Modeling thermomechanical damage mechanisms of concrete

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ABSTRACT

Experiments for finding a direct relation between temperature and the compressive strength of concrete are commonly conducted. The strength decreases with rising temperatures for most test setups and concrete mixes [1]. The resulting curves can be used in material models for numerical simulations. In this case, however, calibration of the resulting properties is a profound problem. It is unclear how the material parameters are to be fitted while still obeying the Clausius-Duhem inequality.

In contrast, a more accurate and reliable material model results from taking the coupling between thermal behaviour and mechanical performance into account. Such a model is considered in this contribution, where the compressive strength f_c as a material parameter has only one value, but the influence of thermal strains and material damage leads to the expected reduction in strength. The thermodynamic consistency can be separately reviewed for each constituent material model. A finite element code that can solve this thermomechanically coupled problem has been implemented [2]. The damage is computed using the gradient enhanced damage model proposed by Peerlings et al. [3].

A loss in strength at higher temperatures due to thermal strains is observed; these strains in turn drive the damage growth, as well as generate internal stresses that will reduce the load bearing capacity of specimens under combined thermal and mechanical loading. Other groups have demonstrated more complex interactions, yet did not project their results back on the compressive strength [4]. Avoiding an unnecessarily complex material model comes at the price of having to explicitly consider the interactions between thermodynamics and mechanics. This way, there is no need to supply a function $f_c(T)$ for each concrete mix. Thus, the number of necessary experiments is reduced and a sensitivity calculation, to find which material parameters have the strongest influence on the remaining strength of concrete under high temperatures, can be conducted.

This is an important step towards solving more complicated problems. With each additional complexity, such as mesoscale, water content, shrinkage and creep, the need to model these cases with simpler material laws, while handling the intricacies numerically, increases.

References

[1] Z. P. Bažant and M. F. Kaplan. *Concrete at high temperatures : material properties and mathematical models.* Concrete design and Construction Series. Longman, 1996. ISBN: 0-582-08626-4.

[2] *NuTo – Numerical Toolkit.* 2016. URL: `https://nutofem.github.io/nuto/`.

[3] R. H. J. Peerlings et al. "Gradient Enhanced Damage For Quasi-brittle Materials". In: *International Journal for Numerical Methods in Engineering* 39.19 (1996), pp. 3391–3403.

[4] Giovanna Xotta, Valentina A. Salomoni, and Carmelo E. Majorana. "Thermo-hygro-mechanical meso-scale analysis of concrete as a viscoelastic-damaged material". In: *Engineering Computations* 30.5 (2013), pp. 728–750. DOI: `10.1108/EC-08-2013-0097`.