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ABSTRACT: In this study, nonlinear dynamic response of carbon fiber reinforced polymer composite plates enhanced with carbon nanotubes resting on elastic foundations in thermal environments using the finite element method is investigated. The effective material properties of the multiscale composite are calculated using Halpin–Tsai equations and fiber micromechanics in the hierarchy. Three types of distribution of temperature through the thickness of the plate namely, uniform, linear, and nonlinear are considered. The governing equations are derived based on Inverse Hyperbolic Shear Deformation Theory and von Kármán geometrical nonlinearity. Five types of impulsive loads namely the step, sudden, triangular, half-sine, and exponential pulses are considered. Numerical results reveal that the deflections of multi-phase composites significantly decrease with a small percentage of carbon nanotubes. Also, it is found that in thermal environment, central deflection of the plate was reduced using a maximum of 1% of the carbon nanotube in polymer composites and adding higher weight percentage showed no significant change in the peaks of central deflection.

1- Introduction

Extraordinary properties such as high strength, high stiffness, high aspect ratio and low density of the carbon nanotubes (CNT), make it an opportunity for combining potential advantages of nanoscale reinforcement and functionality with well-accepted CFRPs to develop multiphase composites. Rafiee et al. [1] investigated nonlinear vibration of CNT multiphase laminated composites integrated with piezoelectric. Nonlinear dynamic response and flexural of polymer/CNT/fiber multiphase nanocomposite plates were analyzed by Bhardwaj et al. [2]. They used double Chebyshev polynomials to solve the problem. To the best of authors’ knowledge, there is no analysis of the dynamic response of CNTs/fiber/polymer multi-phase composites in the thermal environment have been carried out till now. Therefore, in the present study, nonlinear dynamic response of polymer-CNT-fiber multiscale nanocomposite plate in thermal environments using the finite element method is performed.

2- Theoretical Formulation

The effective mechanical properties of these composites can be obtained based on a combination of Halpin-Tsai [3] and micromechanics approach scheme [4], with two steps in the hierarchy as depicted in Fig. 2. The resulting properties of the CNT reinforced multi-phase laminated composite plate are orthotropic and can be expressed as [4]:

\[ E_{11} = V_F E_{11}^F + V_{MNC} E_{MNC} \]  

\[ \frac{1}{E_{22}} = \frac{1}{E_{22}^F} + \frac{V_{MNC}}{E_{MNC}} - \frac{V_F V_{MNC}}{E_{22}^F} \]

\[ V_F^2 E_{22}^F + V_{MNC}^2 E_{MNC} - 2 V_F V_{MNC} \]

\[ V_F E_{22}^F + V_{MNC} E_{MNC} \]  (2)

\[ \frac{1}{G_{12}} = \frac{V_F}{G_{12}^F} + \frac{V_{MNC}}{G_{MNC}} \]  (3)

where \( E, G, \rho, v \) and \( V \) and \( v \) denote the Young’s modulus, shear modulus, mass density, volume fractions and Poisson’s ratio, respectively.

Based on the Halpin–Tsai model, the tensile modulus of composites may be stated as [3]:

\[ E_{MNC} = \frac{E^M}{8} \left[ \frac{1 + 2 \beta_{12}^M V_{CN}}{1 - \beta_{12}^M V_{CN}} \right] \]

\[ + \frac{1}{3} \left( 1 + 2 \frac{d_{CN}}{d_{CN}} \right) \beta_{12}^M V_{CN} \]  (4)

\[ \beta_{12}^M = \left( \frac{E_{11}^CN}{E^M} \right) - \left( \frac{d_{CN}}{4f_{CN}} \right) \]

\[ \left( \frac{E_{11}^CN}{E^M} \right) + \left( d_{CN} / 2f_{CN} \right) \]  (5)

\[ \beta_{44}^M = \left( \frac{E_{11}^CN}{E^M} \right) - \left( d_{CN} / 4f_{CN} \right) \]

\[ \left( \frac{E_{11}^CN}{E^M} \right) + \left( d_{CN} / 2f_{CN} \right) \]  (6)

