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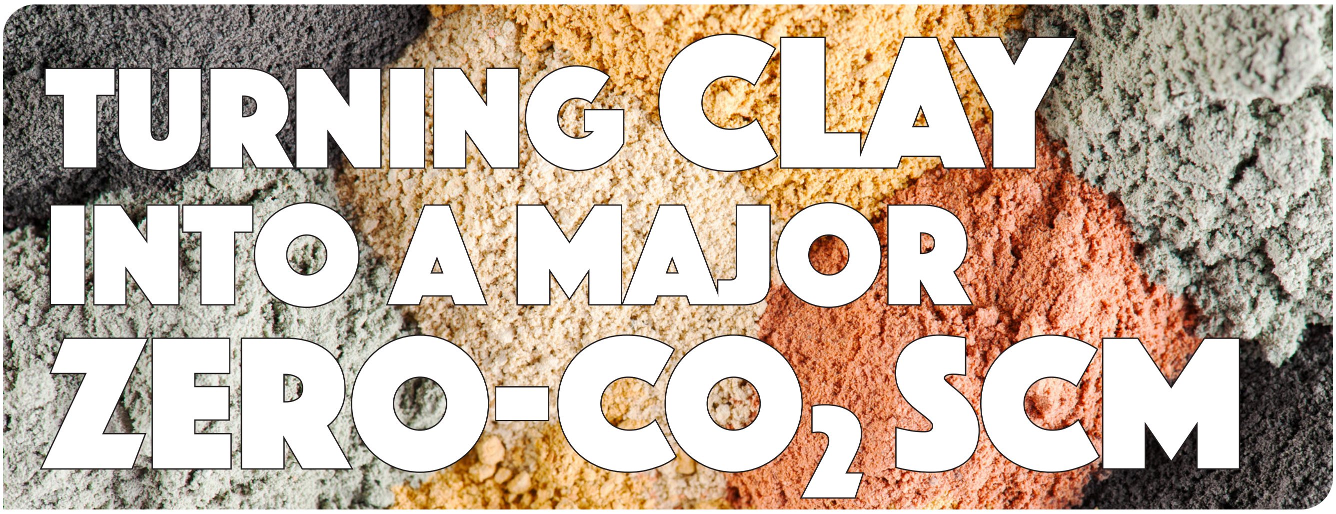
TURNING CLAY INTO A MAJOR ZERO-CO_2 SCM



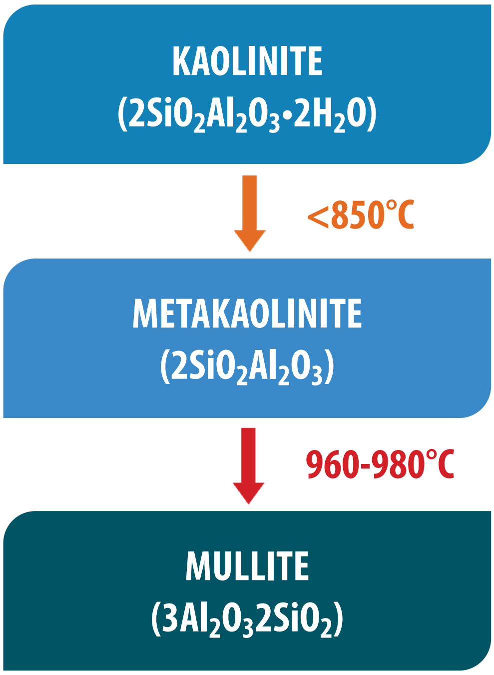
In the coming 20-30 years nearly 2 billion people will move into urban centres. However, around 60% of the infrastructure required is yet to be built. How can such high levels of construction, the equivalent to building 20 cities the size of Paris every year, be achieved in a CO_2-constrained world?

