NON-LINEAR THRMO-MECHANICAL RESPONSE OF FOAM CORE CIRCULAR SANDWICH PLATES

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Abstract

A geometrically nonlinear high-order sandwich panel theory is presented for circular sandwich plates with a compliant core with temperature dependent mechanical properties and subjected to both mechanical loading and thermal induced deformations. The special case of an axisymmetric circular sandwich plate subjected to axisymmetric mechanical and thermal loads, and with axisymmetric boundary conditions is studied numerically. The numerical study includes the interaction of mechanical and thermal loadings. The results reveal that the combination of mechanical and thermal loads shifts the plate response from being linear and stable (strength controlled) response into a strongly nonlinear response with limit point behavior and associated loss of stability.

1 General Introduction

Lightweight sandwich structures are being used increasingly in the aerospace, naval and transportations industries due to their excellent stiffness-to-weight and strength-to-weight ratios. Typical sandwich structures are often composed of a low stiffness/strength (compliant or "soft") core material made of a polymeric foam or a honeycomb that is flexible in the thickness direction, and laminated composite or metallic face sheets. Sandwich structures are typically exposed to mechanical load as well as to aggressive environment that may be associated with elevated temperature conditions. Traditionally, a typical design process of such structures examines the responses due to the mechanical loads and the thermal loading, i.e. the deformations induced by thermal sources, separately. However, the interaction between the mechanical and thermal loads may lead to an unsafe response with loss of stability and structural integrity, especially when the deformations are large and the mechanical properties (e.g. stiffness and strength) degrade as the temperature level is raised. This thermal degradation of the mechanical properties is especially pronounced for polymer foam core materials, where significant degradation of the mechanical properties may occur well within the operational temperature range. The effects of this degradation on the load-thermal interaction response are not well understood by researchers and industry. At the same time there is a growing concern within the wind turbine blade, marine and aeronautical sectors that the simultaneous action of mechanical loads and elevated temperatures may compromise the structural integrity under certain circumstances. In the present paper a model for the combined thermo-mechanical response of circular sandwich plates is developed based on the principles of the High-Order Sandwich Panel Theory (HSAPT).

2 HSAPT Model of Sandwich Plate

In this paper the principles of the HSAPT approach are used to determine the geometrically nonlinear response of a circular sandwich plate when subjected to a combination of mechanical and thermal loadings, where the mechanical properties of the core material change with temperature. The computational model is based on the assumption of large displacements and moderate rotations for the face sheets, and assuming also negligible shear deformations and linear constitutive relations. The core is modeled as a 3D small deformation linear elastic continuum with shear and vertical normal rigidities that are assumed to be of finite value, while the in-plane radial, circumferential and shear rigidities are neglected, see Frostig *et al* (1992) and Santiuste et al. (2010). In addition, the loads are applied to the face sheets only, while the thermal loading is applied to all constituents. Finally, the face sheets and core are assumed to be fully bonded, and the face-core interfaces are able to transfer both shear and vertical normal stresses accordingly. Figs. 1-3 show the HSAPT sign conventions, the geometric definition of the circular sandwich plates, the mechanical and thermal loading schemes, the deformed sandwich plate shapes, and finally the typical variation of foam core elastic moduli with temperature (Divinycell H100 PVC foam). The nonlinear governing equations for the radially symmetric circular sandwich plate case can be expressed by a set of fourteen order ordinary differential equations (ODEs). The boundary value problem constituted by the set of ODEs together with the associated boundary condition can be solved using numerical schemes such as the multiple-point shooting method or the finite-difference (FD) approach using trapezoid or mid-point methods with Richardson extrapolation or deferred corrections along with parametric or arc-length continuation methods, see Keller (1992). Here, the FD approach implemented in Maple has been used. For more details of the state-of-the art on thermo-mechanical modeling of sandwich structures, the full HSAPT model and the full set of numerical results, see Frostig and Thomsen (2010).

3 Sample results and discussion

An elaborate numerical study of the thermo-mechanical nonlinear response of a radially symmetric sandwich plates has been conducted. Fig. 4 shows sample results in the form of equilibrium curves of temperature at the upper face-sheet vs. extremum values of selected structural quantities for different through-thickness temperature gradients. It is observed that loss of stability is encountered at all thermal gradient. Loss of stability occurs when the temperature at the lower face sheet approaches the higher levels of the operating temperature of the core. It should be noticed that the degradation of core properties at the higher temperatures is significant only within a small fraction of the core height near the lower face-core interface. For the case of temperature independent core properties (TI in Fig. 4) the response is completely linear and unaffected by the temperature level. Overall, the numerical study has revealed that the response becomes unstable as the temperature is increased and the mechanical core properties degrade. Hence, in such cases the design of sandwich structures should be controlled by stability criteria rather than stress constraints. The effects of imposing different thermal gradients across the core thickness have also been examined. It should be emphasized here that when the temperature distribution through the core depth is not uniform the core stiffness parameters will vary hjrough the core thickness. This requires a special solution procedure. It has been found that for temperature gradient levels a loss of stability occurs when the temperature at the tensile face sheet approaches the upper limit of the core temperature range. In general, the nonlinear response of a circular sandwich plate is much stiffer than the case of a unidirectional sandwich panel or beam. When comparing with the sandwich panel or beam cases, the presence of circumferential rigidity in addition to the longitudinal rigidity enhances the stiffness of the sandwich circular plate. Thus, the presence of a 2D in-plane stress field stabilizes the load response of sandwich plates when compared to the unidirectional panel/beam response characteristics. However, the use of core materials with temperature dependent mechanical properties that degrade with increasing temperature yields an unstable response independent of the structural configuration (1D beam/panel or 2D plate).

