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Shear coupling effects of the core in curved sandwich beams

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ABSTRACT

We consider a composite package formed by two curved external Euler-Bernoulli beams, which sandwich an elastic core with negligible bending strength but providing the shear coupling of the external layers. This coupling considerably affects the gross response of the composite structure. There is an extensive literature on straight sandwich beams of this type, but very little attention has been paid to the effects of curvature. Here, an analytical linear elastic model is proposed for beams with arbitrary variable curvature. Equilibrium equations and boundary conditions are obtained through a variational approach. Useful simplifications are possible for the case of moderately curved beams and beams with constant curvature.

1. Introduction

Three-layered sandwich structures are commonly used in modern building, aerospace, aeronautical, automotive and naval constructions. They are composed by two external sheets and an inner core, which usually has negligible bending stiffness, but provides the shear coupling of the external layers. Optimal designs can be obtained by choosing different materials and geometric configurations of the face sheets and core. Applications in this category may range from structural insulating panels, consisting in a layer of polymeric foam sandwiched between two layers of structural board (usually sheet metal, plywood or cement), to wood elements made of layers glued together, arriving at steel beams supporting concrete slabs connected by ductile studs.

The type of sandwich that will be considered here is particular. The external layers are supposed to have noteworthy axial and bending stiffness, whereas the inner layer produces their shear-coupling. In other words, the role of the inner core is that of providing shear stresses that contribute to the gross bending stiffness of the composite package, keeping unchanged the relative distance between the external layers. Such a scheme fits to a number of cases. An example is represented by adhesive-bonded beams, where the thickness of the interlayer is so small that the variation of its height can be neglected. In general, when the outer layers are quite thick, the change in curvature due to bending remains moderate even under concentrated loads, because these are "diffused" in the softer interlayer limiting its strain in transversal direction. The required properties can also be obtained with anisotropic cores, for which the elastic stiffness in the out-of-plane direction is much higher than the in-plane stiffness: an example is honeycomb cores, which may be considered rigid in the out-of-plane direction and flexible at right angle to that.

The modeling of composite laminated structures with a "soft" core is one of the most active research fields of the last decades, since an accurate stress analysis is required to design structural parts. Hence, several theories have been developed to describe the structural behavior of sandwich beams [1,2]. In particular, the well-know "First-Order Shear Deformation" approach [3], based on the assumption that planes normal to the midplane remain straight but not necessarily normal to it after deformation, has been followed by many authors in the last decades (see, among others, [4–6]). This theory usually provides good results in terms of maximum displacement under appropriate choice of the shear rigidity. The key role played by the interlaminar shear stress on the response of the laminate composite was pointed out since the Sixties, thanks to the contributions by Pagano [7–9] and Reddy [10,11].

The effect on the deformation of the out-of-plane strain of the interlayer can certainly be of importance and, indeed, it has been a subject of recent research (see Ref. [12] and the list of references therein reported). However, if one assumes that the thickness of the interlayer remains unaltered, the problem is greatly simplified and reduces to the assessment of the degree of shear coupling offered by the inner core. The first analytical model for a composite beam with shear interaction is commonly attributed to Newmark *et al.*

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