Around 4Bnt of clinker, the primary ingredient in cement, is produced every year. It is also the most CO_2-intensive component in cement, with an average of 850kg of CO_2 produced per tonne of clinker. This makes the global cement sector responsible for around 3.4Bnt/yr of CO_2, around 7% of the global total. Given future urban construction needs, this level of emissions is unacceptable if the cement sector is to hit its obligations under the International Energy Agency's 2 Degree Scenario (2DS). Clinker substitution is identified as a solution that will contribute around 37% of the required reduction in CO_2 emissions.

Supplementary cementitious materials (SCMs) have long been used to reduce emissions, as well as costs, while retaining the performance characteristics expected of the final concrete product. The two main SCMs are ground granulated blast furnace slag (GGBS), from the steel industry, and fly ash from coal-fired power stations. However, these are already in short supply, with long-term supplies likely to decline. Demand is set to increase too, meaning that new SCMs must be identified.

Enter calcined clay

Clays are widely available around the planet. However, unlike natural pozzolans, they are not pozzolanic. Fortunately, they can be activated through calcination at 750-850°C (Figure 1). By doing this, kaolin, kaolinite and other minerals in the clay are converted to metakaolin. The process is delicate, as full activation requires almost complete dehydroxylation, but without overheating. If the right balance can be achieved, the result is an amorphous, highly pozzolanic material. Overheating causes a further, undesirable, conversion to unreactive mullite.



Left - Figure 1: The activation of clays via calcination is delicate, requiring careful control of the process temperature.

When calcined clays are substituted for clinker in cement blends at 50%, as defined by the recently-updated EN197-5 CEM II / C-M standard, it is possible to reduce the embodied CO_2 in the end product by up to 40%. This is in line with the 2DS scenario. High mechanical and chemical resistance are retained. With widespread adoption across the planet, this would see the global cement sector's contribution overall CO_2 emissions fall from 7% to 4%, all else being equal.

Practical issues

Pure kaolin deposits are rare. Most clays are combinations of minerals such as kaolinite, halloysite, illite and muscovite. These are often mixed with impurities such as alkali salts, carbonates - often of calcium and magnesium, and oxides, for example iron oxide.

This makes heat treatment more challenging than with pure kaolin. This is because metakaolin is highly reactive and can undergo sintering reactions with impurities to produce inert, non-pozzolanic byproducts. As well as reducing the quantity of desirable product, these can clog industrial machinery and cause production delays.

When designing an industrial process to produce calcined clay, it is important to remember that clay is not 'clay.' The composition of minerals and impurities plays an important role in the process and must be taken into consideration, just as with cement production itself.

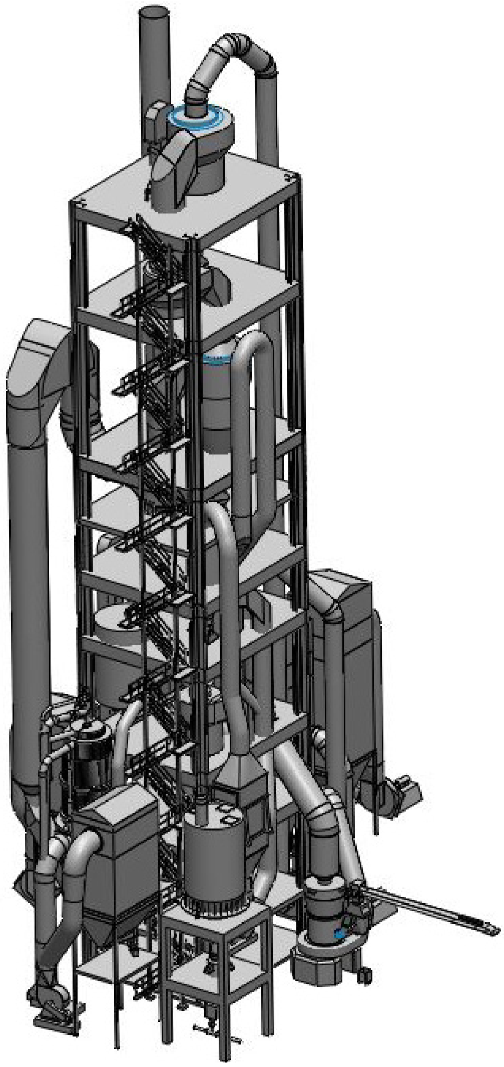
Fives FCB's capabilities

Aware of the great potential of calcined clays in the production of low-CO_2 cements, Fives FCB, the Cement and Minerals Division within Fives Group, has built a calcined clay test bed in northern France. The company has used it to develop advanced solutions for the calcination of clays. The French site has both flash calciner and rotary kiln technologies that can be used to test clients' clay material. It is then possible to assess the characteristics of the final product and thus recommend solutions to individual clients.

