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Industrial Implementation of an Advanced Progressive Damage Model of Laminated Composite Material: a SAMCEF Application for Model Parameter Adjustment through Coupon Test Analysis

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ABSTRACT

To analyze laminated composite material, classical lamination theory has been implemented in several FE codes and is nowadays broadly used to simulate elastic behavior. To push the limit of this assumption, the non-linear stress-strain relation must be taken into account. Some basic models based on Hashin theory have been tested in explicit codes but this type of approach is not allowed in implicit code since no derivative is available. For several years, LMT Cachan has been working on a set of progressive damage material models [1-5, 10-11] to simulate inter and intra-laminar degradation. More recently, those models have been implemented in the industrial FE code SAMCEF [6-9]. Instead of basic user subroutine approach, the full integration gives a better performance and makes possible an in-depth implementation of “non-local approach” that requires additional degrees of freedom.

In principle, the unidirectional ply degradation material model is based on a strain energy potential including damage variable d_{11}, d_{22}, d_{12} where $_{11}$, $_{22}$, and $_{12}$ denote fibers, transverse and shear direction:

$$
\begin{aligned}
E = {} & \frac{\sigma_{11}^2}{2(1-d_{11})E_1^0} - \frac{\nu_{12}^0}{E_1^0}\sigma_{11}\sigma_{22} - \frac{\nu_{13}^0}{E_1^0}\sigma_{11}\sigma_{33} + \frac{\langle\sigma_{22}\rangle_+^2}{2(1-d_{22})E_2^0} + \frac{\langle\sigma_{22}\rangle_-^2}{2E_2^0} \\
& + \frac{\langle\sigma_{33}\rangle_+^2}{2(1-\lambda d_{22})E_3^0} + \frac{\langle\sigma_{33}\rangle_-^2}{2E_3^0} - \frac{\nu_{23}^0}{E_2^0}\sigma_{22}\sigma_{33} + \frac{\sigma_{12}^2}{2(1-d_{12})G_{12}^0} + \frac{\sigma_{13}^2}{2(1-\lambda d_{12})G_{13}^0} \qquad (1) \\
& + \frac{\sigma_{23}^2}{2(1-\lambda d_{22})G_{23}^0}
\end{aligned}
$$

Derivatives of this potential with respect to damage variables give thermodynamic forces Y_{11}, Y_{22} and Y_{12}. The essence of the model is then to characterize the variation of d as a function of Y.

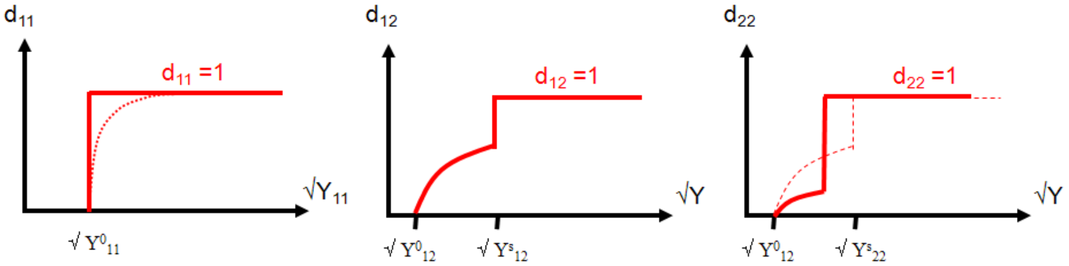

Figure 1: Example of evolution of damage variables as a function of thermodynamic forces

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On top of degradation, permanent deformation can also be taken into account. The additional equation (2) is introduced to model plasticity in the matrix (transverse and shear directions). This equation makes use of four new parameters R_0, β, γ and a.

$$f(\tilde{\sigma}, p) = \sqrt{\tilde{\sigma}_{12}^2 + \lambda(\tilde{\sigma}_{13}^2 + \tilde{\sigma}_{23}^2) + a^2(\tilde{\sigma}_{22}^2 + \tilde{\sigma}_{33}^2)} - R_0 - R(p) \leq 0$$
$$R(p) = R_0 + \beta p^{\gamma} \qquad (2)$$

In this paper we will show how to fit those functions and their parameters based on coupon test results as described in [1]. To characterize elastic properties and maximum stress in fiber and transverse directions, a 0°/90° coupon test must be used. To characterize shear behavior including plasticity, a +45°/-45° coupon must be used in traction and cyclic loading-unloading. Finally, to characterize coupling between d_{12} and d_{22}, a coupon with +67.5°/-67.5° plies is used.

Using the identified parameters, other basic test will be simulated. Comparisons with experimental results will be discussed for 4 points bending and open hole tests.

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