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# Sandwich panels with functionally graded strut-based lattice cores

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Due to their high mechanical performance, sandwich panels are widely utilized in many applications. Among the most frequently used cores in sandwich panels are honeycomb structures. Since the invention of additive manufacturing, new core structures like strut-based lattices which are not possible by conventional manufacturing processes are also being considered as cores for sandwich panels. Depending on the given boundary conditions and load cases, core struts must transfer different loads. Particularly struts near load introduction points and support points are exposed to high local stresses. In the present study, a graded core is used to reduce the effect of local stress concentration near load introduction points and support points. In the graded core higher loaded areas show a higher relative density. In contrast, low loaded areas represent lower relative density, resulting in a reduction of the core weight and a uniform stress distribution. Only the strut diameters are varied. It is demonstrated that systematic optimization allows a well-tailored core gradation and some valuable weight reduction.



## 1 Introduction

Sandwich panels are lightweight constructions, which usually are composed of two thin face sheets made from a high strength material and a low density thick core between. Due to the high ratio of core height and skin height sandwich panels have simultaneously a high bending stiffness and a low weight. For this reason they are widely used in many industry sectors, such like areospace or automotive engineering. The most used cores for sandwich panels are honeycombs, because of their low mass and good mechanical properties.

## 2 Strut-based lattices as cores in sandwich panels

Recently new structures have been enabled as cores for sandwich panels. Strut-based lattices can not be produced by conventional manufacturing processes. Additive manufacturing, however, enables such complex design [1]. Many studies have recently shown that additively manufactured strut-based lattices have mechanical properties similar to honeycombs [2], therefore, they could substitute honeycomb cores in sandwich panels. The advantage of using strut based lattices is that they are not closed cell structures like honeycombs, allowing thermal flows through the core. Hence, they can also be used as multifunctional cores, for example as a heat exchanger in anti ice systems in aeroplanes or wind turbines [3].
This kind of structured lattices is usually made of periodically repeated representative volume elements (RVE). The topology and diameter of the struts in the RVE cell are the important characteristics of the lattice because they define its mechanical properties and the relative density.

## 3 Local stress concentration in sandwich panels cores

The load bearing role of the core in sandwich panels depends on the load case. Under pure bending load the core in sandwich panels with very thin face sheets serves as a spacer. In contrast, under transverse load the core has to transfer shear stresses. Furthermore, the core is important to support the high local load near support und load introduction points. From a lightweight design point of view locally load adapted struts are required, in order to minimize the core weight.
In this work an optimized strut diameter distribution for an almost homogenous stress distribution near support and load points is determined. Starting from a sandwich model with an ungraded core, a sandwich with a graded core is developed. For this aim a FE-Model of a sandwich with a strut-based lattice core is used. The core of the sandwich model is twenty times thicker than the face sheets and has eight layers of face centered square cells. This kind of cells is chosen, because the 45° inclined struts are well adapted to transfer the transverse shear stress in the core. The vertical struts are important to transfer local vertical loads. The core struts are modeled as Timoshenko beam elements with circular cross sections. The aluminum alloy AlSi10Mg ($E_c = 70.000$ MPa) and a high strength aluminium alloy ($E_f = 72.000$ MPa) are used as materials for the core and skin layers, respectively.

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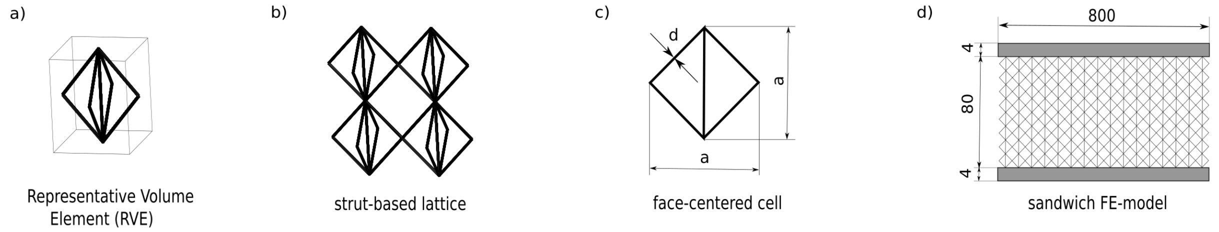


**Fig. 1:** *a*: RVE in unit cell. *b*: Strut-based lattice consisting of 4 RVEs. *c*: Face centered cell. *d*: Sandwich FE-model.

