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Influence of creep on the geometrically nonlinear behavior of soft core sandwich panels

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ABSTRACT

The effects of creep of the core material on the global and local geometrically nonlinear behavior of sandwich panels under axial and/or lateral loading conditions is presented, within the framework of the high-order sandwich theory (HSAPT). The theoretical model combines the concepts of the hereditary (convolution) integral of viscoelasticity based on the principle of superposition, with the HSAPT. From the expansion of the relaxation moduli into Prony series, an incremental exponential law that corresponds to the rheological generalized Maxwell model is obtained, and which allows for a step-by-step time analysis that accounts for the change in deformations and stresses with time. The results show that creep of the core leads to a significant reduction in the local and global buckling capacity of sandwich panels. It is shown that sandwich panels under a combined axial and lateral loading can undergo global buckling with time due to creep, under a sustained load that is less than 50% of their buckling load. Similar trend is also observed for the local buckling (wrinkling) of the compressed face sheet when the panel is subjected to a sustained uniformly distributed load. In both cases, buckling commenced at a relatively low stress levels but it is associated with an unlimited increase of the stresses with time that eventually lead to material failures and total failure of the sandwich panel.

1. Introduction

Soft core sandwich panels are usually made of metallic or laminated composite face sheets and a soft core such as polymeric foam or a nomex honeycomb that are flexible through their thickness. Due to the high stiffness to weight ratio and high energy absorption capability, their use in various industries and structures is rapidly increasing. Under service conditions, sandwich panels can be subjected to different load scenarios, one of them being axial compression that is combined with lateral loading/effects due to imperfections, self-weight, and other effects. Under such loading, local or global instability issues become very important to be considered in their design. While many efforts have been devoted to investigate the buckling of sandwich panels made with soft or stiff cores under instantaneous loading [1,17,21,24,7], the influence of creep on the geometrically nonlinear behavior and buckling capacity of sandwich panels has not been investigated, which is the focus of this paper.

In many applications, a large portion of the applied load can be classified as a sustained one for certain periods of time, where creep effects become critical because many of the core materials exhibit some level of viscoelastic response under sustained loading. When the sandwich panel is subjected to a combined axial compression and lateral loading due to imperfection or other effects, it undergoes increasing lateral and axial deformation with time due to creep. These increased overall deformations change the internal forces and stresses with time due to the geometric nonlinearity that might consequently lead to global or local creep buckling of the sandwich panel under sustained loads that are smaller than the static buckling loads. The creep buckling phenomenon has been widely investigated and observed in various types of structures made from viscoelastic materials such as concrete or polymers (see for example Miyazaki [19], Hamed et al. [9], and Huang and Hamed [11]). Furthermore, since the face sheets are made of materials with different viscoelastic characteristics than those of the core (or from elastic materials), creep leads to

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redistribution of the stresses with time even without the geometrically nonlinear effects, which can affect the overall and the local structural response. These aspects of behavior need to be investigated for a better and a more reliable design of sandwich panels.

The nonlinear response of sandwich panels has been addressed in a number of works using classical approaches of equivalent single plate models (ESL), see Allen [1], Vinson [27] and Noor et al. [20]. This approach has mainly been used for traditional sandwich panels with anti-plane cores (such as metallic honeycomb core), which ignores the presence of localized effects due to the vertical flexibility of the core and the local buckling/wrinkling of the compressed face sheet. Within this modelling approaches, the layered structure is replaced by a solid homogeneous panel with equivalent properties, see for example the Mindlin first-order theory [18], and Reddy's high-order theories [23]. Kardomateas and Huang [15] and Huang and Kardomateas [12] have used the ESL approach to analyse a sandwich panel with very large deformations. In these research works, the core has been considered as a medium that only transfers shear stresses between the face sheets, where the overall sandwich panel has been modelled by an equivalent panel with shear deformation capability. Most of the aforementioned theories disregard the core compressibility and the vertical strain through the depth of the core.

On the other hand, the geometrically nonlinear response of sandwich panels has already been addressed through the High-Order Sandwich Panel Theory (HSAPT), see Frostig and Baruch [7] and [24,25]. In this approach, the sandwich panel is modelled as two face sheets and a core that are combined together through equilibrium and compatibility. The core is modelled as a 2D elastic continuum, where its height may change during deformation. Thus, this modelling approach allows the capturing of the local effects in the core and the face sheets, and the large-displacements kinematics in the face sheets allows the modelling of the local and global buckling behavior. Nevertheless, the influence of creep of the core material on the local and global geometrically nonlinear behavior has not been addressed using this approach.

