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ENERGY RELEASE RATE EVALUATION IN SANDWICH COMPOSITE STRUCTURES BY USING THE DIC

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Abstract: *In this paper a new formalism based on the coupling between the optical full field techniques and the integral invariants is proposed in order to evaluate the fracture parameters in cracked sandwich composite structures. The formalism allows identifying the fracture parameters in terms of energy release rate. From the experimental tests the displacement field is obtained by digital image correlation measurements. In this case the experimental displacement fields are employed to calculate the strain and stress fields by a numerical approach. Then using the mechanical fields defined on the surface of specimen the integral invariants can be used in order to characterize the fracture process. The present study is limited to the identification of the mechanical fields using the experimental displacement fields measured by the optical methods.*

1. INTRODUCTION

Since some years the optical methods find more and more, their applications in the mechanical characterisation of materials and structures. Associated to the full fields techniques, the optical methods can be easily correlated with the energetically approaches such as the integral invariants. Among the optical methods, the digital image correlation seem to be the best to characterise the mechanical behaviour in the case of composite. Another particularity of this optical full fields' technique is the possibility to coupling this one with the numerical approach such as the Finite Element Method (FEM). Using the optical methods, the zone of interest (ZOI) can be discretized either by the subsets similar to the finite elements of the mesh, in the case of DIC. In this paper a feasibility study in order to characterize the fracture behavior in sandwich composite structures [1,2] by digital image correlation technique, is proposed.

2. OPTICAL FULL-FIELD TECHNIQUES [3,4,5,6]

Related with the optical full field methods, digital image correlation is an optical method allows to measure in-plane displacement.

The basic principle of method is based on the comparison between two images of sample plane surface acquired at different states one before deformation and the other one after. Then, the displacements are estimated by comparing the degree of resemblance between these two images subsets. As is shown in Figure 1, in DIC the displacements are calculated into Zone Of Interest (ZOI) discretized by small areas with multiple pixel called subsets (where, m is the subset numbers). Note, that each subset is characterized by a unique light intensity distribution (i.e. gray level). Assuming that during the test the light intensity distribution on the plane surface of sample does not change, the displacements are estimated by searching the subsets changes (translation + rotation + rigid body motion) between the undeformed and the deformed images. Finally the displacement field is build from the displacement vectors (u1, u2) corresponding to displacements of all subsets centers.

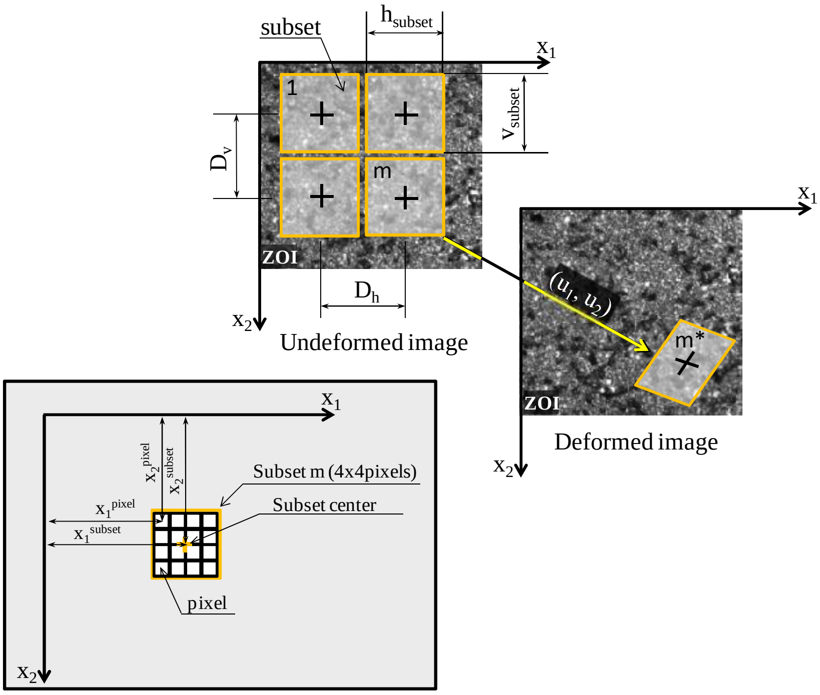

Figure 1: Principle of Digital Image Correlation

Another important aspect in DIC is the specimen plane surface preparation. So, in order to obtain a gray level distribution, it is necessary to create a characteristic speckle pattern a black speckle is deposited on the white background by spraying the black and white paints.