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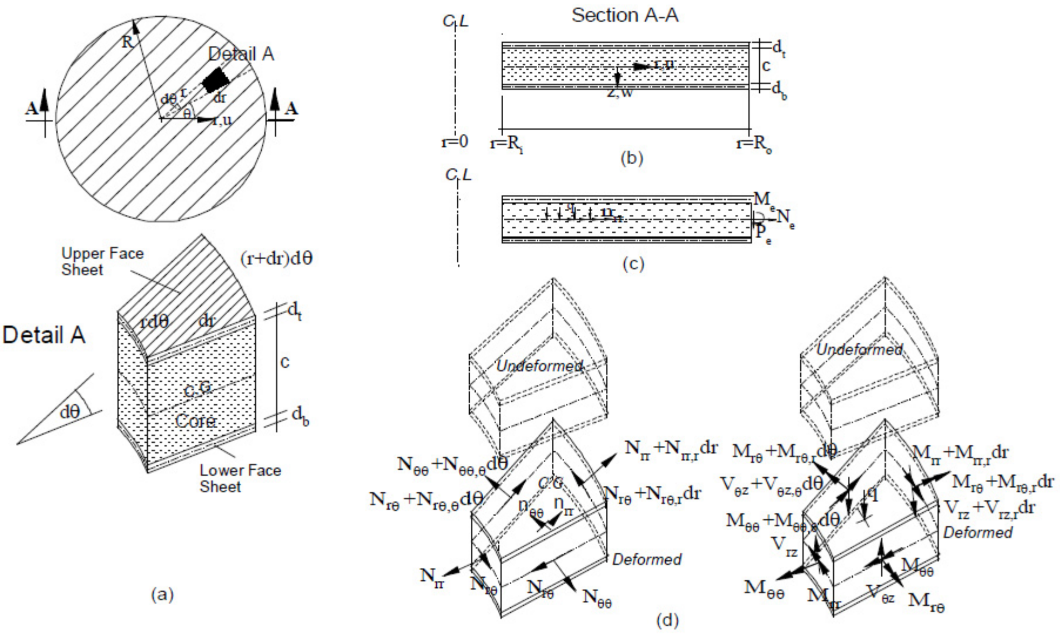

Fig.1. Circular sandwich plate: (a) sign convention; (b) loads; (c) stress resultants in face sheets and core