## 4 Determining an optimized strut diameter distribution

First the objective function of the optimization task has to be defined, which is to minimize the core weight. During the optimization the RVE cell size is not modified. Furthermore, the strut diameter within the RVE is constant, which means there is no gradation within the RVE cell. The strut diameter distribution in the thickness direction $z$ is chosen to be linear. All struts in the same plane layer shall have the same diameter. Another geometric restriction is that the core has to be symmetric with respect to the midplane of the sandwich. In order to minimize the core weight, the diameter of the first and mid layer in the core are varied for a linear strut diameter distribution. These two diameters are the design variables. As constraints the strut stresses must be lower than the yield strength. Every optimization cycle the strut diameter is adapted dependent on the square root ratio of strut stress to material strength. The optimization is stopped, when the ratio of the first layer or fourth layer maximum strut stress to yield strength is higher than 99%.
As a first case let us consider a sandwich beam, which is clamped on the one side (cantilever). The beam is loaded by a single vertical force on the free edge of the top layer. Near the load introduction area the vertical struts are exposed to higher stress than the inclined struts, thus only the stress in the vertical struts is considered during the optimization. While in the start design the stress in the first layer is 240 MPa, which is equal to the yield strength, the stress in the fourth layer is only about 70 MPa, as shown in Fig. 2 (right). It takes 2 optimization cycles to determine an optimized strut diameter distribution with a core weight reduction of 37%, which is illustrated in Fig. 2 (left). In this design only the strut diameter of the first layer in the graded core is larger than the strut diameter of the ungraded core, all other struts have a smaller diameter. After running the optimization procedure the stress distribution is almost homogenous in all four layers. Thus, a better material use is achieved due to the gradation. The same kind of optimization procedure is applied on a three point bending structure (3PB). In this case the optimization and the core gradation lead to a mass reduction of 38%. Fig. 2 shows the optimized strut diameter distribution (left) and the respective stress distribution in the core struts (right).

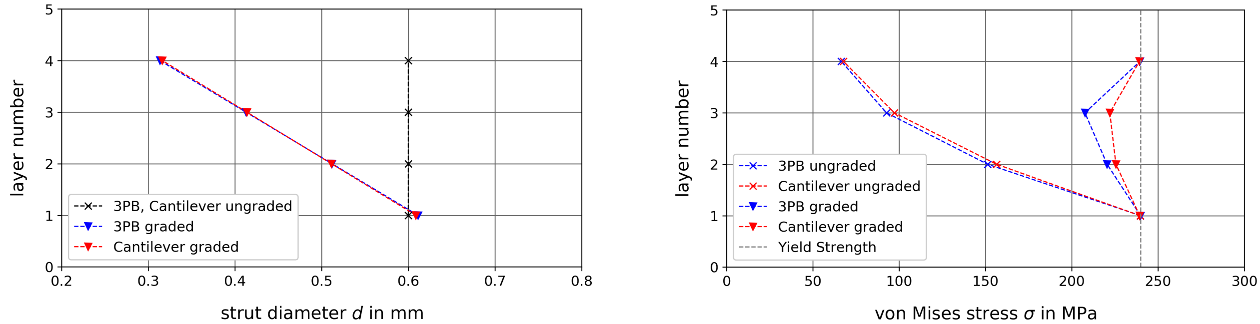


**Fig. 2:** *Left*: Strut diameter distribution in the core layers. *Right*: Stress distribution in the struts at the support and load introduction points.

## 5 Conclusion

In the present work strut-based lattice cores for sandwich panels were investigated. It has been shown that core gradation is very useful in order to reduce the effect of local stress concentration near load introductions and support points in sandwich panels. An optimized linear strut diameter distribution leads to a core weight minimization of up to 38%. Thus, a better material use could be reached due to core gradation.

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