OPTIMAL DESIGN OF A 3D PRINTED SANDWICH PANEL INSERT

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Abstract

In industry, ALM experiences an unseen upswing. But despite its ease of manufacturing, structural engineers face the challenge to lift its whole lightweight design potential. In order to so, the authors elaborated a sequence of optimizations aiming to consider all structural aspects and to outbalance conflicting goals such as performance and weight. In this specific paper, an insert has been optimized so as to not only be lighter but also to sustain more load. The later was actually proven via testing. For the sake of comparison, a conventional milled insert was developed, build and tested as well. Live crack detection through acoustic monitoring during quasi-static and thermal testing revealed the superiority of the optimized and 3D printed part over the milled one.

Keywords

3D printing, additive layer manufacturing (ALM), topology optimization, sizing, industrial optimization

1. INTRODUCTION AND BACKGROUND

This paper summarizes roughly the outcomes of two successive research works. So for more details please consult [1]. With [2], [3] and [4], it has been shown, that manufacturing has a huge imprint on optimal design. Despite the fact, that 3D printing facilitates the built of almost any structure, certain limitations and requirements still need to be honored as well.

Beside this need for considering limitations and requirements, the optimization process shall be such robust, that Michell structures [5] and [6] are interpreted with care and not just blindly built. Since they do not necessarily have to be optimal, as investigated by [8], where solely different filter formulations together with great amount of design degrees of freedom leveraged the resolving of shell or membrane structures (see figure 1).

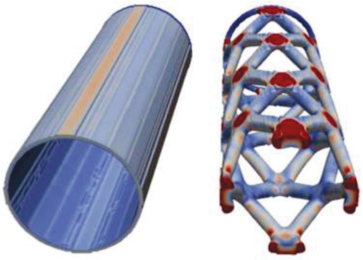

Figure 1. Michell structures do not necessarily need to be optimal [8]

For those reasons, it has been decided to not optimize the 3D printed part in one shot, but in a sequence of optimizations, design interpretations and analyses (see [1]). The demonstrator part to show the advantages of this approach is given by an inserts introducing loads into the sandwich panels of the METimage optical head (MOH) as displayed next.

Figure 2. METimage optical head

METimage itself is one of the key instruments of EUMETSAT Polar System - Second Generation (EPS-SG), which is planned to be in service in 2021. It shall then gather information on clouds, cloud coverage, land surfaces, temperatures of oceans, ice and more. A thorough description of METimage is given by [8].

2. OPTIMIZATION PROCESS FLOW

The basic concept is a sequence of optimizations, namely: problem definition, topology optimization, design interpretation, sizing opimization and detailed analysis.

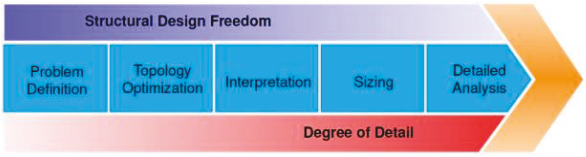

Figure 3. Sequence of steps [1]

Those optimization steps will be explained in short next.

2.1. Problem Definition

First, the frame of the optimization needs to be set up. For this sake, the MOH structure is decomposed into the most relevant parts for identifying major load paths and scenario. Because of the given design – bending soft fittings – the load case is quite pronounced, hence, mainly axial loading in strut direction. This is given with figure 4.

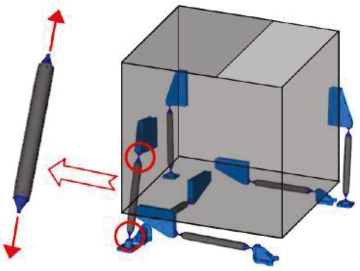

Figure 4. Loading definition [1]

The given dynamics and mass properties yield a strut force of 20kN. Another relevant load case is given by the cool down of the structure to -45°C. The mismatch in the coefficients of thermal expansion leads to stress peaks in stiff areas and / or along great stiffness changes.