In general, only few studies appear in the literature regarding the creep response of sandwich panels, see Huang and Gibson [13], Davies [4], Chen et al. [3], and Kesler et al. [16]. Also here, most of the existing models use equivalent beam approaches that do not properly describe the interfacial stresses distribution and their concentration near the edges and irregular points, nor their variation with time due to creep. In addition, all these studies focused on the typical bending response of sandwich panels, without addressing their geometrically nonlinear and buckling behavior. Further, they have adopted the effective modulus approach to account for creep, which is more applicable for simple structures that their stresses do not significantly change with time. This is not the case in sandwich panels due to the interaction between the viscoelastic core and the elastic face sheets, as well as, the change of the internal stresses with time due to the geometric nonlinearity, which require the use of a detailed time-stepping approach for their description.

Hamed and Bradford [8] developed a theoretical model for the creep analysis of reinforced concrete beams that are strengthened with externally bonded composite materials based on the HSAPT modelling approach that considers the strengthened structure as a layered one that consists of a concrete member, an adhesive layer, and a composite layer. An application of the model into sandwich beams analysis was presented in Ramezani and Hamed [22] considering the coupled thermo-mechanical creep response. In a recent study by Hamed and Frostig [10], the authors investigated the effects of creep of the core material on the geometrically nonlinear behavior of sandwich panels with debond at one of the core-face interfaces within the framework of the HSAPT and using a time-stepping creep analysis that accounts for the change of the deformations and stresses with time. Yet, the influence of creep on the local and global geometrically nonlinear behavior of sandwich panels when subjected to combined axial and lateral loadings have not been investigated.

The present paper uses the nonlinear sandwich model described in Hamed and Frostig [10] to analyse the effect of creep on the overall and localized buckling of sandwich panels with a transversely flexible core. The theoretical model combines the concepts of the hereditary (convolution) integral representation of viscoelastic solids based on Boltzman superposition principle [6], with the HSAPT structural modelling approach. The face-sheets are assumed to possess membrane and flexural rigidities following Euler–Bernoulli hypothesis and using kinematic relations of large displacements with moderate rotations. The core is assumed to possess shear and vertical normal stiffness only with negligible in-plane rigidity. The hereditary integral is converted into a rheological generalized Maxwell model after the expansion of the relaxation moduli into Prony series. The mathematical model used

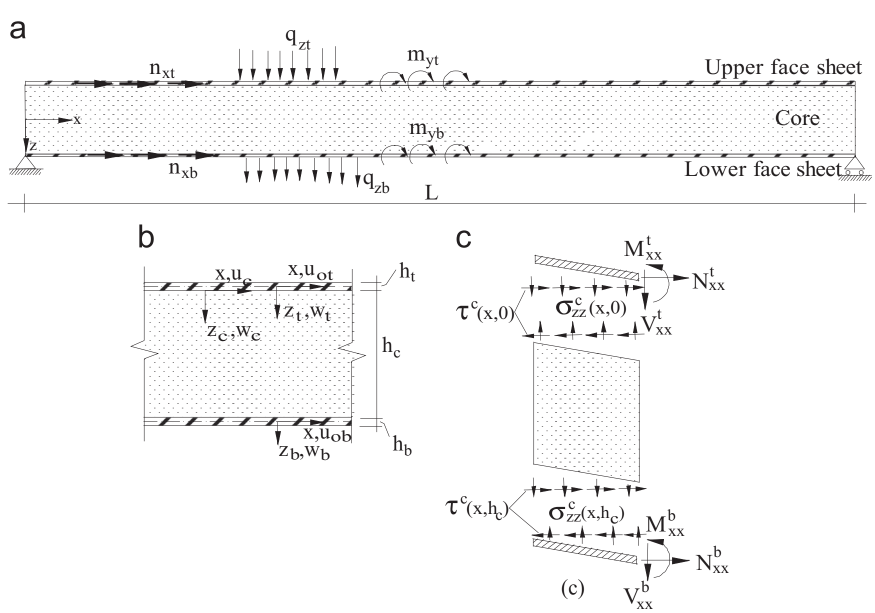

Fig. 1. Geometry, loads, sign conventions, and stress resultants: (a) geometry and loads; (b) deformations and coordinate system; (c) stresses and stress resultants.