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Buckling Analysis of Embedded Functionally Graded Graphene Platelet-Reinforced Porous Nanocomposite Plates with Various Shapes Using the P-Ritz Method

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ABSTRACT: In this study, the buckling of functionally graded graphene platelet-reinforced porous nanocomposite plates with various shapes such as rectangular, elliptical, and triangular ones embedded in an elastic medium is analyzed. To mathematically model the considered plate and elastic foundation, the first-order shear deformation plate theory, and the Winkler-Pasternak model are used, respectively. Three types of graphene nanoplatelet distribution and porous dispersion patterns through the thickness direction are considered for the nanocomposite plate. The effective material properties are obtained via a micromechanical model. By writing the energy functional of the system and using the analytical P-Ritz method, the influences of porosity coefficient, the weight fraction of graphene nanoplatelets, elastic foundation coefficients, and also the length-to-width and thickness ratios on the critical buckling loads are analyzed. It is illustrated that the plate with the non-uniform porosity distribution pattern of the first type and first type of graphene nanoplatelets due to the greater concentration of graphene nanoplatelets on the upper and lower surfaces of the plate and the increase in the stiffness of the plate, it has higher critical buckling load. Also, the maximum critical buckling load is related to shear loading and the minimum critical buckling load is related to biaxial buckling load. Also, by increasing the porosity coefficient, the critical buckling loads of the plate associated with all patterns of graphene nanoplatelets are reduced.

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1- Introduction

In recent years, graphene nanoplatelets are widely used as the reinforcing nanofillers to develop high-strength nanocomposites owing to their exceptional mechanical properties and chemical stability [1].

This paper is concerned with the buckling of functionally graded (FG) porous nanocomposite plates reinforced with graphene platelets. By using the First-Order Deformation Plate Theory (FSDT) to account for the transverse shear strain and P-Ritz method, the governing of equations is derived and then solved to calculate the critical uniaxial, biaxial, and shear buckling loads of the plate on elastic foundation with different porosity distribution and graphene nanoplatelets dispersion patterns also plate with arbitrary shapes such as rectangular, isosceles triangular and elliptical are considered. The elastic foundation is modeled with Winkler and Pasternak parameters. The influence of weight fraction, porosity distribution, and geometric parameters of the plate such as length to thickness ratio also parameters of the elastic foundation are investigated.

2- Problem Formulation

In this paper, three types of FG porous plates along with the even porosity distribution case, denoted by p_3, p_2, p_1 are considered. To further strengthen the mechanical properties, the metal matrix of the composite plate is reinforced by Graphene Nanoplatelets (GPLs). And the distribution of GPLs in the metal matrix may be uniform or non-uniform by adjusting the volume fraction along the plate thickness. Three different GPLs patterns are also considered for each porosity distribution which are A, B, C [2].

The variation of Young's module, shear module, and mass density through the thickness direction for different porosity distributions can be described by Eq. (1) and N_0 is the coefficients of porosity.

$$\begin{aligned} E(z) &= E_{\max}\left(1 - N_0\phi(z)\right) \\ G(z) &= G_{\max}\left(1 - N_0\phi(z)\right) \\ \rho(z) &= \rho_{\max}\left(1 - N_m\phi(z)\right) \end{aligned} \quad (1)$$

The effective Young's module and mass density are obtained based on the Halpin-Tsai micromechanics model.

The adopted admissible P-Ritz functions which satisfy at

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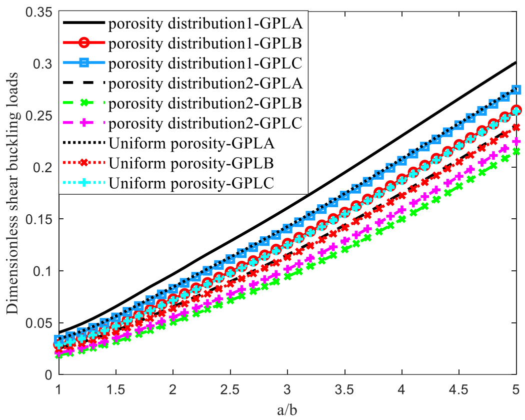

Fig. 1. Comparting of critical buckling load in the shear loads mode in terms of length to width ratio of the rectangular plate under clamped boundary conditions

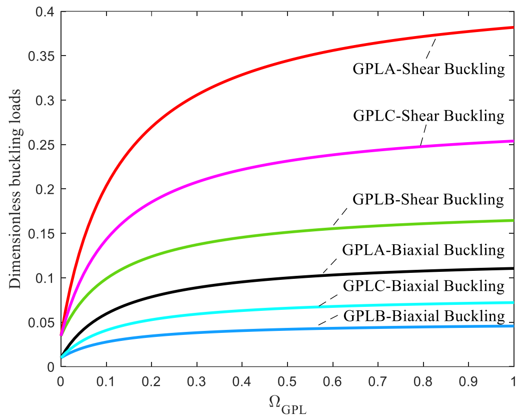

Fig. 2. Comparting of critical buckling load in term of weight fraction of elliptical plate under clamped boundary conditions for porosity distribution of the first type

