Modeling and simulation of lightweight lattice structures for impact energy absorption

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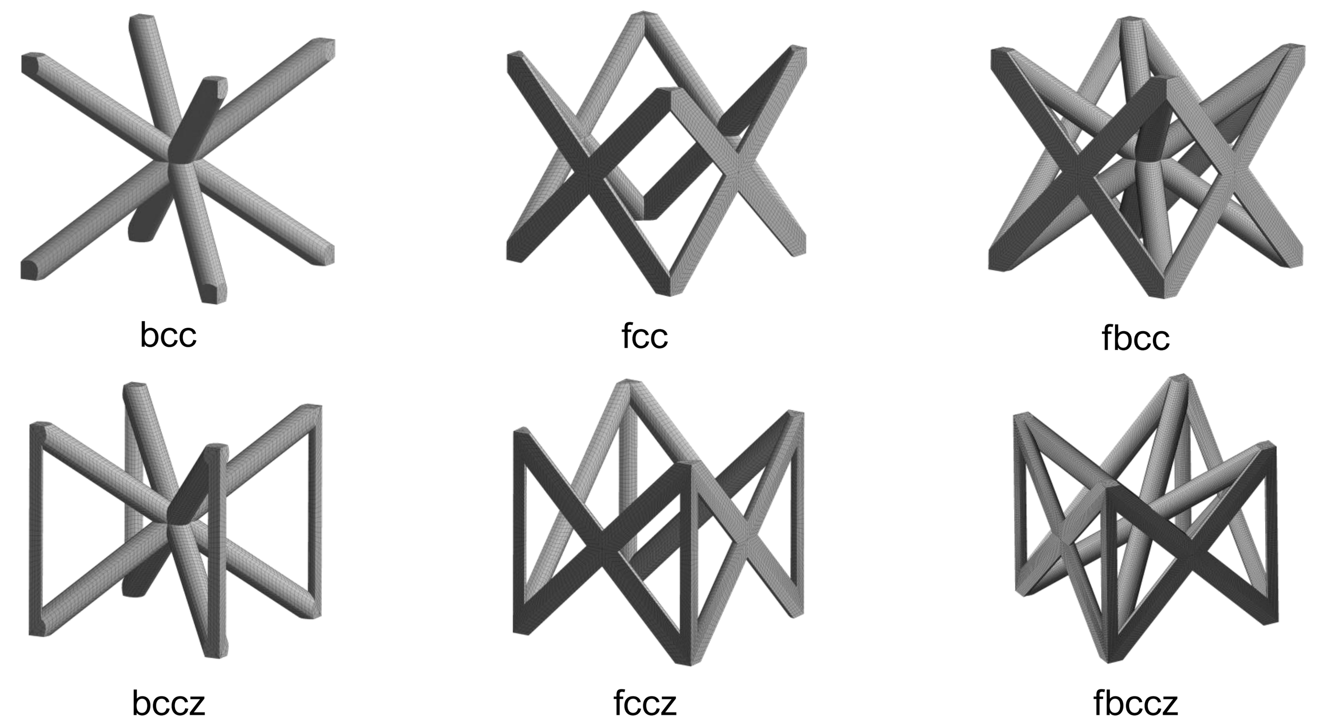
Abstract

