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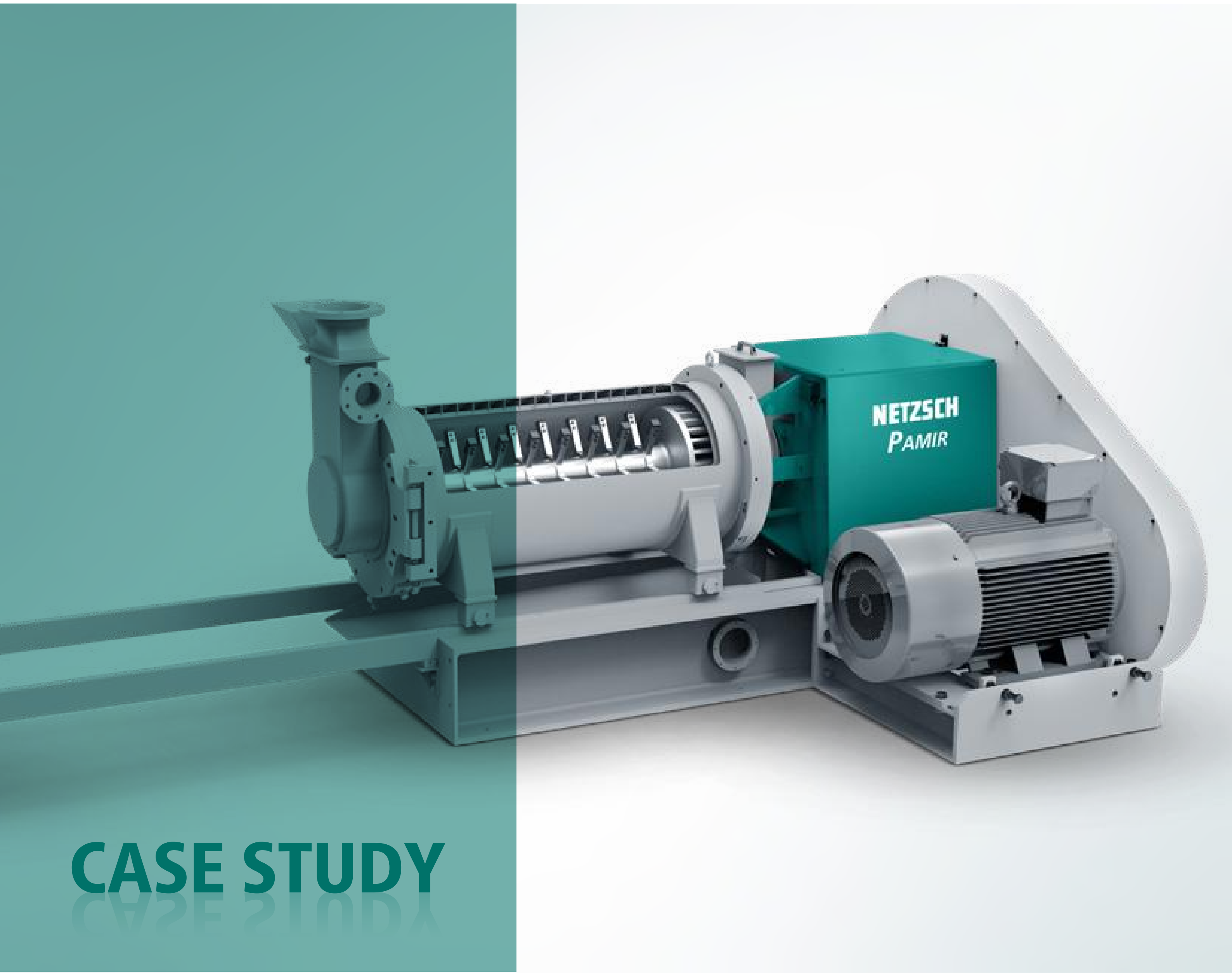

CASE STUDY

Mechanochemical Activation of Supplementary Cementitious Materials (SCMs) in Construction

Business Unit
GRINDING & DISPERSING

Introduction

Mechanochemical activation (MCA) is a rapidly growing technology in many areas of materials science, particularly in construction. It is based on the application of mechanical and chemical processes to modify materials. One of the main applications of MCA is the activation of additives in cement, known as supplementary cementitious materials (SCMs). These materials include fly ash, granulated blast furnace slag, natural pozzolans, and various clays, which can replace part of the Portland cement and thus the clinker content in cement. This achieves a significant reduction in CO_2 emissions during cement production.

