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DESIGN OF STRUCTURAL PARTS BY USING MODERN SIMULATION PROCEDURES

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This paper discusses modern simulation procedures used in design of structural load-carrying parts that are based on the Finite Element Method. The specific focus of the paper is the topology optimization usage within the context of two currently very interesting topics: configuration and optimization of lattice structures and modern additive manufacturing technologies. Both types of structures are presented together with their limits as well as their potentials for optimization. The discussion is illustrated by two numerical examples and experimentally obtained results. In the examples, a simple beam with three points load is optimized regarding to the different topology setups. The stress fields for different loaded optimized versions of structures are presented and the solutions are discussed and compared to the results of the experiment. A standalone topology optimization software CAESS ProTOp is used for the domain configuration and topology optimization in both examples.

Keywords: Topology optimization, Lattice structure, Level set function, Reduced stress concentrations.

1 GENERAL APPEARANCE

The manufacturing feasibility risks of the topology optimization are even higher than those of a conventional optimization. In this context, any method or technique that at least mitigate these risks is welcome. One such approach is the use of lattice structures for the topology optimization.

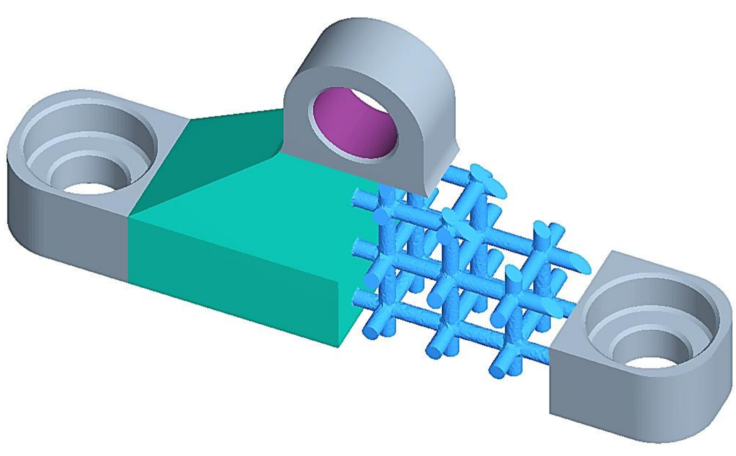

Figure 1. Construction part: mixed solid and lattice configuration.

Using these methods goes well together with the development of the additive manufacturing technologies (called 3D printing) (Lipson 2014). In this article, the process from design of the part, topology optimization and the numerical verification of the results will be presented.

2 THE MATHEMATICAL ASPECT

In topology optimization, any design configuring (e.g. prescribing some lattice configuration with thickness limits) only reduces the design space (Figure 2). This implicitly means that any optimized lattice design will be less optimal than the design obtained by optimizing a full solid configuration. In fact, if we remove all thickness limits in a lattice configuration, and run the optimizer further on, we should ultimately get the design obtained by solid optimization (see Figure 2).

Therefore, solid optimum design is the best design from the mathematical point of view. However, this optimum might have only a limited value in real life engineering applications.