There are advantages and disadvantages to each technology. Rotary kilns are robust and reliable and instantly understood by cement producers. It would even be possible, with minimal alterations, to convert unused cement kilns to produce calcined clays instead. However, the long-residence time of rotary kilns leads to high risk of reaction with impurities and a loss of reactivity. There is also a temperature difference within the clay particles, which may also lead to inefficient calcination. There is also thermal inertia in the kiln, high energy consumption and, for any greenfield installation, high capital expenditure.

Flash calciners in contrast, would allow finely ground clay to be entirely converted to metakaolin at a more precisely-controlled temperature. This allows efficient conversion to metakaolin. Flash calciners are also less expensive to build, have a compact footprint and lower maintenance requirements. For new clay calcination plants, this is clearly the preferred technology. Fives FCB has a long history of flash calcination, with references dating back to the aluminium sector in 1980. Its first calcined clay reference were installed in France in the early 2000s.

Below - Figure 2: Fives FCB pilot plant in northern France.



Left - Figure 3: Schematic of Fives' flash calciner for clays.

Industrial options

In Fives' flash calciner the clay is first ground using a dedicated mill. This ensures as narrow a particle size distribution as possible, to ensure that all particles are optimally calcined. The ground material is then pre-heated, much as in a cement plant, in a series of three FCB Cyclones.

The clay then heads to the flash calciner itself. There are two options. The first is direct firing, with the clay in suspension, much as in a cement plant calciner. However, the risk of overheating is not insignificant. This is why Fives prefers the second option, indirect firing. This uses a dedicated hot gas generator to heat the calcination zone. An additional benefit of this approach is that the hot gas generator can use a high proportion of alternative fuels, which, if they are biogenic, will further reduce the overall embodied CO$_2$ emissions of the final cementitious blend.

Regardless of the firing method, the calcined clay then heads to the colour control section of the plant. This is important because, when heated to temperatures above 700°C, any iron oxides present in the clay will oxidise to hematite (Fe_2O_3), which has the well known reddish colour found in terracotta products. To revert the colour back to a more familiar grey 'Portland' cement colour, the hematite is reduced back to magnetite (Fe_3O_4). This is done in a reducing atmosphere. However, unlike traditional processes that waste a lot of fuel and lead to high CO emissions, Fives' process disconnects the reducing phase from the calcination, performing the reduction only as the material cools.

This brings a number of benefits. Aside from the use of high quantities of alternative fuels already mentioned, there is no need for an afterburner to remove CO. This leads to lower energy consumption. The process only requires a small volume of reducing gases. After the colour-control phase, the final cooling takes place with ambient air in cyclones. The resultant hot air is used for waste heat recovery and sent back to the burning chamber.

Conclusion

Clay calcination offers huge potential for the global cement sector to lower the embodied CO$_2$ emissions of its products. Flash calciners, such as the proven solution from Fives, offer many operational advantages compared to rotary kilns that result in higher pozzolanic reactivity of the calcined clay, higher efficiency and lower CO$_2$ emissions. Reconditioned rotary kilns nevertheless retain an important role. However, regardless of whether they are produced in a flash calciner or rotary kiln, calcined clays have the potential to act as a widely-available, affordable and sustainable SCM for the cement sector around the world, in turn contributing to a major decrease in the sector's overall CO$_2$ emissions.

Left - Figure 4: Clay is not 'clay,' but rather a mixture of different minerals, often with impurities too. Its calcination into a pozzolanic material therefore requires proper consideration.