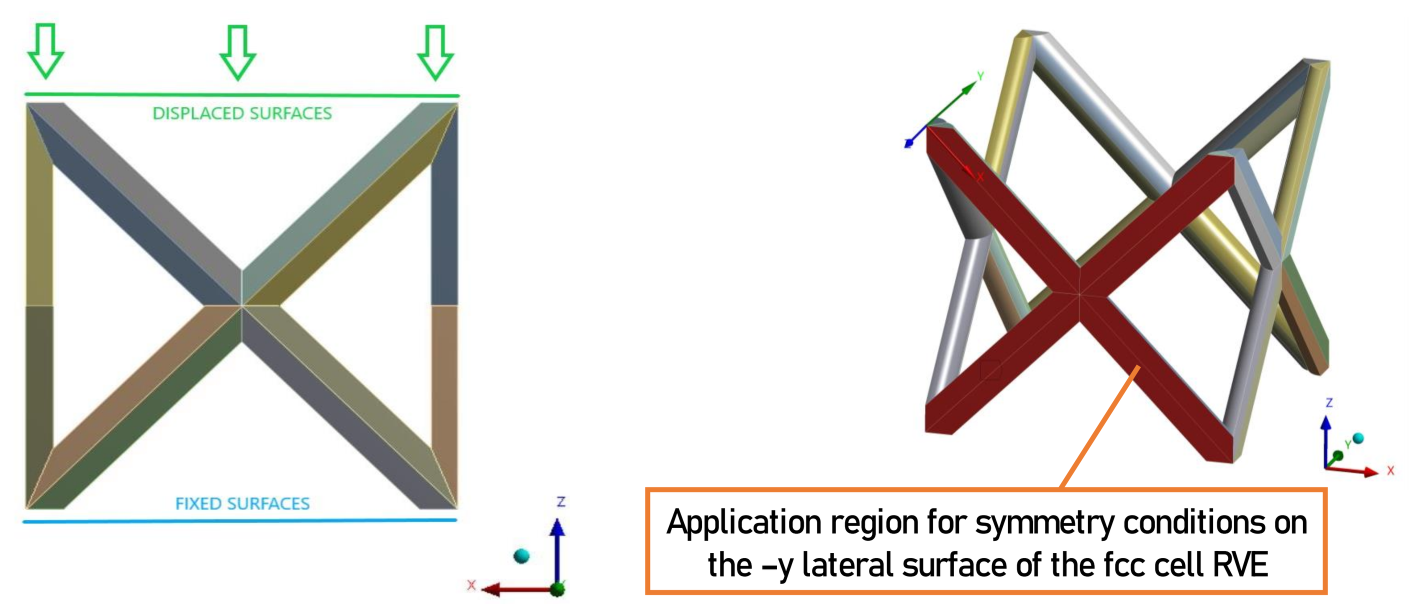
Metal lattice structures possess a wide range of application in the mechanical field, mainly because of their high functionality, lightweight and the possibility to be manufactured using additive manufacturing. One of the most important application nowadays for these materials, especially when it comes to aerospace, biomedical and automotive sectors, is as energy absorbers.
A specific set of lattice cells, selected among the most promising ones for energy absorption, has been tested using FEA (Ansys Workbench 2020 R1).



