OBTAINING THE MODE II ENERGY FRACTURE TOUGHNESS IN A C-ELS TEST BY MEANS OF THE J-INTEGRAL

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Introduction

The Calibrated End-Loaded Split (C-ELS) test is used to determine the mode II fracture resistance of unidirectional fibre-reinforced plastic composites. The existing ISO 15114 test standard [1] is based on Linear Elastic Fracture Mechanics (LEFM) assumptions in which the crack length has to be known or approached.

However, due to the shear loading, the determination of the crack front by means of the conventional optical methods becomes difficult and operator dependent. Furthermore, when using the test with adhesive joints, large plasticity and damage regions will form near the crack tip and the hypothesis based on the existence of a sharp crack front (e.g. in LEFM) are no longer valid.

In this work, an alternative test procedure based on the J-integral theory [2-4], which accounts for large scale fracture process, is developed.

Methodology

The J-integral closed-form solution is derived by selecting an integration path along the external contour to be solved (figure 1) given the path independence $J_\Gamma = J_{TIP}$. The path has to be cut in a section S-S' due to the complexity of the loads induced by the clamping system.

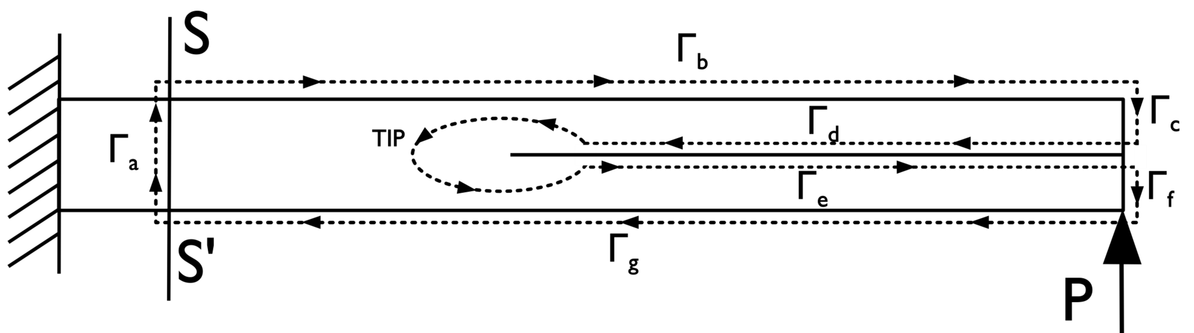


Figure 1.- Integration paths considered in the C-ELS test.

If no friction is assumed, J_Γ is zero everywhere except at the load application point (Γ_g) and at the transversal section S-S' (Γ_a). J_{CELS} can be defined as:

$$J_{CELS} = -\frac{3}{5}\frac{P^2}{G_{12}\,b^2\,h} + \frac{P}{b}\left(\tan(\theta_g) - \tan(\theta_p)\right) + \int_0^{2h}\left[-\frac{1}{2}E_{11}\varepsilon_{11}^2\right] dy$$

The longitudinal strain profile at section S-S' is obtained by three different methods: i) experimentally measured with the Digital Image Correlation (DIC) technique (face B of figure 2); ii) by experimental estimation from a strain gauge located at the specimen top surface and; iii) analytically calculated by means of beam theory hypothesis.

The crack length is also monitored in face A to compare the results of the J-integral to those obtained with the data reduction methods based on LEFM. Figure 2 illustrates the experimental set up with the inclinometers, strain gauge and C-ELS tool used.

