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Numerical Study on Low Velocity Impact Response of Functionally Graded Carbon Nanotube Reinforced Composite Beams

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Abstract

In this work response of functionally graded carbon nanotube reinforced composite beam subjected to the action of an impacting mass is investigated analytically and numerically. Timoshenko beam theory is used to estimate the kinematics of the beam. Material properties of the composite are obtained using a refined rule of mixture. However, for numerical model surface to surface has been used. The beam cross section considered uniform and the impactor assume a Steel made ball. Numerical has reasonable agreement compare with analytical model and results show that the Fem model can predict the beam behavior with very good agreement.

Keywords: Carbon nanotube; Timoshenko beam; Finite element method; Low velocity impact

Introduction

Carbon nanotubes (CNTs) are known as a novel class of materials which have attracted increasing attention in recent years. These materials have exceptional mechanical properties which make them as a potential candidate for the reinforcement of the composites [1]. Distribution of CNTs in a polymeric matrix may be uniform or functionally graded (FG). Lin and Xiang analyzed the linear [2] and nonlinear [3] free vibration characteristics of first order and third order shear deformable FG-CNTRC beams. In the present work the response of FG-CNTRC beams under low velocity impact based on the first order Timoshenko beam theory and FE modeling investigated.

Governing Equations

Consider an FG-CNTRC beam of thickness *h*, width *b*, and length *L* referred to the conventional coordinates system (x, y, z) where as usual $0 \le x \le L$ is through the length, $-h/2 \le z \le +h/2$ is through the thickness and $-b/2 \le y \le +b/2$ is through the width. Due to simplicity in the present study the rule of mixtures is used by introducing CNT efficiency parameters and the material properties of CNTRC beam. Thus, the material properties can be written as [4]:

$$\begin{gathered} E_{11} = \eta_1 V_{CN} E_{11}^{CN} + V_m E^m \\ \frac{\eta_2}{E_{22}} = \frac{V_{CN}}{E_{22}^{CN}} + \frac{V_m}{E^m};\frac{\eta_3}{G_{12}} = \frac{V_{CN}}{G_{12}^{CN}} + \frac{V_m}{G^m} \end{gathered} \quad \text{..............} \quad (1)$$

where E_{11}^{CN}, E_{22}^{CN} and G_{12}^{CN} are the Young's modulus and shear modulus of SWCNTs, respectively. Besides, E^m and G^m indicate the corresponding properties of the isotropic matrix. The coefficients η_1, η_2 and η_3 are introduced to account for the scale dependent material properties. These constants are evaluated by matching the effective properties of CNTRC obtained from the molecular dynamic simulations with those from the rule of mixtures [4]. Furthermore, in Eq. (1), V_{CN} and V_m are the volume fractions of CNTs and matrix phase, respectively, which satisfy the condition $V_{CN} + V_m = 1$.

Referring to the basic relations of strains and displacements, on a generic point of the beam, equation for the strain components can be written as below

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} = \frac{\partial u_0}{\partial x} + z\frac{\partial \varphi}{\partial x};\gamma_{xz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} = \varphi + \frac{\partial w_0}{\partial x} \quad \text{.....................} \quad (2)$$

And the constitutive equations of the beam when only axial and transverse components of stress field are present can be formulated as

$$\sigma_{xx} = Q_{11}(\varepsilon_{xx});\sigma_{xz} = K_s Q_{55}\gamma_{XZ} \quad \text{.....................} \quad (3)$$

In the Eq. 3, K_s is the shear correction factor and is taken as $K_s = \pi^2/12$ [5]. Besides, Q_{11} and Q_{55} are evaluated in terms of the material constants as Eq. (4)

$$Q_{11} = \frac{E_{11}}{1-\upsilon_{12}\upsilon_{21}};Q_{55} = G_{13} \quad \text{...........................} \quad (4)$$

Where, N_x, M_x and Q_x are the normal force, bending moment and shear force resultants that are defined by

$$(N_x, M_x, Q_x) = b\int_{-h/2}^{+h/2}(\sigma_{xx}, z\,\sigma_{xx}, K_s\sigma_{xz})\,dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Finite Element Simulation

The numerical simulations were performed using the commercial finite element code, MSC MARC. The numerical model consisted of 5591 elements for beam and impactor. The model, dimensions and the boundary conditions are shown in Figure 1. At the beginning the horizontal position of impactor assumed 100mm from clamed support and the initial velocity considered 2m/s based on experimental result which are available in reference [6]. The mechanical properties of beam and impactor are presented in Table 1.

