Application of Topology Optimization for Crash with LS-OPT®/Topology

Heiner Müllerschön[1], Nikolay Lazarov[2], Katharina Witowski[1]

[1]*DYNAmore GmbH,* [2]*University of Karlsruhe*

Abstract

Since end of 2009 a new software tool LS-OPT/Topology is available from LSTC. With LS-OPT/Topology nonlinear topology optimization with LS-DYNA can be applied for static and even for dynamic problems. The underlying method is Hybrid Cellular Automata (HCA) which is a heuristic, gradient-free approach. The objective is to obtain a structure with uniform internal energy density subject to a given mass fraction. In the current version LS-OPT/Topology-1.0, topology optimization with hexahedron solid elements, material `*MAT_024` *and some established contacts is possible for single and for multiple load cases.*

In this paper, first experience with the HCA-methodology and the application of LS-OPT/Topology to industrial problems is demonstrated. Capabilities and limitations of the new implementation will be highlighted.

The Hybrid Cellular Automata Method

LS-OPT/Topology [1] uses the Hybrid Cellular Automata method (HCA) for topology optimization. The objective of this method is to find a structure with uniform internal energy density by modifying the density of each element with respect to the current internal energy density while keeping the mass constrained. Figure 1 visualizes the algorithm. After reading the input data, the FE model is mapped to a cellular automata lattice, i.e. each element is assigned a cell. The neighbors of each cell are determined; this information is used later for the updating procedure of the densities. The elements are initialized with uniform density, so that the mass constraint is satisfied. Then, the iterative process starts. After each FE simulation, the density of the elements (design variables) is updated considering the internal energy density (field variables) of the respective element and its neighbors at the end of the analysis and the target mass (constraint). In case the internal energy density of a cell is less than a pre-defined target value, density is reduced. In case the internal energy density of a cell is greater than a pre-defined target value, density is increased. According to the density, the stiffness for each element is adapted. The upper thresholds for density and stiffness are the original material properties. If the density of an element is less than a lower threshold, the element is deleted. This loop is iterated until the convergence criterion is met, i.e. the densities only have small changes (low redistribution). Figure 2 shows the internal energy density for a simple example after a simulation run and the resulting density distribution for the next iteration.
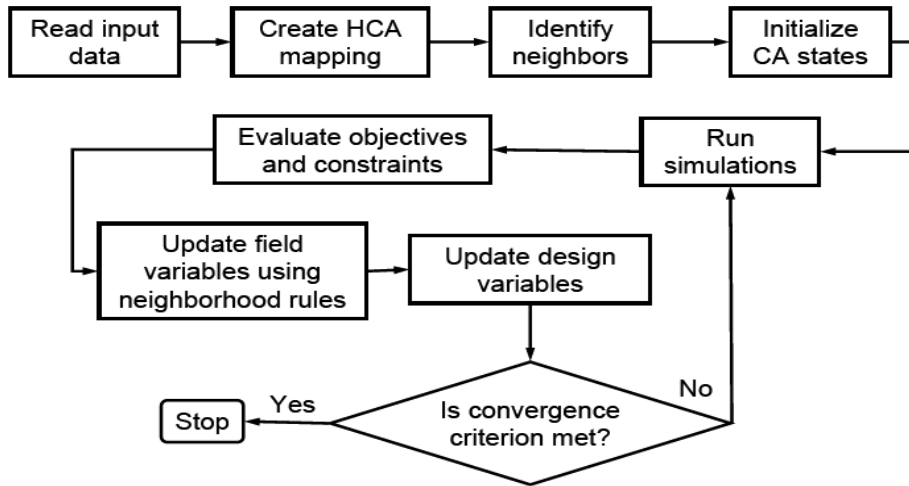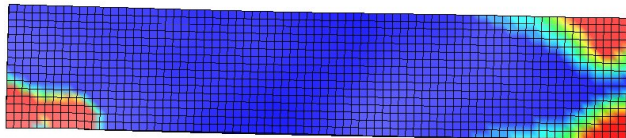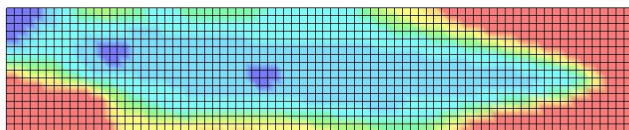
Figure 1: HCA algorithm [1]

Figure 2: cantilever beam with an impact at the right side; top: Internal Energy Density, last plot state, iteration 1; bottom: Density, first state, iteration 2, the density for iteration 2 is determined from the internal energy density of the last state of iteration 1.

