neu
An ACI Center of Excellence for Carbon Neutral Concrete

LOW-CARBON CONCRETE MATERIALS

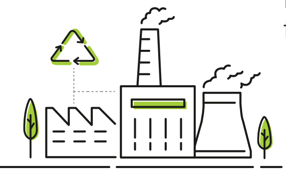
Low-Carbon Concrete Materials Available to Reduce CO_2 Emissions of Concrete Used in Your Project

Concrete plays a critical role in civilized society and is used extensively in our buildings, highways, bridges, and other infrastructure. This is because it is a versatile material that offers a safe, durable, and resilient solution at an efficient cost and it cannot be easily replaced with another building material.

After water, concrete is the most used material on the planet. Because of this, concrete is often cited as having a significant impact on CO_2 emissions. The good news is that the concrete industry is in an excellent position to improve upon this area, and wise use of concrete can make a significant contribution to the achievement of sustainable development goals.

Many solutions exist to produce low-carbon concrete. One such solution is the increased use of supplementary cementitious materials (SCMs) and alternative cements. These materials, including fly ash, slag cement, silica fume, ground glass pozzolan, metakaolin, and portland limestone cement, are available today, permitted by existing specifications and building codes, and have been successfully used in real world projects — a few of which are discussed in this brochure.

Fly Ash

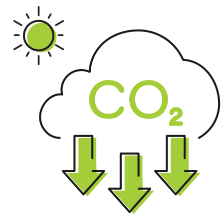


Fly ash is an industrial byproduct of coal combustion, typically from power plants, and is a powdered material that is the most widely used SCM in concrete due to performance, availability, and economic factors. You may also hear it referred to generically as coal ash or harvested fly ash.

How does fly ash contribute to a lower carbon footprint of concrete? Fly ash can be used as a partial substitution for portland cement, which has a significantly higher CO_2 footprint. Replacement amounts typically range from 15% to 40% without compromising the beneficial properties of the concrete. Thus, the use of fly ash has a direct impact in reducing the carbon footprint of concrete. In specific applications, as much as 70% of the portland cement can be replaced with fly ash. Also, adding fly ash has the addiitonal benefit of improving the long-term durability of concrete, leading to more sustainable construction.

Harvested Fly Ash

Harvested fly ash is fly ash that was previously placed in landfills or impoundments for disposal and has now been collected and processed. Harvested ash can be used in place of fresh fly ash when fresh fly ash is not available. It is used in much the same way as fresh fly ash, but may require additional processing, referred to as beneficiation, before use.



How does harvested fly ash contribute to a lower carbon footprint of concrete? Harvested fly ash can replace some of the portland cement in a concrete mixture similar to fresh fly ash, thereby reducing the carbon footprint.

Slag Cement

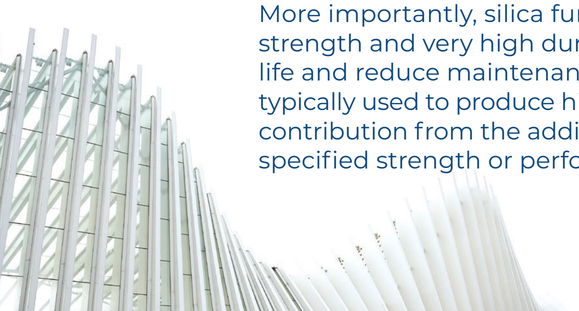
Slag cement, a binder material produced by grinding ground-granulated blast-furnace slag (GGBFS), is a byproduct from the iron and steel industry. In some cases, blended cements are made by combing slag cement with portland cement. Slag cement has been used in concrete projects in the United States for over a century. Earlier usage of slag cement in Europe and elsewhere has demonstrated that long-term performance is enhanced in many ways.

How does using slag cement contribute to a lower carbon footprint of concrete? Slag cement can replace some of the portland cement in a concrete mixture, thereby reducing the carbon footprint. Slag cement can be used at a replacement level ranging from 25% to 80%. For general construction, this is typically between 25% to 50% and in some specific applications this can go up to 80%. In addition, improved durability characteristics of concrete when slag cement is used can increase the life cycle and reduce maintenance or repair, thereby further reducing the CO_2 footprint of concrete in your project.

Silica Fume

Silica fume is a recovered byproduct material formed when producing silicon and ferrosilicon metal in open-arc electric furnaces, where quartz, coal, wood chips, and other furnace burden materials are reduced to extract the silicon products from the quartz. It may be added directly to concrete as an individual ingredient or blended with portland cement. Silica fume is commonly used in combination with fly ash or slag cement, further reducing the CO_2 footprint of the concrete.

How does silica fume contribute to a lower carbon footprint of concrete? Silica fume can be used in quantities typically ranging from 5% to 15% by mass of the total amount of cementitious material in the concrete and thus can contribute to lowering the amount of portland cement used in concrete. More importantly, silica fume has been used to produce concrete with enhanced compressive strength and very high durability. Therefore, using silica fume in concrete can increase the useful life and reduce maintenance or replacement requirements. Higher amounts of silica fume are typically used to produce high-strength concretes, and the concrete producer may use the strength contribution from the addition of silica fume to offset the amount of cement needed to produce the specified strength or performance.