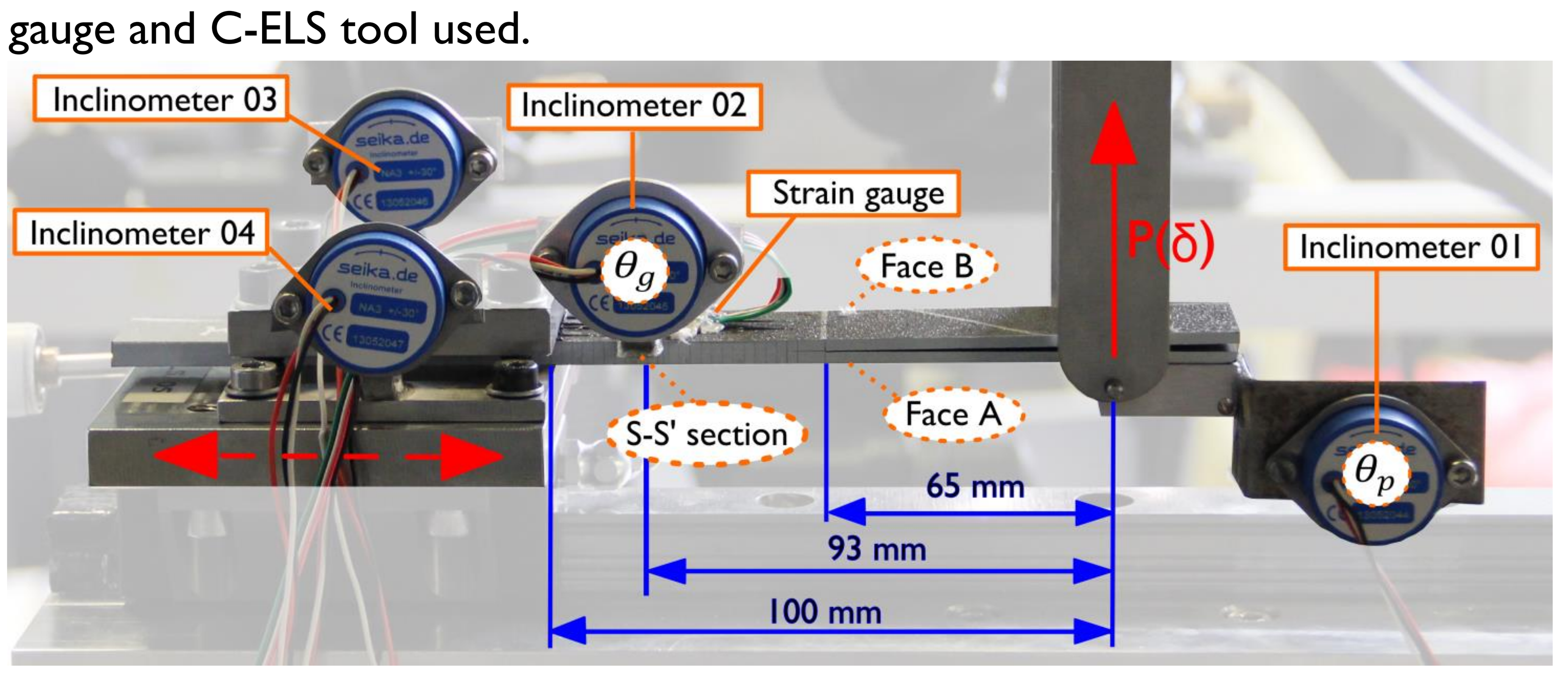


Figure 2- Test setup.

Results

A batch of 6 CFRP specimens was tested. An image of the strain profile at section S-S' of one of the specimens obtained with the DIC and the strain gauge is shown in figure 3.

