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Extending the use of supplementary cementitious materials in concrete

PROJECT

Industrial PhD

AUTHOR

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ORGANIZATION

The Danish Road Directorate

Technical University of Denmark (DTU)

Concrete is the most used construction material in the world, and its production accounts for about 8% of human-generated CO2 emissions. In conventional concrete, the binder is Portland cement, which has the largest CO2 contribution of all constituents. To improve the properties of concrete and reduce its carbon footprint, Portland cement can be partially replaced by Supplementary Cementitious Materials (SCMs), such as coal fly ash, blast furnace slag, or silica fume. These traditional SCMs are industrial by-products and their use in concrete promotes circularity and reduces waste. However, due to the overall decarbonization of the industry, their availability is expected to decrease in the coming years. The concrete industry is therefore looking into alternative SCMs, which can ideally substitute even more Portland cement that traditional SCMs. In this respect, it is essential to evaluate the effect of SCMs on concrete durability, i.e. ensuring that concrete will remain in sufficiently good condition over the service life of a structure – typically 100-120 years for bridges.

This PhD project focused on the impact of SCMs on a particular durability damage mechanism called alkali-silica reaction. From an industry perspective, the project proposed a procedure to assess SCMs with respect to the alkali-silica reaction. In other words, which criteria should an SCM fulfil to ensure its safe use in concrete? To find out which criteria to evaluate and which level to set the project mainly relied on an experimental approach. Various laboratory tests were performed on eight reference SCMs, as shown in Figure 1, which aimed to provide a representative sample of sources.

Figure 1:

Supplementary Cementitious Materials (SCMs) powders selected for testing in this PhD project. The selection intended to represent a range of potential SCMs in terms of origin, chemical composition, and physical properties.

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Coal fly ash
FA

Sewage sludge ash
SSA

Crushed brick
CB

Glass beads
GB

Biomass ashes
BA

Calcined clays
CC

Figure 2:

Concrete field exposure site at the Technical University of Denmark, initiated in 2017. 90 cubes are exposed and monitored to study the effects of concrete composition on the alkali-silica reaction. Small stainless-steel pins are placed at the surface of the cubes to measure their length change.

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The experimental program included tests at different scales, from SCM powders to concrete. As for assessing durability issues, laboratory tests were conducted to accelerate chemical reactions so it was possible to evaluate the effect of SCMs within a reasonable time frame. A field exposure study was also initiated to determine the validity of the accelerated tests. This consisted of placing concrete cubes on an outdoor field exposure site (see Figure 2) and monitoring the state of the cubes over time, then comparing the results with those from the accelerated tests.

The project led to the development of a procedure to screen and qualify cementitious materials. Special attention was paid to selecting or designing tests that can be performed in most laboratories, so they can be used by most industry stakeholders. So far, the outcome of this procedure matches well with the behavior of the concrete cubes, but long-term data are needed to confirm the initial trends. The final deliverable of the project will be a suggestion for the national regulations for concrete, to update the requirements for approving SCMs with respect to alkali-silica reaction.