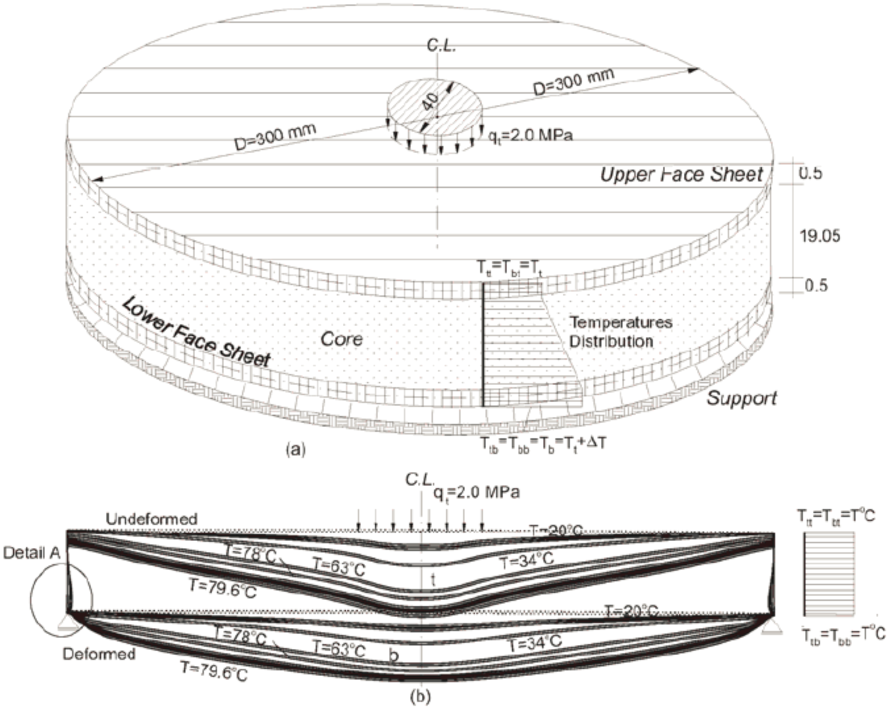

Fig.2. Circular sandwich plate geometry and deformed shapes

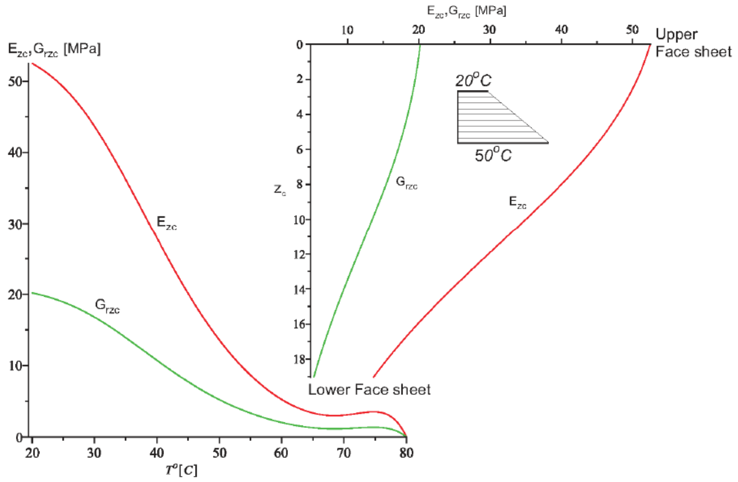

Fig. 3. Variation of Youngs´and shear moduli with temperature; (a) moduli magnitude vs. temperatures; (b) moduli distribution through core depth

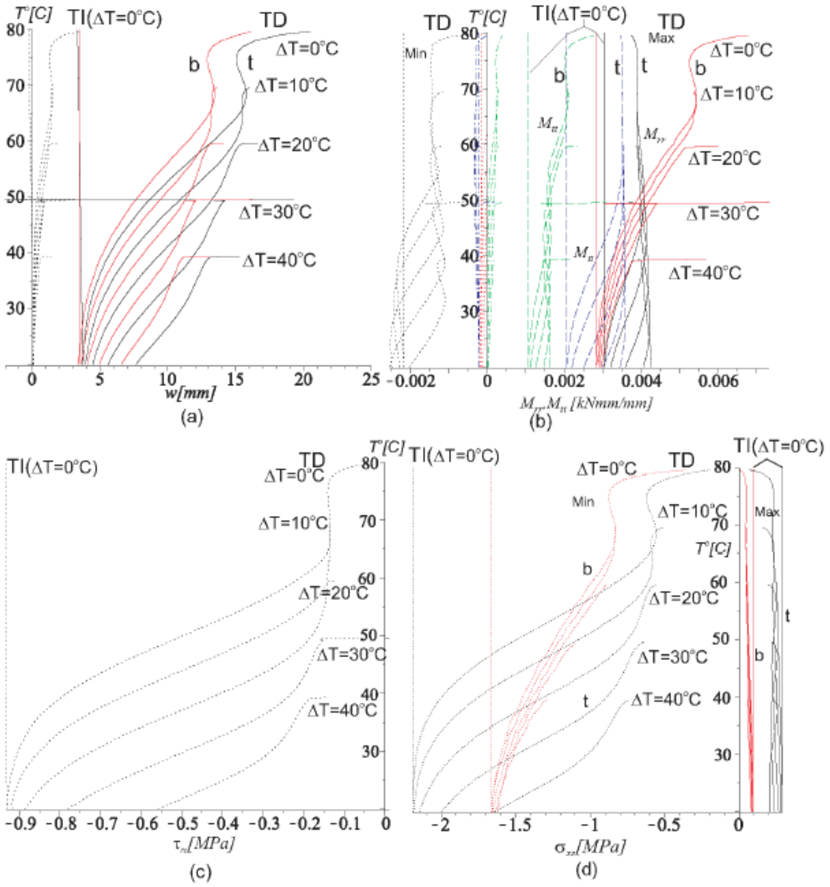

Fig. 4. Equilibrium curves of temperatures vs. extremum values of selected structural quantities for a partially distributed load and different thermal through-thickness gradients. Face sheets: (a) vertical displacements (HSAPT and FE); (b) radial and circumferential bending moments. Core: (c) shear stresses; (d) face-core interfaces vertical normal stresses. Legends: _____ upper face sheet (radial), _____ lower face (radial), _ _ _ _ upper face sheet (circumferential), _ _ _ _ upper face sheet (circumferential).

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