2.2. Topology Optimizatoin

Once the frame is set, the actual optimization phases initiate. First, a topology optimization helps to identify major load paths. Thus, how to most mass-efficiently transmit loads. During this stage, the used Finite Element Model is rather coarse. Figure 5 gives an example of an outcome of such an optimization. The optimization was given by a minimization of compliance, thus by maximizing stiffness for the given force for a given mass fraction.

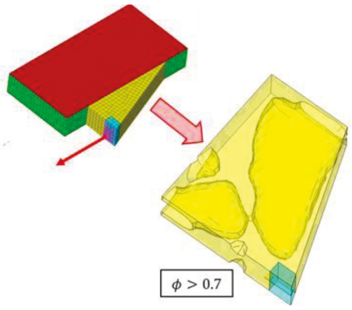

Figure 5. Topology optimization [1]

2.3. Design Interpretation

The design appears to be bionical but is yet far from being optimal. Even not in light of mechanics. This is mainly due to the limited capabilities of resolving shells or membranes. Or in other words, if one would to resolve shells and ribs one would have to use a way more degrees of freedoms and modify filter algorithms (again, see [7]). Another reason for the design interpretation is given by the fact, that there are many more aspects and requirements which needed to be considered, e.g. outgassing, strength of the bond etc.

For those and many more reasons, the topology optimization results were regarded as baseline for discussion. They all however highlighted the primary load path (given by red arrow in figure 6). For the sake of robustness, more load transmission paths shall be considered.

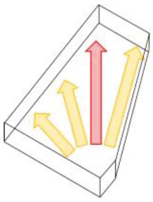

Figure 6. Design interpretation [1]

From engineering judgement, it also appears to be way more reasonable to distribute the load smoothly along the upper and lower side of the inserts, such that the load is continuously introduced into the face sheet. This actually mitigates the actual bottleneck of the structure, the bond and its associated adhesive stress peaks.

2.4. Sizing Optimization

In order to squeeze out the most of the structure, sizing is conduced. Here it is essential to consider all relevant aspects, such that the optimization algorithm is able to converge to meaningful and technically relevant results.

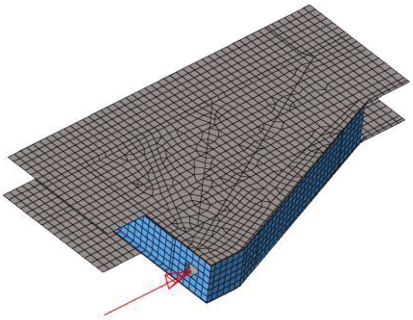

Figure 7. Used FEM

Figure 7 depicts the overall FEM used for sizing. With figure 8, the regions associated with design variables are given.

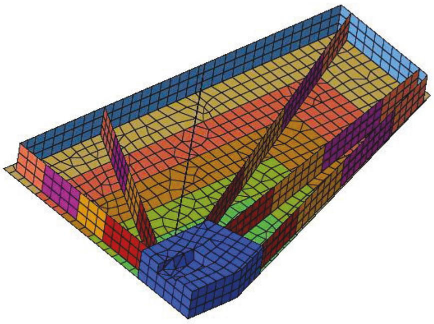

Figure 8. Sizing FEM

With equation (1) a general optimization task is given [2], with f being the objective, $\boldsymbol{g}$ the constraint vector and $\boldsymbol{x}$ the vector of design variables.

$$\min \{f(\boldsymbol{x})|\boldsymbol{g}(\boldsymbol{x})\leq 0\} \tag{1}$$

The design variable vector is composed of the thicknesses of the ribs and the top sheet of the insert.

$$\boldsymbol{x} = [t_{rib,1}, .. , t_{rib,n}, t_{top,1}, .. , t_{top,k}] \tag{2}$$

Constraint vector $\boldsymbol{g}$ is defined by requiring a minimum stiffness of the insert, limiting adhesive stress during quasi-static loading and thermal loading to yield adhesive stresses being smaller than the limit. Lastly, the stresses of the insert itself are limited as well.

The reader shall note, that it is actually not only one constraint per material, but instead a sub-vector since a multitude of elements needed to be considered for enabling the successful use of sensitivities within a gradient-based optimization frame.

