> )	Mixture proportions*, lb/yd <sup>3</sup> (kg/m <sup>3</sup> )	Total concrete CO <sub>2</sub> emission, lb/yd <sup>3</sup> (kg/m <sup>3</sup> )	Breakdown of CO <sub>2</sub> Emissions for 1 yd <sup>3</sup> , % (0.76455 m <sup>3</sup> )				
				Cement	SCM	Aggregate	Plant operations	Transport <sup>#</sup>
1	5000 (351)	564/0/0 (335/0/0)	528 (313)	96.8%	0.0%	0.6%	0.6%	2.0%
2	4000 (281)	470/0/0 (279/0/0)	442 (262)	96.3%	0.0%	0.7%	0.7%	2.3%
3	3000 (210)	376/0/0 (223/0/0)	355 (211)	95.7%	0.0%	0.9%	0.8%	2.6%
4	3000 (210)	301/75/0 (179/44/0)	288 (171)	94.6%	0.0%	1.1%	1.0%	3.2%
5	3000 (210)	282/94/0 (167/56/0)	270 (160)	94.3%	0.0%	1.2%	1.1%	3.4%
6	3000 (210)	244/0/132 (145/0/78)	239 (142)	92.4%	1.2%	1.4%	1.2%	3.9%
7	3000 (210)	188/0/188 (111/0/111)	189 (112)	89.8%	2.1%	1.7%	1.6%	4.9%

\*564/0/0 signifies that the mixture contains 564 lb/yd<sup>3</sup> cement, 0 lb/yd<sup>3</sup> fly ash, 0 lb/yd<sup>3</sup> slag cement

<sup>#</sup>Transport costs is for material shipped to ready mix plant

<sup>+</sup> 1 yd<sup>3</sup> = 0.76455 m<sup>3</sup>

However, focusing entirely on CO<sub>2</sub> emissions will result in the following unintended consequences:

1. Does not encourage the use of recycled or crushed returned concrete aggregates since use of virgin aggregates constitutes only 1% of all CO<sub>2</sub> emissions from a typical cubic yard of concrete. Even replacing all virgin aggregates with recycled aggregates will reduce CO<sub>2</sub> emissions by only 1%. But the use of recycled aggregates is important as it can reduce landfills and support sustainable development. So, there is a need to incentivise its use. Several local governments are requiring less land filling and making land filling more expensive. Also prescriptive specification restrictions on the use of recycled aggregates should be removed. Focus on performance will encourage producers to recycle.
2. Does not encourage the use of water from ready mixed concrete operations (water used for cleaning ready mixed concrete trucks, and precipitation at a plant) since use of mixing water constitutes a negligible amount (<<1%) of all CO<sub>2</sub> emissions from a typical cubic yard of concrete. Use of recycled water should be encouraged since fresh water is becoming increasingly scarce. This can be accomplished by removing specification restrictions that require the use of only potable

water and instead specify water according to ASTM C1602 which allows non potable water and water from ready mixed concrete operations as long as concrete performance data is maintained and met.<sup>6</sup>

3. Does not encourage the use of sustainable practices such as energy savings at a ready mixed concrete plant since CO<sub>2</sub> emissions from plant operations constitutes only 1% of all CO<sub>2</sub> emissions from a cubic yard of concrete.
4. Does not encourage the use of sustainable practices such as energy savings during transport of the materials to the ready mixed concrete plant since CO<sub>2</sub> emissions from transport constitutes only about 3% of all CO<sub>2</sub> emissions from a cubic yard of concrete.

As discussed earlier LCA considers materials over the course of their entire life cycle – material acquisition, manufacturing, construction, operation, and reuse/recycling. However, partial LCA may focus on CO<sub>2</sub> emissions on the material acquisition and manufacturing stage. It does not address the Construction, Operation, and Reuse/Recycling portions of the LCA. Operationally concrete is a very sustainable material – it has several advantages such as long term durability, high solar reflectivity (lower heat island effect), and high thermal

mass (lowers energy consumption). It is almost entirely recyclable. It can absorb CO<sub>2</sub> from the atmosphere during its service life and after it is crushed for recycling. It can be used in applications such as pervious concrete that can reduce storm water runoff and recharge ground water.