Table 1: Mechanical properties of beam and impactor [1].

Impactor					
$E\,(GPa)$		υ	$\rho\left(kg/m^3\right)$		
207		0.3	7960		
Beam					
$E_{11}\,(GPa)$	$E_{22}\,(GPa)$	$G_{12}, G_{13}\,(GPa)$	$G_{23}\,(GPa)$	υ_{12}	$\rho\left(kg/m^3\right)$
144.8	9.65	4.14	3.45	0.3	1389

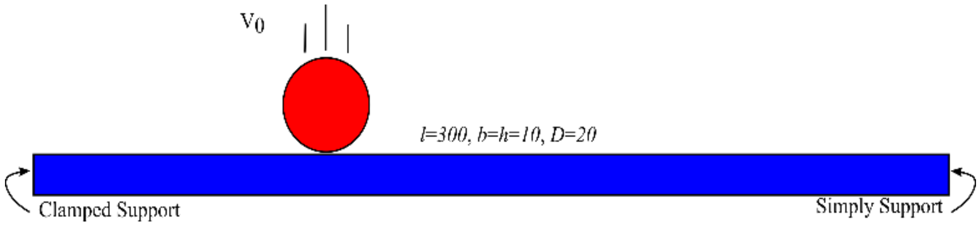

Figure 1: The model used to FE simulation.

Result and discussion

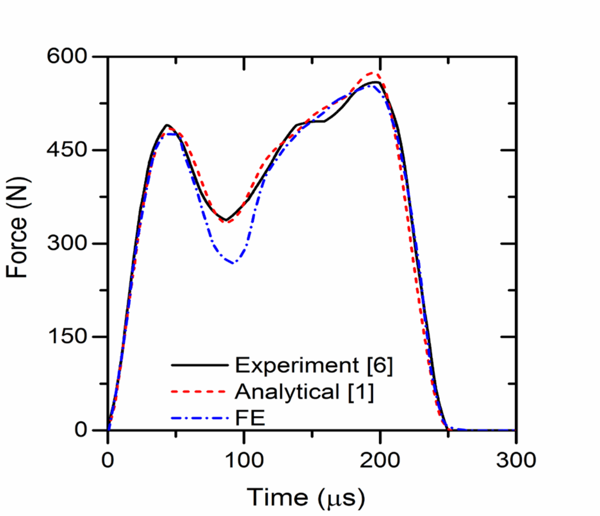

Figure 2: Experimental and analytical results comparing with FE.

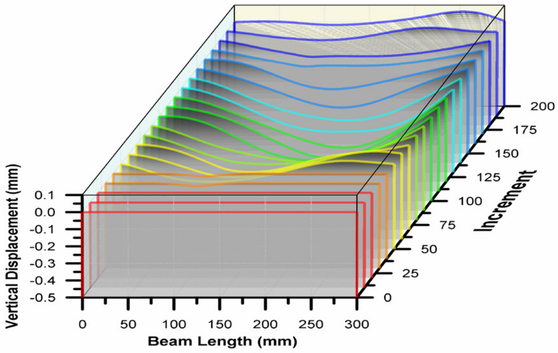

Figure 3: Beam deflection versus simulation increment.

In order to validate the FE model results an experimental result is carried out in this section. Experimental and analytical results are extracted from previous works and reported here. Figure 2 shows the compression between FE, experimental and numerical results. It is observable that the numerical results have reasonable agreement with experiment and analytical solution. The curve has two peaks which are completely observable in mentioned figure. Numerical model predicted a lower value after first peak because in FE model the ball is not completely sphere shape thus the surface of it is not smooth enough thus the contact force decreased compare with experiment and analytical solutions after first contact force peak. Figure 3 illustrates the beam deflection versus time after ball impact. As expected, the deflection starts at impactor position at the beginning of impact then the stress waves move though the beam and make the defilation on the other position of it. The maximum and minimum of beam deflection are about -0.5 to 0.1mm.

Conclusion

The behavior of an FGM beam is investigated by a FE method under low velocity impact. The beam supports were considered clamped and simply support to verify the numerical simulation. The FE model can predict the beam behavior with reasonable agreement with experiment and analytical model. The deflection history of beam extracted and the deflection pattern of beam under low velocity impact obtained in each solution increment.

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