



# ON THE DEVELOPMENT OF A MICROMECHANICS-BASED RELATIONSHIP BETWEEN SALT CRYSTALLIZATION PRESSURE, PORE FILLING, AND DAMAGE IN POROUS BUILDING MATERIALS

N. Lo Presti, A.M. D'altri, L. Patruno, G. Castellazzi, T. Chekai, Hannelore  
Derluyn, S. de Miranda

## ► To cite this version:

N. Lo Presti, A.M. D'altri, L. Patruno, G. Castellazzi, T. Chekai, et al.. ON THE DEVELOPMENT OF A MICROMECHANICS-BASED RELATIONSHIP BETWEEN SALT CRYSTALLIZATION PRESSURE, PORE FILLING, AND DAMAGE IN POROUS BUILDING MATERIALS. SWBSS ASIA (Salt Weathering of Buildings and Stone Sculptures) 2023, Sep 2023, Nara, Japan. hal-04309030

**HAL Id: hal-04309030**

**<https://hal.science/hal-04309030>**

Submitted on 27 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# ON THE DEVELOPMENT OF A MICROMECHANICS-BASED RELATIONSHIP BETWEEN SALT CRYSTALLIZATION PRESSURE, PORE FILLING, AND DAMAGE IN POROUS BUILDING MATERIALS

Nicolò Lo Presti<sup>1</sup>, Antonio Maria D’Altri<sup>1,2,\*</sup>, Luca Patruno<sup>1</sup>, Giovanni Castellazzi<sup>1</sup>, Tinhinane Chekai<sup>3</sup>, Hannelore Derluyn<sup>3</sup>, and Stefano de Miranda<sup>1</sup>

## KEYWORDS

Pore pressure; Salt crystallization-induced damage; Pore Structure; Finite element analysis; Damage modelling

## ABSTRACT

This contribution investigates the relationship between salt crystallization pressure, pore filling, and damage in porous building materials through a micromechanics-based approach. A 3D finite element (FE) model of a microscale representative volume element (RVE) of the porous material is developed, and several load scenarios are applied to the RVE to correlate salt crystallization pressure, pore filling, and damage in the RVE. The resulting relationships are then condensed into a computationally efficient off-line phenomenological model, calibrated on a large FE-based database, capable of predicting the macroscopic damage in the RVE due to any pseudo-time history of salt crystallization pressure and pore filling. The effectiveness of the phenomenological model is verified by comparing its results with the ones computed through the FE model, for load scenarios not included into the calibration dataset, achieving good agreement of results. Finally, the possibility of using this phenomenological model together with available multiphase models to predict moisture transport, salt crystallization pressure, and damage into porous building materials is discussed.

---

<sup>1</sup> DICAM Department, University of Bologna, Italy, am.daltri@unibo.it

<sup>2</sup> CEE Department, Princeton University, USA

<sup>3</sup> Universite de Pau et des Pays de l’Adour, E2S UPPA, CNRS, TotalEnergies, LFCR, Pau, France

## **1 INTRODUCTION**

Environmental actions, such as moisture transport and salt crystallization, are known to play a major role in the deterioration process of porous building materials [1]. Although significant efforts have been devoted to the development of experimental procedures for the assessment of resistance of porous building materials against salt crystallization [2], the development of reliable numerical tools to predict salt weathering is still challenging.

In this contribution, the possibility to derive a micromechanics-based relationship between salt crystallization pressure, pore filling, and damage in porous building materials is investigated and discussed.

Firstly, a 3D finite element (FE) model of a microscale representative volume element (RVE) of the porous material [3] is developed. The RVE geometry is based on a simplified pore structure with statistically representative properties in agreement with experimental data [4]. Secondly, several load scenarios in terms of salt crystallization pressure and pore filling are applied to the RVE, through various pseudo-time histories, and the macroscopic damage is directly measured on the RVE. Accordingly, relationships between salt crystallization pressure, pore filling, and overall damage in the RVE are obtained (Section 2).

