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Topology Optimization for Crashworthiness of Thin-walled Structures

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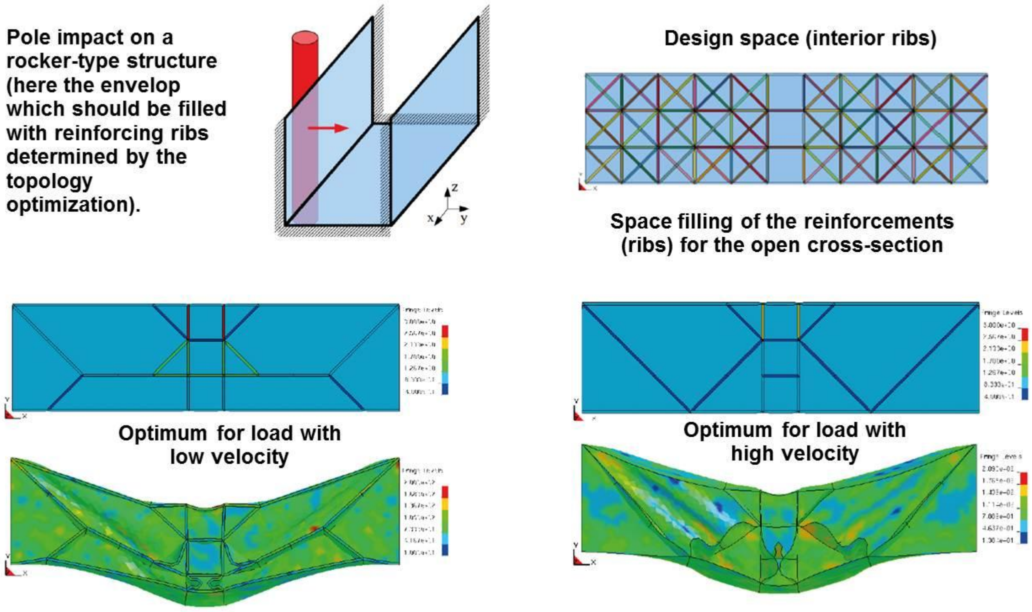
Although topology optimization is well established for linear cases, there are only a few methods available for crashworthiness. This is due to the high non-linearity of the problem and the difficulty to define clear objectives and constraints. In addition, it is difficult to derive methods, which are appropriate for thin-walled structures, the main structural type used for vehicular structures in automotive and aerospace industry.

The approaches available today are either based on the so-called ground structure approach where the design space is filled with beam-type elements, which are then deleted sub-sequentially, e.g. [1]. Due to the rather coarse modelling of possible structures, this approach has only limited applicability. A second group of methods is based on standard (i.e. linear) methods for topology optimization where the crash is modelled via equivalent static loads (ESL) either on a nodal basis or more globally, e.g. [2, 3]. Due to their usage of linear static modelling, these approaches cannot capture all relevant crash aspects. Beside some heuristic approaches, e.g. [4], the main developments were achieved by hybrid cellular automata (HCA) where truly non-linear explicit finite element (FE) simulations are used to assess the crash performance of structures, e.g. [5]. But, the approach has some drawbacks. First it is developed for solid structures based on a voxel discretization of the design space and not for thin-walled structures encountered in most crash structures. Secondly it is questionable if the objective of having a homogeneous energy density is an appropriate design criterion for crash optimization; thin-walled structures perform well if they can develop folding mechanisms with highly located plastic deformation zones (plastic hinge lines) and adjacent areas of less deformation. In these cases, the energy is not distributed homogeneously.

To overcome these drawbacks and to derive a more suitable method, a modified HCA is presented here with new applications based on the methodological developments in the PhD thesis of the second author [6]. Here, the cells for the cellular automata are macro-thin-walled elements which allow better folding patterns and a more appropriate definition of objectives and constraints for crash optimization. The handling of the geometrical changes – now based on walls and not on voxels – is facilitated by SFE CONCEPT, a software enabling efficient parametric modeling and automated variation of FE geometries.

Several examples will be presented for component optimization of structures under axial crash loads, perpendicular crash loads (bending case) and more arbitrary loadings. The obtained optimal topologies / geometries are already suitable for manufacturing because they are based on thin-walled shell elements and not voxels. The latter require a post-processing (smoothening and interpretation) of the topology optimization results which is here not necessary. The load cases correspond to car structures like the rocker or the front rail under impacts usually regarded for the EuroNCAP or similar test scenarios. Via these validations, the potential of the method can be illustrated. As an example, a pole impact problem is shown here (Fig. 1), where the exterior (a C-cross-section) is not changed but the interior is filled with reinforcing ribs to improve energy absorption. In the lower part of this figure, the results are given for an impact with low velocity and higher velocity illustrating the dependency of the topology result on the dynamicity of the problem.



S. Hunkeler, PhD thesis, Queen Mary University of London, 2013

Fig. 1: Example for the topology optimization with hybrid cellular automata for thin-walled structures (HCATWS).

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