Stiffness-oriented Optimization of Material Distribution in Multi-Material Components

D. Lehmhus[1*], A. Struss[1], S. Bosse[2, 3], A.P. Mounchili[4, 5]

[1] Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, [2] University of Bremen, Department of Mathematics and Computer Science, [3] University of Siegen, Department of Mechanical Engineering, [4] University of Bremen, [5] RYTLE GmbH
*dirk.lehmhus@ifam.fraunhofer.de

Optimization of material distribution with the aim of maximizing stiffness is a common problem in engineering design aimed at structures offering low weight and/or limited design space, and several solutions are known [1]. In parallel, manufacturing techniques are being developed which allow realization of arbitrary material distribution in multi-material components: Typically, these focus on bi-material structures and are based either in casting, using a compound casting approach in which one material is introduced as insert around which the other is cast [2], or in additive manufacturing, where multi-material processes are increasingly being realized for several material classes, including polymers and metals [3,4]. The present study considers the Multi Phase Topology Optimization (MPTO) approach originially suggested by Burblies and Busse and further studied by Mounchili at al. [5,6]. This technique is based on iterative linear-elastic FEM simulations and the evaluation of strain energy data on model as well as element level and builds on the fact that association of high stiffness material properties with elements experiencing high levels of strain energy will serve to minimize total strain energy, and thus decrease displacement under a given load. The analysis covers (a) the realization of the MPTO approach based on different algorithms for adapting the material distribution and (b) its capability of identifying best combinations of low weight and high stiffness for a given load case and design space subject to variation of material volume fractions.

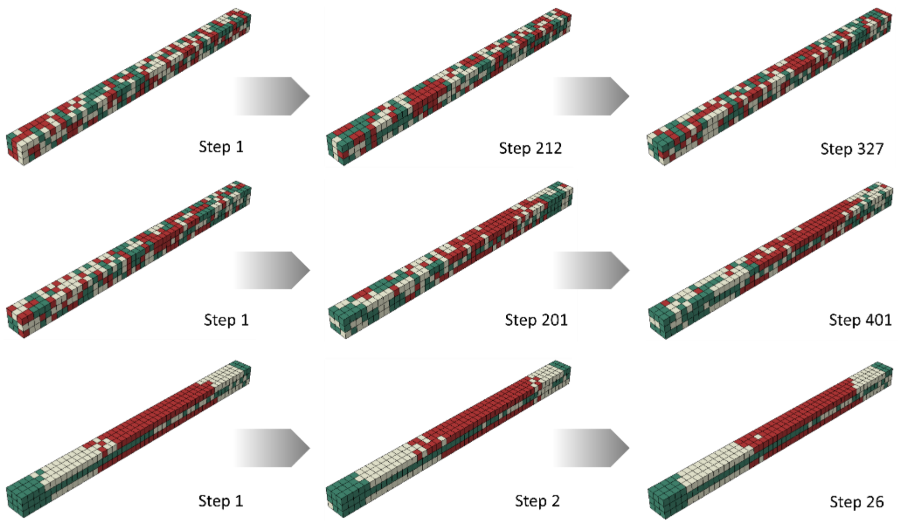

Figure 1. Progress of material redistribution for a three point bending load case: Top row, fully stochastic approach, center row, genetic algorithm, bottom row, physics-based approach with superimposed stochastic variation.

Fundamental investigations on a completely stochastic and a genetic algorithm, with and without added integration of a physics-based sorting approach, are performed on a simple load case and limited model size to support fast optimization runs, thus allowing scrutiny of the scatter of results. The weight optimization problem is addressed using the same model of an asymmetric three-point bending setup incorporating equal fractions of three materials. A final validation is performed on a more complex model and load case with a the number of degrees of freedom increased by two orders of magnitude.

The presentation closes with an outlook on further development paths, which include, on the computational side, pre-filtering of configurations to reduce the number of FEM simulations e.g. via integration of a machine learning-based predictor function, and on the materials engineering side the consideration of material interface characteristics as well as extensions towards incorporating aspects of plasticity.

References

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