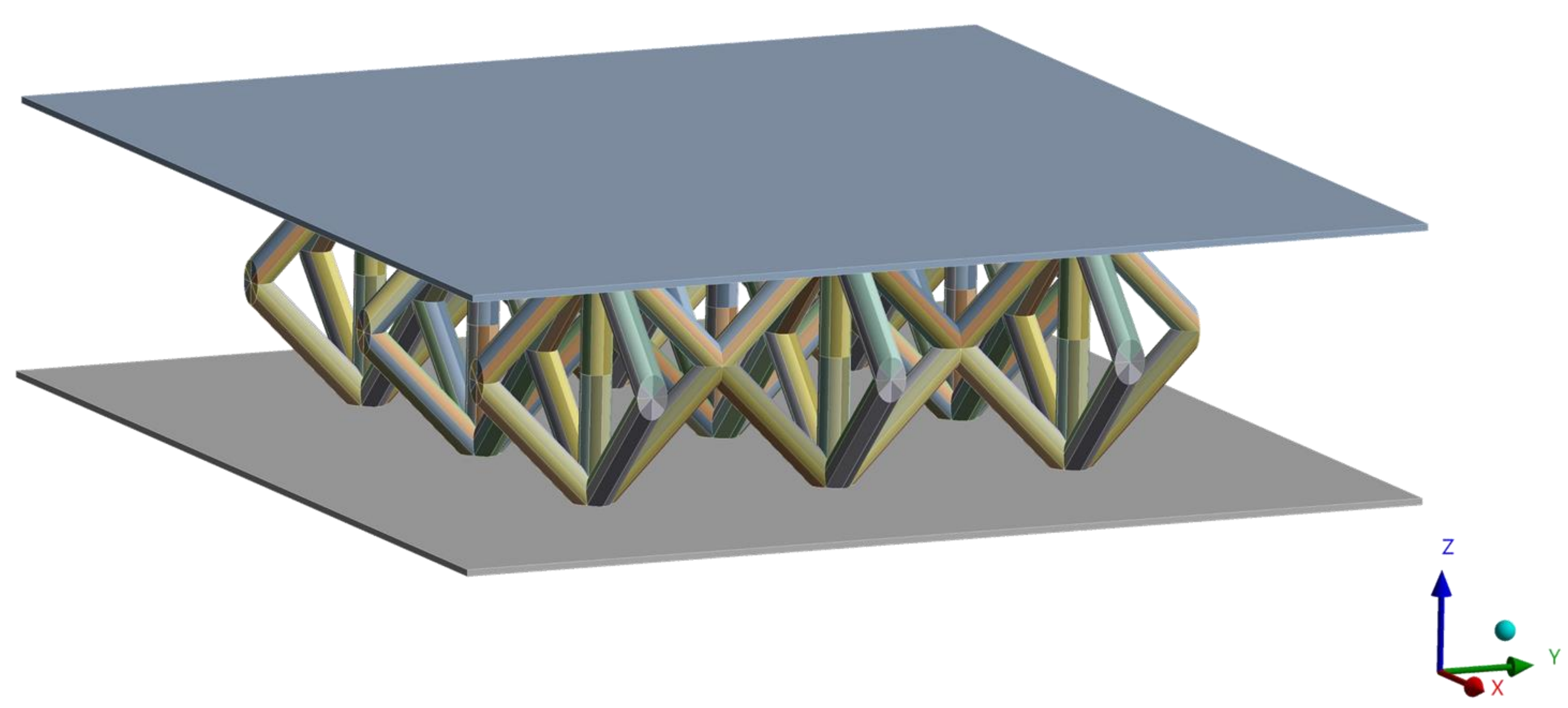
Cells are accurately selected so that bcc and fcc allow the investigation of the effects of different struts orientation while effects of combination and reinforcement are studied testing fbcc and –z cells.
All of the results obtained are therefore used to establish construction guidelines and a methodology for lattice simulations that can be valid for energy absorption analysis.

Simulation methodologies

Topologies have been tested in two different ways: statically and dynamically. In both cases material has been modeled with a bilinear function. First, geometries have been generated using Design Modeler Tool. Static simulations have been a good starting point in order to start appreciating first differences between cells. Model is essential and based on a single RVE; symmetry conditions: lower surfaces are fixed, upper surfaces are displaced in order to determine a compression load have been applied at the border of the RVE.



