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Research Article

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Computational Analysis of Elastically Supported Functionally Graded Plates with Plate Thickness Ratio and Materials Properties Having Rectangular Holes for Post Deforming in Thermal Environments

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Abstract

Computational simulation of FGM (Functionally graded material) plates on foundations with rectangular holes for post deforming in thermal environments are investigated. MATLAB code, stochastic finite element, and FOPT applied for various geometric parameters to find out mean post deforming thermal load and coefficient of variations of post deforming thermal load. The variations in plate thickness ratios, aspect ratios, and power index are investigated along with variations in amplitude ratios. Present HSDT with FOPT is applied for mean post deforming thermal load and uncertainty (COV) of post deforming thermal load parameters and compared for validation with those available literatures analytical method results. There are many applications of these plates in modern life and technology used in aviation industry, Aerospace applications. Table 1 and Table 2 results are for comparison and validation purposes, Table 3, Table 4, Table 5 and Table 6 results are findings useful for further research reference. Figure 1 is the geometry of quarter plate with rectangular hole and Figure 2 presents the comparison of SD/ Mean with uncertain parameters studied in this research paper.

Keywords

Functionally graded materials plates, Uncertain parameters, Elastic supports, Rectangular holes

Introduction

TFGMs plates with rectangular cutouts are used in applications. Previous research is carried out by the researchers on the subject as analytical studies. Notably among them are Shen [1-3], Huang and Shen [4], Yang et al. [5], Wu et al. [6], and Lal et al. [7]. Some other researchers like Pandey et al. [8], Rekha et al. [9], and Komur et al. [10] studied the plate with cutouts.

It is clear that work related to computational analysis of elastically supported functionally graded plates with plate thickness ratio and materials properties having rectangular holes for post deforming in thermal environments has not been investigated in thermal environments using Stochastic finite element method.

In this paper, computational analysis is carried out of FGM plates having variations in plate thickness ratio, aspect ratios, power index, and different materials properties having rectangular holes for post deforming in thermal environments. Stochastic FEM in MATLAB is applied for investigation. The present HSDT results obtained for mean post deforming thermal load are compared and validated with published analytical results and for uncertainty (COV) of post deforming thermal load with independent MCS.

Materials and Methods

IFGM plates are supported whose load displacement relation is expresses as:

$$P = K_1 w - K_2 \nabla^2 w \quad (1)$$

For solution $\pi_1 + \pi_2 + \pi_3 + \pi_4$ with respect to the generalized displaced vector {q} (2)
Eigen value solution of given problems is as:

$$K_o = K_b + K_s, [K_o]\{q\} = [F_t]$$

$$\left|[K_o] + \lambda[K_g]\right| = 0 \quad (3)$$

Comparative study average deforming (validation of present study)

Table 1 shows that critical buckling load obtained for same rectangular plate under biaxial loading condition is exactly half that of uniaxial loading condition. Present HSDT results are validated with Ghandapour et al. [11] and Wadhonkar et al. [12].

Table 2 presents [HSDT] investigations are carried out for the purpose of validation. The laminates $[0, 90]_2$s is considered. The eight layered thickness. It is noticed that present results are validated with Ghannadpour et al. analytical [11].

Geometry, modeling, and study factors

Rectangular plate material properties and geometric properties are expressed as Lal et al. [14]. The laminates are 0.15 mm thick. Higher order shear deformation theory is applied as given in [17].

Validity for random deformation

Figure 2 presents a comparative graph for SD/Mean with uncertainty in material qualities of present is compared with those published [5] and HSDT stochastic approach in conjunction with FOPT, Lal et al. [13].

Results and Discussion

MATLAB [R2010a] coding is done for rectangular holes [10]. A C0 element continuity is expressed in [11]. (Uncertainty at beginning) equal to 0.1 is expressed elaborately in [12, 13].

$$N^*_{cr} = \frac{N_x b^2}{E_2 h^3}, \lambda_{cr} = \frac{N_{cr} a^2}{\pi^2 D_0}$$

Table 2: Comparison of present [HSDT] mean buckling load (Nxb_2/E_2h^3) with semi-analytical buckling load of elliptical cutout.

d/b	e/b	Buckling load (Nxb_2/E_2h^3)	
		Ghannadpour et al. [11]	Investigated Results
0.0	0.0	13.79	13.88
0.5	0.05	13.11	13.40
0.5	0.10	12.19	12.37
0.5	0.15	11.32	11.43
0.5	0.20	10.49	10.53
0.5	0.25	9.70	9.66

