Mechanical Damage Models for Concrete

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INTRODUCTION: To study mechanical behavior of concrete structures, a classical damage model [1] has been implemented in COMSOL® using the external materials functionality [2].

Here, a new implementation of damage models is presented. A generic physics (Domain Ordinary Differential Equation) is used, together with a tailored solver configuration, to store history variables of the constitutive law (Fig. 1). Moreover, a regularization method is also implemented for mesh-independent simulations. Results are compared with experimental tests for validation.

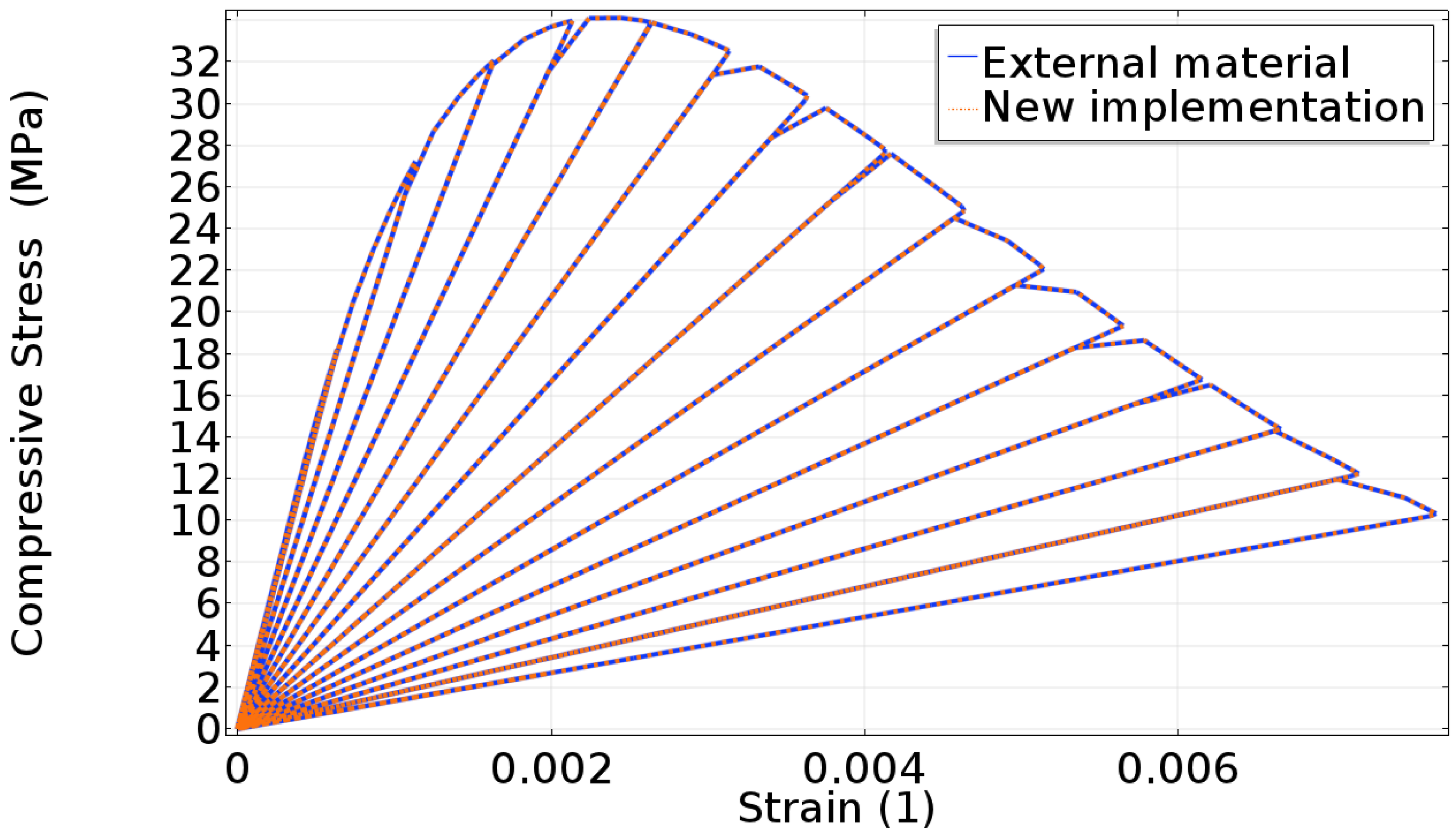

Figure 1. Results of the verification test in terms of stress-strain curves using two different damage model implementations.