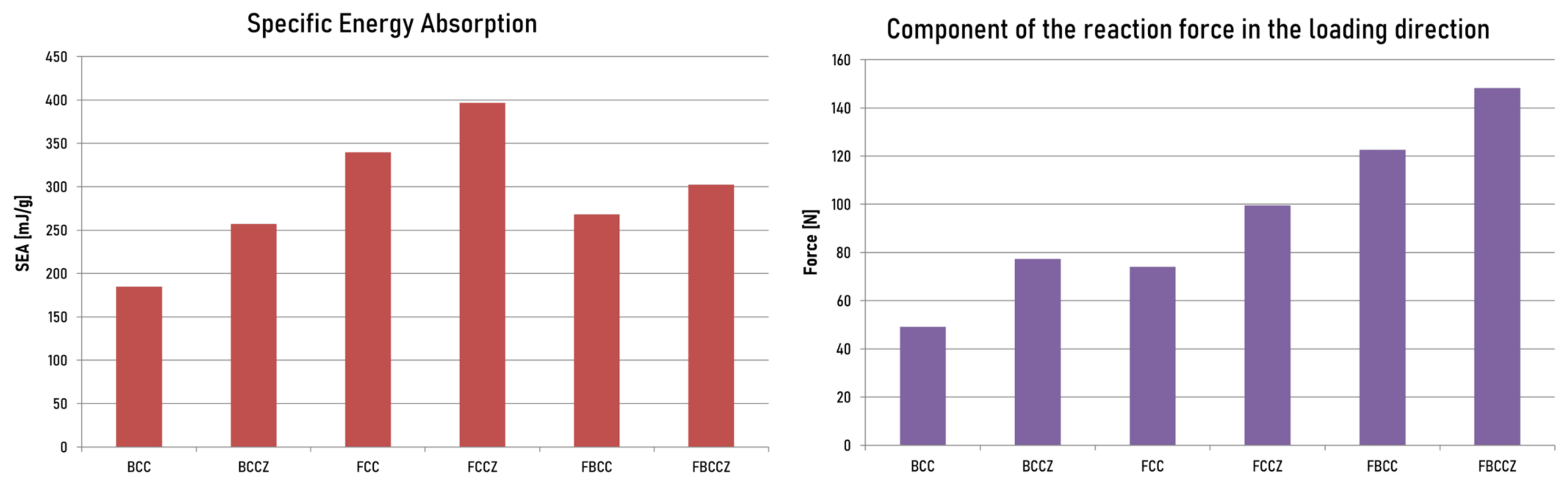
Dynamic crashing simulations offer instead a wider perspective; also, a confrontation between the two testing methodologies is possible in order to determine is static results can predict dynamic behavior. Dynamic simulations are based on a 3x3x1 cells sample: the model presents a fixed plate holding the sample still and a crashing plate applying the load. The sample is crashed at 80%, in order to appreciate densification effects on the results. Mesh has been generated using Multizone tool; contact pairs have been established between fixed/crashing plates and sample, while auto-contact algorithm for parts touching themselves is included in Ansys explicit code, that has been used since the phenomenon lasts less then 1 second.



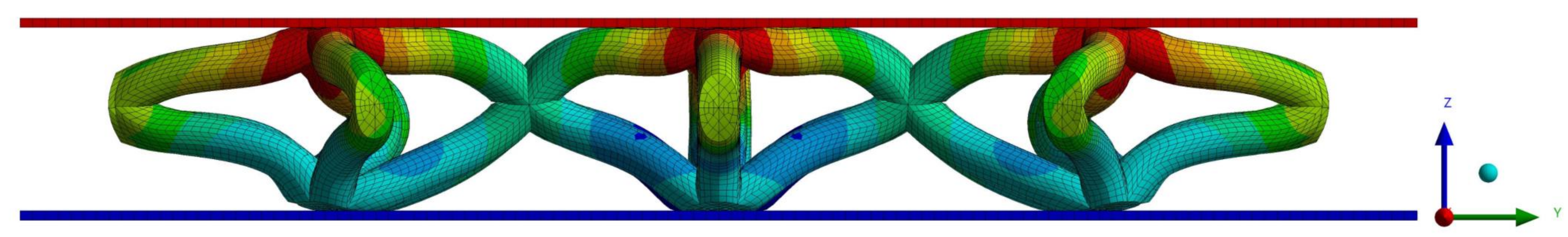
No BCs have been applied on the outer sides of the sample in order to perform a more realistic behavior and deformation. Program controlled initial/min/max timesteps were sufficient to guarantee convergence. Post-processing is necessary in order to obtain substantial results: energy absorption (EA), specific energy absorption (SEA), volumetric energy absorption (VEA), densification strain, plateau/peak stresses and crashing load efficiency (CLE) are calculated.

