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An interface damage model depending on the in-plane deformation

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Many structural problems require the analysis of initiation and evolution of important damage phenomena. The heterogeneity of structure, or particular loading and constraint conditions, concentrate damage and macroscopic separation which are thus forced to appear in a limited number of critical zones, while the remaining parts can still be considered in elastic regime. In particular, the interfaces between different materials are important regions governing the strength and stability of structures. In fact, local ruptures and material de-cohesion develop in macroscopic fractures and separations between parts. Consequently an accurate understanding of fracture initiation and propagation has become ever more important from the serviceability and safety standpoints for structures. These regions are often described by cohesive crack where the fracture process zone is modelled as a fictitious crack, ahead of the actual traction-free crack; the strain localization is idealized as a crack opening and sliding, related to cohesive tractions. However in some cases, the interface presents a state of deformations that cannot be completely describe by relative displacement, for example in the presence of in-plane elongation [1] or confinement effects.

This is the case of external strengthening of quasi-brittle substrates (masonry or concrete) by means of Fiber Reinforced Polymer (FRP) that has gained great importance in the last few years especially in historic and monumental buildings due to its low invasiveness, great efficiency and low weight-to-strength ratio. In fact, debonding in FRP reinforcements is a typical failure mode. The fracture process initiate and propagate in a narrow region (the adhesive and a thin layer of substrate cover) separating two well defined domains. The role of the interface is essential to the stress transfer between FRP and substrate influencing the structural behaviour in terms of stiffness, strength and failure behaviour.

Numerical models for FRP debonding are typically based on shear stress–tangential slip interface laws that are calibrated by direct shear tests [2]. In this case, relative displacement between FRP reinforcement and substrate is lumped within the interface layer, whose constitutive law collects all compliance and non-linear contributions of adhesive and external substrate layer. This modelling approach demonstrated success for specific test configurations and design procedure, but there is still a need for models that can satisfactorily predict the debonding failure phenomena in more general cases. In fact, the cohesive interface law is strongly influenced by boundary effects [3] and should take into account and reflect the complex behaviour and processes taking place in a substrate "compliance volume" [4]. In Figure 1 the stresses obtained numerically in the substrate and reproducing the shear test proposed in [5] for two load levels (60% and 100% of the maximum value of transmissible force P_{max}) are reported. In both cases, the process zones under the gluing surface evidence non negligible stresses σ_x that certainly influence the bonding behaviour. Moreover, this confinement effect changes and peeling stresses may appear at the extremities of the reinforcement thus leading to noticeable changes of the transmittable shear stresses.

In the present work, an enhanced formulation for cohesive interface analogous to [6] that keep into account the effect of in-plane deformations of the gluing surface is proposed. Starting from this kinematical assumption an enriched formulation of interface finite element is proposed. In fact, the interface is commonly modelled by zero thickness finite element characterized by the duality in energy of tractions and displacement discontinuities. The enriched formulation introduces also a constitutive correlation between the in-plane deformation (elongation or confinement) of the interface and the membrane state of stress. This assumption permits to easily translate at the interface level the constitutive laws of the continuum. An interface damage model which accounts for the mode I and mode II and the axial deformation of the interface is proposed starting by the use of Drucker-Prager failure criterion. Simple numerical simulations are presented in order to illustrate the capabilities of the model. Later on, some numerical applications are carried out in order to assess the performances of the proposed model in reproducing the mechanical behaviour of the concrete and masonry elements strengthened with external FRP reinforcements.

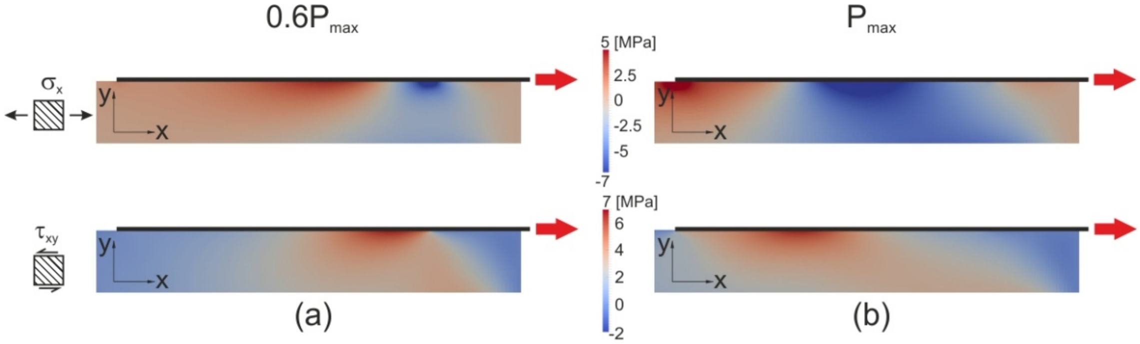

Figure 1: Finite Element simulation of the debonding tests in [5]. (a) stresses in the substrate at 60% of the maximum force. (b) stresses in the substrate at the maximum force.

REFERENCES

[1] F. Freddi, M. Frémond, “Damage in domains and interfaces: a coupled predictive theory” *Journal of Mechanics of Materials and Structures*, 1, 1205-1234, (2006).

[2] B. Ferracuti, M. Savoia, and C. Mazzotti, “A numerical model for FRP–concrete delamination,” *Composites Part B: Engineering*, 37, 356–364, (2006).

[3] K. Benzarti, F. Freddi, M. Frémond, “A damage model to predict the durability of bonded assemblies. Part I: Debonding behavior of FRP strengthened concrete structures” *Construction and Building Materials*, 25, 547-555, (2011).

[4] J. Toti, S. Marfia, E. Sacco. Coupled body-interface nonlocal damage model for FRP detachment. *Comput. Methods Appl. Mech. Engrg.* 260, 1–23, (2013).

[5] P. Carrara, D. Ferretti, F. Freddi, and G. Rosati, “Shear tests of carbon fiber plates bonded to concrete with control of snap-back,” *Engineering Fracture Mechanics*, 78, 2663–2678, (2011).

[6] G. Giambanco, G. Fileccia Scimeni, and A. Spada, “The interphase finite element” *Computational Mechanics*, 50, 353–366, (2012).