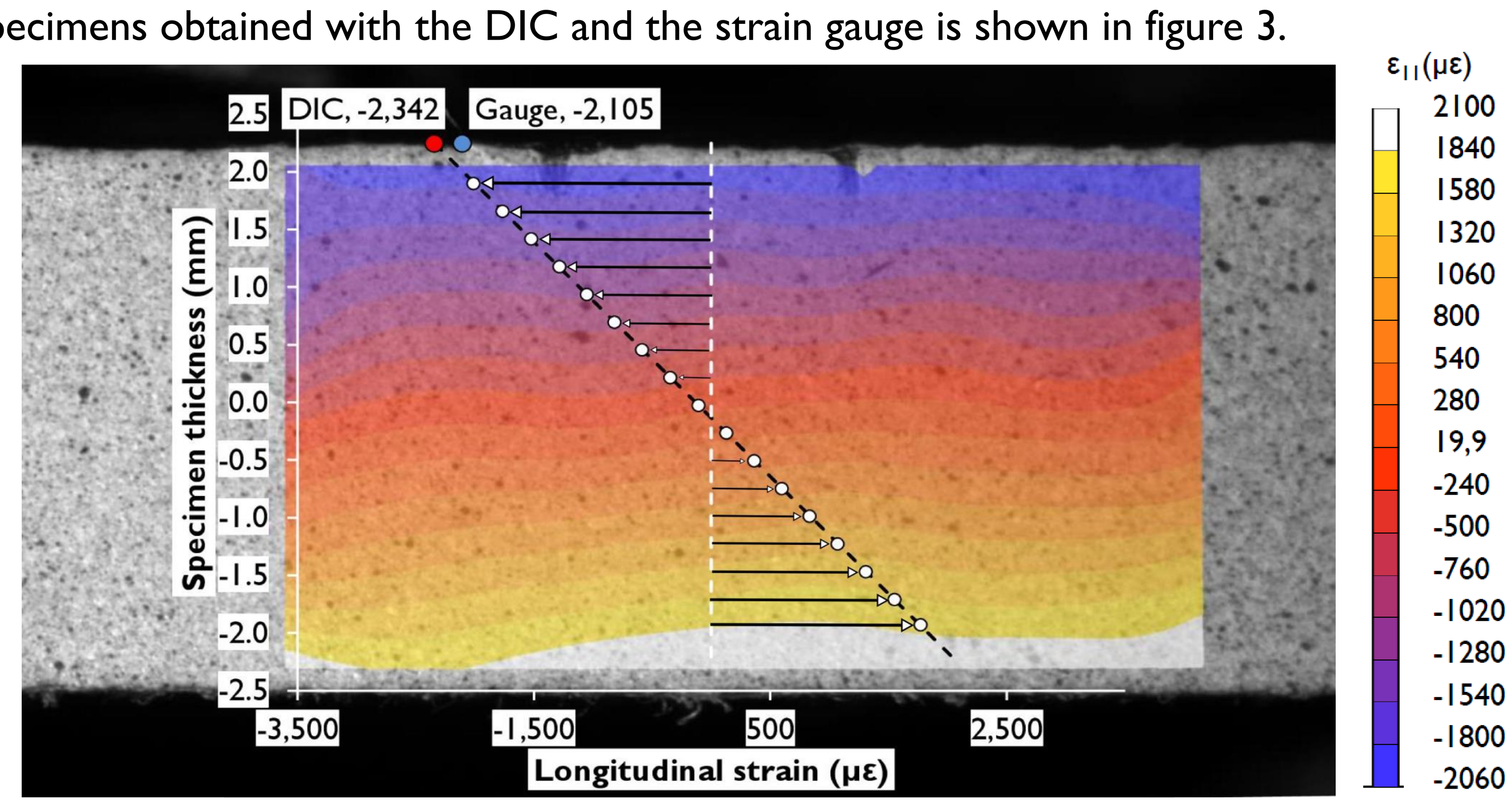
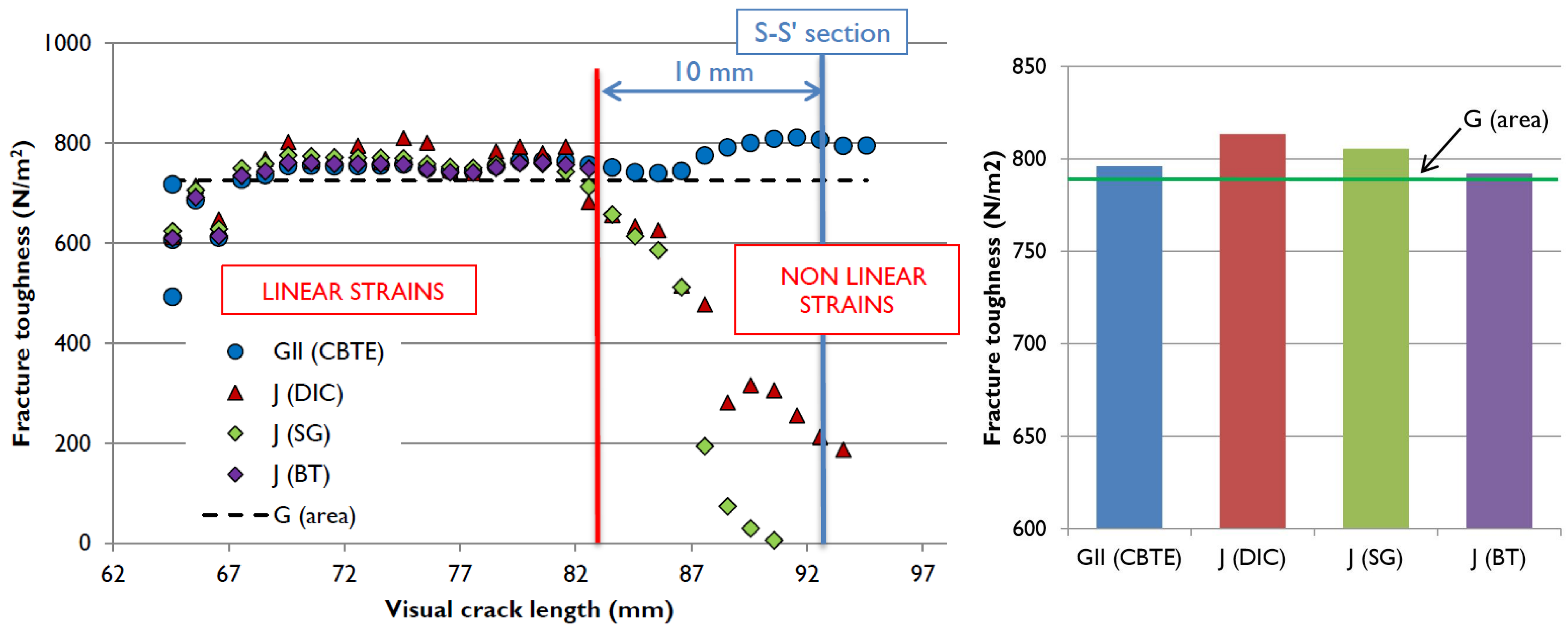


