Development and validation of a composite material law for crash simulations

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More and more structural parts are building using organic matrix composite materials in order to reduce the weight of aircraft structures. In order to reduce the number of tests required at the different scale of the building block approach, an increase of the knowledge regarding strain rate dependency of such materials is still a topic of interest. Particularly most of the strain rate dependent material laws are based on or validated with tests performed on split Hopkinson bars [1,2]. Few results are available in the literature concerning the intermediate strain rate, typically ranging between 10^{-3} s^{-1} and 100 s^{-1}. Consequently, this study is first dedicated to the experimental characterisation of the rate effect for this specific range of strain rate. For that purpose, tensile tests have been performed on a servo-hydraulic jack on off-axis specimens. Various off-axis angles have been considered: 15°, 30°, 45°, 60°, 75° and 90°. The geometry of the coupon for each angle has been defined thanks to a numerical study in order to reduce stress concentration near to the tabs and maximise the stress field homogeneity within the specimens. Three different loading speeds with at least three specimens were tested in order to evaluate discrepancy. A Photron SA-X high speed camera has been used to evaluate strain using a Digital Image Correlation software (Aramis GOM). Moreover, as multiple failure locations are observed for high loading rate tests, high speed imaging allow the localisation of the first failure.

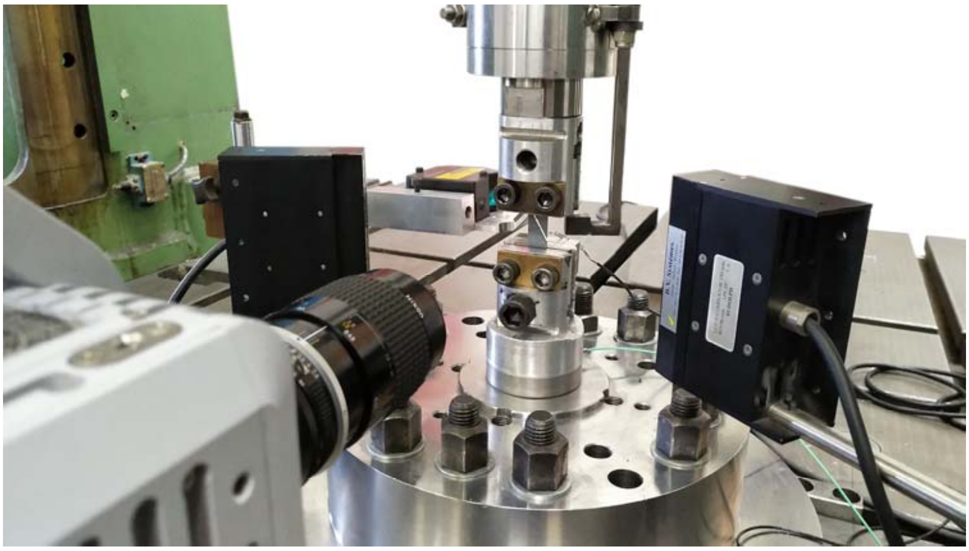

Figure 1 – Illustration of the experimental setup

These results have been used in order to include rate dependency in an advanced material law initially proposed by ONERA for quasi-static loadings. This model written at the ply scale is based on a visco-elastic behaviour law until a ply failure criterion is reached. A Hashin like failure criterion is used and two failure modes are considered: fibre failure and matrix failure. The degradation of the ply properties is obtained with 2 damage variables: d1 for fibre failure and d2 for matrix failure. Improvements regarding rate dependency of this material law have been studied for its three main aspects: the visco-elastic behaviour, the failure criterion and the damage evolution law. Regarding the visco-elastic behaviour, previous works [3] have shown that a bi-spectral visco-elastic model is required in order to take into account the short relaxation times required to accurately described rate dependency for high strain rate tests and long relaxation times for low strain rate tests. The main drawback of this model is its computational cost due to the important number of viscous mechanisms that have to be considered. As full-scale crash simulation is the targeted application case, a modified version of this model has been proposed. It still has an accurate prediction of the different modulus evolutions with the loading rate but it has a reduce computational cost. Concerning the loading speed dependency of the failure criterion, dynamic off-axis tensile tests will be used as input data to analyse and improve the failure criterion. Finally, improvements of the different damage evolution laws will be based on results available in the literature [4].

Finally, this material law has been implemented in an explicit finite element code in order to validate it on more complex coupons.

References:

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Short author bio:

Julien Berthe: He graduated from the Ecole Normale Supérieure de Cachan in 2010, he received a Ph.D. degree from the Ecole Centrale de Lille in 2013. Since 2018, he is the Head of the Research Unit Design & Dynamic Resistance which is part of the ONERA Materials and Structures Department. His research deals with the strain rate and temperature dependencies of organic matrix composite material behavior with two main aspects: the experimental characterization and the numerical modeling of such dependencies.