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ORIGINAL RESEARCH PAPER

Engineering

STABILITY OF FUNCTIONALLY GRADED CARBON NANOTUBE REINFORCED COMPOSITE SQUARE PLATES WITH A CIRCULAR HOLE

KEY WORDS: stability, carbon nanotube, reinforced composite, finite element method, circular hole

D. Nikhitha*

Department of Civil Engineering, RVR & JC College of Engineering, Chowdavaram, Guntur, India-522019. *Corresponding Author

ABSTRACT

In the present investigation, static stability of functionally graded carbon nanotube reinforced composite (FGCNTRC) square plates with a circular hole is investigated using the finite element method . A higher-order shear deformation theory is used in the investigation. An eight nodedisoparametric plate bending element with nine degrees of freedom at each node is used. The critical loads are presented for various volume fractions and CNT patterns for two sets of boundary conditions.

INTRODUCTION

The discovery of carbon nanotubes (CNTs) is a major development in science. They possess superior mechanical, electrical and thermal properties. Due to their superior properties, CNTs are used as reinforcement in polymer matrix composites for structural application. The CNTs are reinforced in a matrix of polymer. CNTs may be aligned in one direction .The distribution of CNTs through thickness of a structural component like a plate/shell may vary and hence they are functionally graded through thickness. CNT reinforced polymer composite plates and shells find application in aerospace, nuclear power plants, automobiles and ships.

Arani [1] et al. analysed buckling of laminated composite plates reinforced with single-walled carbon nanotubes (CNTs) using the finite element method. The effects of CNTs orientation angle, boundary conditions and aspect ratio were considered. Mehrabadi et al. [2] investigated the mechanical buckling of functionally graded anaocomposite rectangular plate reinforced by aligned and straight single-walled carbon nanotubes.The influences of uniaxial and biaxial load, CNTs profiles were presented. Rashid and Yahaya [3] presented numerical analysis for buckling of functionally graded carbon nanotube composite plates using finite element method. The effects of boundary conditions and length to thickness ratios were considered. Zhang et al. [4] studied the stability of functionally graded functionally graded carbon nanotube composite thick skew plates.

Parametric studies including CNT distributions, skew angle were conducted. Kiani[5] investigated the shear buckling of carbon nanotube plates in thermal environment. It was shown that shear buckling strength may be increased by proper distribution of CNTs. Basha and Sai Ram [6] studied the buckling of functionally graded carbon reinforced composite plate with cutout. Critical loads were presented for simply supported boundary condition. Boulal et al. [7] investigated the buckling behaviour of carbon nanotube composite plates supported by Kerr foundation.Effect ofAspect ratios, volume fraction, types of reinforcement, parameters constant factors of Kerr foundation on the buckling analyses were studied.

From the review of literature, it may be noted that the buckling of functionally graded CNT reinforced composite plate with a circular cutout has not been considered by the earlier researchers. Hence, the objective of this investigation is to study the buckling of functionally graded carbon nano-tube reinforced composite (FGCNTRC) plate with a circular cutout by the finite element method . The formulation is based on higher-order shear deformation theory. An eight node disoparametric plate bending element is used with nine degrees of freedom at each node. The critical loads of functionally graded carbon nanotube reinforced composite plate with a circular hole are presented for two sets of boundary conditions.

FORMULATION

Consider a functionally graded CNT reinforced composite plate with a circular cutout as shown Figure1. An eight-node isoparametricplate bending element is considered in the present analysis. Nine degrees of freedom are considered at each node.The stiffness matrix and geometric stiffness matrix of the element are obtained using the principle of minimum potential energy. From the stiffness matrices and geometrical stiffness matrices of the elements ,respective global matrices [K] and [K_G] are obtained .The critical loads(λ)are obtained from the condition

$$|[K] - \lambda[K_G]| = 0$$

This is a generalized Eigen value problem which is solved using the subspace iteration method. A Fortran code is developed for the formulation.

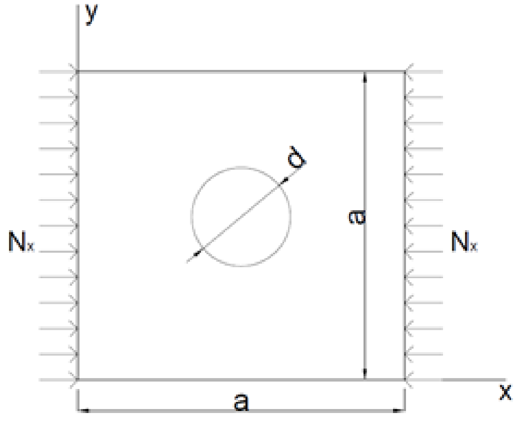

Figure 1 : Square Plate With A Cutout

RESULTS

Critical loads are presented for functionally graded carbon nanotube reinforced composite plate subjected to uniaxial compression in the plane of the plate with the CNTs aligned in the loading direction (Figure1). Critical loads are presented for four patterns of CNTs as shown in Figure 2.

