

On the use of drilling rotations for DIC-based identification of interface parameters in adhesive structural joints

N. Valoroso

Dipartimento per le Tecnologie, Università di Napoli Parthenope, Italy, nunziante.valoroso@uniparthenope.it

In recent years adhesive bonding technologies have become widespread in industry and at present they are being employed on a daily basis. Actually, in modern world adhesives are almost ubiquitous and applications include everyday products as food packaging materials, electronics, where bonding is replacing soldering techniques to connect integrated components in a stress-free way, and high-tech solutions such as in the body of Formula 1 racing cars, where innovative joints and extreme combinations of materials are realized by bonding parts together. This virtually unlimited range of applications calls for an intensive research and development work in order to fully exploit the potential of adhesive joints.

As for most structural components consisting of the assembly of individual elements, failure of adhesive joints due to damage growth at bonded interfaces, leading to fracture development by sliding and separation, is one of the most important failure modes and for its simulation the cohesive zone concept initially proposed by Barenblatt [1] has become increasingly popular in the last decades. One of the reasons of its success is probably the flexibility of the cohesive approach to fracture, which provides a phenomenological description of the complex microscopic processes leading to the progressive decay of cohesive forces and the formation of traction-free surfaces. For situations where interface positions are a priori known, cohesive models are used in conjunction with zero-thickness interface elements. These have to adequately resolve the process zone and be compatible with the surrounding continuum elements in order to obtain meaningful answers. Moreover, the availability of trustworthy estimates of material parameters that characterize the traction-relative displacement law and the general coherence between the data reduction schemes and the FE model in which the cohesive law is used are not secondary aspects, since the assumptions made for computing the material parameters from experiments have a direct impact on the results of computations.

In this study the fundamental problem of parameter identification via inverse analysis based on full-field kinematic data obtained via Digital Image Correlation (DIC) is discussed with special attention on resolving the surface motion of adhesive joints up to failure. This is not an easy task since computational failure analysis would require elements that are highly flexible and accurate, and with reduced sensitivity to mesh distortion, whilst for identification purposes elements with low number of nodes are quite desirable since they result in low connectivity of the structural stiffness matrix and reduced computational effort. For instance, in 2D problems in elasticity the comparative running time of a 4-noded quadrilateral is about eight times smaller than of 8-noded elements at the price of slightly worse accuracy for the small strain case [2].

Finding the optimal trade-off between accuracy and computational cost is critical. Hence, for the problem at hand we suggest to simulate the response up to failure of different joint configurations using interface elements with drilling rotations located along the bondline [3]. The interest of such interface elements is motivated by the fact that it can be coupled with membrane/shell elements with in-plane rotations, which are well-known to exhibit excellent accuracy and convergence features both for regular and distorted meshes, see e.g. [4].

The interface elements and constitutive relationship first presented in [5] have been implemented in a customized version of the finite element code FEAP [6] along with a suitable procedure for the computation of sensitivities, i.e. the gradients of displacement and reaction forces with respect to the material parameters. This is indeed a key ingredient for identification purposes since, on one hand, it may allow to determine the location of measurements with the highest information content during experiments and, on the other side, it can also provide the search direction in a gradient-based minimization algorithm.

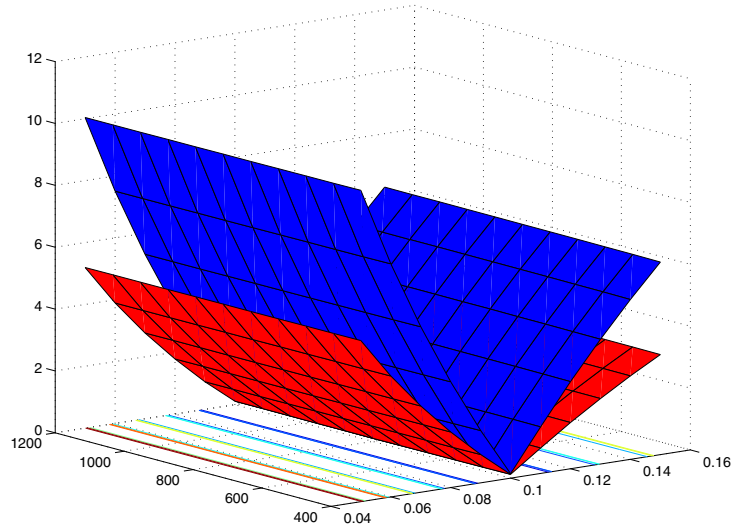


FIG. 1 – Comparison of computed cost function used for identification. Standard interface elements (red) VS drilling interface elements (blue).

A rough comparison between the performances of classical 4-noded interface elements along with Enhanced Assumed Strain (EAS) quadrilaterals and the new interface element coupled with membrane elements with drilling degrees of freedom is shown in Figure 1 in terms of the cost function used for identification of mode-I parameters using the DCB geometry [7]. Moreover, apart from the different magnitude of the gradient of the cost function, which yields better convergence properties in the inverse procedure, the standard interface element is also likely to converge for an element size that is approximately double with respect to the one for which the drilling element provides the correct answer. Accordingly, the achievable improvements in view of identification are neither marginal nor negligible since the inverse procedure may require hundreds of forward analyses with a very refined mesh in order to obtain reliable estimates of interface parameters in presence of noisy data such as kinematic measurements obtained from DIC.

Références

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