Optimization of a Crash Management System

Problem Description

This section describes the design of a bumper in a given installation space. The AZT crash repair test is considered as load case, Figure 3. The objectives are to remove the impact energy by plastic deformation of the bumper and to reduce the mass of the bumper. The given constraints are a maximal force level of the barrier contact force and that the bumper has an extruded section. LS-OPT/Topology is used to determine a suitable geometry for the bumper in the given installation space. The crash simulations are performed using the LS-DYNA® explicit solver.
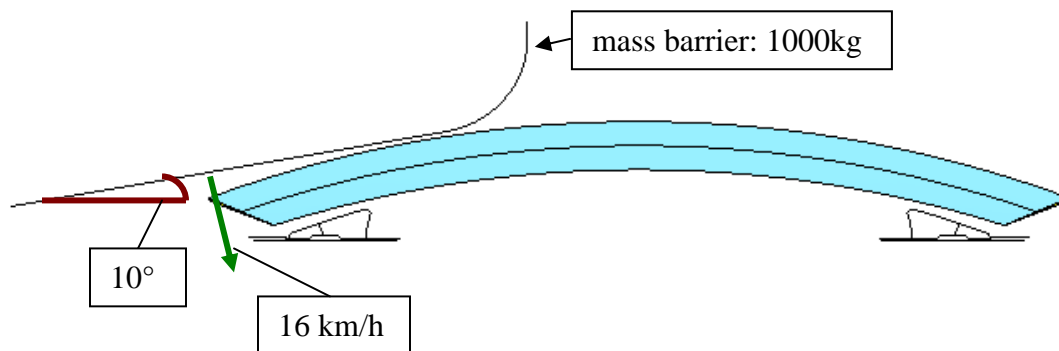

mass barrier: 1000kg

10°

16 km/h

Figure 3: Load case AZT repair crash

Setup of the Optimization Problem in LS-OPT/Topology

The starting geometry is an as large as possible region in the installation space that has an extruded section, Figure 6. The design part is modeled using 565800 eight-noded solid elements with an average edge length of 2.5mm and *MAT_PIECEWISE_LINEAR_PLASTICITY. LS-OPT/Topology supports only this element type and material model for now. The size of the elements is an agreement between flexibility of the model and computational effort. For contact definitions involving the design part, *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE and *CONTACT_AUTOMATIC_SINGLE_SURFACE are available.