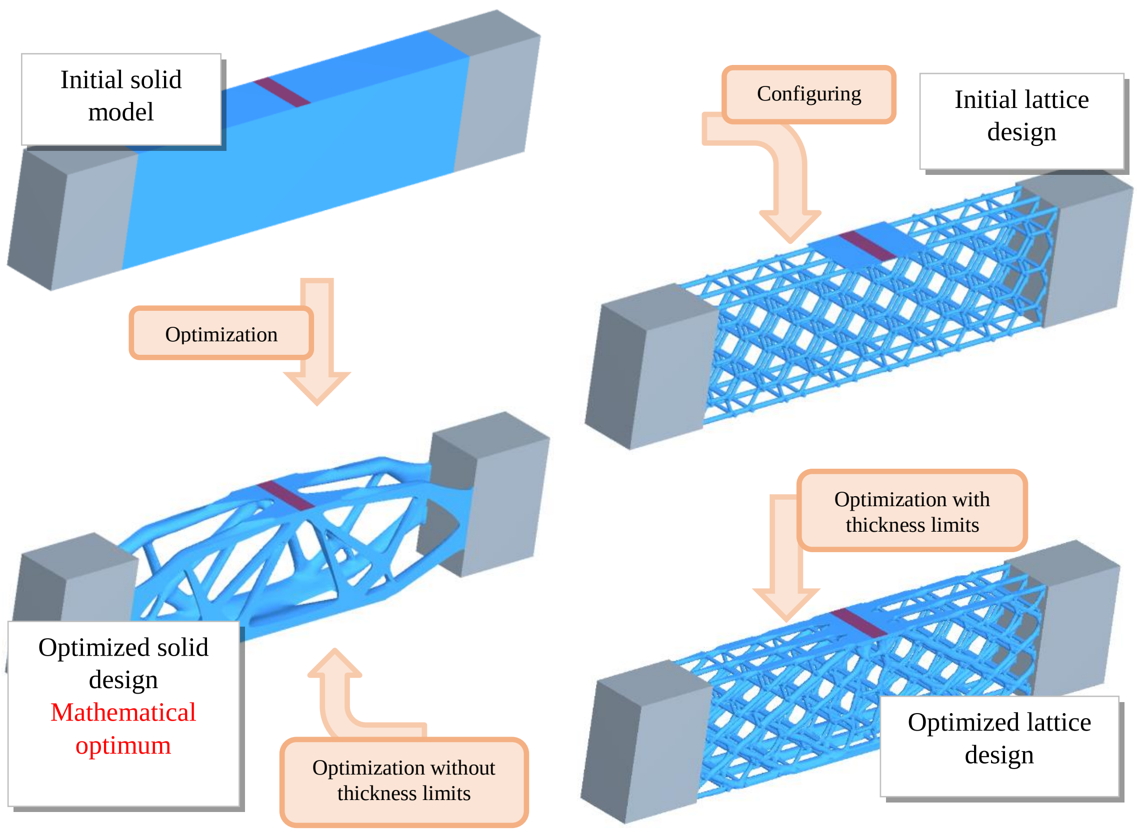

Figure 2. Optimization cycle.

3 EXAMPLE

For presentation in this article was chosen 3-point test example, whereas the measure-ment and the visualization of results are simple. CAD model and boundary conditions of the examples are shown in Figure 3. The model was meshed with 2 million finite elements.

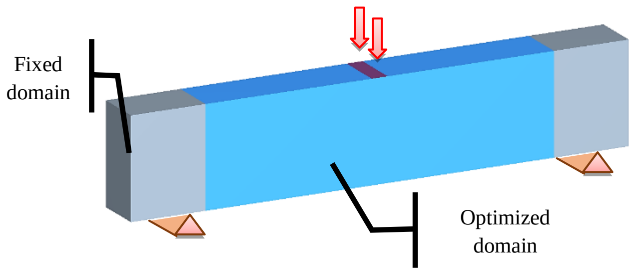

Figure 3. CAD model with boundary conditions.

The model consists of two parts: the optimization part in middle (blue) and fixed domains (grey). Four examples, as shown in Figure 4, will be considered from the solid model in Figure 3.

