On the macro modelling of the Alkali-Aggregate Reaction in concrete: Numerical implementation in Abaqus Explicit

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Extended abstract

Structural problems related to alkali–aggregate reaction (AAR) have been identified in concrete structures since the beginning of the twentieth century. In fact, AAR is one of the most problematic factors affecting the performance and ageing of reinforced concrete (RC) structures worldwide. Problems due to AAR were first noted in California in the 1930s and were reported by Stanton (1940) from the California State Division of Highways. It was known as a nefarious chemical reaction between alkalis in cement and silica in aggregates. As evidenced from accelerated tests, AAR generally follows a sigmoid curve (S-shaped): slow, fast, slow (Larive, 1998). For real structures, AAR requires high relative humidity (RH) in the concrete (RH >80%). The latent period of AAR can be long, which makes its early diagnosis sometimes difficult. Moreover, an increased temperature accelerates AAR. Thus, it is well established that the kinetics of AAR is driven by temperature and moisture, and the induced strain is assumed to be oriented according to the stress state (Saouma, 2014).

Due to the complexity of AAR and its multi-physical nature, the use of chemomechanical modelling is very helpful for making predictions in terms of displacements and concrete damage. Moreover, macro-modelling approaches are frequently preferred for performing engineering work for real structures. In this regard, modelling of the non-linear behaviour of concrete is highly recommended for existing damaged and aged structures. The use of elaborated numerical analyses based on finite-element (FE) methods allows reproduction of the present behaviour and making future predictions. In the phase of reproducing the present behaviour, the calibration process aims to match the measured displacements and the observed damage (cracking). The approaches based on the linear elastic assumption of concrete are unrealistic and somewhat conservative, basically for the prediction of failure mechanisms.

In this context, this paper presents the implementation, in the Abaqus/Explicit modelling software, of a chemomechanical model of AAR for concrete. With this approach, developing a special constitutive cracking model for concrete to solve the problem is not required; instead, commercially available FE software can be used. In fact, the effects of AAR are introduced by way of the Vuexpan user subroutine jointly with the concrete damage plasticity (CDP) model of Abaqus. The proposed AAR model is considered as an engineering tool; hence it addresses AAR at macroscale, using few input engineering parameters without compromising accuracy. The Abaqus/Explicit solver was chosen as it deals effectively with very large FE models simulating highly non-linear deformation due to AAR. To the authors' knowledge, this is the first time that the effects of AAR have been implemented into Abaqus/Explicit jointly with the CDP model by way of the Vuexpan user subroutine.

Verification of the proposed model is carried out at the material level and a case study of a real hydraulic structure affected by AAR located in North America is presented. At the material level, the proposed AAR kinetic progress incremental scheme was validated considering various scenarios of temperature from literature benchmarks and the model response was found to be very satisfactory. In addition, verification of degradation of the stiffness and the tensile strength was carried out using test results from the literature. For the selected hydraulic structure, the analyses accounted for temperature and RH spatial distributions, non-linear AAR kinetics, the creep effect, concrete damage and the steel reinforcement yielding. The AAR parameters were determined using a calibration procedure to reproduce the displacements from the numerical model. To this end, two points were considered, one belonging to the intake structure and the second located at the powerhouse (turbine floor). Good agreement was obtained between the recorded displacements and those predicted by the numerical model. This provides confidence for carrying out future predictions (displacement, concrete damage and steel reinforcement plastic strain) using the proposed approach.

References

[1] Larive C (1998) Apports Combinés de L'expérimentation et de la Modélisation à la Compréhension de L'alcali Réaction et de ses Effets Mécaniques. Laboratoires des Ponts et Chaussées, Paris, France, Technical Report LPC OA 28 (in French).

[2] Stanton TE (1940) Expansion of concrete through reaction between cement and aggregate. Proceedings of the American Society of Civil Engineers 66(10): 1781–1811.

[3] Saouma VE (2014) Numerical Modeling of AAR. CRC Press, Boca Raton, FL, USA.

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