



Desiccation shrinkage of cementitious materials as an aging, poroviscoelastic response

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ABSTRACT

This paper describes and evaluates a new model that utilizes aging poroviscoelasticity for predicting the shrinkage of cementitious materials induced by loss of moisture from the pore structure (i.e. desiccation). The new model incorporates well-accepted mechanisms for desiccation shrinkage and accounts for the effect of changing concentrations of dissolved species in the pore fluid. Additionally, the model is used to interpret viscoelastic behavior during the drying process via comparisons of model predictions with measured shrinkage of hardened portland cement paste. It was found that while a poroelastic model under predicts the measured shrinkage, the poroviscoelastic model significantly over predicts the shrinkage unless intrinsic aging of the C–S–H gel is included in the model.

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1. Introduction

Shrinkage of concrete due to loss of evaporable pore water can lead to crack development and reduction in durability. Concrete shrinkage due to loss of pore water is often subdivided into autogenous and drying shrinkage, with autogenous shrinkage associated with loss of evaporable pore water through consumption in the hydration reaction, and drying shrinkage associated with loss of evaporable pore water through transport to an open boundary. While often divided, autogenous and drying shrinkage only differ in how the pore water is removed; mechanistically, the shrinkage deformations are identical. Therefore, this paper treats modeling of desiccation shrinkage, where desiccation refers to either self-desiccation through the hydration reaction, or desiccation due to loss of pore water/vapor through an open boundary (or a combination of both types of desiccation). The objective of this paper is to derive a new desiccation shrinkage model for cementitious materials and to compare model predictions with measured shrinkage of hardened cement paste (HCP).

Shrinkage due to loss of evaporable pore water from cementitious materials has typically been attributed to three primary mechanisms (or driving forces) [1,2]:

1. changes in capillary pressure,
2. changes in disjoining pressure, and
3. changes in the surface energy of the solid phase.

Most modeling efforts have focused on changes in pore fluid pressure associated with capillary pressure and disjoining pressure,

which are simultaneously determined from changes in relative humidity (RH) and/or temperature using the well-known Kelvin–Laplace relationship [2,3]. Change in the surface energy of the solid phase is an inverse function of the degree of saturation, and is thus thought to be most prominent at low levels of saturation [1].

Poroelasticity has been successfully used to model deformation of HCP and other porous materials caused by pore fluid pressure changes (see e.g. [4–9]). Bentz et al. [10] modeled the drying shrinkage of partially saturated porous Vycor® glass rods using a poroelastic model. The approach involved the use of a modified version of Biot's elastic constitutive equation¹ (using a saturation factor) to account for the partial saturation conditions inherent to drying. Coussy et al. [4,12] formalized the use of a saturation factor based on the work of Bishop [13] and derived an “effective pore pressure” to be used with poroelasticity to predict shrinkage of cement-based materials. The effective pore pressure included changes in pore fluid pressure (associated with mechanisms 1 and 2 above) and the interfacial energy of the system (associated with mechanism 3 above). Lura et al. [14–16], Coussy et al. [4], Weiss et al. [17], and Rougelot et al. [18] have used the Kelvin–Laplace equation and poroelasticity to model shrinkage of cementitious materials as a function of RH . Lura et al. noted good agreement between measured and modeled shrinkage for specimens at higher RH ; however, the model under predicted shrinkage at lower RH , and the difference was attributed to viscoelastic effects not accounted for in the model.

¹ Bentz et al. [10] refer to the work of Mackenzie [11] (which predates Biot) in their paper. Mackenzie's model is identical to that of Biot's isotropic poroelastic model, but Mackenzie overly restricts the model to bodies with spherical pores whereas Biot makes no restriction regarding pore geometry.

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