

# Modeling of drying shrinkage

## PROBLEM

Drying shrinkage, resulting from the action of water and dissolved ions in the various pores in cement paste, can cause substantial problems in the use of concrete, such as surface cracking. Drying shrinkage in cement paste displays substantial hysteresis: a sample will not recover during wetting the length it had at the same humidity during drying. This behavior is opposite to that of many porous materials and is instead similar to that of clays, where shrinkage is predominantly due to the loss of the expansive action of water in nano-scale layers when water is removed from these layers. The lack of an accurate model of the structure of cement paste and of the action of water at fundamental scales has thus far hindered a prediction of drying shrinkage in the cement paste.

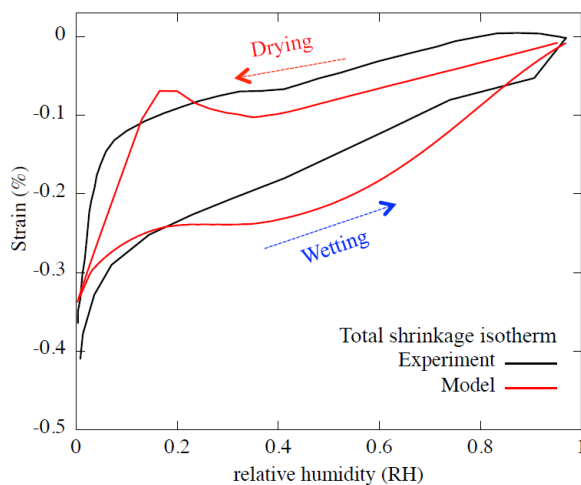


Fig. 1: A comparison of experimentally-measured shrinkage (Feldman, Fifth International Symposium on the Chemistry of Cement, 1968) and the prediction of our model.

shrinkage, and especially its hysteresis, is due to the removal of interlayer water, which occurs only below ~20% relative humidity. The degradation behavior of a particular sample of cement paste may thus depend on whether it is ever subjected to a humidity below this threshold. Some details disagree with experiment, e.g. a predicted substantial relaxation of shrinkage around 30% humidity on drying. But further improvement of the model is expected as NMR data, capable of accurately determining the water content of each pore type, become available, and as a new generation of sorption data is generated, motivated by the new understanding of the sorption isotherm.

## IMPACT

This model links together quantitatively drying shrinkage, water sorption isotherm, and pore structure (sizes and connectivity) of cement paste. Thanks to its simplicity, it can be used for rapid predictions of water sorption isotherms and shrinkage for a paste with known pore structure or, vice-versa, to extract quantitative information on the pore structure from measured sorption and shrinkage data. Since mechanical properties are strongly influenced by evaporable water, the model will have a range of possible applications including materials design and quality control.

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## APPROACH

We propose a semi-analytical model of drying shrinkage that for the first time predicts both drying and rewetting behavior using parameters taken from the water sorption isotherm. We start by identifying three categories of pores with different sizes. We combine specific inputs from experimental sorption isotherms and our recent model of pore blocking (Pinson et al., arXiv 1402.3377) to determine the size distribution of the pores and calculate the water content of pores with different size during wetting and drying. We then use this information to make a prediction of shrinkage based on three contributions: Laplace pressure and surface tension, accounted for using conventional models, and the expansive effect of water in pore spaces below the nanometer size range, treated here with the simple approximation that swelling is proportional to interlayer water content.

## FINDINGS

Our model of sorption is able to describe trends in experimental adsorption isotherms. The largest component of