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Homogeneity of magnetic field influence on buckling of three layer polyethylene plate

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ABSTRACT

The paper describes buckling of rectangular plate made of polyethylene. The plate is built of three layers. External faces are solid and the core is porous. The plate is described with broken line hypothesis. On the two opposite ends of the plate are pockets with porous structure as well. Each pocket is filled in with ferrofluid. Magnetic field is generated by coils systems and acts on ferrofluid in pockets. System of magnetic field coils consists of two subsystems. First of the subsystems is a Helmholtz coil, which has high homogeneity of magnetic field. The bigger radius of Helmholtz coil, the bigger volume of homogeneous magnetic field. The second subsystem is Golay coil, that generate transverse gradient magnetic field. Homogeneity of gradient magnetic field for Golay coil is much worse that for Helmholtz coil. Such systems of coils generate magnetic field changing in space. Changing dimensions of coils the homogeneity of magnetic field is changing as well. It causes that induced force in the pockets is also changed. In the paper critical states are obtained for static load and equation of motion are solved for equilibrium paths for example plates.

1. Introduction

Sandwich structures have a number of applications because of their properties. These structures have been developed since the middle of the 20th century, especially in last years. Of particular importance in mechanical or civil engineering have sandwich structures, which are characterized by low weight and considerable stiffness. The core of these structures has lower density than the density of the faces. Similarly smart materials like ferrofluids have wide spectrum of applications.

The bases of the theory of sandwich structures were described by Plantema [1]. Vinson [2] presented strength and stability problems of sandwich structures. Allen [3] described the bases of the theory of sandwich structures. Buckling and postbuckling behavior of thin plates, subjected to static and dynamic load were studied by Kubiak [4,5]. Ventsel and Krauthammer [6] presented principles of thin plate and shell theories. Carrera [7] formulated the zig-zag hypotheses for multilayered plates. Altenbach et al. [8] analysed three-layer laminates with thin and soft core layer with the use of the first order shear deformation plate theory. Belica et al. [9] presented a nonlinear approach with regard to the dynamic stability of an isotropic metal foam circular cylindrical shell subjected to combined loads. Pawlus [10,11] presented the computational results of critical loads calculations of annular three-layered plates with a soft core. Magnucka-Blandzi [12] carried out a theoretical study on dynamic stability of a metal foam circular plate. Jasion et al. [13] presented analytical, numerical and experimental data of the global and local buckling-wrinkling of the face sheets of sandwich beams. Smyczynski and Magnucka-Blandzi [14] analysed the stability of a five layer sandwich beam with the use of broken line hypothesis of the deformation of a flat cross section of the beam. Magnucki et al. [15–17] presented analytical investigations of bending and buckling of a rectangular plates and beams made of a porous material. Magnucka-Blandzi [18] presented mathematical modeling of an in plane compressed rectangular sandwich plate with a metal foam core. Kedzia et al. [19] indicated the process of preparing the magnetic fields with high homogeneity. Kedzia and Magnucki [20] determined static and dynamic equilibrium paths for one layer rectangular plate with pockets filled in with ferrofluid under magnetic field. Chen et al. [21] studied the elastic buckling and static bending analysis of shear deformable functionally graded (FG) porous beams based on the Timoshenko beam theory. Grygorowicz et al. [22] analytically and numerically studied elastic buckling of a three-layered beam with variable mechanical properties of the core. Fallah et al. [23] investigated the postbuckling analysis of FG circular plates under asymmetric transverse and in-plane loadings, based on the first-order nonlinear

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von Karman theory. Marjanović and Vuksanović [24] proposed extended layerwise plate theory of Reddy, for the analysis of delaminations, and used as a basis for development of enriched finite elements. The proposed model assumes layerwise linear variation of in-plane displacements and constant transverse displacement through the plate thickness. Hohe and Librescu [25] focused of a survey of recent developments and contemporary trends in the modeling of the deformation and buckling behavior of sandwich shells. Jabbari et al. [26,27] studied critical buckling of functionally graded soft ferromagnetic porous (FGFP) rectangular plates, under magnetic field with simply supported boundary condition. They also investigated the compressibility of fluid and porosity on the buckling strength. They presented the effect of pore pressure on critical magnetic field of plate and the effect of important parameters of poroelastic material on buckling capacity. Also the compressibility of fluid and porosity on the buckling strength were the fields of their interest. Mojahedin et al. [28] used the energy method for the buckling analysis of radially loaded solid circular plate made of porous material. Properties of investigated porous plate, where pores were assumed to be saturated with fluid, varied across its thickness. Yang et al. [29] presented based on an energy method analyses of magnetoelastic buckling and bending of ferromagnetic thin plates in transverse, oblique, and longitudinal fields. He pointed that the critical magnetic field is not only related to the ratio of the thickness to the cantilevered length, but also to the susceptibility and the demagnetizing factors that are primarily dependent on the ratios of the thickness to width and the thickness to the total length. Uslu Uysal and Guven [30] investigated the buckling behaviors of adhesively bonded sandwich plates subjected to in-plane shear force, in-plane normal compression force, and out-of-plane distributed load for both point supported concept and linear supported concept.

