The interphase elasto-plastic damaging model applied to masonry structures

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ABSTRACT

Masonry is a heterogeneous material formed by blocks usually separated by mortar joints. Such a material, given its composition, presents a mechanical response strongly affected by the static and kinematic phenomena occurring at each constituent and at their joints. Therefore, some different length scales of interest may be identified. Substantially, it is possible to distinguish a macroscopic length scale from a mesoscopic length scale. The macroscopic length scale is of the order of the typical dimensions of the structural element. The mesoscopic length scale is of the order of the typical dimensions of the basic constituents of the heterogeneous material and the constitutive modeling needs the introduction of mechanical devices able to simulate the interactions between the adherents. Among these devices is quite popular the zero thickness interface model where the contact stresses and the displacement discontinuities are the primary static and kinematic variables.

However in masonry structures the response of joints depends on joint internal stresses as much as contact stresses. The introduction of internal stresses as additional static variables brings to an enhancement of the classical zero-thickness interface models [1]- [2]. This new model is referred as interphase. Therefore, with the term interphase we shall mean a layer separated by two interfaces from the bulk material or a multilayer structure with varying properties and several interfaces.

Under the hypothesis that the fibers along the normal direction to the middle surface remain rectilinear during the deformation process and that the stress and strain states are constant along the joint thickness, the kinematic equations are written as:

$$\varepsilon(x_1, x_2) = \frac{1}{2h}\left([\mathbf{u}] \otimes \mathbf{I}_3 + \mathbf{I}_3 \otimes [\mathbf{u}]\right) + \frac{1}{2}\nabla^s\left(\mathbf{u}^+ + \mathbf{u}^-\right) \tag{1}$$

where ε is the strain state, $[\mathbf{u}] = \mathbf{u}^+ - \mathbf{u}^-$, $\mathbf{I}_3 = \{\delta_{i3}\}$, ∇^s is the symmetric gradient operator. $\mathbf{u}^+$ and $\mathbf{u}^-$ are the displacement vectors at the physical interfaces Σ^+ and Σ^- respectively (see Figure 1).

Using standard arguments of structural mechanics the equilibrium equations can be derived:

$$\begin{aligned} &\mathbf{t}^+ - \sigma \cdot \mathbf{I}_3 + \tfrac{h}{2} div\sigma = \mathbf{0}; \quad \mathbf{t}^- + \sigma \cdot \mathbf{I}_3 + \tfrac{h}{2} div\sigma = \mathbf{0} \quad on\,\Sigma \\ &\mathbf{m} \cdot \sigma = 0 \quad on\,\Gamma \end{aligned} \tag{2}$$

where $\mathbf{t}^+$ and $\mathbf{t}^-$ are the contact tractions at Σ^+ and Σ^-, σ is the stress state in the joint, Σ and Γ the joint middle surface and its contour respectively.

The possibility to distinguish the internal stresses from the contact tractions permits to introduce different failure conditions for the physical interfaces and for the joint material. In particular, it is admitted to describe the formation and propagation of fractures separately with respect to the loss of adherence at

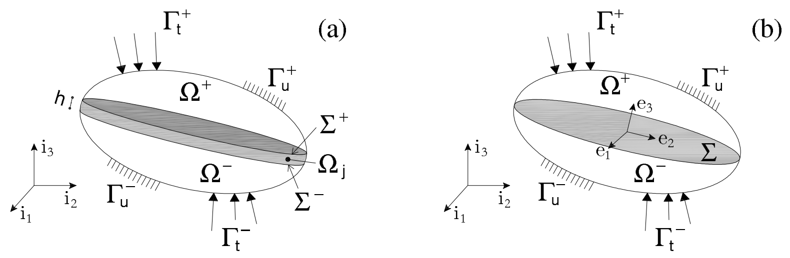

Figure 1: (a) Mechanical scheme of a third body iterposed between two adherents; (b) Interphase mechanical scheme

the physical interfaces. In fact, while the inelastic phenomenon of damage propagation can be associated with all the stress components of the vector σ, the conditions on the eventual plastic sliding at the physical interfaces can be written making reference to the contact stresses only.
The damage of the joint material is modelled by two different damage parameters ω^+ and ω^-, for tensile and compressive stress state respectively. The global damage parameter ω is obtained as a weighted mean according to [3].
The evolution of damage is controlled by the activation functions in tension (+) and compression (-), namely

$$\phi_d^{\pm} = \varsigma^{\pm} - \varsigma_0^{\pm} - \chi_d^{\pm} \tag{3}$$

where $\varsigma_0^{\pm}$ are energy threshold values, while $\varsigma^{\pm}$ and $\chi_d^{\pm}$ are mechanical variables termodinamically associated to the kinematical variables chosen for the description of damage evolution.
In a similar way, the activation and evolution of plastic sliding at the physical interfaces is governed by the classic bilinear Coulomb law, written as a function of contact stresses only.
With the aim to make some numerical analysis at the mesoscale level for masonry structures the interphase model has been implemented in an open-source finite element analysis program. The original finite element has four nodes and it has been developed in an isoparametric form for 2D applications.
The numerical examples regard simple tests to assess the numerical performance of the element for block-joint-block systems, and more complex tests on structural elements such as vaults and walls. Particular attention is paid to the possibility to simulate the reinforcement of such structures by means of FRP strips.
Summarizing, in the present work the nonlinear interphase model is presented as an innovative tool for the description of the inelastic phenomena that take place at joints and interfaces in masonry structures. The problems of damage propagation and inelastic strain evolution are faced on the base of a thermodynamically consistent theory. The model is implemented in a research-oriented finite element analysis program code. Numerical simulations are provided to show the main features of the model.

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