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Effect of Opening and Stiffener on Geometric Nonlinear Dynamical Behavior of Single-Curved FGM Shells under the Blast Loads

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ABSTRACT: Functionally Graded Materials (FGMs) are kinds of composite materials that due to the continuity of mixture of constituent materials, have more effective mechanical properties which leads to eliminate the interlayer stress concentration. The most common usage of such materials is in thin-wall structures, such as plates and shells. One of the most effective factors in behavior of such structures especially in single-curved shells, thermal loads or Impact loads is caused by explosion. Also, due to some executive needs, make opening in shells and their behavioral changes are important and suggesting solution will be necessary. Therefore, in order to prevent large displacement and resistance improvement, using shells made of FGM and suitable stiffeners, will be suggested. In this study, ABAQUS finite element software has been used to survey the Effect of opening and stiffener on geometric nonlinear dynamical behavior of single-curved FGM shells under the blast loads. In order to do this, the effect of volume fraction index, the effect of different openings and stiffeners has been studied. Results show that by increasing the volume fraction index, the maximum amount of displacement of the shell decreased. Making opening in the center of the shells, has better function in contrast with making opening distribution in the level of shells. By increasing moment of inertia of longitudinal and circular stiffeners, the maximum displacement has been decreased. Also, by utilizing opening distribution and longitudinal stiffeners, the maximum amount of displacement can be reduced.

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1. INTRODUCTION

Functionally Graded Materials (FGM) are kinds of composite materials and due to the continuity of the mixture of constituent materials, have more effective mechanical properties which lead to eliminating the interlayer stress concentration. The most common usage of such materials is in thin-wall structures, such as plates and shells. By the usage of mixing rule, FGM materials properties such as elastic modulus, density, and Poisson's ratio are changeable across the thickness. This change in properties is defined according to Table 1, Eq.s (1) and (2).

$$V_c(z) + V_m(z) = 1 \tag{1}$$

$$P(z,\ T) = \left[P_c(T) - P_m(T)\right]V_c(z) + P_m(T) \tag{2}$$

$P(T)$ and $V(z)$ respectively represent the properties of mechanical materials related to temperature and volumetric function of the constituent materials in the direction of thickness; Also ***c*** and *m* respectively show the ceramic and metal phases of FGM shells [2, 3].

Blast is one of the most effective factors in behavioral changes of thin-wall structures such as single-curved shells, thermal and impact loads; which leads to their nonlinear dynamical behavior. In order to determine the characteristics of each blast, it is necessary to survey different parameters by using (3), (4), (5) relations [4].

$$Z = \frac{D}{\sqrt[3]{M}} \tag{3}$$

$$P_{so} = \frac{1772}{Z^3} - \frac{114}{Z^2} + \frac{108}{Z} \tag{4}$$

$$P_t(t) = \left(P_{so} - P_0\right)\left(1 - \frac{t}{t_p}\right) e^{-\frac{\alpha t}{t_p}} \tag{5}$$

In these relations, $P_t(t)$ is the amount of pressure in the desired time, P_o is the amount of atmospheric pressure, P_{so} is the amount of peak overpressure, t_p is the explosion time duration, á decay is a constant amount and *D, M* and *Z* are respectively the distance of the explosion center to the point according to meter, mass of explosive material according to kilograms and scaled distance.

In this research, after verifying the FGM shells modeling method [5, 6], first the properties of each layer by the usage of dominant relations in FGM materials calculated [7] and then shells were modeled by utilizing multi-layer equivalent method (Figure 1).