Such micromechanics-based relationships are then condensed into a computationally efficient offline phenomenological model, calibrated on a large FE-based database, able to predict the damage in the RVE due to any pseudo-time history of salt crystallization pressure and pore filling. The effectiveness of the phenomenological model is thus checked by comparing its results with the ones computed through the FE model, for load scenarios not included into the calibration dataset (Section 3).

The possibility to use this phenomenological model together with available multiphase models [5,6] to predict moisture transport, salt crystallization, pressure and damage into porous building materials is finally discussed (Section 4).

## **2 FINITE ELEMENT MODEL**

A solid FE model of the RVE is generated by considering the actual porosity and the mean pore radius of the material. A nonlinear plastic-damage constitutive law is adopted for the material matrix, by assuming homogenized mechanical properties. Several load scenarios are applied to the RVE with varying salt crystallization pressure and pore filling pseudo-time histories. After de-loading the pore pressure, the macroscopic damage  $D$  is directly measured on the actual condition of the RVE. According to this, relationships between salt crystallization pressure, pore filling, and macroscopic damage are obtained (Figure 1). In particular, Figure 1 shows an example of macroscopic damage  $D$  – pressure relationship for constant pore filling (in particular, the saturation degree of crystallized salt,  $S_s^s$ , is set equal to 1), as well as an example of damaged RVE.

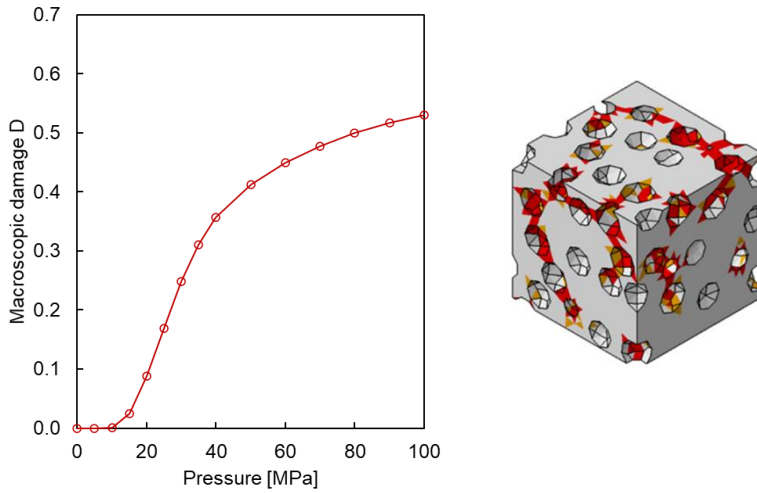


Figure 1: Example of macroscopic damage  $D$  – pressure curve for constant pore filling ( $S_p^s=1$ ), left, and example of damaged RVE, right.

### 3 PHENOMENOLOGICAL MODEL

The aforementioned relationships are subsequently condensed into an offline phenomenological model that is computationally efficient. Such model is calibrated using a large database of FE simulations. To verify the efficacy of the phenomenological model, its outcomes in terms of predicted macroscopic damage  $D^*$  are compared against those obtained by the FE model (in terms of macroscopic damage  $D$ ) for load scenarios that were not part of the calibration dataset, as shown in Figure 2.