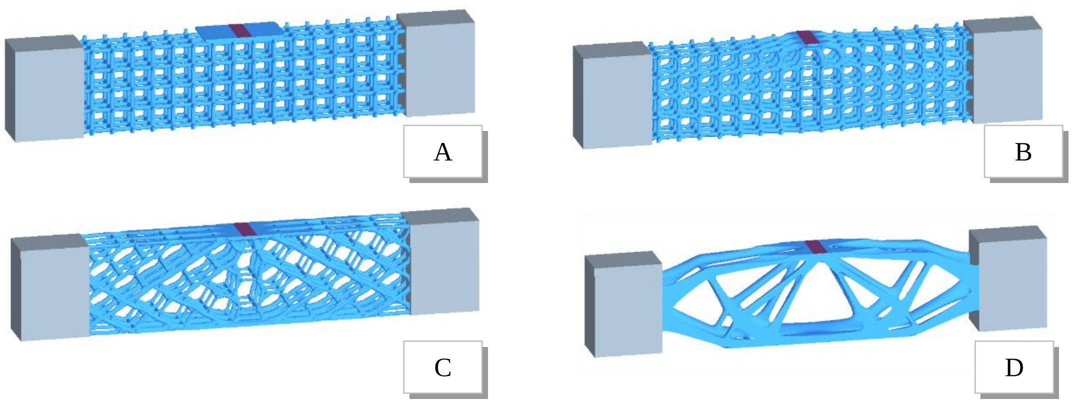

Figure 4. Examples: (A) rectangular lattice; (B) optimized rectangular lattice; (C) optimized honeycomb lattice (HC); (D) optimized solid structure.

First example A represents a not optimized lattice structure, where the grid is rotated in an unfavorable position. The other three examples (B, C, D) are all optimized. For all examples we will investigate, how topology optimization is improving the structures considering higher stiffness and reduced stress concentrations. We are comparing the optimized structures to the experiment results as well. The volume of all optimized cases is around 12% of the starting volume of full solid model. According to the theory, the quality of all four cases should be classified in the order as follows: A (worst case), B, C and D (the best). Configuring of the domain and topology optimization were performed with the software package CAESS ProTOp 4.0.0 (Center for Advanced Engineering Software and Simulations 2017).

4 NUMERICAL AND EXPERIMENTAL RESULTS

Stress field for all four examples is shown in Figure 5. The scale is in all cases the same: purple colored areas are above 50 MPa.

Considering the Figure 5, it is possible to suggest that the best solution is the case D, where the optimizer would have no additional topology constraints. Stresses are relatively low and almost constant throughout the whole structure. It is quite clear that the engineer would never achieve such a constant stress field and design of the structure without using such an optimizer.

The higher stresses are in case A as expected. The size and concentration of the stresses are incomparably higher than in other cases B, C, D.

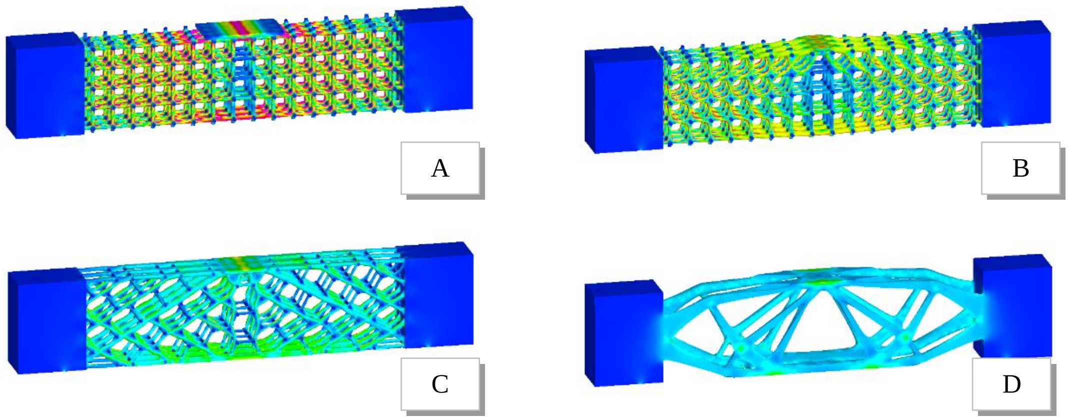

Figure 5. Stress field: (A) rectangular lattice; (B) optimized rectangular lattice; (C) optimized honeycomb lat-tice (HC); (D) optimized solid structure.