The paper is devoted to a rectangular sandwich plate under in-plane compression load (Fig. 1). The plate with sizes a, b consists of three layers: upper face, the core and the lower face. The core has porous structure.

On each of the two opposite edges of a plate for $x = 0$ and $x = a$ there are two pockets. These pockets with porous structure are filled in with ferrofluid. Cells in the pockets avoid to ferrofluid flow along the edge. Magnetic field coils are placed near the ferrofluid. The coil system consists of two magnetic field coil subsystems. The first one (MC-main coil) generates homogeneous magnetic field. The second one is a gradient coil (GC). Helmholtz or double Helmholtz coil can be used as MC and they generate magnetic field of high homogeneity. Gradient coil is "saddle" coil with homogeneous transverse gradient magnetic field. This coil is also called Golay coil. Coils are presented schematically as loops in Fig. 2a and Golay coil is shown in Fig. 2b. Golay coils can be changed with

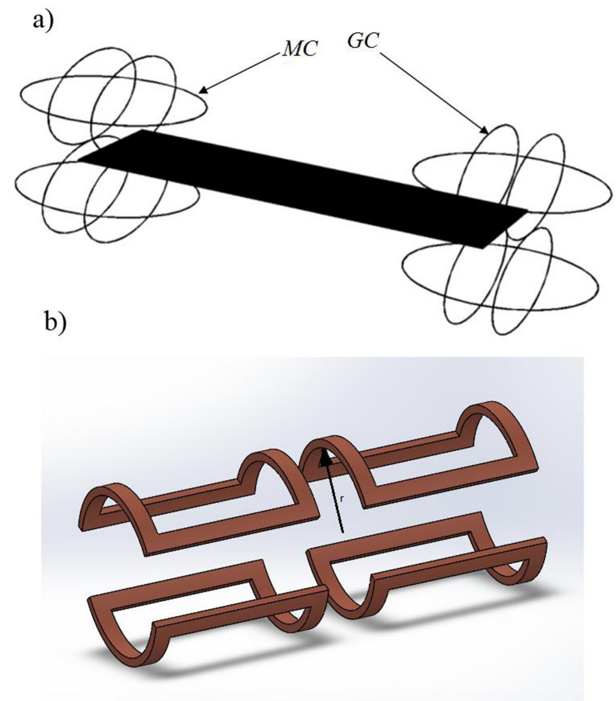

Fig. 2. (a) Arrangement of a coils respect to plate, (b) Golay coil with arc radius r.

other transverse gradient coils e.g. elliptic coils. Elliptic coils homogeneity is different than Golay coils.

Such system of coils schematically presented in Fig. 2 generates magnetic field that changing in space. Generated magnetic field acts on ferrofluid in the pockets on the edges of the plate, where compression force is induced. Depends on the radius of the coils different compressive load can be obtained. Changing radius of each subsystem of the coils gives different volume of homogeneous magnetic field. Further the strength of magnetic field is changed. Especially, it is important for Golay coil. Homogeneity of such coil is plotted in Fig. 3.

Intensity $\hat{N}_x^0$ of the load is expressed by Kelvin force applied per unit volume of ferrofluid [31]:

$$\hat{N}_x^o = N_x^0(y) \cdot t_s \cdot \mathbf{f}_x^m = N_x^0(y) \cdot t_s \cdot \mu_0(\mathbf{M}\nabla\mathbf{H})_x = N_x^0(y) \cdot t_s \cdot \frac{1}{2}\mu_0\chi(1+\chi)(\nabla H^2)_x \quad (1)$$

where

M = χH is the magnetization vector,

χ is the magnetic susceptibility,

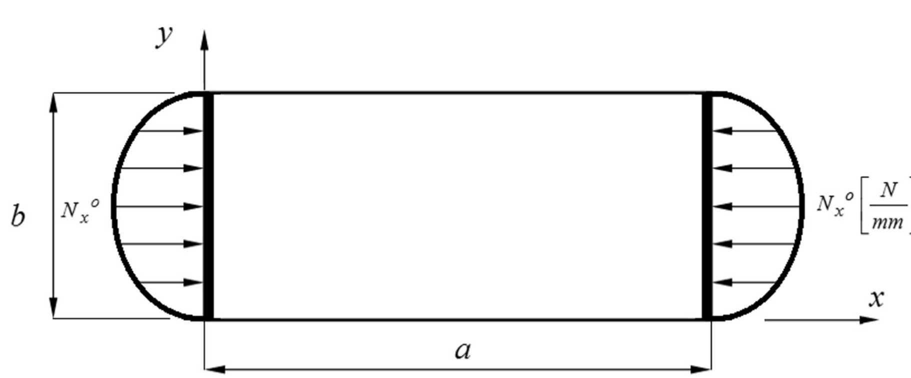

Fig. 1. Scheme of the loaded plate.