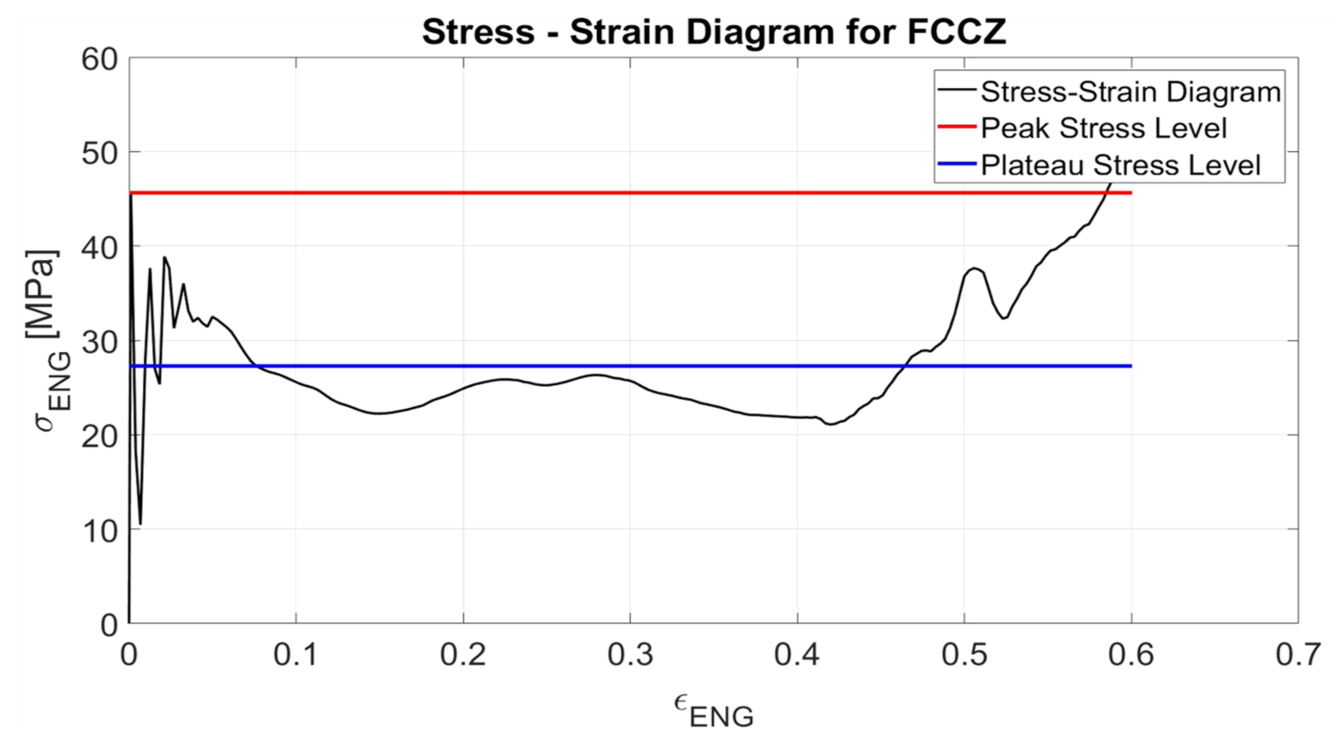
Results

Results from static simulations offer a starting perspective of the cells characteristics:

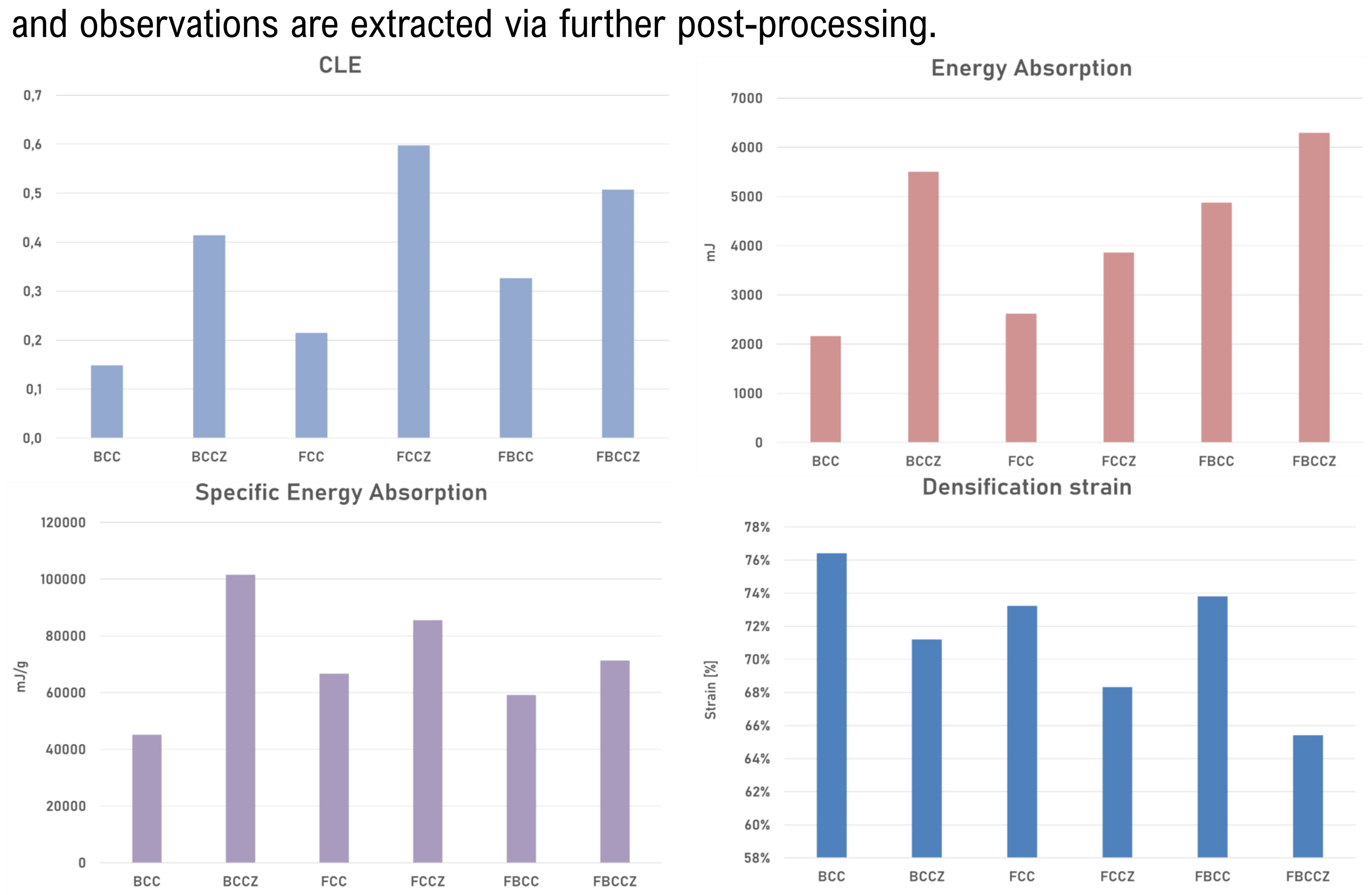


While SEA shows the compromise between energy absorbed and mass, reaction force is important because, besides being strictly related to EA, a low reaction force means that inertial reactions are limited. It is clear how fcc/fccz are the best from the point of view of SEA; bcc and fcc shows lower reaction force. Deeper results are given by dynamic crashing simulations:





Stress-strain diagrams obtained show typical cellular solids behavior: once this is confirmed, senseful parameters that could lead to appropriate construction guidelines and observations are extracted via further post-processing.



EA and SEA levels are quite different from the ones obtained with static simulations because of the effect of the densification: bccz, among reinforced cells, presents the highest densification strain therefore a high EA and the highest SEA. From the point of view of the CLE, fccz performs the best results, presenting a low peak stress and a high plateau stress. Finally, fbccz obtains once again highest pure EA.

Conclusions

First, it can be concluded that vertical reinforcement is always efficacious: therefore, conclusions are given is terms of –z cells.
Cells work in different ways: bccz is extremely good for total crashing, because of its high densification point (only dynamic simulations could unveil this). Instead, fccz, though not performing best SEA, is the lightest reinforced cell that has been analyzed. Therefore, this cell can be employed for non-total crashing phenomenon and also, it gained the highest CLE resulting as the cell performing the most efficient load path. While fbccz performs high EA, though SEA is limited because of its mass. Also, the methodology employed for this investigation results into a good perspective of the topologies selected: going from static simulations (used as a benchmarking analysis) to more specific tests can be useful to better understand phenomenon that could be initially hidden, also considering future designs.

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