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Table 1. FGM mechanical properties [1]

Materials properties	Elastic Modulus (GPa)	Density (kg/m^3)	Poisson's Ratio
Aluminium (Metal)	67	2702	0.33
Silicon carbide (Ceramic)	302	3100	0.17

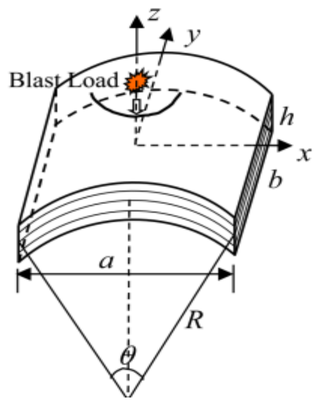

Fig. 1. Geometry and Cartesian coordinates of FGM single-curves shells [8].

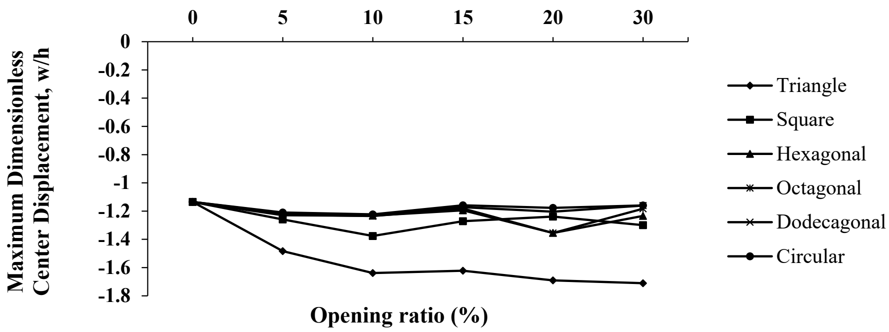

Fig. 2. Maximum displacement without FGM central shells dimension with different openings

In order to evaluate the FGM materials which were used in single-curved shells, volume fraction index effect with a seven-volume fraction ($n = 0.0, 0.2, 0.5, 1.0, 2.0, 5.0, \infty$) have been analyzed. Observes show that by increasing the volume fraction index, the amount of displacement of the central shell has been decreased, so that the maximum displacement in full-metal shells ($n = \infty$) and minimum displacement in full-ceramic Shells ($n = 0$) have occurred and other shells response are located between maximum and minimum conditions.

In order to analyze the nonlinear dynamical behavior of FGM shells with different openings, single-curved shells with focused and extensive opening have been studied. In focused condition, Triangular, Square, Hexagonal, Octagonal, Dodecagonal and Circular openings have been analyzed and according to Figure 2, the circular opening has the best opening level. The opening percent has been chosen according to the opening area ratio to shell area (relation 6) and the amounts of 0 to 30 percent.

$$OR = \frac{A_{opening}}{A_{shell}} \times 100 \tag{6}$$

In some cases, it is not possible to optimize the shell by way of changing geometrical dimensions and the number of layers. In this situation, a stiffener can be used in order to strengthen the shell, so that the role and effect of changing geometrical dimensions of stiffener on FGM cylindrical shells under the blast loads can be studied. To do this, two kinds of longitudinal and circular stiffeners have considered. Longitudinal stiffener (Figure 3-a) is located entirely in the shell length and circular stiffener (Figure 3-b) is located radially. These stiffeners are metal and have been prepared for executing in the inner level of shells.

According to the analyzes, by increasing the thickness and height of stiffeners and the scaled area in FGM single-

(**b**) (**a**)

Fig. 3. Geometry the model of FGM cylindrical shells with longitudinal (a) and circular (b) stiffeners

curved shells with longitudinal and circular stiffeners, lead to decreasing maximum displacement, so that scaled area, height, thick-ness have the effect of high to low on the maximum displacement of the shells, respectively. Also in order to analyze the number and the type of stiffeners arrangement on the FGM cylindrical shells, longitudinal and circular stiffeners with the same area by the number of 1, 2, 3 and 4 have been studied with different types of arrangement. Studies show that the central shells maximum displacement in the case of utilizing longitudinal stiffeners have the least amount of displacement. Also if the number of stiffeners becomes more than one, in the case that one stiffener located longitudinal and others circulars, the maximum displacement will be less than other conditions.

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