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VALIDATION OF A PROGRESSIVE FAILURE MODEL USING TECHNOLOGICAL SPECIMENS

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ABSTRACT

The design of composite structures is of main interest for the aerospace industry. The utmost difficulty relies on the complexity of the damage mechanisms taking place before failure and the influence of the mechanical loading history on the damage kinetics. In addition, the presence of geometrical singularities requires well-adapted criterion [1] or non-local formulations [2] to properly predict the strength of the structure. To overcome these difficulties, engineers in the industry have developed design techniques that reckon on experimental data at different scales that are used to calibrate advanced models. These approaches have proven their relevancy; however, their domain of validity remains moderate. Advanced composite constitutive models bolster both the validation and extension of their domain of utilisation. Although these validations are often carried on elementary coupons, performing mechanical tests on specimens having undergone complex loading histories or specimens featuring geometrical singularities similar to those found in structures is still a practise that needs to be performed.

To assess the validation of the progressive failure model proposed by Onera [3], a technological fifty plies composite laminate specimen of 9 mm thickness is proposed featuring four notches and a non-conventional stacking sequence of ±θ° and 0° plies. The aim is to validate the identified damage model at the coupon level by comparing it to the predicted damage and cracking kinetics without carrying out any previous calibrations of neither the model nor the failure criteria. To do so, the geometry of these technological specimens is designed aiming at two purposes: to intensify the damage mechanisms in the surroundings of the geometrical singularities and to allow the experimental monitoring of cracking with a heavy instrumentation. Figure 1 shows the geometry of the technological specimen and the different instrumentation devices that were used *in situ* at a loading frame of 50 t of maximal capacity during tensile tests.

Damage monitoring is fulfilled by means of two acoustic emissions sensors and six digital image correlation (DIC) optical cameras. The displacements fields on both the specimen surface and in one of the notches are monitored with two stereo DIC system. A second and a third notch are monitored by an optical microscope and monochrome optical camera. The acquisition frequency of the DIC systems is increased during specifics periods of the tests to optimize the temporal resolution of the damage mechanisms monitoring. Special attention was drawn to the synchronisation of data recorded during the heavily instrumented tensile tests. These measurements allowed both the global behaviour of the specimen as well as the damage mechanisms occurring at the ply level to be monitored. During loading of the specimen, the cracking evolution at the bottom of the notches is observed. Since two pairs of notches are machined at different positions of the specimen, *post-mortem* observations of damage are performed at the notches that do not drive failure.

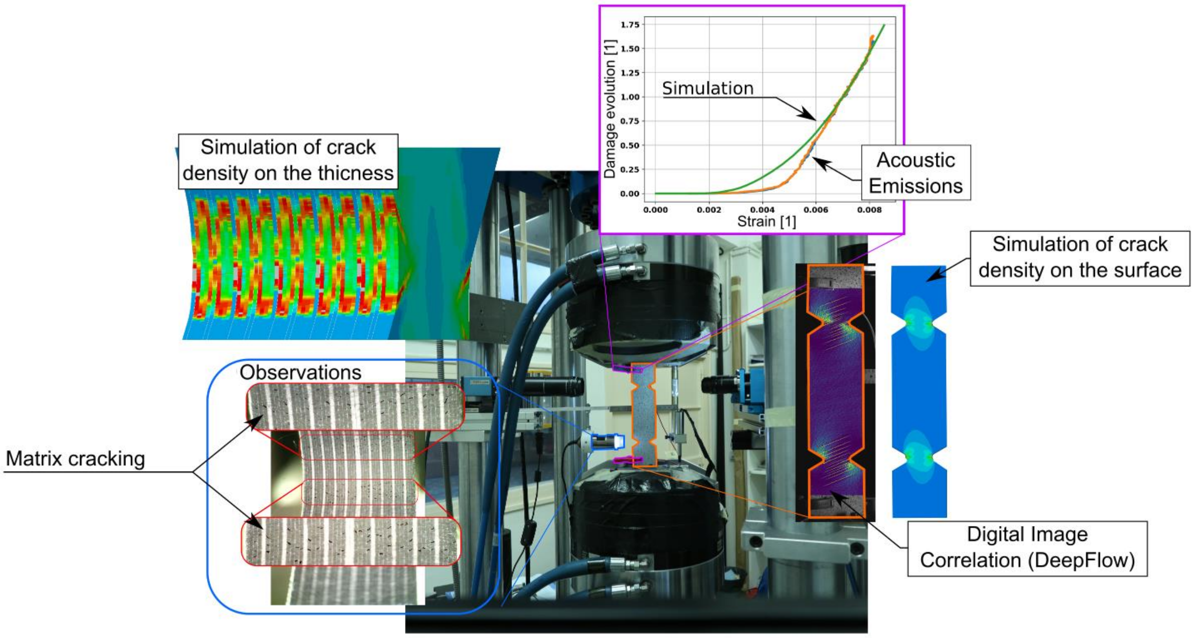

Figure 1: Schematic view of the instrumentation for validating the Onera progressive failure model using technological specimens.

In addition to the non-standard experimental setup, the originality of this work relies on the validation of the damage kinetics of the transverse cracking of the considered model. Indeed, this kind of model provides quantitative information of the damage by means of the evolution of the crack density. For stacking sequences of simple cross-plies, this quantity can easily be compared to a crack count on the specimen surface. In this work, we propose a novel method of comparison between these quantities even in the presence of strong stress gradients. The crack count is fulfilled thanks to an advanced algorithm based on digital image correlation data that allows to accurately count cracks on the specimen surface. This comparison allows to quantitatively validate the damage threshold and the damage kinetics on the plies on the surface of the specimen. Furthermore, the measurements performed with acoustic emissions also validate the global cracking kinetics estimated by the model. Finally, the non-local fiber failure criteria performed on open-hole specimens is also validated through failure estimation of these specimens.

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