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Buckling of functional graded polymeric sandwich panel under different load cases ☆

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ABSTRACT

In the present paper, 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 were studied for both point supported concept and linear supported concept. The functionally gradient polymeric adherends and elastic, homogeneous adhesive were used in the assembly. The epoxy resin was used and two types of graphite powder materials were selected PAM96/98 and PV60/65 as filler. The graphite powders were added to the epoxy resin as 3%, 6%, 9%, and 12% vol. The structure and graphite distribution were investigated by light microscope and the elasticity modulus of adherends were predicted based on the image processing program. The influences of the type and volume of graphite powders on the buckling behavior were studied by finite element analyses. The critical buckling loads were predicted and their mode shapes were presented. The highest critical buckling load was determined in PV60/65 structure panels for three different load cases due to the fact that the PV60/65 graphite powder was compatible with epoxy resin.

1. Introduction

Polymer systems are widely used in different engineering areas due to their unique attributes including ease of production, light weight, and ductile nature. However, polymers have lower elasticity modulus and strength as compared to metals and ceramics. Mechanical properties of the polymers can be improved by the inclusion of fillers (fibers or particles) to form the polymer matrix composites [1–5]. According to this approach, the polymer properties have been improved while their preferred features were kept [6–11]. As is known that, another way for improving material used is to form a graded microstructure, i.e. functional graded polymeric materials (FGPMs). This change in the microstructure makes FGPMs the different than homogeneous materials and traditional composite materials. Within the different FGPMs micro-structural phases have different function and the overall FGPMs attain the multi-structural status from their property gradation. By gradually varying the volume fraction of constituent materials, their properties exhibit a smooth and continuous change from one surface to another, thus interface problems are eliminated. These materials also have certain advantages over existing isotropic materials and conventional composites, especially in applications which demand good toughness and strength characteristics [12,13]. In the polymers, like in other materials, compositional and micro structural gradients are intended to admit an optimum combination of component properties, for example weight, surface hardness, wear resistance, impact resistance, surface and volume resistance and toughness [14]. They are important in engineering applications as both structure and materials selection. Thus, this concept provides the materials scientists and engineers to design new materials for some special applications, for example, in aerospace, automobile, biomedicine, nuclear energy, gas turbine engine, and many other fields.

Also many researchers have focused on design of FGM (functionally graded material) sandwich structures and their analyses [15–18] In general, a sandwich composite laminate is composed of at least two thin adherends made of either isotropic or anisotropic material surrounding a core [19]. The sandwich structure is joined together with film adhesive between layers. The adherends are used to carry compressive loads and axial tensile while the adhesive is used to carry shear loads and support against compressive loads normal to the adherends. The materials used in the construction of sandwich structures can vary with application. The adherends of a sandwich structure are typically made from aluminum alloys, titanium, high tensile steel or multi-layered ply composites [20,21]. However, the FGPMs have replaced these materials. Because, the adherends in sandwich structures carry in-plane

☆ Dedication: "In memory of Prof. Dr. Ing. Doğan Özgür (Ayancık 1938 – Istanbul 2014)".

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stresses. If these in-plane stresses are high enough, the adherends could yield, dimple or wrinkle and compromise the stability and strength of the sandwich structure [22]. Sandwich structures are desirable in aerospace structural applications due to their attractive properties they possess including high specific stiffness and design versatility. Design versatility allows freedom to tailor the stiffness, strength, and weight for an intended application. However, sandwich structures are not fully suitable in structural designs, due to their poor damage tolerance. In particular, sandwich structures are prone to the delamination of adherends, caused by the failure of the adhesive bond. The adherend delamination failure can occur due to excessive stresses in the transverse normal direction and/or transverse shear stresses. Failure prediction of sandwich composites is also complicated by the fact that there are many more modes of failure when compared to isotropic homogenous materials [21,23]. Sandwich structures have a number of disadvantages that should be carefully considered. Design of a sandwich structure begins with defining the possible failure modes and associated failure loads for each condition [24]. The common failure mode includes the adherend tension failure, the adherend compression yield, and the adherend buckling under compression. The sandwich panel may be constrained by stiffness and general buckling requirements. The strength or failure requirements are generally at the local level. Each layer of a sandwich presents its own failure modes [20]. Plate-buckling is a phenomenon that occurs in thin plates supported on four sides when subjected to forces. The plate will return to the initial position when the force does not act any more. It is valid only when the applied force is smaller than the critical plate-buckling force. If the applied force is higher, the plate will remain in the deformed position forming buckles. These formed buckles were investigated for polymer plates subjected to the bucking and dynamic buckling [25,26] and the semi-analytical method was compared with FEM for analysis [27]. Particular case of plate-buckling is sheared plate-buckling where a plate is subjected to in-plane shear force. The basis of plate buckling was given by Euler in 1744 developing the bifurcation theory. As can be seen above mentioned literature, many researchers have studied in detail buckling phenomena in the polymeric plates/sandwich structures for different materials models, boundary conditions, and load direction. An interesting experimentally weighted work, in connection with present study, on the homogeneous isotropic glass sandwich structures subjected to the in-plane shear force and other load types can be found in the present literature [28,29].