To get an extruded section, a set of solids has to be defined that may be extruded to get the whole part, Figure 5. A screenshot of the LS-OPT/Topology graphical user interface that specifies the design part, the extrusion set and the constraint on the mass of the design part is displayed in Figure 4. The mass fraction is determined from the mass of the starting design and the intended mass.
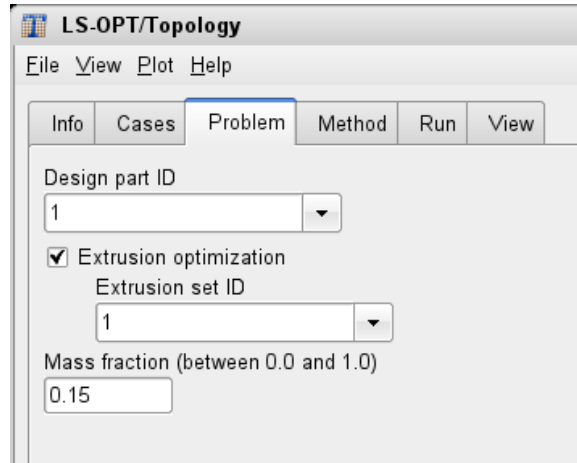
Figure 4: Problem definitions in LS-OPT/Topology – specification of design part, extrusion set and mass fraction
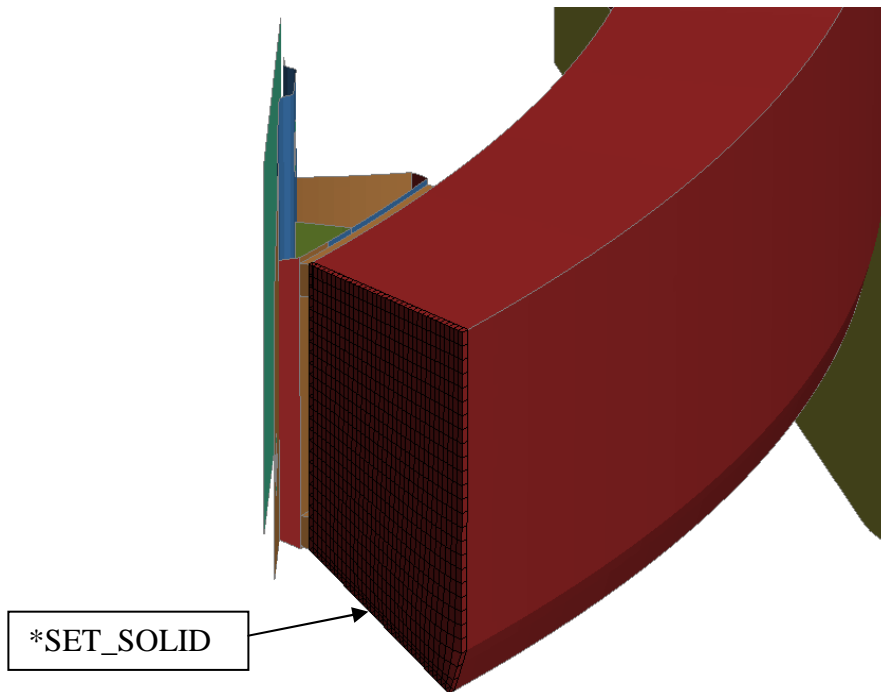

Figure 5: *SET_SOLID specifies the possible installation space as an extrusion profile

Topology Optimization

Based on the material properties of the design component, 95 material cards, independent of the model size, are introduced with densities from the minimal density to the full density and accompanying the young's modulus and the yield stress values. In the LS-DYNA input file one part for each material is defined. The material with the full density has the original material properties. The file *lst_mat.k* containing the material and part cards is created. In the beginning, each element is assigned to the same part, so that the mass constraint is satisfied, i.e. in this
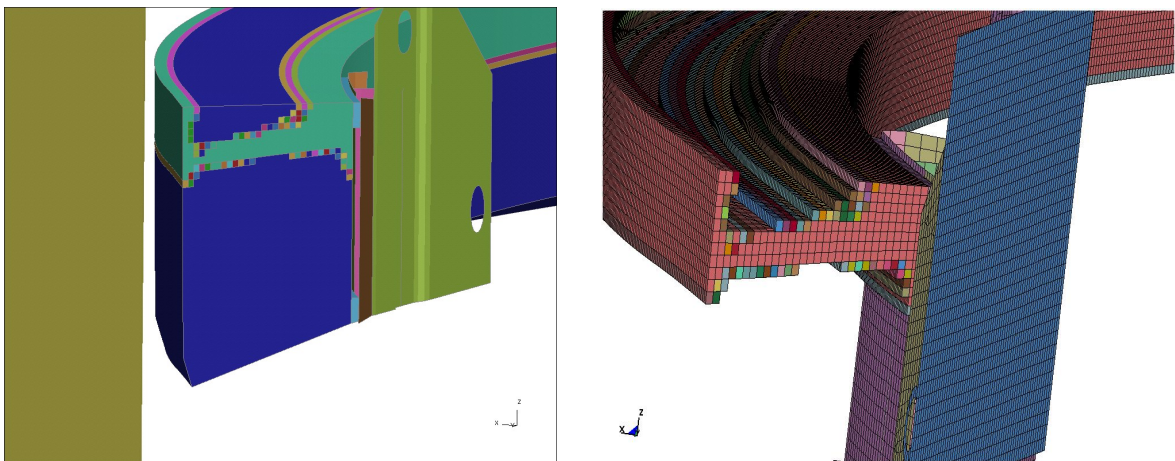
example, the target mass is 15% of the initial mass (specification in the GUI see Figure 4), hence all elements are initialized with a density of 15% of the full density.