Figure 3.- Strain profile measured at S-S' with DIC (Face B) and the strain gauge.

During the test, the longitudinal strain profile is linear until the crack tip is about 10 mm away from S-S' section (a = 83 mm). While the strain profile is linear, the strains at the top face obtained by DIC and the strain gauge are in good agreement, see figure 3.

The results of J-integral have been compared to the CBTE [1] and the area data reduction methods, see figure 4. Despite not being used in the calculation, the results of the J-integral have been plotted against the crack length for comparison purposes, see figure 4a.



(a) Specimen (b) Batch (linear strain profile region)

Figure 4.- Fracture thoughess obtained from the LEFM (G_{II}) data reduction methods and J-integral.

The results show that the G_{II} obtained with the CBTE and Area methods are in good agreement with J-integral while the strain profile is linear. When nonlinearities occur (10 mm away from S-S' section), the results of the J-integral start to deviate from the LEFM data reduction methods because the path does not enclose all the singularities that occur near the crack tip.

Conclusions

A test procedure and a data reduction method based on the J-integral has been developed for a C-ELS test. If the deflections are small and the strain profile is linear the results of the J-integral are comparable to those obtained by data reduction methods based on LEFM (CBTE and Area method).

References

[1] ISO 14115:2014, Fibre-reinforced plastic composites – Determination of the mode II fracture resistance for unidirectionally reinforced materials using the calibrated end-loaded split (C-ELS) test and an effective crack length approach; 2014.
[2] AJ. Paris, P.C. Paris. Instantaneous evaluation of j and o-star. International Journal of Fracture. 1988;38(1):19–21.
[3] U. Stigh, K.S. Alfredsson, A. Biel. Measurement of cohesive laws and related problems. IMECE 2009: Proceedings of the ASME International Mechanical Engineering Congress and Exposition 2009;11:293–8. (doi:10.1115/IMECE2009-10474).
[4] C. Sarrado, A. Turon, J. Renart. An experimental data reduction method for the Mixed Mode Bending test based on the mode-decomposed J-integral approach. (Summited, 2014).

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