



Non-linear thermo-mechanical behaviour of delaminated curved sandwich panels with a compliant core

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ABSTRACT

A non-linear analysis of a delaminated curved sandwich panel with a compliant core, and a delamination (debond) at one of the face–core interfaces, and subjected to a thermal field and a mechanical loading or combined is presented. The mathematical formulation outlines the governing equations along with the stress and displacements fields for the cases where the core properties are either temperature independent (*TI*) or temperature dependent (*TD*). A variational formulation is used following the principles of the high-order sandwich panel theory (HSAPT) to derive the field equations along with the appropriate continuity conditions. The non-linear analysis includes geometrical non-linearities in the face sheets caused by rotation of the face cross sections, and high-order effects that are the result of the radially (transversely) flexible (or compliant) core. The core stress and displacements fields with temperature-dependent (*TD*) mechanical properties are determined in closed form using an equivalent polynomial description of the varying properties. The numerical study describes the non-linear response of delaminated curved sandwich panels subjected to mechanical concentrated loads, thermally induced deformations and simultaneous thermal and mechanical loads. In the combined loading case the mechanical loads are below the limit point load level of the mechanical response, and the imposed temperature field is varied. The results are displayed in terms of plots of various structural quantities along the sandwich panel length (circumference), equilibrium curves and strain energy release rate curves. It is shown that the combined thermo-mechanical response shifts the linear or non-linear responses, observed for the separate cases of either temperature induced deformations or mechanical loading, into a strongly non-linear response with limit point behaviour and large stresses in vicinity of supports, loads and tips of delaminated zone.

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1. Introduction

Lightweight curved 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. Such sandwich structures may contain different types of defects, that can be induced either in the manufacturing process or inflicted during service life due to e.g. impact or fatigue damages. The most detrimental form of defects appears in the form of debonds (delamination) at one of the face–core interfaces, or at both face–core interfaces in more extreme cases. Typical modern sandwich panels are often composed of a low stiffness/strength core material made of polymeric foam or a nomex honeycomb that is flexible in the thickness direction, and laminated composite or metallic face sheets. The core usually provides the shear resistance/stiffness to the sandwich structure, as well as a transverse (through-thickness) support to the face sheets that is associated with core radial

normal stresses. The face sheets resist the bending moments and the in-plane loads (in the form of a couple) through their composite action. It should be noted that an imperfection in the form of a debond jeopardizes the composite action of the layered sandwich panel, and thereby cause the face sheets to behave as isolated panels without any mechanical interaction within the debonded region. Traditionally, the design process of sandwich structures examines the responses due to the thermal loading, i.e. the deformations induced by thermal sources and the mechanical loads 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. The thermal degradation of mechanical properties is especially pronounced for polymer foam core materials, where significant degradation of the mechanical properties can occur well within the operational temperature range. For example, PVC foams (Divinycell® and Airex®) lose all stiffness and strength at about 80–100 °C, while PMI foams (Poly-methacrylimide, e.g. Rohacell®) lose the heat distortion resistance

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