Influence of alkali-silica reaction on the physical, mechanical, and structural behaviour of reinforced concrete - DTU Orbit (23/08/2019)

**Influence of alkali-silica reaction on the physical, mechanical, and structural behaviour of reinforced concrete**

Alkali-silica reaction (ASR) is one of the major concrete deterioration mechanisms in the world. Cracking in concrete structures due to ASR has been observed worldwide. In Denmark numerous concrete structures have been built with a critical amount of ASR-reactive aggregate, mostly as porous opaline and porous calcareous opaline flint in the fine aggregate fraction. During the last few decades, an increasing number of bridges in Denmark have been severely damaged due to ASR. In the most severe cases, the ASR-damaged bridges have been demolished and reconstructed due to uncertainty about their residual load-carrying capacity. The decisions to demolish and reconstruct these bridges have been based on visual appearance of drilled concrete cores and rough estimates of their residual load-carrying capacity. Research into the mechanical properties of drilled cores and the residual load-carrying capacity of ASR-damaged flat slab bridges in service is very limited.

This PhD thesis contributes to the documentation and better understanding of the influence of ASR on the physical and mechanical properties of ASR-damaged concrete, and on the residual load-carrying capacity of an actual ASR-damaged flat slab bridge. The ASR-damaged concrete originated from ASR-damaged flat slab bridges in service and from laboratory-casted and laboratory-accelerated reinforced slabs. In this study, slab segments from three ASR-damaged slab bridges without shear reinforcement were examined. All the examined slabs had following features in common: (a) significant amount of ASR cracks were observed on and inside the slabs, (b) the ASR cracks were oriented parallel to the plane of the slabs, and (c) ASR occurred in the fine aggregate fraction.

In this PhD study, both the compressive strength and tensile strength of drilled cores, from all slabs, were found to be negatively influenced by ASR. However, the compressive and tensile strength depended on the orientation of the ASR cracks inside the cores. It was found that the compressive strength in the direction perpendicular to ASR cracks can be significantly smaller than the strength in the direction parallel to ASR cracks. Consequently, evaluation of compressive strength based on vertically drilled cores (ASR cracks oriented perpendicular to the load direction) can be rather conservative. It is argued that the difference in compressive strength for the two crack orientations (perpendicular or parallel to the load direction) will decrease as the amount of ASR cracks in the concrete increases. An explanation of the effect of ASR cracks and their orientation on the compressive strength is proposed. The tensile strength of concrete specimens depended on the test method applied. Both direct and indirect tensile strength test methods showed shortcomings when testing ASR-damaged specimens.

The residual load-carrying capacity was determined on 18 beams cut from six reinforced slab segments from a severely ASR-damaged flat slab bridge. Nine beams were tested in a three-point bending setup and nine beams were tested in an asymmetrical four-point bending setup. The ASR cracks had a significant influence on the propagation of load-induced cracks in the beams. Additionally, the test setups had different influence on the failure mechanism and measured load-carrying capacities. Most of the beams tested in the three-point setup suffered ductile rotational failure in diagonal cracks and most of the beams tested in the four-point setup suffered ductile shear failure. It was found that the measured load-carrying capacities were at least equivalent to the calculated load-carrying capacities based on the compressive strength of vertically and horizontally drilled cores. It was measured that the ASR-induced expansions resulted in significant tensile strains and stresses (pre-stress effect) in the reinforcing bars. The measured tensile strains were not proportional to the extent of ASR cracks in the beams or to the compressive strengths.

This PhD study also contributes to better understanding of the time-dependent effect of ASR on the physical and mechanical properties of laboratory-casted and laboratory-accelerated reinforced slabs. The sources of alkali to the concrete were found to have a significant influence on the development and orientation of the ASR cracks inside the slabs. The external supply of saturated NaCl solution from the upper slab surfaces was found to be crucial to develop ASR cracks with orientations comparable to those observed on actual bridge slabs, while the slabs with high initial Na$_2$O eq. content developed random map-cracks. The development of ASR cracks inside the slabs exposed to NaCl solution had a negative and rapid influence on the compressive strength of vertically drilled cores. Although accelerated at high temperature and high RH, it was found that the rate of the downwards penetration and development of ASR cracks inside the slabs was very fast. In this study it is argued that the correlation between vertical expansion and surface expansion of the slabs can be divided into three phases, which may lead to challenges in the interpretation of internal ASR cracking based on the surface expansion measurements.

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