Ground Glass Pozzolan

Ground glass pozzolan is made from consumer and industrial glass waste streams. It is a relatively new SCM compared to fly ash, slag, or silica fume. Most of the markets for waste glass involve the need for comminution (size reduction), size separation, and color separation.

How does ground glass pozzolan contribute to a lower carbon footprint of concrete? Glass used to make the pozzolan is a waste material that would typically be landfilled. It can be used to replace some of the portland cement in a concrete mixture, and thus the CO_2 footprint of concrete is reduced. Ground glass pozzolan is typically used at replacement levels between 10% and 40% of total cementitious materials by mass. Many studies have shown that this SCM helps to increase the strength and durability of concrete.

Metakaolin

Metakaolin is a natural pozzolan (found in nature and originating from magma within the earth) produced by heat-treating kaolinite clays. The use of metakaolin in concrete has grown rapidly since the mid-1980s. Natural pozzolans in most cases will act like certain fly ashes.

How does metakaolin contribute to a lower carbon footprint of concrete? Metakaolin can replace some of the portland cement in a concrete mixture, thereby reducing the carbon footprint. It is typically used at replacement levels between 5% and 15% of total cementitious materials content by mass. Metakaolin is used in applications where high strength is required, and to improve the durability of concrete.

Portland Limestone Cement (PLC)

Portland limestone cement (PLC) or Type IL blended cement is a portland cement that has between 5% and 15% portland cement replaced with finely ground limestone by mass. It performs similar to portland cement in concrete and therefore can be exchanged with portland cement at a 1:1 replacement level. PLC has been used in concrete around the world for decades.

How does PLC contribute to a lower carbon footprint of concrete? With a portion of the portland cement replaced with limestone in PLC, it can typically result in a carbon footprint reduction of 10%. With optimization by a cement plant, up to 15% limestone can be used in a PLC which can reduce the CO_2 footprint by up to 15%. Also, concrete mixtures designed with PLC are compatible with commonly used SCMs. Thus, using PLC along with other SCMs can contribute to an even greater reduction in carbon footprint.

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Can we use SCMs and alternative cements effectively?

Design experts have successfully used fly ash, slag cement, silica fume, ground glass pozzolan, metakaolin and PLC in concrete in the past as demonstrated in many real-world applications. More importantly, in many cases these materials have been used to improve the overall quality of concrete while reducing carbon footprints. And the beauty of most of these materials is that they can be used in conjunction with other materials to produce concrete with greater performance.

As with any concrete mixture, it is important to note that when SCMs and alternatives cements are used, performance in concrete may be affected by the quality and performance of other constituents of the mixture and the environment conditions. It is therefore advisable that actual performance in concrete be determined by testing with trial batches. When correctly proportioned, concrete that contains SCMs and/or alternative cements may perform similarly or even exceed specified performance in some cases while significantly lowering the embodied carbon.

EXAMPLES OF PROJECTS THAT USED SCMS TO REDUCE CO_2 EMISSIONS OF THE CONCRETE

Burj Khalifa, Dubai

Photo: Tayssir Kadamany

- 8700 psi (60 MPa) piling concrete
- Compressive strength (56 days): 10,880 psi (75 MPa)
- 70,000m^3, self-consolidating concrete
- Cementitious Binder: 660 lb/yd^3 (390 kg/m^3) of 56% moderate sulphate resistant portland cement/ 37% fly ash/7% silica fume
- Carbon Reduction: 13,810 tons (12,530 tonnes) of CO_2eq

More at: https://bit.ly/3ZINmJ6

One World Trade Center, NY

Photo: Pixabay

- Compressive strength: 12,000 psi (83 MPa) @ 56 days
- Over-design for safety: 1,900 psi (13 MPa)
- Port Authority of New York/New Jersey Requirements:
  - Quantity of portland cement in the mixture: Less than 400 lb/yd^3 (240 kg/m^3)
- Concrete mixture with up to 71% portland cement replacement using fly ash, slag cement and silica fume
- Greenhouse gas emissions savings: 17,400 tons (15,790 tonnes) CO_2eq

More at: https://bit.ly/3rI0emm

432 Park Avenue, NY

Photo: Timon Cornelissen

- High performance, white concrete
- 56-day compressive strength: 14,000 psi (96 MPa) for the lower floors, and 10,000 psi (69 MPa) for the upper floors
- Sustainable mixture with 70% replacement of portland cement with fly ash, slag cement and metakaolin.
- Greenhouse gas emissions savings: 10,560 tons (9,580 tonnes) CO_2eq

More at: https://bit.ly/48ExPy5

Salesforce Tower Chicago, IL

Photo: Bradley Pfanenstiel

- 850-ft (259-m) tall high-rise building in Chicago
- 3rd-party-verified EPDs specified for all concrete mixtures.
- Substantial reduction of carbon emissions from industry baselines.
- Project utilized 15 mixes, including straight PLC mixes, binary, ternary, and quaternary mixes.
- Portland Limestone Cement: 50%-100%
- Slag cement replacement: 19%-30%
- Fly ash: 10%-27%
- Silica fume 2%-4%
- Strength development for mixes more than 10,000 psi (70 MPa)

More at: https://bit.ly/3RHH1vI