MAZARS' DAMAGE MODEL: Following damage mechanics theory, a scalar damage variable ***d***, is defined, ranging from 0 to 1 (from intact state to fully damaged), leading to a nonlinear stress (**σ**) – strain (**ε**) relation: $\sigma = (1-d)E \cdot \varepsilon$

Mazars' damage model considers isotropic damage, assuming distinct evolution laws under tensile or compressive stresses. Damage (Fig. 2) depends on the evolution of a history variable that stores the maximum value of compressive and tensile strains.

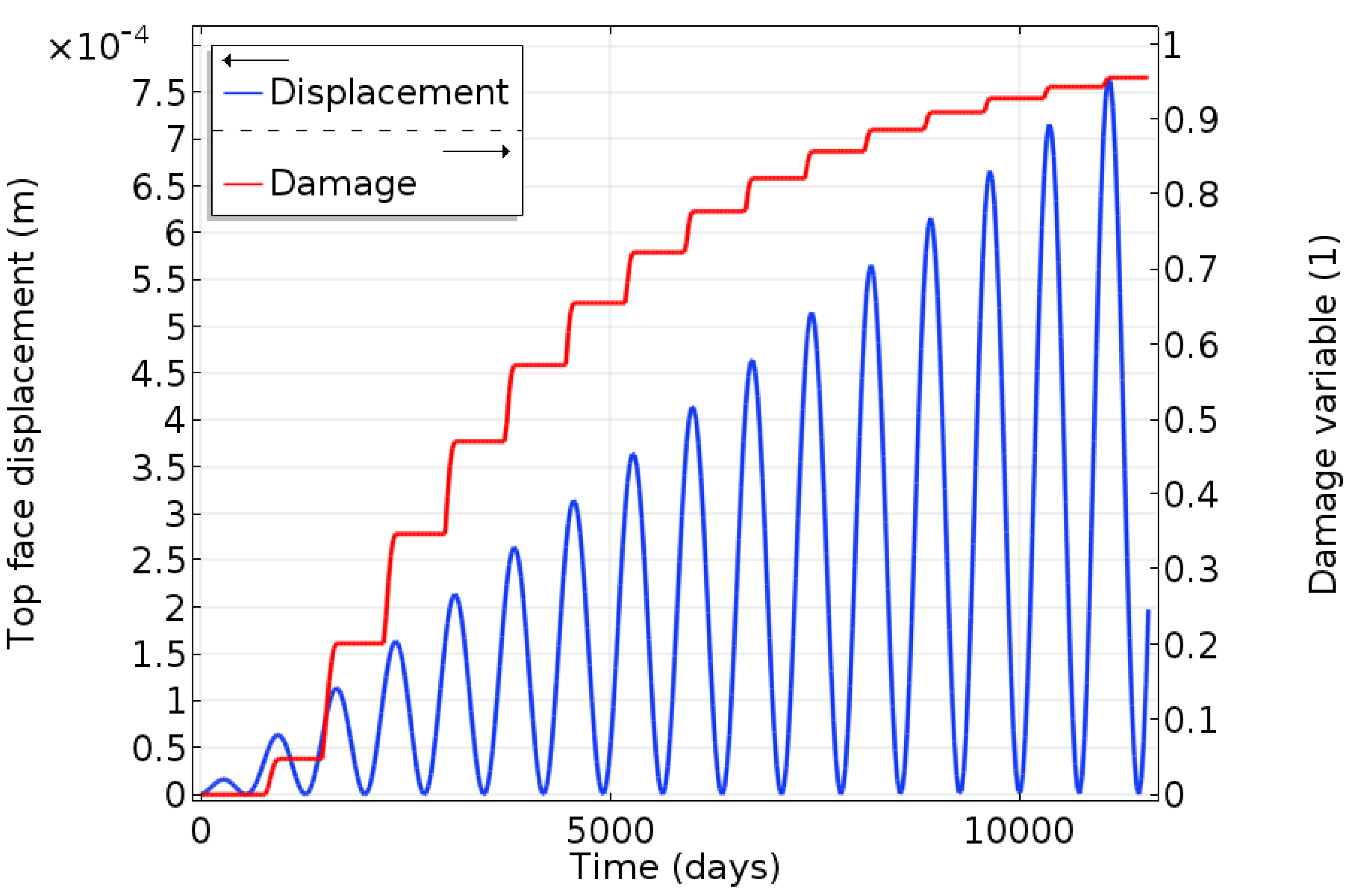

Figure 2. Imposed displacement in top face and resulting damage variable evolution for compression test with loading/unloading cycles.

