Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 96 (2016) 930 – 938

Procedia Computer Science

20th International Conference on Knowledge Based and Intelligent Information and Engineering Systems, KES2016, 5-7 September 2016, York, United Kingdom

Numerical modeling of non-destructive testing of composites

Igor Petrov[a], Alexey Vasyukov[a], Katerina Beklemysheva[a*], Alexey Ermakov[a], Alena Favorskaya[a]

[a]*Moscow Institute of Physics and Technology, 9 Intitutsky per., Dolgoprudniy, 141700 Russian Federation*

Abstract

Low-velocity strikes are considered as one of the most dangerous load types for composites, especially in aviation. They do not lead to an immediate destruction of a whole detail, but inner damage, provoking a delamination between layers or between fiber and matrix, lowers the material strength and may cause a destruction during the flight. This inner damage can only be noticed via complex study, which increases an exploitation cost. Numerical modeling can help to interpret the results obtained from common portable devices, which are currently used for metals. The modification of known methodology can be reliably used for composites. In this research, a hybrid grid-characteristic method of 1-2 order on irregular tetrahedral grid is used. A carbon fiber polymer matrix of unidirectional composite is modeled as a homogeneous orthotropic media with a single distinguished direction along the fiber. As a result, the one-dimensional graphics, which correspond to A-scans in real devices, were obtained. The detailed analysis of received data confirms a rationality of proposed methodoly.

Peer-review under responsibility of KES International

Keywords: numerical modelling; grid-characteristic method; composites; composites destruction; non-destructive testing

* Corresponding author. *E-mail address:* amisto@yandex.ru

1. Introduction

Modern technology utilizes the composites in a great variety of ways, including bearing structures, which require the endurance under static, dynamic, and fatigue loadings. Composites have low weight and high strength in comparison with traditional construction materials, and that make them extremely useful, for example, in aviation. However, the certain problems were exposed during their exploitation, including the complexity of ultrasonic Non-Destructive Testing (NDT)[1,2,3,4,5,6,7]. Portable devices that are currently used for a non-destructive testing are designed for isotropic homogenous materials and use ray method, which does not consider the interconversion of

Peer-review under responsibility of KES International
doi:10.1016/j.procs.2016.08.272

wave types[8]. They are not effective for composites, which are heterogeneous, anisotropic and has specific inner damage types that are not so dangerous for metals[9,10].

One of the most dangerous inner damage types is a delamination between layers and between fiber and matrix[11,12,13]. It do not lead to an immediate destruction of a whole detail, but unpredictably lowers material strength and may cause a destruction during exploitation, e. g., in aviation during the flight. This damage type can appear due to low-velocity strikes: exposure to weather, maintenance, and transportation failures[14]. It only can be noticed via complex study, which cannot be conducted outside the laboratory[15]. While dangerous for the whole construction damages can be observed with the naked eye for metals, it is much harder for composites. The requirement of laboratory study increases the exploitation cost and lowers the usability of composites in mass production. Numerical modeling can help to interpret the results obtained from common portable devices, which are currently used for metals. The modification of this methodology can be reliably used for composites.

The current research is dedicated to the numerical modeling of the problem via a hybrid grid-characteristic method of 1-2 order on irregular tetrahedral grid[16,17,18]. This method is based on the characteristic properties of the elastic deformable solids as a set of equations and models accurately propagation, reflection, and refraction of wavefronts, including their interconversion on different border and contact types. The method was verified on various problem statements by comparison with experiments in different science fields, including seismology[19,20], materials science[14,21,22], and biomechanics[18,23]. A carbon fiber polymer matrix unidirectional composite is modeled as orthotropic media with a single distinguished direction along the fiber[24].

The remainder of this paper is organized as follows. Section 2 describes the material models and the numerical method. Problem statement is presented in Section 3. The obtained wavefronts and their analysis are presented in Section 4. The analysis of A-scans (one-dimensional graphics, which represent a time dependence of receiving signal) for steel and composite monolayer is presented in Section 5 and Section 6, respectively. Section 7 includes the conclusions.

2. Mathematical model and numerical method

Two materials are used in this research. The first one is steel and it is modeled as isotropic elastic deformable solid, ρ = 7800 kg/m^3, λ = 99.43 GPa, μ = 78.13 GPa (ρ – material density, λ and μ – Lame parameters). The second one is a composite monolayer – carbon fiber with unidirectional laying and epoxy matrix – and is modeled as a homogenous orthotropic elastic deformable solid with a single distinguished direction along the fiber, E_{11}^+= 16483 MPa, E_{11}^- = 13376 MPa, E_{22}^+ = 805 MPa, E_{22}^- = 854 MPa, G_{12} = 437 MPa, ρ = 1580 kg/m^3, ν = 0.32. E_{11}^+ is Young's modulus along the fiber laying, tensile load; E_{11}^- is Young's modulus along the fiber laying, compression load; E_{22}^+ is Young's modulus across the fiber laying, tensile load; E_{22}^- is Young's modulus across the fiber laying, compression load, G_{12} is a shear modulus, ρ – density, ν is a Poisson modulus.

The closed system of equations for deformable solid consists of motion equations, rheological correlations, and the equation of state:

$$\rho \dot{v}_i = \nabla_j \sigma_{ij} + f_i \quad ,$$

$$\dot{\sigma}_{ij} = q_{ijkl}\, \dot{\varepsilon}_{kl} + F_{ij} \tag{1}$$

where ρ is a density, v_i is a displacement speed components, ∇_j is a covariant derivative by j coordinate, σ_{ij} is a stress tensor, ε_{ij} is a strain tensor, f_i is a mass forces, F_{ij} is the right part, depending on a rheology model, q_{ijkl} is the fourth order tensor also depending on a rheology model. The system can be rewritten as follows:

$$\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{A}_x \frac{\partial \boldsymbol{u}}{\partial x} + \boldsymbol{A}_y \frac{\partial \boldsymbol{u}}{\partial y} + \boldsymbol{A}_z \frac{\partial \boldsymbol{u}}{\partial z} = \boldsymbol{f} \ , \tag{2}$$

where $\boldsymbol{u} = \left\{ v_x, v_y, v_z, \sigma_{xx}, \sigma_{yy}, \sigma_{zz}, \sigma_{xy}, \sigma_{xz}, \sigma_{yz} \right\}^T$ is a vector of unknown functions, x, y, z are independent spatial variables, t is a time, $\boldsymbol{f}$ is the right parts vector. The exact form of matrices **A** for isotropic and anisotropic models can be found in[17] and[24], respectively.