Considering the Figure 5, it is possible to suggest that the best solution is the case D, where the optimizer would have no additional topology constraints. Stresses are relatively low and almost constant throughout the whole structure. It is quite clear that the engineer would never achieve such a constant stress field and design of the structure without using such an optimizer. The higher stresses are in case A as expected. The size and concentration of the stresses are incomparably higher than in other cases B, C, D.

For the better illustration, how important topology optimization is, the same detail of case A (Figure 6) and case B (Figure 7) is taken into consideration. We can see that in case A there are very high stress concentrations. As mentioned before, in case A, the grid is rotated in an unfavorable position, but in real situation with multiple load cases, practically engineer could not know what favorable layout of the grid is. Thus, the 'manual' choice of the lattice configuration is practically unavoidable of the high stress concentrations in the structure.

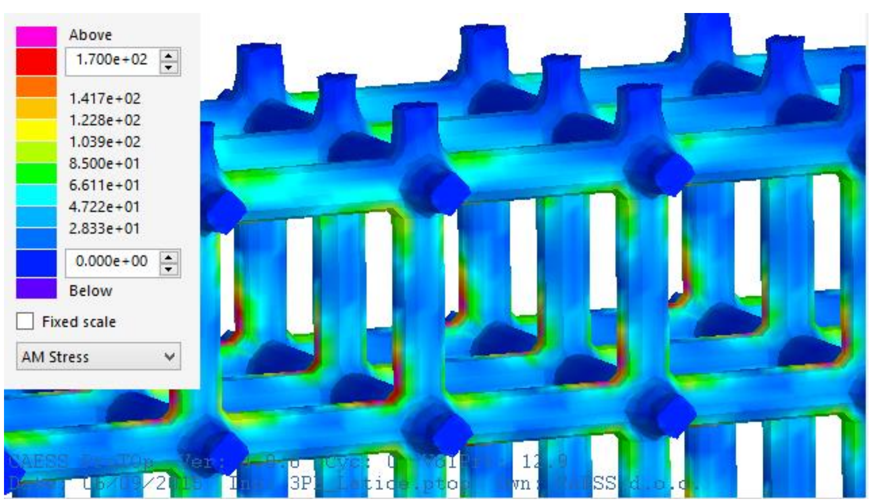

Figure 6. Detail of case A (Stress field: 0 - 160 MPa).

In case B, we started with the same lattice structure as case A. After topology optimization, presented in Figure 7, we can see that despite of the unfavorable position of the lattice structure, stress field is definitively improved. Stress concentrations are almost inconspicuous and distribution in general is much more uniform. Also, the maximum stresses are much lower.

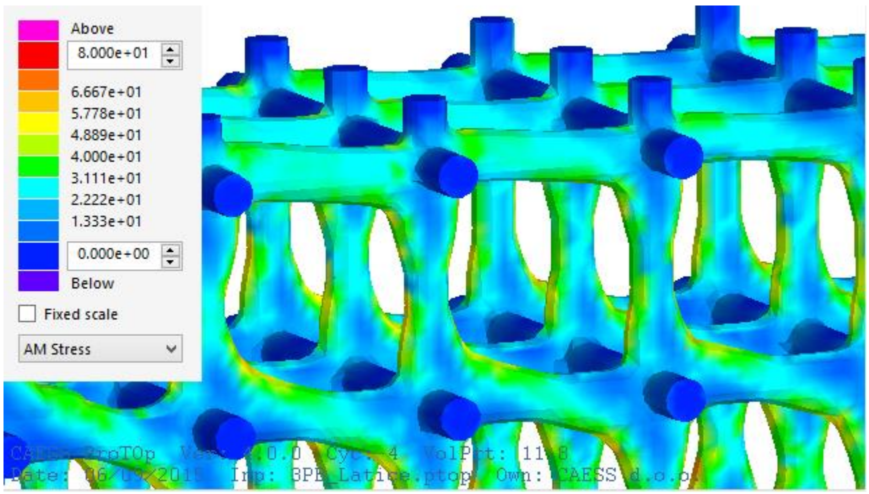

Figure 7. Detail of case B (Stress field: 0 - 80 MPa).

