Evolutionary Crashworthiness Topology Optimization of Thin-Walled Structures

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As in many other disciplines, also in crashworthiness, the extensive growth of computers' power led to the development of techniques for numerical simulations. In particular, this allows to use numerical optimization methods to develop better structures and shorten the vehicle design cycle, what is a must in case of the hard competition on the car market. One of the most important tasks realized by optimization algorithms is the identification of optimal structural concepts in early phases of the design process. This problem is addressed by topology optimization techniques[1], which aim to develop optimal structural concepts within a defined design space and under specified boundary conditions. Nowadays, those methods play a vital role in many branches of industry in fast prototyping of efficient mechanical structures. Nevertheless, due to the complexity of crash phenomena and considerable simplifications made in most of the optimization approaches[2-9], the use of crashworthiness topology optimization techniques is still limited and new methods have to be developed.

A basis for most of the state-of-the-art methods for crashworthiness topology optimization, form so-called voxel elements, being three-dimensional, regular brick finite elements. The basic idea in such cases is stated as follows: Firstly, define the design domain in the space that is not occupied with non-structural vehicle elements such as wheels, engine, etc.; Secondly, fill the volume of the design space with voxels; Thirdly, eliminate redundant voxels by an iterative numerical optimization procedure. This results in creation of so-called zigzag structures that can be used as a reference for positioning of the structural beams. Such a design is assumed to be optimized with respect to the given objective (e.g. energy absorption, plastic deformation, etc.), although due to the heuristic assumptions this is only true for selected use cases. Additionally, important vehicle body components are made of thin-walled sheet metal structures. In such a case plastic buckling is the principal phenomenon that influences the crashworthiness behavior. In the optimization process based on voxel elements, structures made of thin metal sheets cannot be obtained, which leads to completely different phenomena, not corresponding to the buckling of thin-walled structures. As a result, the use of an optimized design obtained from any voxel-based optimization method as an inspiration for final thin-walled structure is questionable and alternative methods have to be developed.

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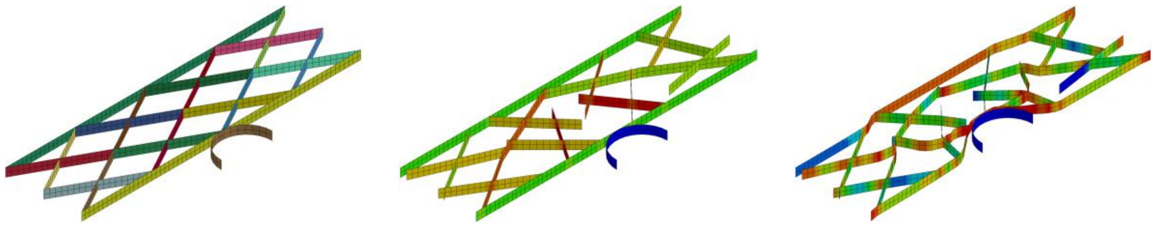
We propose a novel approach using evolutionary algorithms for optimization of thin-walled structures. Unlike in the other approaches for crashworthiness topology optimization of thin-walled structures[9-11], in evolutionary optimization methods, no heuristic assumptions about the properties of the optimization problem are made, and therefore, any actual quantifiable user defined objective function can be optimized directly. For evaluation of the method, a 2D transverse bending of a rib-reinforced thin-walled structure is considered. Parameterization of the design is realized through defining the position, orientation, length and thickness of each reinforcing rib. The ribs can cross each other and join if they are sufficiently close to each other. As an optimization method both standard Evolution Strategy (ES) and the state-of-the-art Covariance Matrix Adaptation Evolution Strategy (CMA-ES) are used and their performance is compared. The results show that evolutionary optimization algorithms can be efficiently used for crashworthiness topology optimization of thin-walled structures.



a). Initial design. **b). Thickness distribution for the optimized design.** **c). Effective stress at the end of the crash simulation.**

Figure 1. Initial layout of the reinforcing ribs and the best design obtained with the Covariance Matrix Adaptation Evolution Strategy (CMA-ES).

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