For each iteration, one LS-DYNA simulation is performed. Since the simulations use the internal energy densities from the previous iteration to update the material properties, it is not possible to run multiple jobs in parallel. LS-OPT/Topology supports the use of queuing systems to run the LS-DYNA simulations. For this project, the queuing system PBS has been used.

The stopping criterion for the optimization loop is achieved if the density redistribution (Figure 7) falls below the convergence tolerance. Here, the optimization converges after 30 iterations, which means 30 LS-DYNA simulations have been performed in total.

Results
The resulting geometry of the topology optimization after 30 iterations is shown in Figure 6. Figure 7 displays the density redistribution and Figure 8 the total internal energy density.

Figure 6: Starting geometry (left) and geometry after topology optimization (right)

The objective of a topology optimization with LS-OPT/Topology is to get a uniform distribution of the internal energy density in the design part. With the current version it is not possible to specify constraints on e.g. contact forces, hence the maximal force level of the barrier contact force cannot be considered. Figure 9 shows the contact force and the maximal force level, and it is obvious that it is essential to have a possibility to specify additional constraints for topology optimization to be able to handle such problems.
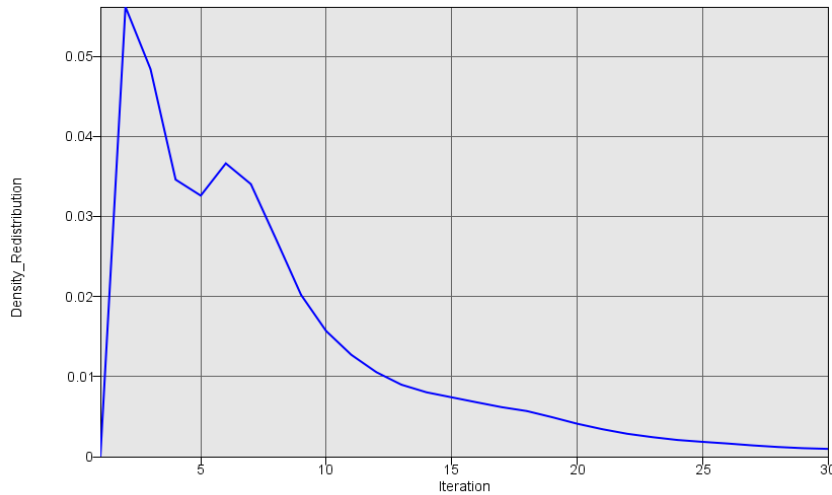
Second stage
Since it is not possible to consider additional constraints in LS-OPT/Topology version 1.0, the idea is to re-model the bumper with shell elements considering the results of the topology optimization, and determine optimal sheet thicknesses by parameter optimization using LS-OPT.
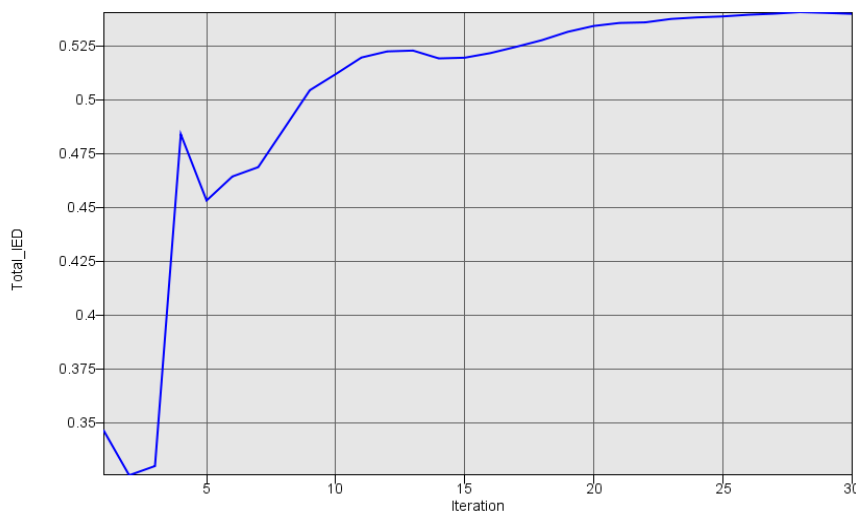
On this, it is possible to integrate the constraint on the contact force while minimizing the mass in the optimization process. The new shell model is displayed in Figure 10.

