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What is Green Concrete?

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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[1] rated appliance or a vehicle providing high gas mileage. 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[2] and Green Globes[3], 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.

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_2 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_2

Every one ton of cement produced leads to about 0.9 tons of CO_2 emissions and a typical cubic yard of concrete contains about 10% by weight of cement[4]. There have been a number of articles written about reducing the CO_2 emissions from concrete primarily through the use of lower

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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.[5].

Following observations can be made:

Since a cubic yard of concrete weighs about 2 tons, CO_2 emissions from 1 ton of concrete varies between 0.05 to 0.13 tons.

Approximately 95% of all CO_2 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.

However, focusing entirely on CO_2 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_2 emissions from a typical cubic yard of concrete. Even replacing all virgin aggregates with recycled aggregates will reduce CO_2 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 incentivize 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_2 emissions from a typical cubic yard of concrete. Use of recycled water should be encouraged since fresh water is becomingly 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[6], which allows non potable water and water from ready mixed concrete operations as long as concrete performance data is maintained and met.
3. Does not encourage the use of sustainable practices such as energy savings at a ready mixed concrete plant since CO_2 emissions from plant operations constitutes only 1% of all CO_2 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_2 emissions from transport constitutes only about 3% of all CO_2 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_2 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_2 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 stormwater runoff and recharge ground water.

It is important to keep a holistic cradle to grave perspective when it comes to the use of a material. Based on research Gajda et al.[7] 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_2 emissions. The global cement industry accounts for approximately 5% of global CO_2 emissions[8]. So whatever way one looks at it focusing on just the production of concrete accounts for a very small percent of overall CO_2 emissions. This is not to say that progress should not be made in reducing the CO_2 emissions from concrete as produced. However one should keep in mind that whatever CO_2 emission reductions that are possible will still account for at best a 2% global CO_2 reduction (assuming a challenging 40% reduction in global CO_2 emissions from cement manufacture from now on).

Table 1. Total CO_2 Emissions for 1 cubic yard (yd^3) of Concrete for Different Strength Classes and Mixture Proportions[5]

Ready Mix ID	Strength Class, psi	Mixture Proportions*, lb/yd^3	Total Concrete CO_2 emission, lb/yd^3	Breakdown of CO_2 Emissions for 1 yd^3, %				
				Cement	SCM	Aggregate	Plant Operations	Transport#
1	5000	564/0/0	528	96.8%	0.0%	0.6%	0.6%	2.0%
2	4000	470/0/0	442	96.3%	0.0%	0.7%	0.7%	2.3%
3	3000	376/0/0	355	95.7%	0.0%	0.9%	0.8%	2.6%
4	3000	301/75/0	288	94.6%	0.0%	1.1%	1.0%	3.2%
5	3000	282/94/0	270	94.3%	0.0%	1.2%	1.1%	3.4%
6	3000	244/0/132	239	92.4%	1.2%	1.4%	1.2%	3.9%
7	3000	188/0/188	189	89.8%	2.1%	1.7%	1.6%	4.9%

*564/0/0 signifies that the mixture contains 564 lb/yd^3 cement, 0 lb/yd^3 fly ash, 0 lb/yd^3 slag cement

#Transport costs is for material shipped to ready mix plant

Summary

1. CO_2 emissions from one ton of concrete produced vary between 0.05 to 0.13 tons. 95% of all CO_2 emissions from a cubic yard of concrete is from cement manufacturing. It is important to reduce CO_2 emissions through the greater use of SCM.
2. It is important not to focus solely on CO_2 emissions from cement and concrete production. Doing so limits the total global CO_2 reduction possible to at best 2%. Keeping a holistic cradle to cradle perspective and using LCA can help reduce CO_2 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_2 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_2 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_2 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_2 emissions. ■

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