According to the Inverse Hyperbolic Shear Deformation Theory [5], the displacement field of laminated plate theory

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can be expressed as:

\[
\begin{align*}
    u(x,y,z,t) &= u_a(x,y,t) - 2z \frac{\partial w}{\partial x} + \Theta(z) \phi(x,y,t) \\
    v(x,y,z,t) &= v_a(x,y,t) - 2z \frac{\partial w}{\partial y} + \Theta(z) \phi(x,y,t) \\
    w(x,y,z,t) &= w_a(x,y,t)
\end{align*}
\]  

(7)

where \( u_a, v_a, \) and \( w_a \) denote the displacements at the mid-plane of the reference plane of the plate and \( \phi \) and \( \phi \) are rotations about the \( y \) and \( x \) axes, respectively. \( \Theta(z) \) indicates the transverse shear function and is presented by [5]:

\[
\Theta(z) = \cot^{-1}\left( \frac{rh}{z} \right) - \frac{4z}{b(4r^2 + 1)}; r = 0.46
\]

(8)

The governing equations are derived based on the principle of virtual work and solved by the finite element method with Newmark’s numerical integration method. In this paper, the four-noded rectangular conforming element based on HSDT is used. The element is \( C^1 \)-continuous via 15 DOF at each node.

3- Results and discussion

To validate the results of the present work, an example previously used by Kant et al. [6] is re-solved. In Fig.1, the results of this study for the central deflection histories are compared with those presented by Knat et al. [6]. There is a good agreement between the results obtained through the proposed method and the results of those of Kant et al. Table 1 presents the effect of temperature rise and volume fraction of fibers on the maximum deflection for simply supported CNT reinforced multi-phase laminated composite plate with different SWCNTs weight percentage. As may be observed, when the plate temperature increases, the peak central deflection increases, as well. That is because increasing the plate temperature causes the structure to lose the stiffness generally. Also, as may be noted, increasing the CNTs weight percentage leads to a plate with a higher bending rigidity and subsequently, higher natural frequencies and smaller response times. Due to this reason, central deflection has decreased with the increase of the weight percentage. From Table 1, it is noticed that under thermal environment, central deflection of the plate was reduced using a maximum of 1% of the CNT in polymer composites and adding higher percentage of weight showed no significant change in the peaks of central deflection. The reason is that, the thermal expansion coefficients of nanocomposite decreases as weight percentage of carbon nanotube changes from 0 to 1% while increases when the weight of carbon nanotubes is more than 1%.

4- Conclusions

The nonlinear dynamic response of polymer-CNT-fiber multiscale nanocomposite plate in thermal environments has been studied using the finite element method. Results are to

Table 1. Effect of temperature rise and volume fraction of fibers on the central deflection (10^4 m) for simply supported CNT reinforced multi-phase laminated composite plate with different SWCNTs weight percentages.

<table>
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<th>( F^N/F^M )</th>
<th>( w_{cn} )</th>
<th>( AT = 0 ) [K]</th>
<th>( AT = 100 ) [K]</th>
<th>( AT = 200 ) [K]</th>
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<td></td>
<td></td>
<td>( V_e )</td>
<td>( V_e )</td>
<td>( V_e )</td>
</tr>
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<td>0</td>
<td>15.3957</td>
<td>12.9177</td>
<td>10.7348</td>
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<td>15.3957</td>
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<td>10.7348</td>
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<td>12.9177</td>
<td>10.7348</td>
</tr>
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</table>
explore the effects of various parameters. It is concluded that:

- A small amount of CNT (1–2 percent) can decrease the maximum central deflection of plates subjected to dynamic loads.
- Under the thermal environment, central deflection of the plate was reduced using a maximum of 1% of CNT in polymer composites and adding higher weight percentage showed no significant change in peaks of central deflection.

References


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