Four design variables are defined to modify the sheet thicknesses of the four parts of the bumper. The objectives are the minimization of the mass of the bumper and the minimization of the sum of squares error between the calculated force curve and a target curve with a constant value, which is the given maximal force level. The barrier contact force is constrained by the maximal force level.

For details on the optimization problem, see [3].

Figure 7: Density redistribution. Mean value of density redistribution of all solid elements within the design component, scaled with the full density

Figure 8: Total internal energy density (IED). Sum of internal energy density of all solid elements within the design component.
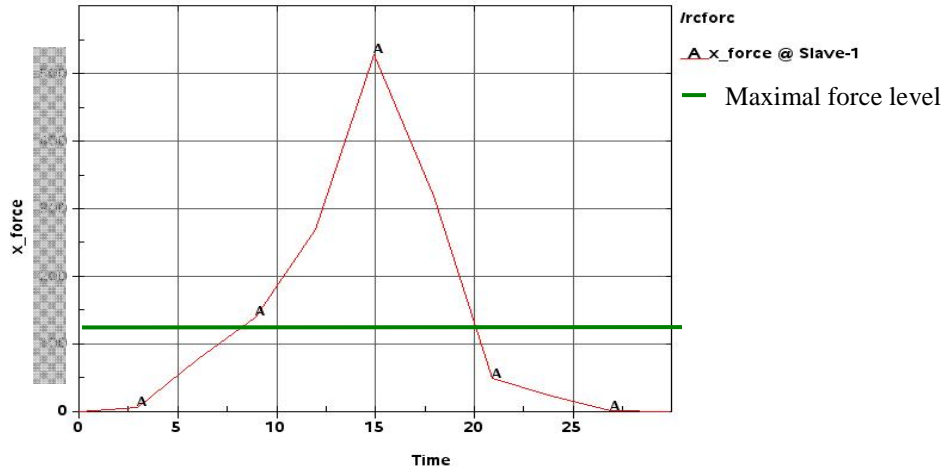
Figure 9: Contact force curve of result from topology optimization and maximal force level
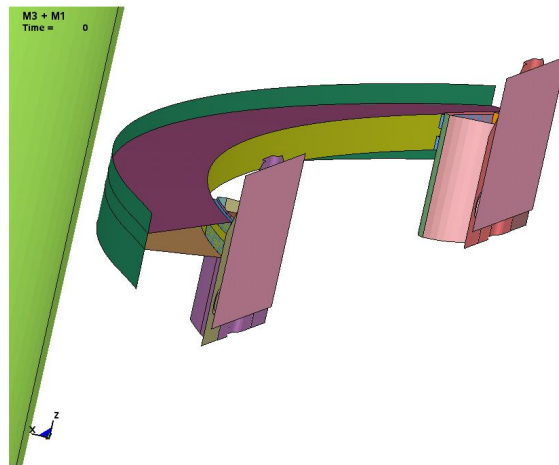

Figure 10: Geometry developed from results of topology optimization used for optimization of sheet thicknesses with LS-OPT
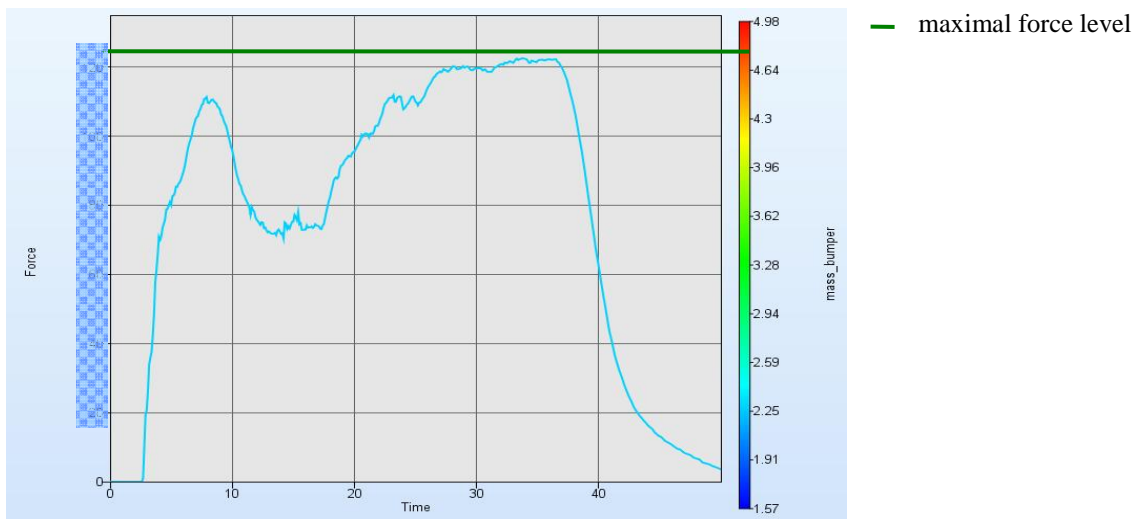