It is important to keep a holistic cradle to cradle perspective when it comes to the use of a material. Based on research Gajda *et al.*<sup>7</sup> concluded that occupant energy-use accounts for 99% of life cycle energy use of a single family home. Less than 1% of the life cycle energy used in that home was due to manufacturing cement and producing concrete. When taken as a whole the U.S. cement industry accounts for approximately 1.5% of U.S. CO<sub>2</sub> emissions. The global cement industry accounts for approximately 5% of global CO<sub>2</sub> emissions.<sup>8</sup> So whatever way one looks at it focusing on just the production of concrete accounts for a very small percent of overall CO<sub>2</sub> emissions. This is not to say that progress should not be made in reducing the CO<sub>2</sub> emissions from concrete as produced. However one should keep in mind that whatever CO<sub>2</sub> emission reductions that are possible will still account for at best a 2% global CO<sub>2</sub> reduction (assuming a challenging 40% reduction in global CO<sub>2</sub> emissions from cement manufacture from now on).

## Summary

1. CO<sub>2</sub> emissions from 1 ton of concrete produced vary between 0.05 to 0.13 tons. 95% of all CO<sub>2</sub> emissions from a cubic yard of concrete is from cement manufacturing. It is important to reduce CO<sub>2</sub> emissions through the greater use of SCM.
2. It is important not to focus solely on CO<sub>2</sub> emissions from cement and concrete production. Doing so limits the total global CO<sub>2</sub> reduction possible to at best 2%. Keeping a holistic cradle to cradle perspective and using LCA can help reduce CO<sub>2</sub> by a much greater amount since there is evidence to show that most of the energy is consumed during the operational phase of the structure (heating and cooling). Concrete is very effective in reducing energy consumption due to its high solar reflectivity, and high thermal mass among other benefits.
3. Focusing solely on CO<sub>2</sub> emissions from cement and concrete production increases the perception that concrete is not sustainable which is inaccurate since operationally concrete has substantial sustainability benefits. An incorrect perception can lead to a less sustainable material choice (for example a steel frame building or an asphalt roadway).
4. Focusing solely on CO<sub>2</sub> emissions from cement and concrete production does not encourage the use of recycled or crushed returned concrete aggregates; use of water from ready mixed concrete operations; use of sustainable practices such as energy savings at a ready mixed concrete plant and use of sustainable transport practices. This is because only 5% of CO<sub>2</sub> emissions from a cubic yard of concrete is due to use of virgin aggregates, water, plant operations and material transport to the plant.
5. Removal of prescriptive specification restrictions and focusing on performance and the use of incentives is an effective way to encourage sustainable concrete with low CO<sub>2</sub> emissions.

## References

1. <http://www.energystar.gov/>
2. Leadership in Energy and Environmental Design (LEED), U.S. Green Building Council, Washington, DC, <http://www.usgbc.org/>
3. Green Globes, The Green Building Initiative, Portland, Oregon, <http://www.thegbi.org/>
4. Concrete CO<sub>2</sub> Fact Sheet, 2PCO<sub>2</sub>, 13 pp., June 2008, National Ready Mixed Concrete Association, Silver Spring, MD, [www.nrmca.org](http://www.nrmca.org)
5. Medgar L. Marceau, Michael A. Nisbet, and Martha G. VanGeem, Life Cycle Inventory of Portland Cement Concrete, SN3011, Portland Cement Association, Skokie, IL, PCA, 2002, [www.cement.org](http://www.cement.org)
6. ASTM C1602 / C1602M - 06 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete, American Society of Testing Materials, Volume 4.02, [www.astm.org](http://www.astm.org).
7. Gajda, John, Van Geem, Martha G., and Marceau, Medgar L., Environmental Life Cycle Inventory of Single Family Housing, SN2582a, Portland Cement Association, Skokie, IL, PCA, 2002, [www.cement.org](http://www.cement.org)
8. Ernst Worrell, Lynn Price, C. Hendricks, L. Ozawa Meida, Carbon Dioxide Emissions from the Global Cement Industry, Annual Review of Energy and Environment, Vol. 26, 2001 <http://industrial-energy.lbl.gov/node/1930>



**Dr. Karthik Obla, P.E.**, received his Ph.D. in civil engineering from University of Michigan, Ann Arbor and is a licensed professional engineer in the state of Michigan and Maryland. Presently, he is the managing director, Research and Materials Engineering at the National Ready Mixed Concrete Association (NRMCA). He has over 18 years of experience in concrete materials technology and research and has interests in mixture proportioning, durability, quality control, specifications, and the use of recycled materials. He is a Fellow of ACI and a winner of ACI's Young Professional Achievement Award. Dr. Obla is an active member of various ACI, ASTM, and TRB technical committees and serves as Chair for ASTM C09.49 – Pervious Concrete and ACI 232 – Fly ash. He served as Vice-President and President for the ACI San Antonio Chapter. Prior to joining NRMCA in 2003 he was technical manager at Boral Material Technologies for several years. ■