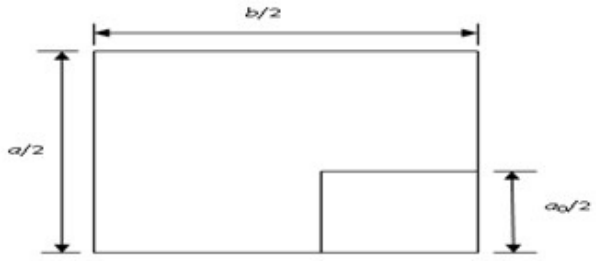

Figure 1: Quarter plate with rectangular hole.

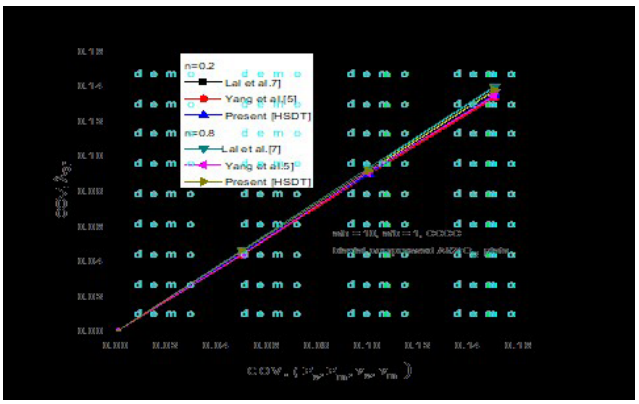

Figure 2: Comparison of SD/Mean with uncertain parameters.

Where, $D_0 = \frac{E_c h^3}{12(1-v_c^2)}$, $\lambda_{Tcr} = \lambda_{cr} * \alpha_0 * T \text{ x } 10^3$, and

$$K_1 = k_1 * D_{11}/a^4, K_2 = k_2 * D_{11}/a^2$$

Table 1: Comparison of present [HSDT] mean buckling load (Nxb_2/E_2h^3) with semi-analytical buckling load without cutout uniaxial and biaxial for the plate. The properties of the material of the lamina are given *as* E_1 = 130.0 GPa, $E_2 = E_3$ = 10.0 GPa, $G_{12} = G_{13}$ = 5.0 GPa, $\nu_{12} = \nu_{13}$ = 0.35, $\nu_{23} = \nu_{32}$ = 0.49. Stacking sequence is varied mentioned below.

	Without cutout Uniaxial			Without cutout Biaxial	
Stacking Sequence	Wadhonkar et al. [12]	Ghandapour et al. [11]	Present [HSDT]	Wadhonkar et al. [12]	Present [HSDT]
(0/90)2s	16.54	16.55	16.8619	8.27	8.3550
[30/-30]2S	23.37	23.16	23.8519	11.684	11.8503
(45/-45)2s	25.65	25.92	25.7946	12.826	12.5792

Table 3: Plate studied for mean thermal postbuckling load and COV of thermal postbuckling load with rectangular cutouts, TID material properties, plate thickness ratio (a/h) = 20, plate aspect ratio (a/b = 1), plate dimensions length (a = 50), (width b = 50). Elliptical cutout for varying power Index (n), amplitude ratios (W_{max}/h = 0.0 - 1.0), Foundation parameters.

a/h	n	W_{max}/h	Rectangular Hole					
			($k_1 = 0, k_2 = 0$)		($k_1 = 100, k_2 = 0$)		($k_1 = 100, k_2 = 10$)	
			Average	SD/Mean	Average	SD/Mean	Average	SD/Mean
20	0.0	0.0	0.9702	0.1009	1.0093	0.1009	1.1244	0.1008
		0.5	1.0784	0.0946	1.1171	0.0949	1.2269	0.0956
		1.0	1.1674	0.1020	1.1978	0.1027	1.3162	0.1013
	0.5	0.0	0.6453	0.0880	0.6843	0.0888	0.7986	0.0901
		0.5	0.7244	0.0821	0.7626	0.0832	0.7992	0.0967
		1.0	0.8635	0.1136	0.9099	0.0911	1.0060	0.1139
	1.0	0.0	0.5014	0.0856	0.5403	0.0859	0.6537	0.0865
		0.5	0.5671	0.0787	0.6035	0.0798	0.7140	0.0817
		1.0	0.6624	0.1078	0.6040	0.0863	0.7282	0.0871
	2.0	0.0	0.3884	0.0979	0.4269	0.0947	0.5387	0.0892
		0.5	0.4390	0.0880	0.4751	0.0867	0.5845	0.0838
		1.0	0.9941	0.2738	0.4941	0.1011	1.0230	0.2029
	5.0	0.0	0.3118	0.0925	0.3496	0.0880	0.4590	0.0814
		0.5	0.3471	0.0844	0.3829	0.0818	0.4908	0.0775
		1.0	0.3551	0.0847	0.4212	0.0883	0.5448	0.0790
	10.0	0.0	0.2765	0.0806	0.3139	0.0774	0.4217	0.0738
		0.5	0.3047	0.0751	0.3405	0.0733	0.4473	0.0711
		1.0	0.3810	0.0683	0.3999	0.0773	0.4897	0.0734