REGULARIZATION BY IMPLICIT GRADIENT METHOD: A gradient-enhanced formulation [3] to regularize the FE solution is implemented in COMSOL® using the Helmholtz eq. interface. This model is used to simulate uniaxial compression and 3-point bending tests (Fig. 3).

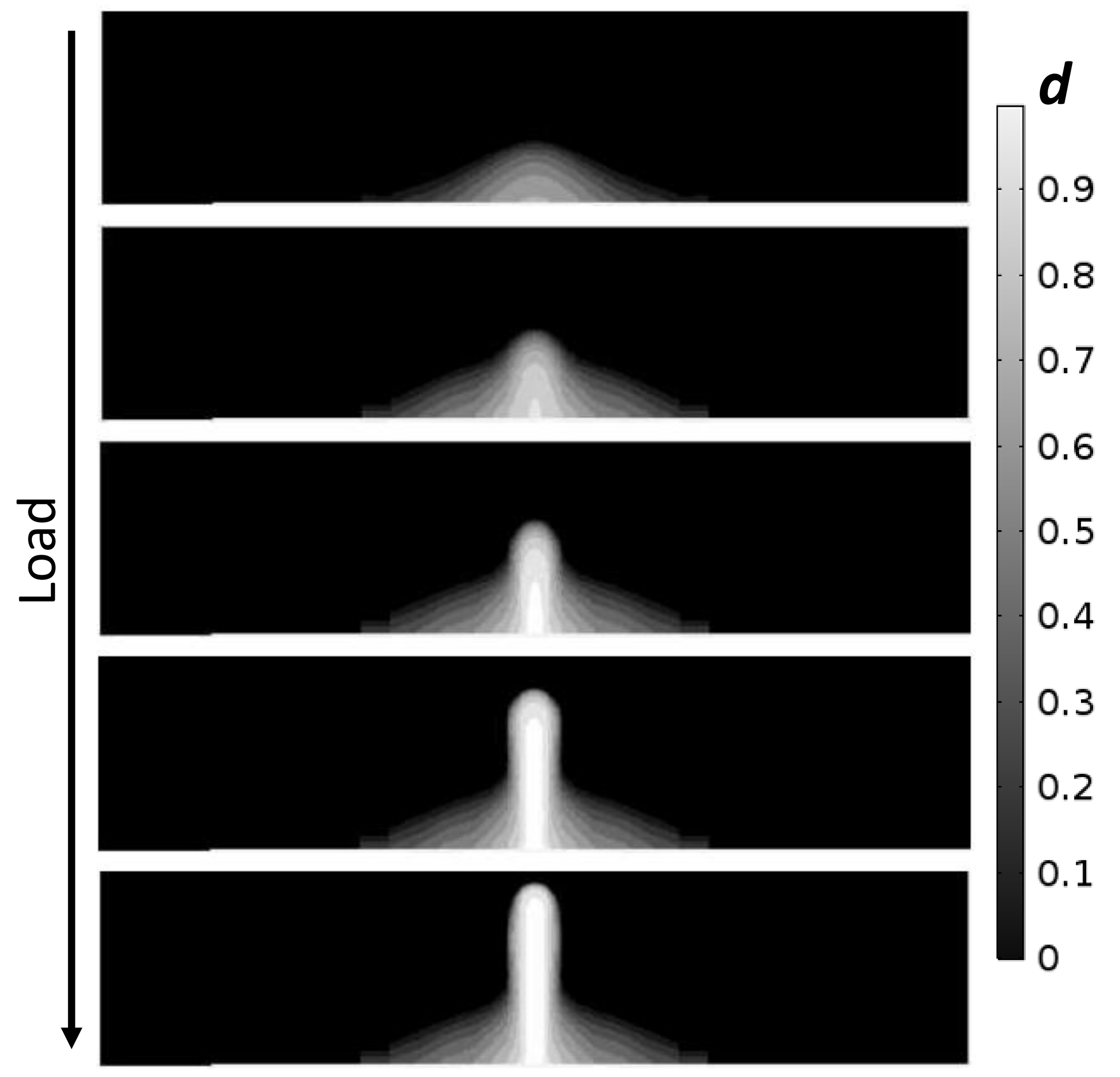

Figure 3. Damage vs. loading in 3-point bending test.

