A non linear finite element approach with cohesive-frictional interfaces for the Mode II Transverse Crack Tension test insight

Guido Borino[1], Francesco Parrinello[1]
[1]*Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, Università di Palermo, Italy*
E-mail: guido.borino@unipa.it, francesco.parrinello@unipa.it

Keywords: interface, Mode II fracture, Transverse Crack Tension test.

In many circumstances structural failure modes are driven by the formation and propagation of fractures. For instance in composite laminate structures one of the most worrying condition is delamination, which is an interlaminar progressive fracture. Fracture toughness is the material mechanical parameters which ensure fracture safe condition and it is also an essential parameter for performing nonlinear structural analysis, no matter if based on Fracture Mechanics or by means of Interface Cohesive theories. It is then of paramount relevance to evaluate the critical fracture energy by means of simple and reliable laboratory tests. Several tests are available for the direct determination of mode I and mode II fracture energies. If for mode I, fracture energy determination is nowadays well defined and the Double Cantilever Beam (DCB) test is normed and universally adopted, it is not the same for mode II fracture energy. The tests based on bending beams theory such as End Notched Flexure (ENF), End Loaded Split (ELS) test and Four Point End Notched Flexure (4ENF) are all widely used tests, which however for different reasons have not been fully accepted. The main troubles with the mode II classical tests stems from problems with unstable crack propagation, difficulty in monitoring the crack tip advancement, frictional dissipation effects, large process fracture process zones and bulk dissipative mechanisms, which may affect the evaluation of the Fracture energy. Among the

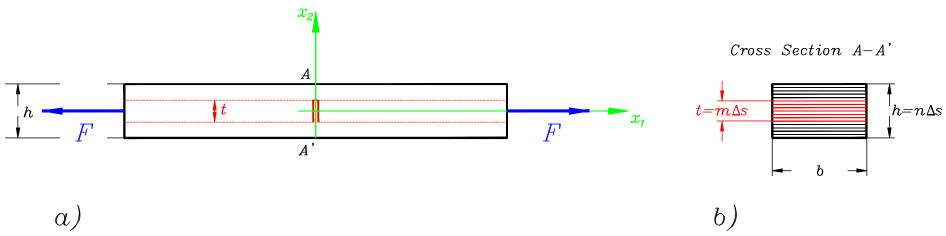

Figure 1: Scheme of TCT test specimen. a) longitudinal view with the trajectory of the four cracks departing from the two tips. b) Central weakened cross section.

above mentioned mode II delamination tests, a new test (not based on bending) named Transverse Crack Tension (TCT) test, [1] is getting popular for its simplicity of execution. In fact, it does not require any special experimental tool except a standard tension test apparatus and the derivation of the fracture energy is straightforward. The specimen is an unidirectional laminate plate formed by n-packed laminae with the fibers oriented along the axis of the plate (axis x_1 of Fig. 1). At the mid cross section, inside the core of the specimen and before curing, m-laminae are cut (with possibly a gap). The specimen is then loaded in simple tension along the axis x_1.

The critical load F_c that produce a longitudinal delamination propagation is directly related to the mode II critical fracture energy $G_{IIc} = \sigma_n^2(h-t)/(4E_1h)$, with $\sigma_n = F_c/[(h-t)b]$, where h, t and b are the height, the height of the central cut and the width of the specimen, whereas E_1 is the Young modulus in x_1 direction. Despite of the simplicity of the procedure, some warning have been posed on the reliability of the obtained results. Namely, the test gives results strongly affected by the size of the sample, which prejudices the possibility to correctly apply the most common theoretical and computational approaches to fracture mechanics, which do require a truly structural independent fracture energy parameter. What is actually observed is that the measured Fracture Energy as the rate h/t become larger and larger. In [2, 3] the authors gave a possible explanation stating that beside delamination process, frictional effects along the fracture surfaces and volumetric plastic deformation takes place during the test which in turn produce an extra dissipation which affects the computed Fracture Energy.

In [5] extremely accurate full field experimental stress analysis techniques shows the presence of very high shear stress concentration at the crack tip and compressive stress at the process zone which seem to confirm the presence of additional dissipation mechanisms. In [4] on the basis of accurate nonlinear FE numerical simulations, it is showed that inserting into the interface model frictional features and adopting constitutive equation which allow the development of plastic shear strains at the bulk, the Energy dissipated is indeed size-dependent. Very recently [6] a variation of the standard TCT test has been proposed. In order to overcome the size dependent solution, the specimen is modified inserting four cut of lenght a_0 at the two tips of the transverse crack along the longitudinal direction. With such a simple modification it has been shown that the stress concentration is released, the fracture is driven along the x_1 direction and the fracture energy is no more size dependent.

In this paper the authors investigate the main features of the modified TCT test, making use of a nonlinear finite element analysis in which a cohesive-frictional interface element recently proposed, [7], is adopted. The numerical analysis shows that the modified TCT, confine in an acceptable way the size effects and also give suggestion on the amplitude of the initial crack length a_0.

References

[1] Prinz, R., Gädke, M., ”Characterization of interlaminar mode I and mode II fracture in CFRP laminates”, In: Proc. Inter. Conf. Spececraft Structures and Mechanical Testing, 97-102 (1991).

[2] Wisnom, M.R., ”On the increase in fracture energy with thickness in delamination of unidirectional glass fibre-epoxy with cut central plies”, J. Reinf. Plastic Comp., 11, 897–909, (1992).

[3] Cui, W.C., Wisnom, M.R., Jones, M., ”An experimental and analytical study of delamination of unidirectional specimens with cut central plies”, J. Reinf. Plastic Comp., 13, 722-739, (1994).

[4] van der Meer, F.P., Sluys, L.J., ”A numerical investigation into the size effect in the transverse crack tension test for mode II delamination”, Composites Part A, 54, 145-152, (2013).

[5] Scalici, T., Pitarresi, G., Valenza, A., Catalanotti, G., Camanho, P.P., ”Experimental evaluation of through-the-thickness stress distribution in transverse crack tension test sample”, 20th Int. Conf. Composite Materials, http://iccm20.org/fullpapers/file?f=2JdDvmR3eD (2015).

[6] Scalici, T., ”Analisi e sviluppo di un setup sperimentale per la determinazione della tenacit a frattura a modo II nei materiali compositi e ibridi”, PhD Dissert., Univ. Palermo, Italy, (2016).

[7] Parrinello, F., Marannano, G., Borino, G., ”A thermodynamically consistent cohesive-frictional interface model for mixed mode delamination”, Eng. Fract. Mech., 153, 61-79, (2016).