In the present study, is mainly addressed the buckling problem as in [28,29] a sandwich structures subjected to in-plane shear force, in-plane normal compression force, and out-of-plane distributed load. Connection concepts of sandwich panels were selected as point supported and linear supported. Linear supported connection concept was adopted following the present literature [28,30]. However, the behavior of the sandwich panels in the structures are assumed to be FGPMs and recently developed a new FGPMs model [31] is used. Accordingly, the panels of sandwich structure were built polymeric gradient materials based on epoxy resin filled with graphite, the details of this new material model is given in the Section 2. This paper is focused on the buckling behaviors in the new designed sandwich panels. The detailed analysis models for buckling behavior prediction were built up by using finite element method for the sandwich FGPMs structures. The main objective of this study is to determine a rational graphite powder type/volume ratio to increase the critical buckling load capacity.

2. Description of the present FGPMs (functionally graded polymeric materials) model

The present FGPMs model used here as described in the articles [31,4,32–34] shows that possibility of graphite powder PAM96/98 and PV60/65 applications as innovatory filler of polymers. Graphite powders PAM96/98 and PV60/65 produced by Koh-I-Noor (Czech Republic) were used as filler and also PAM96/98 and PV60/65 properties are shown in Tables 1 and 2, respectively [35].

Epoxy resin (Epidian 6) which was cured with Z1 material and produced by "Organika Sarzyna" Chemical Plant S.A. (Poland), was used as polymeric matrix components [33] Then, the graphite ratios of 3%, 6%, 9%, and 12% vol. were chosen and added into the epoxy resin. Centrifugal casting as one of the most effective methods for polymeric gradient materials creation was chosen in this material production. FGPMs specimen were sliced from the mold of sample casting.

FGPMs specimens were wet grind with grindings paper with different grain size 800# up to 2400# on machine and that were polished with using "diamond suspension", grain size 1 μm. During polishing by diamond suspension, samples were cooled by Blue lubricant made by Struers Company, then samples etched in ethyl acetate pure (Poch Company, Gliwice, Poland). All samples were observed by the light microscope LECIA (MEF4A) in magnification 200X equipped with Axiovision software [31]. The PV60/65 ratios of 3%, 6%, 9%, and 12% vol. present in Fig. 1.

Thirty images were taken from each sample through the observation time. The graphite particles in FGPMs structure were detected and the area percentages of the detected elements were calculated by using image analyzer Leica QWin. In Fig. 2 is shown the panorama photograph of structure of a specimen containing 3% vol. of graphite PV60/65, In Table 3, I, II, III, IV, and V represent the five regions outside to inside and the percentages of graphite area density in these regions were given.

The influences of this filler (PAM96/98 and PV60/65) on properties indicate that processing of these new materials may be accompanied with some problems as example electrical [36], magnetic [37,38], and wear resistant [39] problems.

In this model presented, the prediction of the Young moduli for five regions is necessary. Several models for predicting the Young's module of polymer composites with non-spherical fillers have been proposed in the literature for instance Guth model, Brodnyan model, Halpin–Tsai model, Lewis–Nielsen model and Verbeek–Focke Model. The Halpin–Tsai equations [40] are widely used to predict the elasticity modulus of unidirectional composites [41,42] and this model is used in the present study. The Halpin and Tsai equations are general form of the Kerner equation and many other equations [43]. In result, the modulus of elasticity of FGPMs was determined by

$$\frac{E_{composite}}{E_{polymer}} = \frac{1+\xi\eta v_f}{1-\eta v_f} \tag{1}$$

where ξ is a shape factor that depends on the geometry of the filler particle and v_f is the % vol. of filler, the shape factor was assumed as 5.1 due to the fact that graphite shape was flake [43], and the parameter η is determined by

$$\eta = \frac{E_{filler}/E_{polymer}-1}{E_{filler}/E_{polymer}+\xi} \tag{2}$$

Table 1
Properties of PAM96/98 [31,35].

Type	PAM96/98
Density	2.40 g/cm^3
Content of carbon	97.0%
Content of ash	3.0%
Content of sulphur	0.00%
Humidity	0.20%
Range of grain size	d10% = 6.23 μm d50% = 16.38 μm d90% = 36.94 μm
Specific surface on a base grain size analyses	0.510 m^2/g