***Table 1.** Results from compressive test with and without regularization.*

Mesh size (mm)	Peak load (N)	
	without	with
1.67	3,310	5,375
2.9	4010	5,375
5	4320	5,375
10	4630	5,375

***μ* MODEL:** A more recent damage model [4] is also implemented in COMSOL® to accurately represent concrete under multiaxial stress states (Fig. 4).

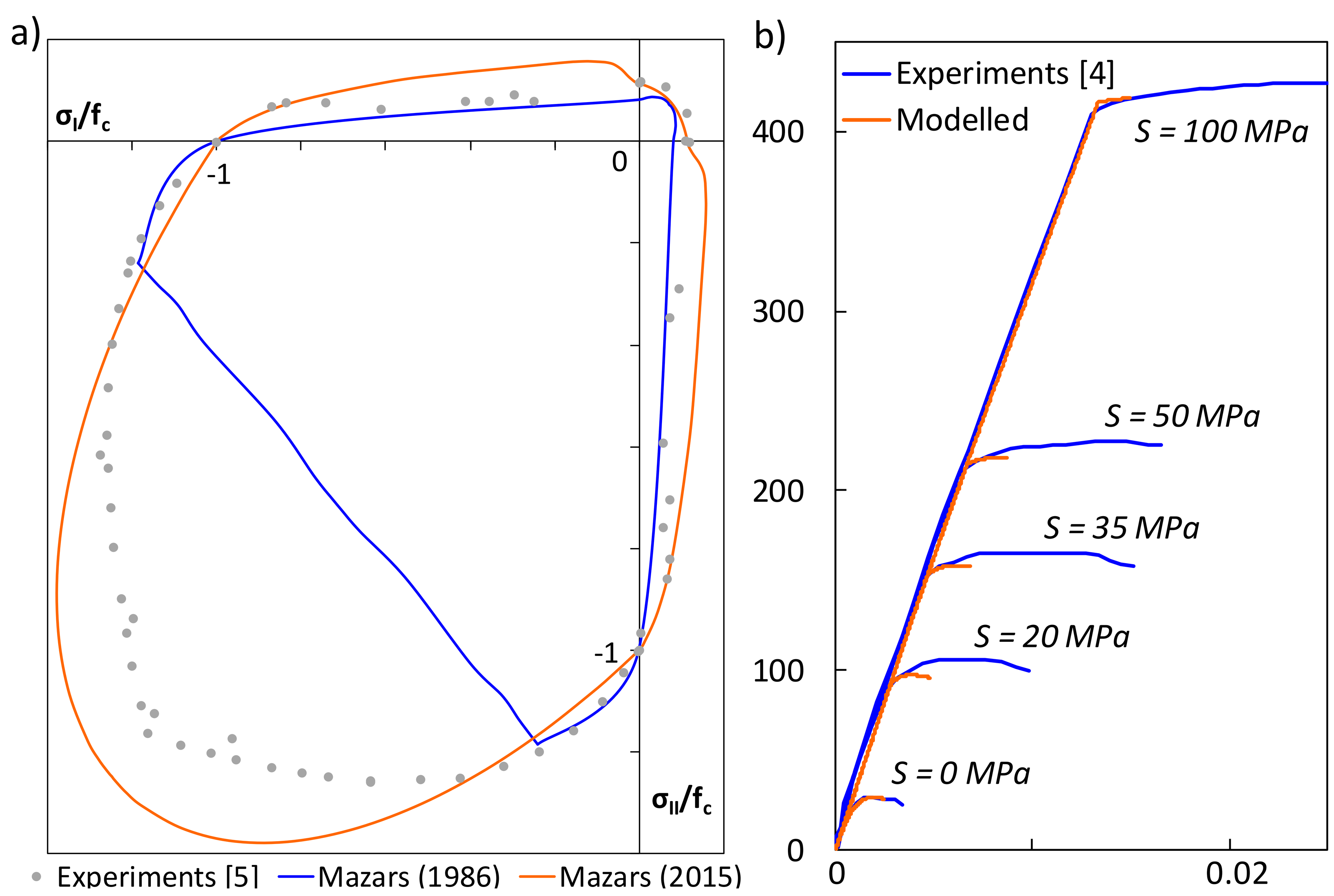

Figure 4. Comparison of results from (a) biaxial and (b) triaxial loading tests.

CONCLUSIONS: Regularized damage models can be implemented in COMSOL® to represent concrete mechanical behavior under diverse stress states. Generic physics interfaces are used for history variables storage and to obtain mesh-independent results.

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