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MULTI-SCALE HOMOGENIZATION OF THIN FOAM LAYERS USING SHELL THEORY

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ABSTRACT

Commonly, components in car body structures consist of sheet metal in form of hollow beam members. To increase the impact strength of these beams, local reinforcements are often introduced. The main function of these reinforcements is to stabilize the outer faces of the beam, to retain the distance between them and to prevent localized buckling collapse. It thereby improves the bending resistance of the structure. One can think of many ways to design these reinforcements. One example is to employ an additional substructure of sheet metal inside the beams. Another possibility is to introduce composite structural inserts, filling the cavities in the beams, at certain locations in the body. The characteristics of the attachment between the reinforcement and the surrounding parts has significant influence on the total performance in both cases. Proper attachment will assist the transport of impact loads through the structure and thereby contribute to an optimal reinforcing effect. To provide a bond between either the sheet metal layers or between the composite inserts and the surrounding metal faces, thin layers of structural foam is used. Examples of advantages of using foam are its applicability and weight effectiveness.

For the optimal design of these reinforcements and for crash analysis in general, proper simulation methodology is required. The focus is here on, on the one hand, the response of the thin foam layer in the thickness direction, and on the other hand, the total structural behavior of the layer. As to the behavior in the thickness direction, we note that the foam layer is porous and has in this case typically closed cells with a certain variation of size. We can expect a relation of one order of magnitude between the size of the largest pores and the thickness of the foam layer, typically 4 mm. In addition, due to the manufacturing process, porosity and pore sizes typically varies in the thickness direction. Therefore, the principle of scale separation can generally not be assumed for the homogenization of stresses with respect to the thickness direction.

In order to model the fine scale variation of the solution in the thickness direction of the foam layer, it is proposed to adopt shell kinematics. This will govern the structural behavior of the complete foam layer. Moreover, a fluctuation field is present locally at selected material points to resolve the fine scale deformation in the thickness direction, cf. Ref. [1]. To this end, the shell kinematics is derived from second order expansion of the deformation map with respect to the shell midsurface. A ”displacement”

type of formulation is thereby obtained involving extensible directors, cf. Ref. [2], which, along with the midsurface placements, determine the macroscopic deformation state of the foam layer. We emphasize the solid-like capabilities of the shell formulation (including extensible director and transverse shear kinematics) since the considered foam layer will potentially be subjected to loading normal to the shell plane as it functions to maintain the distance between the panels.

As to homogenization of stresses, we adopt computational homogenization (in the spirit of Ref. [3]) of the material response on the micro scale with respect to the stress resultants for a shell element representing the foam layer on the macro scale. Thereby, a representative volume element (RVE) for the microstructure of the foam is established so that it includes the full thickness of the layer, while it has limited extension in the plane of the layer. To the kinematics on the micro scale, a second order Taylor expansion of the deformation map follows from the shell formulation. In addition, a fluctuation of the deformation on the micro scale is added to the deformation of the macro scale. The resulting stresses of the boundary value problem on the micro scale are homogenized to stress resultants on the macro scale corresponding to the shell formulation. These resultants are the membrane forces and bending moments in the shell plane, the out-of-plane shear force and the normal force in the thickness direction. This procedure of homogenization of the stresses together with the derivation the tangential stiffness relations for the solution of the boundary value problem on the macro scale couples the macro and micro fields of deformation and resulting stresses together. Figure 1 shows the behavior of an RVE (with traction-free top and bottom surfaces) subjected to different attainable macroscopic deformation modes provided by the shell formulation. The porous material structure in this example consists of 25 repeated cells.

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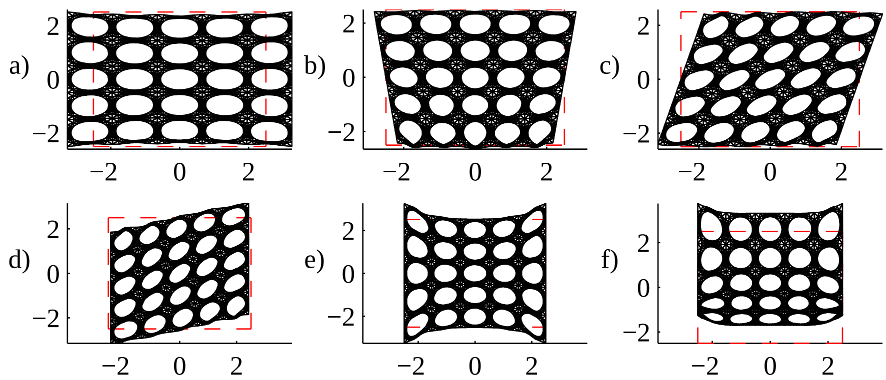

Figure 1: Deformed mesh of the basic deformation modes: a) membrane stretch, b) curvature, c) in-plane shear, d) out-of-plane shear, e) thickness stretch and f) non-homogeneous stretch. Undeformed configuration boundary is indicated by dashed lines in the figures.