Compression Response of Optimized Thermoplastic Composite Lattice Core Sandwich Structures

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1 Introduction

Owing to their high specific stiffness and strength, composite lattice structures have recently gained increasing interest for use as core material in high-performance sandwich applications, as the lattice members comprising the core display a stretch-dominated behavior under macroscopic loading [1]. By virtue of their open cellular architecture, composite lattice cores offer great potential for load-tailored design and integrated functionality. We characterize the structural behavior of ultra-lightweight thermoplastic composite lattice core sandwich structures and investigate the achievable performance enhancements through structural optimization and load-tailored design.

2 Modeling

A pyramidal lattice core comprising four circular cross section members of length L within a unit cell, and characterized by the member inclination angle θ, the slenderness ratio $\lambda = 2L/d$, and a nodal offset δ is considered as the reference core topology. With a relative density ρ^* of the lattice core

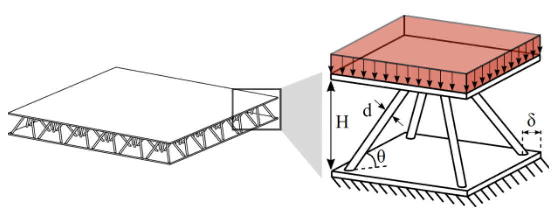
$$\rho^* = \frac{\pi d^2}{2[L\cos\theta + 2\delta]^2 \sin\theta}$$

analytical models for the equivalent compression stiffness and strength of the pyramidal lattice can be derived from the elastic deformation of the members, which allow for identifying optimum core topologies for maximum performance under consideration of manufacturing constraints.

$$E_z = \rho^* E_c \sin^2\theta \left(\sin^2\theta + \frac{3}{\lambda^2}\cos^2\theta\right)$$

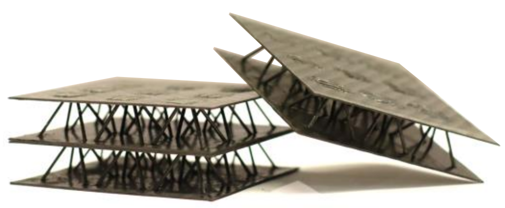
$$\sigma_z = \rho^* \sin\theta \left(\sin\theta + \frac{3}{\lambda^2}\cot\theta\cos\theta\right)\sigma_{cr}$$

where $\sigma_{cr} = min \begin{cases} X_c & \text{Core member crushing strength} \\ \frac{\pi^2 E_c}{\lambda^2} & \text{Core member buckling strength} \end{cases}$



3 Materials & Fabrication

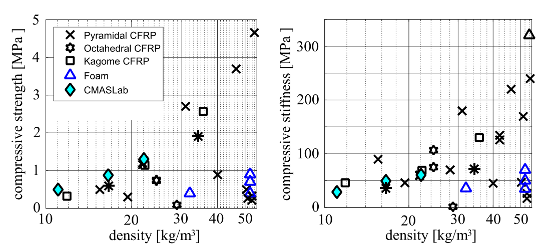
The structures are entirely made from continuously carbon fiber-reinforced polyamide 12 (PA12). The lattice core comprises unidirectional CF/PA12 members, obtained by pultrusion of multiple commingled yarns using the Continuous Lattice Fabrication (CLF) process [2]. A strong core-to-facesheet bond, which is usually the weakest link in composite lattice core sandwich structures, is realized by thermoplastic welding through the local application of heat and pressure.



Lattice core sandwich panels with $\rho_{core} = 11\ kg/m^3$

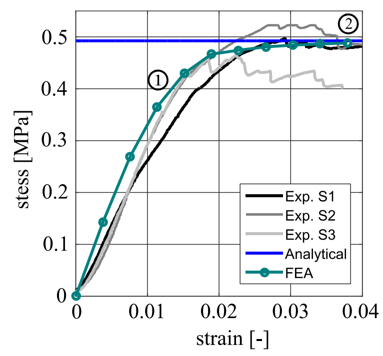
5 Performance Comparison

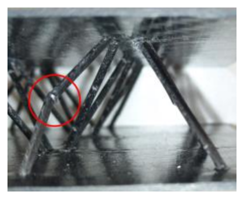
The performance comparison with other composite lattice core structures published since their introduction by Finnegan et al. [3] shows that our optimized lattice cores outperform the compression strength of all previous composite lattice cores in the density range between 10 and 25 kg/m³ and are competitive in terms of compression stiffness, underlining the great potential of optimized topologies and the novel materials and processing techniques used. Foam cores, inherently featuring a bending-dominated microstructural behavior, are inferior to composite lattice cores, both in term of stiffness and strength.



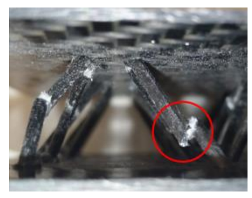
4 Compression Response

Under out-of-plane compression loading, the structures initially show a linear-elastic response until failure is initiated by core member buckling. In the post-buckling regime, the lattice core fails gradually rather than catastrophically with progressive buckling and stress redistribution among the core members, maintaining significant load-carrying capacity over a wide range of strains. Correlation of the compression response with the developed analytical models and nonlinear FEA shows very good agreement.

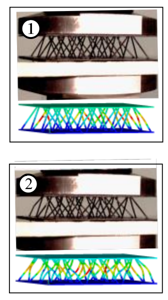




Core member buckling



Core member crushing



5 Conclusion

Through the combined use of optimized core topologies, novel materials and processes, we have realized and characterized optimized, fully thermoplastic composite lattice core sandwich structures in the very low density regime of sandwich core materials ($10 < \rho_{core} < 25\ kg/m^3$) with outstanding compression performance, whose structural behavior can be predicted well with analytical and numerical methods.

6 References

[1] V.S. Deshpande et al. „Foam topology bending versus stretching dominated architectures", Acta Materialia, 2001
[2] M. Eichenhofer et al. „Continuous lattice fabrication of ultra-lightweight composite structures", Additive Manufacturing, 2017
[3] K. Finnegan et al. „The compressive response of carbon fiber composite pyramidal truss sandwich cores", Int. J. Mat. Res., 2007
[4] C. Karl et al. „Fabrication and compression response of optimized thermoplastic composite lattice core sandwich structures" (in progress)

Partners

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