Table 4: Plate studied for mean thermal postbuckling load and COV load with elliptical cutouts, TID material properties, Plate thickness ratio (a/h) = 10, plate aspect ratio (a/b = 1), Plate dimensions length (a = 50), (Width b = 50). Rectangular cutout CCCC support for varying power index (n), Amplitude ratios (W_{max}/h = 0.0 - 1.0).

n	W_{max}/h	Rectangular Cutout ($a_0/b_0 = 1.5$)					
		($k_1 = 0, k_2 = 0$)		Support 1		Support 2	
		Mean	COV	Mean	COV	Mean	COV
0.0	0.0	5.5275	0.1007	5.8028	0.1008	6.6421	0.1005
	0.5	6.3331	0.0923	6.6022	0.0929	7.4448	0.0943
	1.0	6.3532	0.1062	6.8320	0.1092	7.2662	0.1079
0.5	0.0	3.7142	0.0883	3.9912	0.0893	4.8231	0.0909
	0.5	4.2852	0.0808	4.5857	0.0820	5.1562	0.0898
	1.0	4.8242	0.1387	5.0222	0.1395	5.6085	0.1281
1.0	0.0	2.8937	0.0844	3.1696	0.0851	3.9915	0.0863
	0.5	3.3769	0.0757	3.6536	0.0775	4.3776	0.0968
	1.0	3.7257	0.1239	4.9186	0.2771	6.1595	0.1915
2.0	0.0	2.2279	0.0917	2.4975	0.0886	3.2990	0.0848
	0.5	2.2315	0.0813	2.8268	0.0810	3.4301	0.0847
	1.0	2.8958	0.1166	3.0246	0.1127	3.6959	0.1057
5.0	0.0	1.7372	0.0858	1.9883	0.0811	2.7499	0.0764
	0.5	1.7598	0.0865	2.1569	0.0916	2.8975	0.0752
	1.0	2.1466	0.1055	2.2553	0.0800	3.2135	0.1343
10.0	0.0	1.5227	0.0793	1.7625	0.0758	2.5014	0.0720
	0.5	1.7240	0.0728	1.8672	0.0831	2.5256	0.0732
	1.0	1.9553	0.1202	1.8726	0.0853	2.5829	0.0781

Where, $D_{11} = \left(E_2 * b^3\right) / \left(12\right) * \left(1 - \upsilon_{12}{}^2\right)$

$$\lambda_{cr} = N_{cr} * \alpha_c * \Delta T * 1000$$

Where, λ_{cr} and λ_{Tcr} are dimensionless parameters of plate and materials Al/ZrO_2 and Al/Al_2O_3.

Table 3, it is noticed that for same plate thickness ratio on increasing volume fraction index the mean and COV decreases, however on increasing amplitude ratio increase for plate supports. On further increasing the plate thickness ratio the mean and COV further decrease to lower values, however it is higher for supports.

Table 4, it is seen that for given power index the expected mean and COV of thermal postbuckling load increase on increasing amplitude ratios for plate without and with Winkler and Pasternak elastic foundations. However, these values further decrease on increase of volume fraction index. It means on increase of power index the buckling tendency increases for given temperature in present study.

Table 5, it is seen that for same aspect ratio on increasing volume fraction index the mean and COV of thermal postbuckling load decreases. However, on increasing amplitude ratio for plate on support, thermal postbuckling load increases. It is higher for support. On further increasing the aspect ratio the Mean and COV further increase to higher values, however it is higher for supports COV for volume fraction index (0.5) is much higher than other so this must be avoided for design purpose.