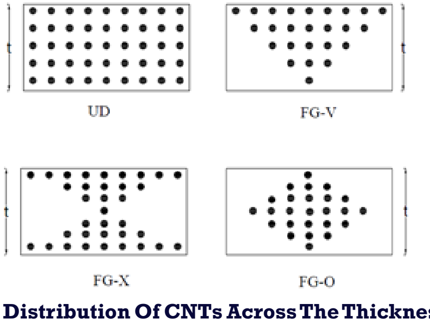

Figure 2 : Distribution Of CNTs Across The Thickness Of Square Plate

The following material properties are used in the investigation. For CNTs $E_{11}^{CN} = 5.6466\text{TPa}$, $E_{22}^{CN} = 7.0800\text{TPa}$, $G_{12}^{CN} = 1.9445\text{TPa}$, $\rho^{CN} = 1400 kg/\text{m}^3$, $V_{12}^{CN} = 0.175$. For polymeric matrix (PmPv), $E^m = 2.1GPa$, $\rho^m = 1150 kg/\text{m}^3$, $v^m = 0.34$.

Three different volume fractions (V_{CN}) of carbon nanotubes are considered. The efficiency parameters considered for each distribution are given below.

$$\eta_1 = 0.149, \eta_2 = 0.934, \eta_3 = 0.934 \; for \; V_{CN}^* = 0.11$$
$$\eta_1 = 0.150, \eta_2 = 0.941, \eta_3 = 0.941 \; for V_{CN}^* = 0.14$$
$$\eta_1 = 0.149, \eta_2 = 1.381, \eta_3 = 1.381 \; for V_{CN}^* = 0.17$$

The transverse shear moduli of the CNT composite are assumed as. $G_{12} = G_{13} = G_{23}$.

The critical loads of functionally graded carbon nanotube reinforced composite plates with a circular hole for different volume fractions are presented in Table 1-4.

Table 1 Non-dimensional critical load parameter k = $\frac{N_{xcr} a^2}{E_m t^3}$ of FG-CNTRC square plate (d/a=0.1). Boundary condition : Loaded edges are simply supported; Unloaded edges are clamped

V^*_{CN}	a/t	UD	FG-V	FG-O	FG-X
0.12	10	6.49	6.58	6.47	6.48
	50	36.19	22.09	49.72	49.73
0.17	10	6.43	6.57	6.43	6.78
	50	43.80	26.49	60.77	60.79
0.28	10	10.38	10.67	10.44	10.46
	50	55.93	33.80	77.43	77.45

Table 2 Non-dimensional critical load parameter k= $\frac{N_{xcr} a^2}{E_m t^3}$ of FG-CNTRC square plate (d/a=0.1). Boundary condition : Loaded edges are clamped; Unloaded edges are simply supported

V^*_{CN}	a/t	UD	FG-V	FG-O	FG-X
0.12	10	5.22	5.10	4.92	4.90
	50	95.20	63.63	92.04	92.43
0.17	10	4.88	4.82	4.62	4.61
	50	90.43	76.33	87.27	87.86
0.28	10	8.43	9.39	8.10	8.10
	50	152.84	151.65	151.58	152.47

Table 3 Non-dimensional critical load parameter k= $\frac{N_{xcr} a^2}{E_m t^3}$ of FG-CNTRC square plate (d/a=0.2). Boundary condition : Loaded edges are simply supported; Unloaded edges are clamped

V^*_{CN}	a/t	UD	FG-V	FG-O	FG-X
0.12	10	6.27	6.34	6.27	6.28
	50	27.85	17.73	37.47	37.47
0.17	10	6.12	6.23	6.14	6.15
	50	33.27	20.69	45.13	45.13
0.28	10	10.05	10.30	10.15	10.17
	50	43.18	27.17	58.72	58.72

Table 4 Non-dimensional critical load parameter k= $\frac{N_{xcr} a^2}{E_m t^3}$ of FG-CNTRC square plate (d/a=0.2). Boundary condition : Loaded edges are clamped; Unloaded edges are simply supported.

CONCLUSIONS

- In the case of FG-CNTRC plate with a cutout , for a/t = 10, the critical load is more when the loaded edges are simply supported and unloaded edges are clamped; for a/t = 50, the critical load is more when the loaded edges are clamped and unloaded edges simply supported.
- In the case of FG-CNTRC plate with a cutout, when the loaded edges are simply supported and unloaded edges are clamped, the critical load decreases with the increase in d/a from 0.1 to 0.2 .
- In the case of FG-CNTRC plate with a cutout when the loaded edges are clamped and unloaded edges are simply supported, the critical load increases with the increase in cutout size for all type of distributions considered for a/t = 10 . The critical load may decrease or increase with the increase in cutout size depending on type of distribution for a/t =50 .

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