Influence of debonding on mechanical properties of fiber reinforced composites

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Abstract

The paper deals with the numerical method of determining mechanical properties of composites using a mixture of micromechanical and numerical approach. Employing the Finite Element Method extends an analytical only approach due to the possibility of modelling some defects which could occur in modelled structure. The influence of a specific kind of imperfection as debonding was considered. The effect of fiber debonding from a matrix was introduced by cohesive zone application. In the present work, a representation of a glass-fibres reinforced composite was created using Representative Volume Element. Mechanical properties were determined based on components of stiffness matrix in Classical Laminated Plate description.

Keywords: micromechanics, debonding, cohesive zone, Representative Volume Element.

1. Introduction

Aerospace industry demands to use materials with high strength to weight ratio. For this reason composite materials, mainly fiber reinforced composites are widely used as different parts of aircraft structures. High mechanical properties result from an appropriate combination of constituents with different properties, size, shape or arrangement of fibers in matrix. Mechanical behaviour of composite material is rather complex due to their heterogeneous and anisotropic (or orthotropic) characteristic.

It makes that prediction of mechanical properties of fiber-reinforced composite materials became an area of interest for researches. The approach focused on investigating mechanical properties and composite behaviour where the interaction between constituents is taken into consideration is a micromechanics concern. At a micromechanical level properties of fiber-reinforced composite could be determined in three ways: experimentally, analytically or based on the Finite Element Method.

It is well-known that experimental test is the most reliable method. Nevertheless performing standard research is a very time consuming matter and requires a special laboratory equipment. To avoid this problem, in recent years, a lot of analytical method were investigated in details [5]. The most common method is the Rule of Mixture. However, simply formulas allowing to predict mechanical properties seems to be insufficient when transverse mechanical properties of fiber-reinforced composite are considered [5,6]. Further methods developed by Halpin and Tsai, Tsai, Mori Tanaka or Chamis seem to greatly improve this correlation.

Other possibility to predict mechanical properties is an approach based on the Finite Element Method. In numerical techniques Representative Volume Element (RVE) [5] is used. In literature overview some research in the field of the FEM could be found [2]. The advantage of numerical model over analytical approach is the possibility of modelling some defects which could exist in real composite volume. One kind of imperfection is the technological debonding between fiber and matrix which could occur as a result of significant difference in stiffness of composite constituents. In results, mechanical properties of entire material could be worse.

The aim of this research is to investigate the influence of debonding between fiber and matrix on mechanical properties of FRP material and the comparison of results with outcomes obtained from perfect numerical model.

2. Subject of the study

In the paper a fiber-reinforced composite with unidirectional E-glass fibers as reinforcement phase and epoxy as matrix phase was considered. Fiber volume fraction equals 60% with nominal diameter of a cross-section of circular fiber 3.5μm. In micromechanical analysis constituents are assumed to be isotropic and homogenous. The properties of the constituent materials are shown in Table 1 with the references to the sources.

Table 1: Mechanical properties of composite constituents

	Marix [6]	E-glass fiber [8]
E [MPa]	3 500	72 000
ν [-]	0.40	0.21
G [MPa]	1821	30 000

3. Numerical computations

Numerical model was generated in the FEM commercial software package Ansys® [1]. The structural solid element SOLID185 was employed to create a 3D model of RVE components (both - fiber and matrix). The structural element INTER205 reproduced the process of debonding of a particular fiber from matrix. The Cohesive Zone Model (CZM) elements were then located around a fiber. Fracture criterion which is necessary to model CZM, was assumed to be a function of Mode I (opening), Mode II (shearing) and Mode III (tearing). Thus the interlaminar fracture toughness is measured by the strain energy release rate [4]. Assumed critical energy-release rates are listed in Table 2.

Table 2: Values of critical energy-release rates [7].

	[J/m^2]
G_I	604
G_{II}	720
G_{III}	720

Dimensions of the RVE are presented in Figure 1.

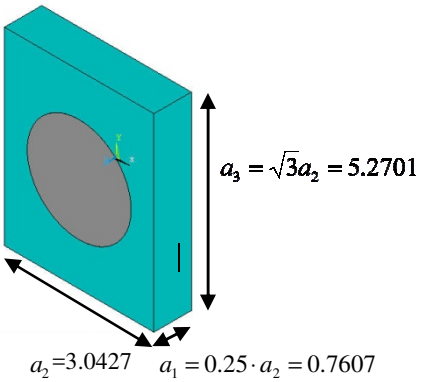

Figure 1: Numerical model of Representative Volume Element with assumed dimensions

The RVE was subjected to an average strain. By determining appropriate stress values, particular components of stiffness matrix were determined with the formula:

$$C_{\alpha\beta} = \sigma_\alpha = \frac{1}{V}\int_V \sigma_\alpha(x_1, x_2, x_3)dV \tag{1}$$

where σ_α is a principal stress;

$C_{\alpha\beta}$ - matrix of stiffness (α,β=1,2,3).

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{12} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{12} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_4 \\ \gamma_5 \\ \gamma_6 \end{bmatrix} \tag{2}$$

Thus, the elastic properties of the homogenized material could be computed according to the following formulas:

$$E_1 = C_{11} - \frac{2C_{12}^2}{C_{22} + C_{23}} \tag{3}$$

$$\nu_{12} = \frac{C_{12}}{C_{22} + C_{23}} \tag{4}$$

$$E_2 = [C_{11}(C_{22} + C_{23}) - 2C_{12}^2]\frac{C_{22} + C_{23}}{C_{11}C_{22} - C_{12}^2} \tag{5}$$

$$G_{12} = C_{66} \tag{6}$$

where E_1 and E_2 are apparent longitudinal and transverse moduli of a composite material and ν_{12} and G_{12} are in-plane Poisson ratio and Kirchhoff modulus, respectively.

Analogous computations were performed for ideal model and the one with an introduced possibility of constituent separation. The applied procedure gave an insight into the influence of a some degradation process on to the mechanical properties of considered composite material.

4. Conclusions

A finite element parametric model based on the Representative Volume Element approach including the CZM layer was created to predict the longitudinal (E_1, ν_{12}) and transverse (E_2, G_{12}) mechanical properties of a glass-fiber-reinforced epoxy composite. Results of this analysis allowed to compare few models of different fiber arrangements and mutual spacing within the matrix and potential imperfection distribution. From the performed numerical computations one can assess an impact of composite material constituent imperfect junction on the apparent lamina mechanical properties. This lead to information of potential mechanical properties degradation when compared to perfect composite material model assumption.

More details and some exemplary data determined during this analysis will be presented during the conference.

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