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Review

A multiscale projection approach for the coupled global–local structural analysis of photovoltaic modules

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ABSTRACT

The present contribution deals with the modeling and computational simulation of photovoltaic modules in the context of structural mechanics. Thereby, the focus is on the division of the boundary value problem of linear elastomechanics into two characteristic scales. The multiscale modeling starts at the global scale by means of an eXtended LayerWise Theory for a symmetric three-layered composite structure. A specially developed finite element is used to realise the discretisation. For the local structural analysis, a three dimensional unit cell is introduced which is representative in both plane directions and represents the structure of a photovoltaic module in transverse direction completely. The coupling of these two scales is carried out by the projection of the global deformations on the boundaries of the local structure, while the focus is on the transition from composite structure to three dimensional continuum. Thereby, characteristic coordinates for the location of a solar cell and an exemplary loading scenario are considered.

Overall, a modeling and simulation approach is presented which permits a numerically efficient solution of structure–mechanical problems on photovoltaic modules through a sequential procedure of a deductive multiscale approach.

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1. Introduction

1.1. Motivation

Structural mechanics analyses of photovoltaic modules gain increasing importance since the photovoltaic industry has a keen interest in the durability of their products, not least because electrical power losses can be correlated to mechanical failures, e.g. solar cell cracks and breakage [1,2]. Fig. 1 indicates a typical photovoltaic module structure. Until now, high numerical expense of the predominantly 3D finite element analysis of whole photovoltaic modules in detail was needed. There, the majority of analyses is related to problems of elastostatics. Due to the extreme differences in material properties (e.g. the Young's modulus $E^c \ll E^s$, s stands for skin layers and c for the core layer, respectively) of constituents and the relatively low thickness of the core layer compared to the skin layers ($h^c \ll h^s$, where h is the thickness of the corresponding layer), considerable effort on discretisation of the problem is required to gain sufficiently accurate results, resulting in a prohibitive amount of CPU time. Thus, the main drawback of this procedure is its high computational burden. Beside this, the problem of vanishing bending stiffness plays a decisive role which is not considered in standard solid finite elements definitions.

Due to the slenderness of a photovoltaic module ($H \ll L_{\min}$, with the overall thickness $H = \sum h^K$ of the composite structure with K layers and the minimum in-plane length $L_{\min}$), the mechanical contemplation allows a degeneration to a surface problem [3–5] such that composite structure theories can be applied. Since the classical theories in this field, summarised e.g. in [6,7], like the first order shear deformation theory (FOSDT) fail to predict accurate results at the current problem [8,9], extensions of existing theories are required. Among many different formulations, zig-zag or layerwise theories [10–12] are mostly appropriate for the analysis of photovoltaic modules. Naumenko and Eremeyev [13] have developed an

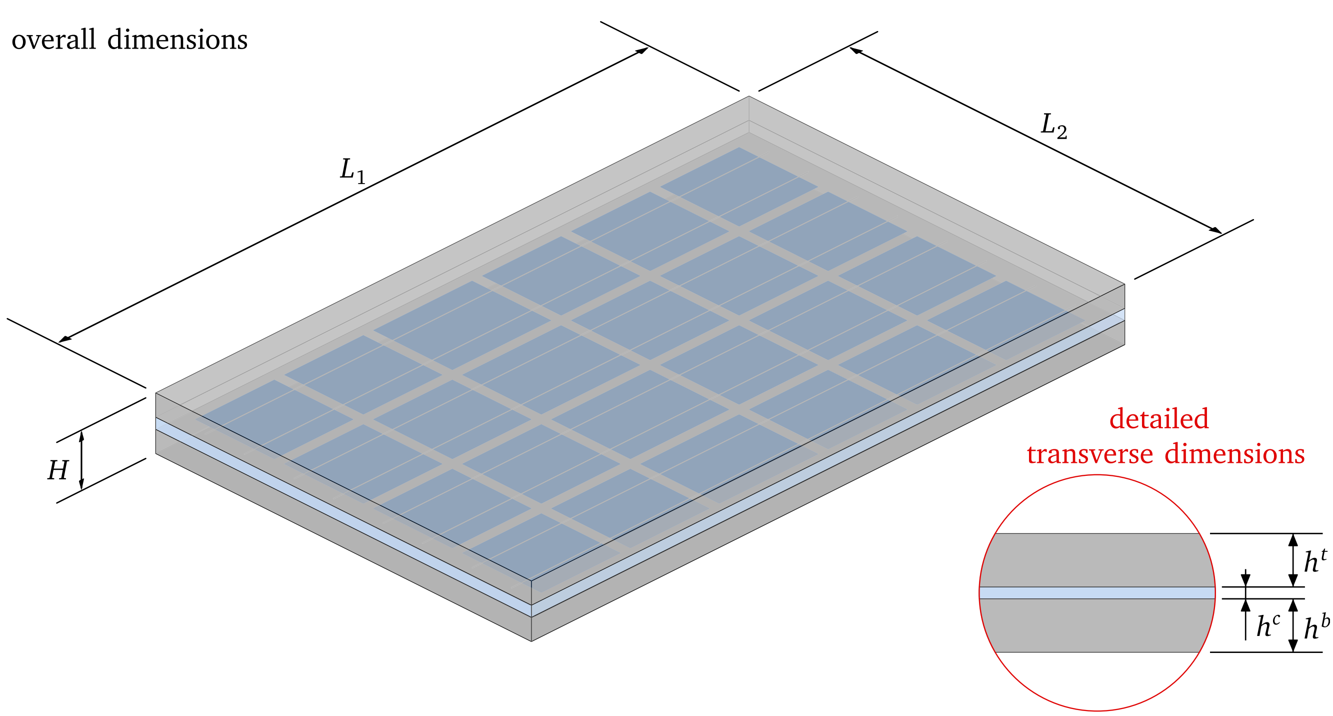

Fig. 1. Longitudinal and transverse geometrical measures of the body $\mathfrak{B}$ mapped by a typical photovoltaic module structure (not to scale).