The optimization is here realized via NASTRAN, which was considered to be advantageous since it acquired analytical gradients making it fast and efficient. All runs converged within ten iterations, but different in terms of constraint violation. This violation was here however given by the undermining of stiffness which is tolerable.

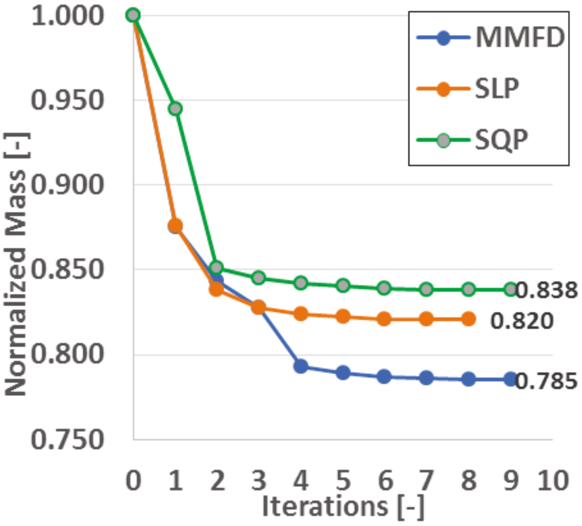

Figure 9. Convergence plots of all three algorithms

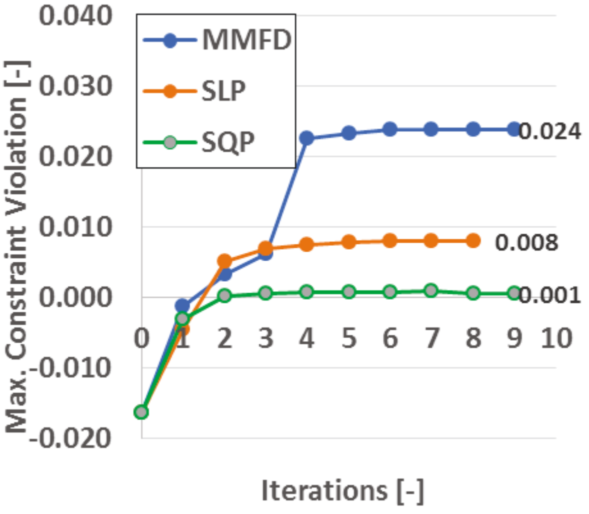

Figure 10. Course of maximum constraint violation per algorithm

With figure 11 the found optimum is given in terms of thickness. As can be observed, the thickness radially decreases allowing the continuous transmitting of load into the adhesive, thereby reducing stress peaks at the outer edges.

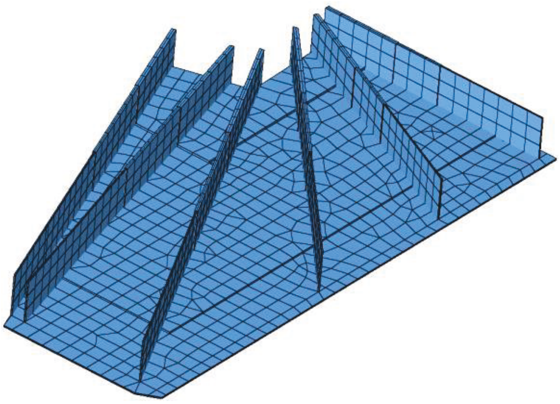

Figure 11. Thickness distribution of the optimal design

3. CONCLUSION

This paper briefly outlined a sequence of optimizations. This sequence allowed the mass efficient design being built using 3D printing. Moreover, the characteristic design allowed a seamless load transmission into the face sheet of the sandwich without provoking extreme stress peaks in the adhesive. By this continuous load transmission the actual bottleneck of inserts has been mitigated; adhesive and or failure in face sheets for thermo-elastic of quasi static loading. It shall again be noted, it is just rarely the case, that the inserts as such fails, it is the adhesive region being critical.

Next, such 3D printed inserts shall be qualified, such that alike parts actually fly in near future. Possible issues to be addressed are fracture control and reproducibility.

4. ACKNOWLEDGEMENTS

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