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DYNAMIC NONLINEAR DEBONDING AT INTERFACES IN THIN-WALLED LAYERED SYSTEMS

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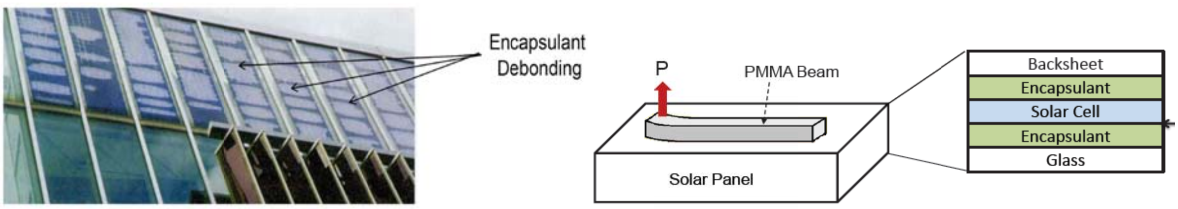
Several systems in nature and technology are composed of different materials separated by interfaces with a not negligible thickness. In many cases, especially when their thickness is comparable to those of the other layers, the interfaces do not act as simple adhesive layers, but have a fundamental role in determining the overall behaviour of the whole system. This is for instance the case of photovoltaic modules, where polymeric layers with a not negligible thickness are used to encapsulate silicon solar cells and glue them to glass or polymeric covers necessary for their environmental protection (Fig. 1). In such complex structures, the encapsulating polymeric layers contribute to increase the ductility of the silicon cells, to reduce the internal stress constraints due to a thermo-elastic mismatch between the different layers and they also act as dampers in case of dynamic and impulsive loadings. On the other hand, they are also weak regions, possible seats for debonding. Decohesion between glass and silicon cells, as well as between the silicon cells and the thin backsheet are in fact observed in real conditions (see Fig. 1) [1]. It can be due to both thermal actions and mechanical dynamic loadings due to transportation or wind gusts.



(a) Encapsulant debonding in photovoltaic modules (b) Mechanical test for measuring encapsulant adhesion

Figure 1. An example regarding photovoltaic modules demanding models for predicting the fracture mechanics properties of the finite thickness encapsulant layers (figures from (Novo et al. [1]).

The problem of modelling such materials is conventionally solved by introducing zero-thickness interface elements with a cohesive zone model (CZM) to describe the phenomenon of interface decohesion. However, this approach leads to neglect the effects that the finite thickness interfaces have on the overall quasi-static and dynamic behaviour of the system. In the quasi-static regime, a damage mechanics formulation has been proposed to derive a CZM by taking into account the material degradation inside a physically-defined finite thickness interface [2]. The obtained inelastic stress vs. relative displacement relations are applied to zero-thickness interface elements, although their nonlinear shape is dependent on the evolution of damage and is not given a priori as for a classical CZM. As regards the dynamic behaviour of finite thickness interfaces, few contributions are available in the literature. The influence of the mass of thick structural interfaces and interfaces made up of inertial elastic layers on the dynamic behaviour has been noticed in [3], although the problem of nonlinear dynamic propagation is still open.

In the present contribution, the effect of finite thickness interfaces on the dynamic behaviour of thin-walled layered materials is investigated. The weak form of the dynamic equilibrium is written by including not only the contribution of cohesive interfaces related to the virtual work exerted by the cohesive tractions for the corresponding relative displacements, but also considering the work done by the dynamic forces of the finite thickness interfaces resulting from their inertia properties. The implementation of this constitutive model is carried out within a 2D interface element in FEAP [4], where an implicit solution strategy is adopted to solve the mechanical nonlinearity and the time integration.

A parametric analysis is carried out on the double cantilever beam test to quantify the roles of interface stiffness and mass on debonding. Their effect regards both the dynamic increase factor, which is further increased as compared to the case when interface thickness effects are neglected (Fig. 2), and the energy dissipated during the post-peak response. Finally, the proposed computational approach is applied to study decohesion problems in layered materials with complex structures, such as photovoltaic modules.

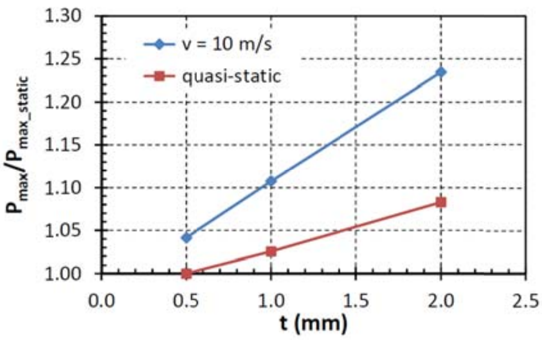


Figure 2. The effect of the interface thickness on the peak load in a double-cantilever beam test, for a quasi-static and a dynamic loading condition.

REFERENCES

[1] F. Novo, R.H. Dauskardt, D. Miller, M. Kempe , N. Bosco and S. Kurtz, Quantifying adhesion and debonding of encapsulations for solar modules, *2012 PV Module Reliability Workshop*, February 29, 2012.

[2] M. Paggi and P. Wriggers, Stiffness and strength of hierarchical polycrystalline materials with imperfect interfaces. *J. Mech. Phys. Solids,* Vol. **60**, pp. 557-571, 2012.

[3] D. Bigoni and A.B. Movchan, Statics and dynamics of structural interfaces in elasticity. *Int. J. Solids Struct.*, Vol. **39**, pp. 4843–4865, 2002.

[4] O.C. Zienkiewicz and R.C. Taylor, *The finite element method*, 6th Edition, Elsevier, 2005.