3. EXPERIMENTAL SETUP

The testing machine is an electromechanical press with a load capacity of 50kN. The test is run under displacement control and the velocity of the cross-head is fixed at 0.01 mm/s. As shown in Figure 2 the sandwich composite specimen is loaded in opening mode using a system which includes a steel pyramid and two rollers. The loading system allows perfect lips displacement symmetry.

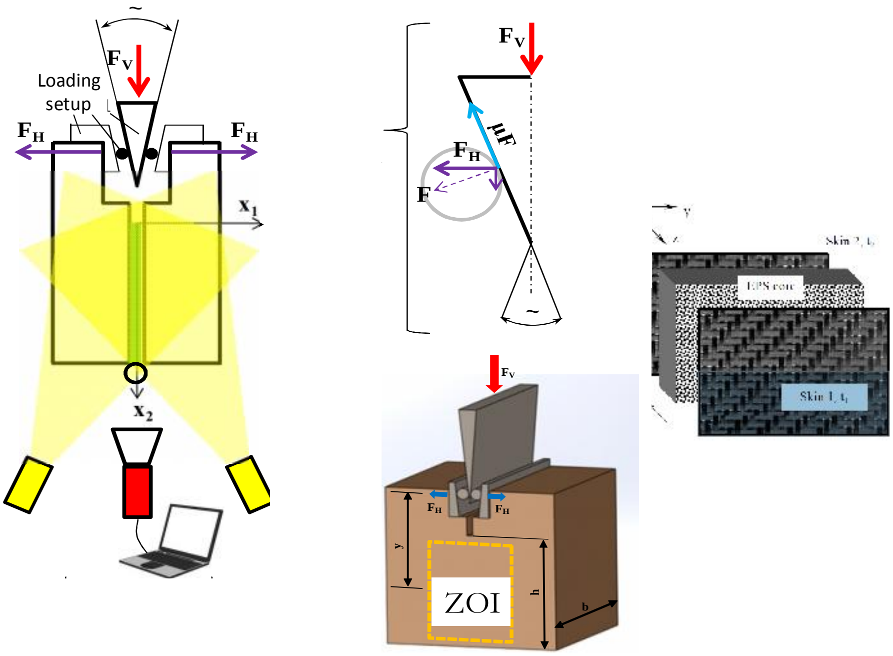

Figure 2: Experimental setup

Besides, Figure 3 puts in evidence the crack lips displacement symmetry during the test. In fact the plotted displacements correspond to the rollers displacement measured by mark tracking method.

