Asymptotic Homogenization Method used to predict the effective properties of laminated composites considering delamination influence.

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The present work aims to predict the behavior of effective elastic properties for laminated composites, considering localized damage in the interface between two layers. In practical terms, the damage in the adhesion, which influences on the effective elastic properties of laminate, is evaluated like a delamination between adjacent layers.
An anisotropic and periodic elastic body is considered. The elastic body occupies a bounded region Ω^ε in R^3 space, with Lipschitz boundary $\partial\Omega^\varepsilon = \overline{\partial_1\Omega^\varepsilon} \cup \overline{\partial_2\Omega^\varepsilon}$, such that $\partial_1\Omega^\varepsilon \cap \partial_2\Omega^\varepsilon = \emptyset$, where $\partial_1\Omega^\varepsilon$ and $\partial_2\Omega^\varepsilon$ are boundary portions. Figure 1(a) shows the 3D laminated composite with composite layers (1 and 3) and interface layer represented by layer 2, where $\Gamma^\varepsilon_{\beta,\beta+1}$ are the interface separating of the composite layers β and $\beta+1$ ($\beta = 1{,}2$), which depend on the slow variable $\boldsymbol{x}$. $\Gamma_{\beta,\beta+1}$ are the interfaces in the unit cell, which are dependent of the fast variable $\boldsymbol{y}$. The medium is assumed to be stacked in the x_1 direction (axis normal to the laminate) with all material parameters independent of x_2 (axis normal to the fibers) and x_3 (axis aligned to the fibers). Figure 1(b) shows the unit cell, with a localized delamination in the layer 2 (interface), where $\theta_2 l_2$ is the length of delamination, and θ_2 is the damage degree (the factor of the delamination extension). In addition, it is important to notice that $\theta_1 + \theta_2 + \theta_3 = 1$.

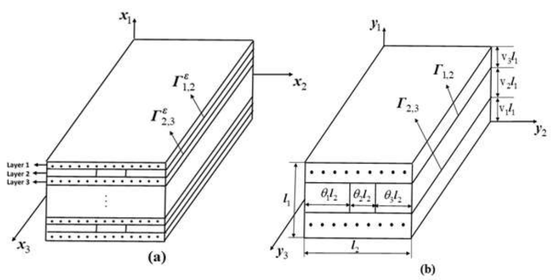

Figure 1 – Analytical model: (a) laminated composite; (b) unit cell with delamination in the layer 2 [1].

The effective properties of laminated composites with localized delamination are calculated via AHM (with two-scale asymptotic homogenization method) and via an in-house Finite Element software written in Julia language. Four different stacking sequences of laminated composites are evaluated ($[0]_n$, $[0/90]_n$, $[30/-30]_n$ and $[45/-45]_n$) with an epoxy layer in the interface of the plies, considering different values for the interface thickness between layers and for different delamination extensions.

The mathematical background of the AHM is well established [1-4], and states that the homogenized fourth order elasticity tensor of a three dimensional media can be written as

$$C_{ijkl}^{H} = \int_{Y} C_{ijkl} + C_{ijhs} \frac{\partial \chi_{h}^{kl}}{\partial y_{s}} dY \text{ ,} \#(1)$$

where Y is the dimension vector of the Unit Cell, $\boldsymbol{C}$ is the fourth order elasticity tensor of the base materials, $\boldsymbol{v}$ is a virtual displacement, and $\boldsymbol{\chi}$ is the periodic solution of the equilibrium problem

$$\int_{Y} C_{ijpq} \frac{\partial \chi_{p}^{kl}}{\partial y_{q}} \frac{\partial v_{i}}{\partial y_{j}} dY \;=\; \int_{Y} C_{ijkl} \frac{\partial v_{i}}{\partial y_{j}} dY \text{ .} \#(2)$$

It is investigated how the properties of the laminated composites are affected by the delamination extension and the thickness of interface between layers. It is possible to conclude that the effective coefficient values decrease as the damage extension increases due to the fact that the delamination area increases. Besides, for all effective coefficients, except the effective coefficients C_{1122}^{H}, C_{1133}^{H} and C_{2233}^{H}, in the case of without delamination, the coefficients decrease as the adhesive region thickness increases, and almost all coefficients decrease for complete separation of the interface. Numerical and analytical results are compared in order to show the potentialities and limitations of the proposed approaches.

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