Background on SCMs and their Importance

The conventional production of Portland cement consumes a lot of energy and releases large amounts of carbon dioxide. Primary or Scope 1 emissions, amounting to approximately 500 kg of CO_2 per ton of cement, are generated during the burning of clinker through the decomposition of $CaCO_3$ into CaO and CO_2 and the combustion of fossil or alternative fuels required for this process. Scope 1 emissions account for approximately 85% - 90% of the total CO_2 footprint of cement. Minimizing the clinker content in cement and concrete mixes using SCMs offers significant potential for reducing these emissions. In addition, SCMs can have a positive impact on the long-term strength, water demand, chemical resistance, and workability of cement.

SCMs such as fly ash, granulated blast furnace slag, and silica fume are by-products of other industries and therefore contribute to waste recycling. Although these materials have inherent pozzolanic properties that qualify them for use in concrete mixes, their reactivity is significantly enhanced by mechanochemical activation. In addition, materials such as clays, which have little or no pozzolanic properties by nature, can also be made usable by MCA. When activating clays, waste materials from existing pits or low-grade clays from the clay and ceramics industry can also be mechanically activated, thus offering a similar resource-efficient production of SCMs as the by-products mentioned above.

Fundamentals of Mechanochemical Activation

Mechanochemical activation means that mechanical energy, in the form of grinding or deformation, is applied to a material and this energy initiates or accelerates chemical reactions. When SCMs are mechanically treated, the material is crushed by an intensive grinding process, and its surface area increases dramatically. The increased surface area allows chemical reactions to proceed more quickly and efficiently.

In addition to increasing the surface area, the process of mechanochemical activation also leads to changes in the crystalline structure of the material. This means that crystalline structures are broken down and amorphous, reactive phases are created, which form additional C-S-H and C-A-H phases with the portlandite produced during the hydration of the cement. This secondary C-S-H formation can lead to higher strengths due to higher density. This applies, among other things, to materials such as fly ash, which contain few reactive phases and whose reactivity is dramatically improved by mechanochemical activation.

Activation Mechanisms

Mechanochemical activation follows several basic mechanisms:

Specific Surface Enlargement: Grinding significantly increases the surface area of the material, making more reaction sites available.

Defect Formation: Mechanical stress leads to lattice defects and fractures in the crystal lattice, making them more chemically reactive.

Phase Transformation: Mechanical energy can transform stable crystalline phases into amorphous, higher-energy phases that are more chemically reactive.

Increased Solubility: Mechanochemical activation also increases the solubility of the materials in the cement matrix, which enables the additional formation of the C-S-H and C-A-H phases and supports the hardening of the cement.

Applications and Benefits of Mechanochemical Activation

The application of mechanochemical activation to SCMs offers many significant advantages:

Improved Reactivity: SCMs that have been mechanochemically activated exhibit significantly higher reactivity. This means that they react better with water and the other cement components, thus optimizing their performance in the concrete mixture.

Reduction in Cement Content: The increased reactivity of SCMs means that the proportion of conventional Portland cement in a concrete mix can be further reduced without compromising strength or durability.

Sustainability: Mechanochemical activation makes it possible to use more mineral waste as a secondary raw material to produce SCMs, and less climate-damaging Portland cement is used in construction projects.

Cost Savings: The increased use of SCMs through mechanochemical activation is not only environmentally friendly, but also economically advantageous, as SCMs are generally cheaper than Portland cement.

Energy Source: Especially in clay activation compared to thermal calcination, MCA has the additional advantage that 100% green electricity is used as the energy source in the process (excluding pre-processes such as drying). This leads to a further reduction in total CO_2 emissions compared to fossil fuels.

Process Flexibility: Due to the electrically powered machines, start-up and shutdown are not a major problem, especially when compared to calcination in rotary kilns. The operation of MCA plants can compensate for fluctuations in the power grid caused by renewable energy and enable significant savings in electricity costs.

Challenges and Future Developments

Despite the promising advantages of mechanochemical activation, there are also challenges that need to be overcome. Previous activation studies were often carried out in vibratory or planetary mills. The process parameters and working principles of these laboratory machines are generally not transferable to industrial plants. Activation in a dry agitator ball mill has proven to be an excellent alternative. With the Pamir series, NETZSCH offers a dry agitator ball mill that can perform both grinding and activation of various SCMs and is available in a wide range of sizes from laboratory to industrial production machines.

For the marketing of a complete industrial plant, there are strong partnerships with thyssenkrupp Polysius GmbH in Beckum, Germany, and with Minerva Engineering Inc. in Turkey. As a reliable partner for the planning, installation, and commissioning of complete process groups, Polysius or Minerva performs these tasks in close cooperation with NETZSCH.

Conclusion

Mechanochemical activation is a promising method for improving the reactivity of SCMs and offers a sustainable and economical way to revolutionize cement production in the future. It contributes to the reduction of CO_2 emissions in the cement industry and opens new possibilities for the use of industrial by-products in the construction industry. Through further research and technological innovation, mechanochemical activation can become an integral part of modern cement and concrete production.

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