Table 1. Comparting of critical buckling loads of nanocomposite plate reinforced with graphene nanoplatelets for $\left(a/b=1,\ N_0=0/5,\ \Omega_{GPL}=0/01\right)$

Pattern	a/h	p_x	[2]	$p_x=p_y$	[2]
	20	0.02922	0.02899	0.01551	0.01550
GPL A	30	0.01363	0.01343	0.00713	0.00712
	40	0.00784	0.00767	0.00406	0.00405

least boundary condition for the deflection and rotation of the plate are given by Eq. (2):

$$
\begin{aligned}
w(\tau,\xi,\eta) &= \sum_{q=0}^{p}\sum_{i=0}^{q} c_m (2\xi)^i (2\eta)^{q-i}\,\phi_b^w(\xi,\eta)e^{i\omega\tau}\\
\phi_x(\tau,\xi,\eta) &= \sum_{q=0}^{p}\sum_{i=0}^{q} d_m (2\xi)^i (2\eta)^{q-i}\,\phi_b^x(\xi,\eta)e^{i\omega\tau}\\
\phi_y(\tau,\xi,\eta) &= \sum_{q=0}^{p}\sum_{i=0}^{q} e_m (2\xi)^i (2\eta)^{q-i}\,\phi_b^y(\xi,\eta)e^{i\omega\tau}
\end{aligned}
\tag{2}
$$

According to the p-Ritz method, the minimizing of total potential energy with respect to unknown displacement parameters yields:

$$
\Pi^* = \frac{\Pi}{\Delta} = \overline{U} + \overline{V}_e + \overline{V} \tag{3}
$$

The stiffens matrix has a structure of:

$$
\begin{bmatrix} k^{cc} & k^{cd} & k^{ce} \\ & k^{dd} & k^{de} \\ sym & & k^{ee} \end{bmatrix}
\begin{Bmatrix} c_i \\ d_i \\ e_i \end{Bmatrix} = 0 \tag{4}
$$

The critical buckling loads are obtained by setting the determinant of the stiffness matrix to be equal to zero.

3- Results and Discussion

At the first step to validation and accuracy, the obtained result is compared with the Ref. [3] for rectangular nanoplates for uniaxial and biaxial loading under the first type of porosity distribution. It can be seen, that the result obtained are highly accurate.

The variation of the dimensionless critical shear buckling load of a rectangular plate with respect to length to width ratio for different porosity distribution and graphene platelets pattern under clamped boundary condition is illustrated in Fig. 1. The reinforced effect of GPLs with symmetric pattern A is the most obvious, compared to those GPLs with patterns B and C.

Fig. 2 depicts the variation of dimensionless buckling loads of porous nanocomposite elliptical plate with the changing weight fraction for porosity distribution and GPL patterns. It can be seen from this figure that the dimensionless critical buckling loads grow evidently with the addition of GPL weight fraction and the maximum dimensionless critical buckling loads that occurred in the first type GPL for shear buckling loads under clamped boundary condition.

The dimensionless shear critical buckling loads versus porosity distribution coefficients curves for isosceles triangular nanocomposite plate under various boundary conditions are plotted in Fig. 3. It can be seen that the influence of porosity distribution coefficients under the S1C2F3 boundary condition is negligible.

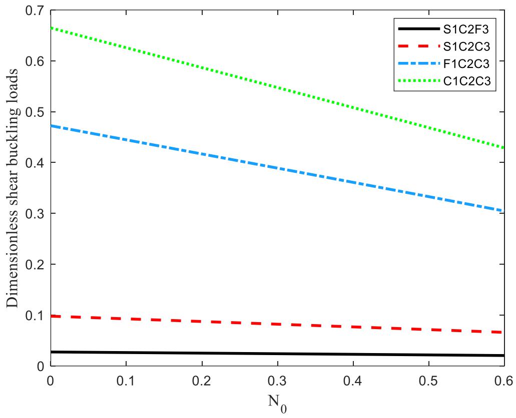

Fig. 3. Comparting of critical buckling load in the shear loads mode in terms of the porosity distribution coefficient of the isosceles triangular plate under different boundary conditions.

4- Conclusions

The best buckling can be achieved with the non-uniformly symmetric porosity distribution 1 and GPL pattern A, indicating that centralizing internal pores on the mid-plane and dispersing nanofillers around the surface can obtain the highest flexural rigidity of porous nanocomposite plates the identical consumptions of the matrix materials and nanofillers.

The uniaxial, biaxial, and shear buckling loads decrease with the increase of porosity coefficient, while the critical buckling loads grow evidently with the addition of GPL weight fraction.

By increasing the length to width ratio of the rectangular nanocomposite plate, the critical buckling load values increase and the greatest increase is obtained in the porosity pattern of the first type and the distribution of GPL pattern A.

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