At the end, all results were validated with the software package Simulia Abaqus 6.14 (Simulia Abaqus 2017). In simulations, the load was prescribed as displacements. Note that the magnitude of the load by numerical simulations is not the same as in the optimization. A comparison of the experimental and numerical results is shown in Figure 8. The dotted lines indicate the potential variations of the numerical results. These are possible because of variations of the elasticity module of the used material.

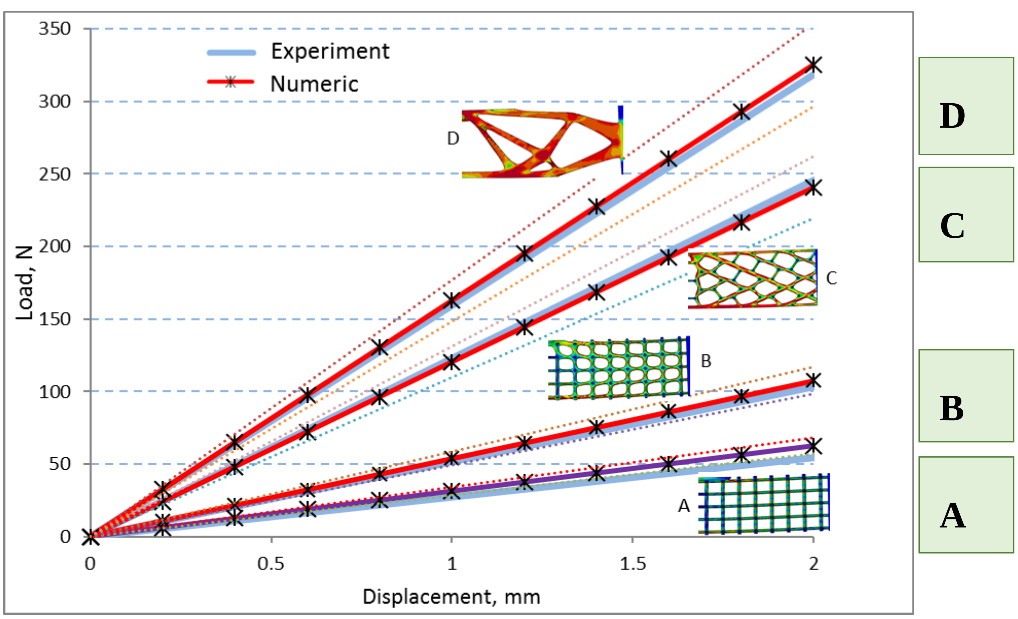

Figure 8. Comparison of experimental and numerical results

From the presented results, we can draw two observations: (1) in accordance with the expectations the stiffness of all four cases is classified as follows: A (less rigid), B, C, D (most rigid), and (2) the correlation between the measurement and numeric is surprisingly good. The numerical methods, which are used, can provide realistic results, if everything is done correctly.

5 CONCLUSIONS

Lattice structures, as generated by employing suitable cell mapping tools, typically exhibit stress concentrations which may lead to crack initiation. Therefore, running topology optimization on a generated lattice structure should be done by all means. Experience shows that already partly optimized structures exhibit drastically reduced stress peaks.

Numerical and experimental results show that topology optimization has the potential to bring enormous benefits in terms of structural stiffness, weight, and stress levels. In addition to that, the resulting structure is practically free of any stress concentrations and therefore exhibits a higher damage initiation load.

An engineer still has a very demanding task: the correct identification of all load cases and other boundary conditions of the structure. Errors in this part of the process can be critical.

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