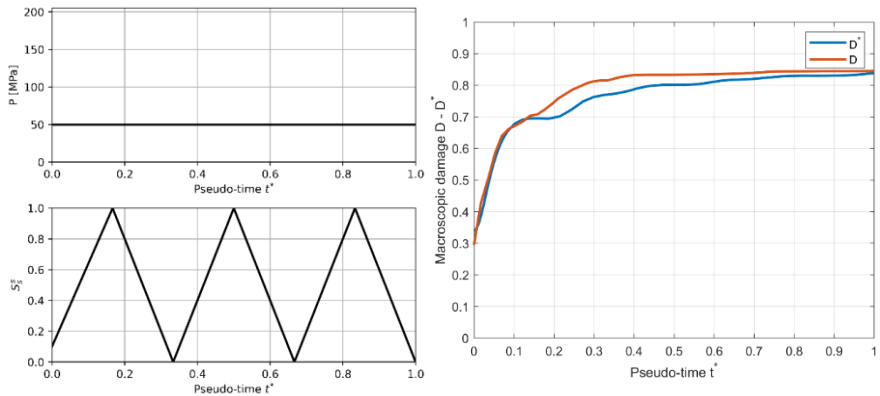


Figure 2: A posteriori comparison between FE and phenomenological models. Top left: adopted pseudo-time history of the pore pressure. Bottom left: adopted pseudo-time history of the pore filling. Right: comparison of the evolution of macroscopic damage between FE ( $D$ ) and phenomenological ( $D^*$ ) models.

## 4 MULTIPHYSICS SIMULATIONS

Such phenomenological model is finally coupled with existing multiphase models [4,5] to predict moisture transport, salt crystallization, pressure and damage into porous building materials through multiphysics simulations. An example of application is shown in Figure 3, where the drying of a porous building material initially saturated with saline solution and an evaporating top surface is shown in terms of pore filling (left) and macroscopic damage  $D^*$  (right) contour plots.

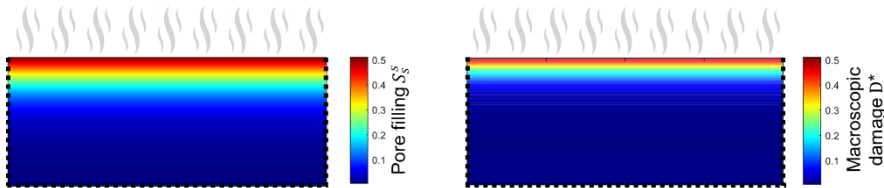


Figure 3: Example of multiphysics simulation of a drying phase: pore filling (left) and macroscopic damage  $D^*$  (right) contour plots.

## 5 CONCLUSIONS

In conclusion, this study explored the possibility to develop relationships between salt crystallization pressure, pore filling, and damage in porous building materials using a micromechanics-based approach. In this context, a phenomenological model based on micro-FE outcomes has been employed together with existing multiphase models to conduct multiphysics simulations to account for salt crystallization-induced damage into porous building materials.

## ACKNOWLEDGEMENTS

The support from the European project CRYSTINART through the Joint Programming Initiative on Cultural Heritage (JPI-CH) is gratefully acknowledged. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101029792. H. Derluyn acknowledges the support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 850853)".

## REFERENCES

- [1] Lubelli, B., et al., "Towards a more effective and reliable salt crystallization test for porous building materials: state of the art." *Materials and Structures* 51 (2018): 1-21.
- [2] Lubelli, B., et al., "Recommendation of RILEM TC 271-ASC: New accelerated test procedure for the assessment of resistance of natural stone and fired-clay brick units against salt crystallization," *Materials and Structures*, in press.

*Nicolò Lo Presti, Antonio Maria D’Altri, Luca Patruno, Giovanni Castellazzi, Tinhinane Chekai, Hannelore Derluyn, and Stefano de Miranda*

- [3] Grementieri, L., et al., “A multi-scale approach for the analysis of the mechanical effects of salt crystallisation in porous media”. *International Journal of Solids and Structures*, 126, 225-239.
- [4] Castellazzi, G., et al. “A coupled multiphase model for hygrothermal analysis of masonry structures and prediction of stress induced by salt crystallization.” *Construction and Building Materials* 41 (2013): 717-731.
- [5] D’Altri, A. M., et al. “Towards a more effective and reliable salt crystallisation test for porous building materials: Predictive modelling of sodium chloride salt distribution.” *Construction and Building Materials* 304 (2021): 124436.
- [6] Castellazzi, G., et al. “A staggered multiphysics framework for salt crystallization-induced damage in porous building materials.” *Construction and Building Materials* 304 (2021): 124486.