Figure 11: Contact force curve of result from sheet thickness optimization with LS-OPT and maximal force level

Figure 11 shows the barrier contact force of the optimal run form the optimization with LS-OPT and the maximal force level, and now the constraint on the force is satisfied. The mass of the optimal bumper is 2.8 kg. The deformed bumper is displayed in Figure 12.

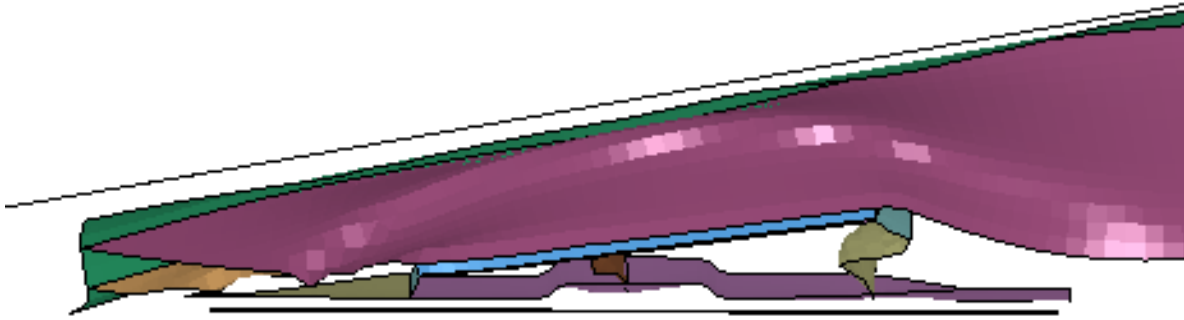Hence the combination of LS-OPT/Topology and LS-OPT led to a suitable result.

Figure 12: Plot of the deformed bumper of the optimal design

Summary

This paper includes first experience with the application of LS-OPT/Topology on an industrial problem. The optimization has been performed in two steps. Firstly, topology optimization with the HCA method implemented in LS-OPT/Topology and secondly sheet thickness optimization with LS-OPT on the basis of a design incitation resulting from the first topology optimization step. The two step approach is necessary in order to consider a maximum force constraint and it also helps to refine the optimization on the basis of a shell design which represents a feasible design solution. Shape optimization on the shell design might be an additional option, but hasn't been addressed in this study.

References

 [1]   Roux, W., LS-OPT/Topology A Topology Optimization Tool for LS-DYNA - User's Manual, Version 1.0, Livermore Software Technology Corporation, Livermore, 2009
[2]   Stander, N., Roux, W., Goel, T., Eggleston, T., Craig, K., LS-OPT User's Manual, Version 4.0, Livermore Software Technology Corporation, Livermore, 2009
[3]   Feuerstein, M., Witowski, K., Müllerschön, H., Optimization of a Crash Management System considering Multiple Load Cases using ANSA and LS-OPT, 2008
[4]   Patel, M., Crashworthiness Design using Topology Optimization. PhD thesis, Univ. Notre Dame, Indiana, US., 2007
[5]   Burks, A.W., Essays on Cellular Automata. In: Von Neumann's self-reproducing automata, pages 3(64), Univ. of Illinois Press., 1970