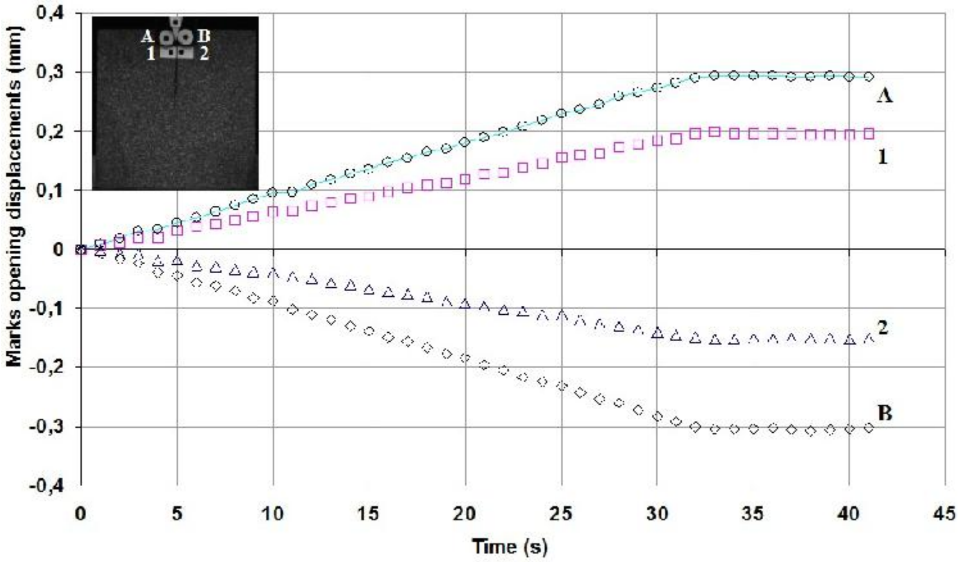

Figure 3: Experimental displacement of the loading rollers

As is show in Figure2, the specimen is a sandwich composite. The sandwich structure taken into account to accomplish the damping analysis presents two carbon/epoxy skins reinforced with a 0.3 kg/m2 twill weave fabric and an expanded polystyrene (EPS) 9 mm thick core with a density of 30 kg/m3 [1], [2]. The final structure's thickness is 10 mm. The carbon-fibre fabric used in this structure is a high rigidity one, that presents so called twill weave. The main feature of this weave is that the warp and the weft threads are crossed in a programmed order and frequency, to obtain a flat appearance. The skins were impregnated under vacuum with epoxy resin and sticked to the core.
During the test, the load-displacement evolution is recorded using a LVDT sensor and a load cell. Furthermore, an 8-bit Charge Coupled Device (CCD) camera (1392x1040 pixels^2) is synchronized with the testing machine to measure the displacement fields by DIC.

4. INTEGRAL INVARIANT J-INTEGRAL

In fracture mechanics the J-integral is associated with strain energy release rate or the work per unit of crack area. The theoretical concept of the J-integral was developed by Cherepanov [7,8] and Rice [9,10] who showed that the J-integral is independent of the path defined around the crack tip (Figure 4). The crack is oriented in x_1-direction, and the crack tip represents the origin of the coordinate system.

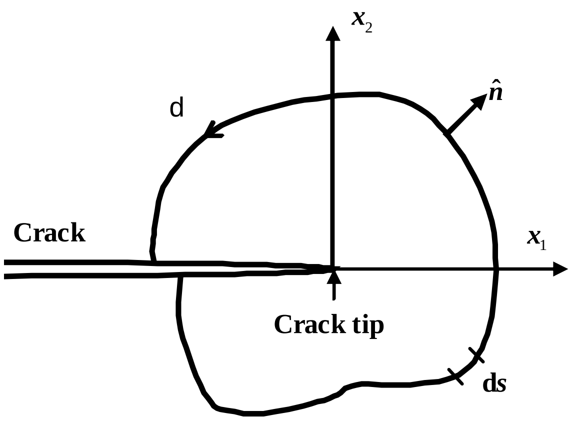

Figure 4: Domain of integration of J

The J-integral can be expressed in the following form:

$$J = \int_{\Gamma} \left(W \cdot n_1 - T_i \cdot \frac{\partial u_i}{\partial x_1} \right) \cdot ds \tag{4}$$

$$W = \frac{1}{2} \cdot \sigma_{ij} \cdot \varepsilon_{ij} \tag{5}$$

$$T_i = \sigma_{ij} \cdot n_j \tag{6}$$

Where: W is the elastic strain energy density, T_i is the traction along the contour Γ, n the unit normal of the contour path, u is the displacement vector, σ_{ij} and ε_{ij} are the stress and strain tensors, respectively.
By introducing Equations (5) and (6) in (4), we can see that the J-integral evaluation is based on the knowledge of the mechanical fields in terms of displacement, strain and stress. Therefore, the displacement vector (u) will be evaluated experimentally by DIC method, while the strain (ε_{ij}) and stress (σ_{ij}) tensors will be calculated from numerical approach.