Table 6, it is seen that for SSSS support and Al/ZrO_2 plate material, on increasing minor axis values the Mean and COV of thermal postbuckling load increases, however on increasing amplitude ratio increase for plate supported. It is higher for support. On change to Al/Al_2O_3 plate material.

Table 5: Plate studied for mean thermal postbuckling load COV postbuckling load with elliptical cutouts, (a/h = 30). Plate dimensions length (a = 50), (Width b = 50). Rectangular cutout (a_0/b_0 = 1.5) for varying plate aspect ratio (a/b), power index (n).

a/b	n	W_{max}/h	Rectangular Cutout					
			($k_1 = 0, k_2 = 0$)		Support 1		Support 2	
			Mean	COV	Mean	COV	Mean	COV
1	0.0	0.0	0.3388	0.1010	0.3504	0.1010	0.3852	0.1008
		0.5	0.3722	0.0956	0.3828	0.0960	0.4172	0.0963
		1.0	0.4490	0.0914	0.4320	0.0983	0.4925	0.0940
	0.5	0.0	0.2249	0.0879	0.2364	0.0885	0.2707	0.0898
		0.5	0.2492	0.0830	0.2601	0.0839	0.2937	0.0859
		1.0	0.3204	0.0758	0.3295	0.0804	0.3442	0.0871
	1.0	0.0	0.1747	0.0860	0.1861	0.0862	0.2202	0.0865
		0.5	0.1945	0.0801	0.2053	0.0809	0.2389	0.0823
		1.0	0.2519	0.0747	0.2587	0.0844	0.2789	0.0832
	2.0	0.0	0.1356	0.0995	0.1469	0.0967	0.1806	0.0912
		0.5	0.1508	0.0909	0.1614	0.0893	0.1950	0.0859
		1.0	0.1951	0.0820	0.1960	0.0849	0.2246	0.0843
	5.0	0.0	0.1096	0.0944	0.1209	0.0904	0.1542	0.0836
		0.5	0.1203	0.0873	0.1310	0.0846	0.1618	0.0832
		1.0	0.1517	0.0748	0.1576	0.0771	0.1872	0.0771
	10.0	0.0	0.0975	0.0810	0.1088	0.0781	0.1418	0.0744
		0.5	0.1061	0.0763	0.1169	0.0745	0.1498	0.0719
		1.0	0.1314	0.0675	0.1411	0.0663	0.1722	0.0719
2	0.0	0.0	1.3565	0.1000	1.3586	0.1000	1.4123	0.1000
		0.5	1.6177	0.0971	1.5596	0.1041	1.6790	0.0969
		1.0	2.1326	0.0836	1.3610	0.0753	2.1496	0.0840
	0.5	0.0	1.1880	0.1086	1.1915	0.1088	1.2452	0.1082
		0.5	1.1093	0.1024	1.1135	0.1022	1.1687	0.1019
		1.0	1.2356	0.1385	0.9851	0.3208	1.2569	0.0795
	1.0	0.0	0.5882	0.5885	0.2902	1.5321	0.3373	0.3378
		0.5	1.1304	0.0717	0.3919	0.0832	0.9788	0.0730
		1.0	0.5241	0.3293	1.0957	0.7909	0.9239	0.0834
	2.0	0.0	0.5882	0.5885	0.5904	0.5717	0.6395	0.5122
		0.5	0.6077	0.2715	0.5222	0.1609	0.6743	0.1713
		1.0	0.5533	0.0376	0.5524	0.0272	0.5182	0.5900
	5.0	0.0	0.2398	0.2680	0.2428	0.2595	0.2904	0.2247
		0.5	0.1820	0.4748	0.2172	0.3176	0.2341	0.3689
		1.0	0.1144	0.6532	0.3470	0.0642	0.0405	0.2565
	10.0	0.0	0.1340	0.4609	0.1373	0.4432	0.1843	0.3257
		0.5	0.0719	0.1892	0.0746	1.1274	0.1315	0.5716
		1.0	0.2114	0.2510	0.2122	0.2607	0.6550	0.0968

Table 6: Plate studied for mean thermal postbuckling load and COV postbuckling load with elliptical cutouts, TID material properties, rectangular cutouts, TID material properties, a/h = 20, n = 5.0, (a_0/b_0) for (a_0 = 0, 2.5, 5, 7.5, 10, 12.5, and b_0 = 25) for different type of materials (Al/ZrO_2), (Al/Al_2O_3), variations in aspect ratios, Amplitude ratios (W_{max}/h = 0.0 - 1.0).

