An ACI Center of Excellence for Carbon Neutral Concrete

CASE STUDY: BURJ KHALIFA

DUBAI, UNITED ARAB EMIRATES

Towering 828 meters above Dubai, the Burj Khalifa, the world's tallest building, is a marvel of design and engineering innovation that has redefined the limits for skyscraper construction. Part of this innovation can be attributed to the use of silica fume and other supplementary cementitious materials in concrete to reduce the carbon footprint of the immense structure. The tower's design combines local cultural influences with cutting-edge technology to achieve high performance and sustainability in an extreme desert climate.

Common practice of concrete requires Ordinary Portland Cement (OPC) to make it work. The amount of OPC needed per cubic meter of concrete varies depending on the situation, strength, and other requirements. The process of making cement produces a substantial amount of CO_2, about 900 kg/tonne (1800 lbs/ton). Billions of tonnes of cement are produced each year, so concrete production is a major source of CO_2 emissions.

A promising way to reduce the environmental impact of concrete production is to replace a portion of OPC in the concrete mix with supplementary cementitious materials (SCMs). SCMs are inorganic material such as silica fume (SF), fly ash (FA), or slag cement (Slag) that reacts pozzolanically or hydraulically.

Silica fume is a very fine powder that is produced as a byproduct of the production of silicon metal and ferrosilicon. Fly ash is a fine mineral residue that is produced from coal-fired power plants. Slag cement, also known as ground granulated blast furnace slag (GGBS), is a finely ground ferrous slag that is produced from steel production. These SCMs are well known for their ability to improve the properties of concrete, such as its strength, durability, and resistance to water penetration. The use of SCMs is a key method to reduce the environmental impact of concrete production. By using SCMs, we can produce concrete that is both sustainable and high-performance.

The use of SCMs can significantly reduce the CO_2 emissions associated with concrete production. For example, silica fume produces only about 15 kg of CO_2 per tonne (30 lbs/ton) of product, while fly ash produces around 100 kg of CO_2 per tonne (200 lbs/ton) and slag cement produce around 150 kg of CO_2 per tonne (300 lbs/ton) of product.

Ternary and quaternary blends of SCMs with OPC are frequently used in major projects. Typical ranges of ternary blends are OPC with 5 to 15% silica fume and either 20-50% fly ash or 40-80% slag. These blends can provide even greater reductions in CO_2 emissions, while still maintaining the performance of the concrete. **For example, by changing from a pure OPC based concrete to a well-blended SCM mix design, the carbon footprint can be reduced from about 400 kg CO_2/m^3 (674 lbs/yd^3) to around 250 kg/m^3 (421 lbs/yd^3).**

A good comparison is to consider a standard designed **28 MPa** (4000 psi) concrete with a cement content of 297 kg/m^3 (500 lbs/yd^3) with a carbon footprint of around **300 kg/m^3** (506 lbs/yd^3) to the carbon footprint of the Burj Khalifa project. The **Binder Efficiency** of this 4,000 psi mix is **8 psi/lb**.

The Burj Khalifa is a great example that silica fume and other SCMs can be successfully used to produce concrete with great performance while still achieving sustainability in the environment.

ENVIRONMENTAL IMPACTS

- **Carbon Footprint: 231 kg/m³** (389 lbs/yd³); If the mix was pure OPC, this would be 410 kg/m³ (691 lbs/yd³)
- **For 70,000m³ (91,557 yd³), this gives a reduction of 12,530 tonnes (13,812 tons).**

PROJECT TEAM

Architect: Skidmore, Owings & Merrill of Chicago

Concrete Contractor: Hyder Consulting

Concrete Producer: Samsung C&T of South Korea, BESIX

PRODUCTS USED

Concrete	60MPa piling concrete, 70,000m³ (91,557 yd³), self-consolidating concrete, high resistance to sulfates and chlorides.
Cementitious Binder	390 kg/m³ (657 lbs/yd³) of 56% moderate sulfate-resisting portland cement / 7% silica fume / 37% fly ash.
Compressive Strength [56 Days]	75MPa (10,920psi)
Binder Efficiency	16.6 psi/lb.

Project information provided courtesy of Ferroglobe