5. EXPERIMENTAL RESULTS

As illustrated in Figure 5 the domain of integration can be assimilated by crowns defined by the centers of the correlation windows. By using the finite elements mesh generated from the experimental data, the J-integral is evaluated numerically via Equation (4) along different crowns (Γ_i) surrounding the crack tip.

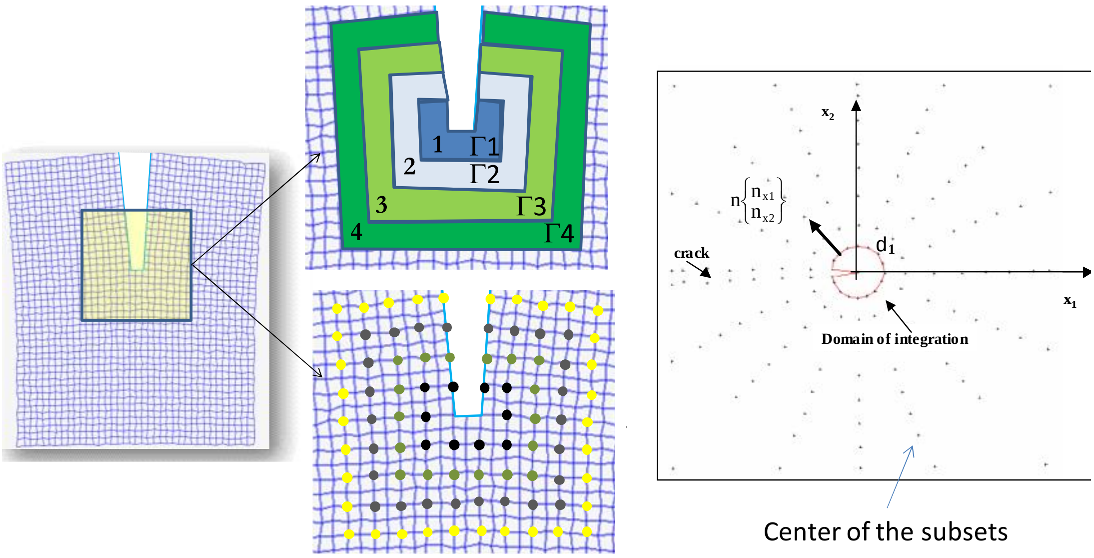

Figure 5: Domain of integration using the experimental results

The J-integral values versus loading amplitude and size of the domain of integration are presented in Table 1.

Load (N)	J –integral (J/m²)			
	Γ_1	Γ_2	Γ_3	Γ_4
280	25.33	25.01	24.99	25.42
560	55.23	55.03	55.02	54.98

The results presented in Table 1 show a low variation of the energy release according to integral path. These slight differences can be explained by experimental displacement field noises. In this case the displacement field optimization may be considered in order to increase the accuracy of the experimental fields.

6. CONCLUSION

In this study, a new experimental technique is proposed in order to characterize the fracture parameters in sandwich composites. The DIC is employed in order to measure the displacements fields on the specimen surface. Based on the experimental optical full field measurements the energetic approach is used to evaluate the energy release rate. Using the experimental displacement and the strain fields the stress tensor is calculated via a constitutive law. The stress fields are evaluated using the finite elements method. In fact the approach of this study consists of a combination of experimental and numerical techniques in order to evaluate the different mechanical fields employed in the energetic approach such as J or G-integral. For this purpose the experimental data are implemented in a finite element code in order to generate a finite element mesh. In this case the stress fields are calculated using the experimental data by imposing real boundary conditions. Now, using the mechanical fields measured or evaluated by coupling experimental with numerical approaches the J-integral is calculated for several loading steps and for different crowns defined around the crack tip. The J-integral evolution versus crown size shows the energy release rate invariance. The slight differences can be explained by the displacement field noises.

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