Type of material	a_0/b_0	W_{max}/h	Rectangular Cutout					
			(k_1 = 0, k_2 = 0)		Support 1		Support 2	
			Mean	COV	Mean	COV	Mean	COV
Al/ZrO_2	0.0	0.0	0.6719	0.0754	0.7158	0.0736	0.8425	0.0722
		0.5	0.7209	0.0870	0.7605	0.0836	0.8822	0.0781
		1.0	0.8685	0.1092	0.8968	0.1054	0.9990	0.0954
	0.1	0.0	0.9375	0.0754	0.9674	0.0735	1.0889	0.0720
		0.5	1.0210	0.0742	1.0446	0.0721	1.1573	0.0703
		1.0	1.2688	0.0726	1.2595	0.0715	1.2489	0.0734
	0.2	0.0	0.9905	0.0754	1.0040	0.0736	1.1086	0.0717
		0.5	1.0795	0.0736	1.0864	0.0717	1.1819	0.0698
		1.0	1.3436	0.0701	1.3193	0.0692	1.3203	0.0717
	0.3	0.0	1.0481	0.0754	1.0446	0.0737	1.1324	0.0716
		0.5	1.1430	0.0731	1.1323	0.0714	1.2098	0.0695
		1.0	1.4264	0.0684	1.3868	0.0674	1.4420	0.0658
	0.4	0.0	1.1139	0.0754	1.0932	0.0739	1.1642	0.0715
		0.5	1.2155	0.0727	1.1864	0.0713	1.2467	0.0693
		1.0	1.5206	0.0670	1.4637	0.0661	1.4903	0.0647
	0.5	0.0	1.1896	0.0754	1.1514	0.0741	1.2059	0.0715
		0.5	1.2982	0.0724	1.2505	0.0712	1.2928	0.0691
		1.0	1.6270	0.0660	1.5551	0.0652	1.5642	0.0638
Al/Al_2O_3	0.0	0.0	0.5615	0.1001	0.6122	0.0910	0.5800	0.0825
		0.5	0.6044	0.1173	0.6495	0.1068	0.6042	0.0917
		1.0	0.7341	0.1315	0.7602	0.1235	0.6740	0.1044
	0.1	0.0	0.7841	0.0972	0.8193	0.0898	0.7481	0.0824
		0.5	0.8577	0.0941	0.8831	0.0870	0.7890	0.0803
		1.0	1.0751	0.0858	0.9623	0.0858	0.8326	0.0796
	0.2	0.0	0.8283	0.0966	0.8398	0.0899	0.7485	0.0823
		0.5	0.9068	0.0924	0.9080	0.0863	0.7922	0.0798
		1.0	1.1392	0.0823	1.0937	0.0802	0.8740	0.0792
	0.3	0.0	0.8763	0.0959	0.8636	0.0901	0.7523	0.0822
		0.5	0.9600	0.0909	0.9360	0.0858	0.7982	0.0794
		1.0	1.2063	0.0552	1.1550	0.0761	0.8733	0.0791
	0.4	0.0	0.9309	0.0952	0.8937	0.0903	0.7614	0.0823
		0.5	1.0198	0.0898	0.9707	0.0856	0.8096	0.0792
		1.0	1.2900	0.0774	1.1883	0.0771	0.9474	0.0735
	0.5	0.0	0.9936	0.0947	0.9318	0.0905	0.7769	0.0825
		0.5	1.0888	0.0887	1.0155	0.0851	0.8278	0.0790
		1.0	1.3797	0.0756	1.4597	0.1021	0.9863	0.0713

Conclusion

Computational analysis of elastically supported FGM plates with rectangular cutouts for post deforming in thermal environments is carried out. Thermal postbuckling load of FGM plate subjected to uniaxial compression decreases. In the rectangular cutouts, one which aligned perpendicular to load direction represents higher buckling load than one aligned in. It concludes that when plates with rectangular cutouts are supported, postbuckling is at higher temperature for same properties compared to without foundations. This parameter is one of the other important parameters while considering plates with rectangular cut out because thermal stresses are more in cutout section.

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None.

Conflict of Interest

Author assures no conflict of interests are relevant to the content of this article.

Credit Author Statement

Rajesh Kumar: Conceptualization, Methodology, Investigation, Data analysis, Writing - original draft preparation, Writing - review and editing. The author read and approved the manuscript.

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