A modified honeycomb for better energy absorption capacity

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A joint initiative of

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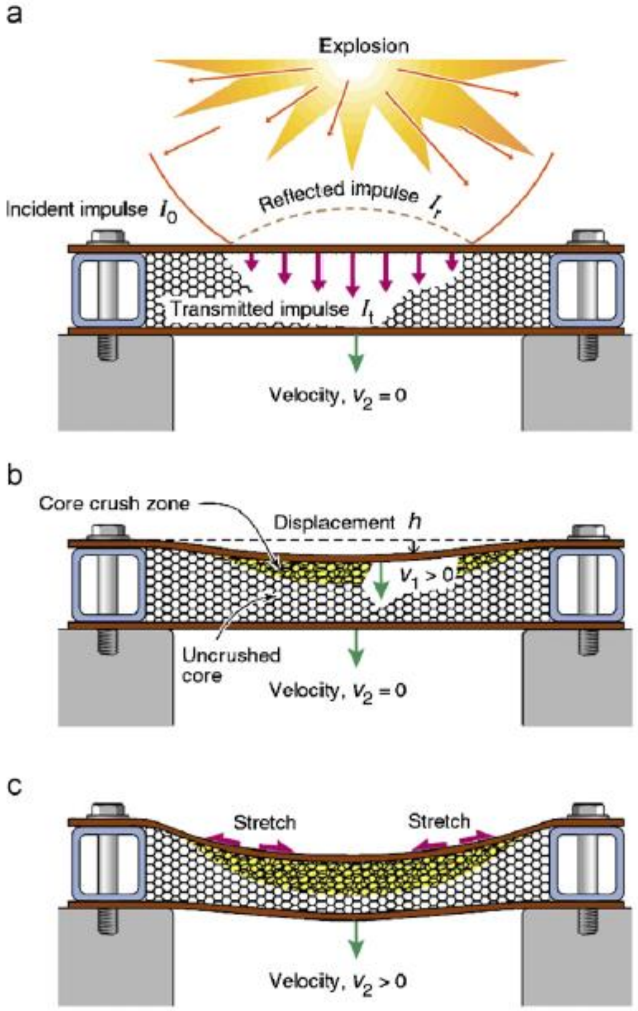
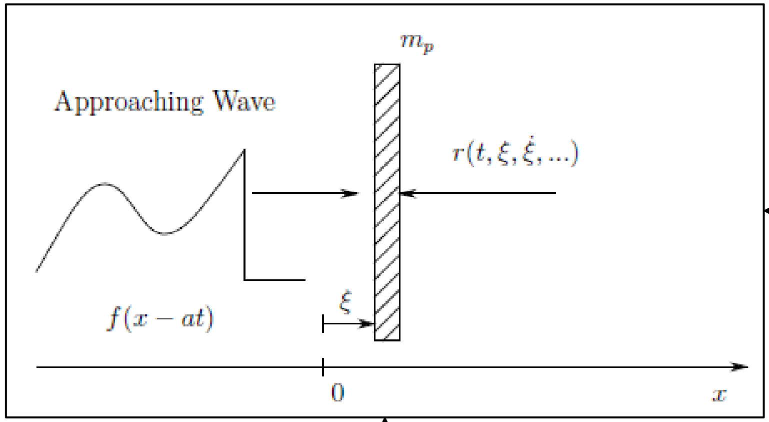
Introduction to sacrificial claddings

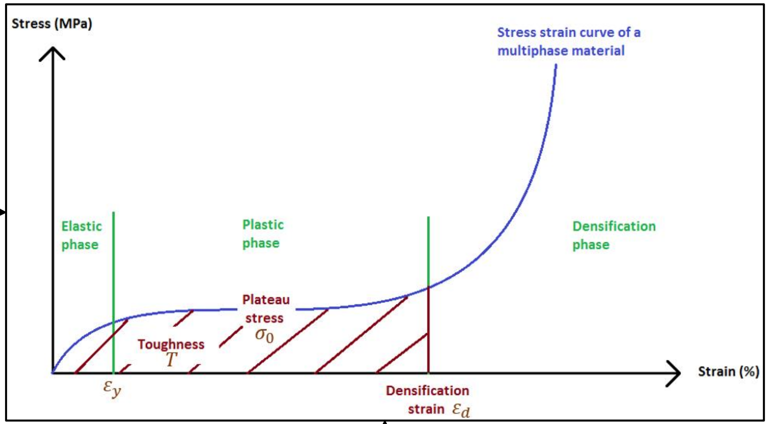


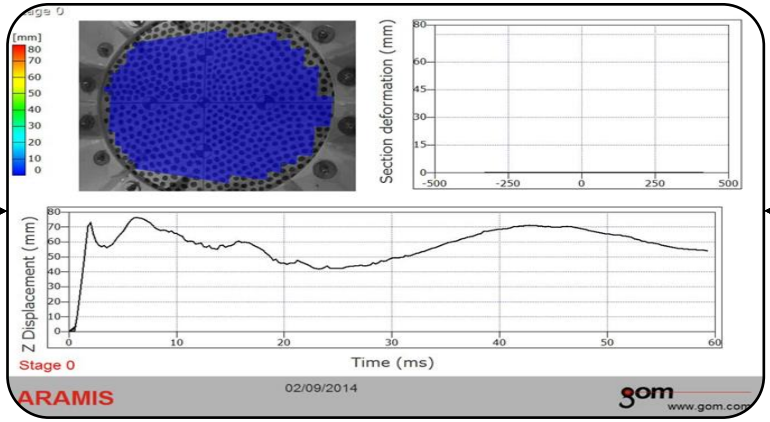
From Dharmasena

a) Blast interaction with the front plate: FSI effects and energy conversion/redirection



b) Front plate interaction with the core: load transmission, shock transmission and energy dissipation mechanisms

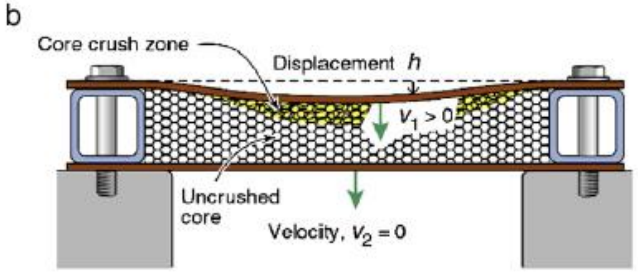




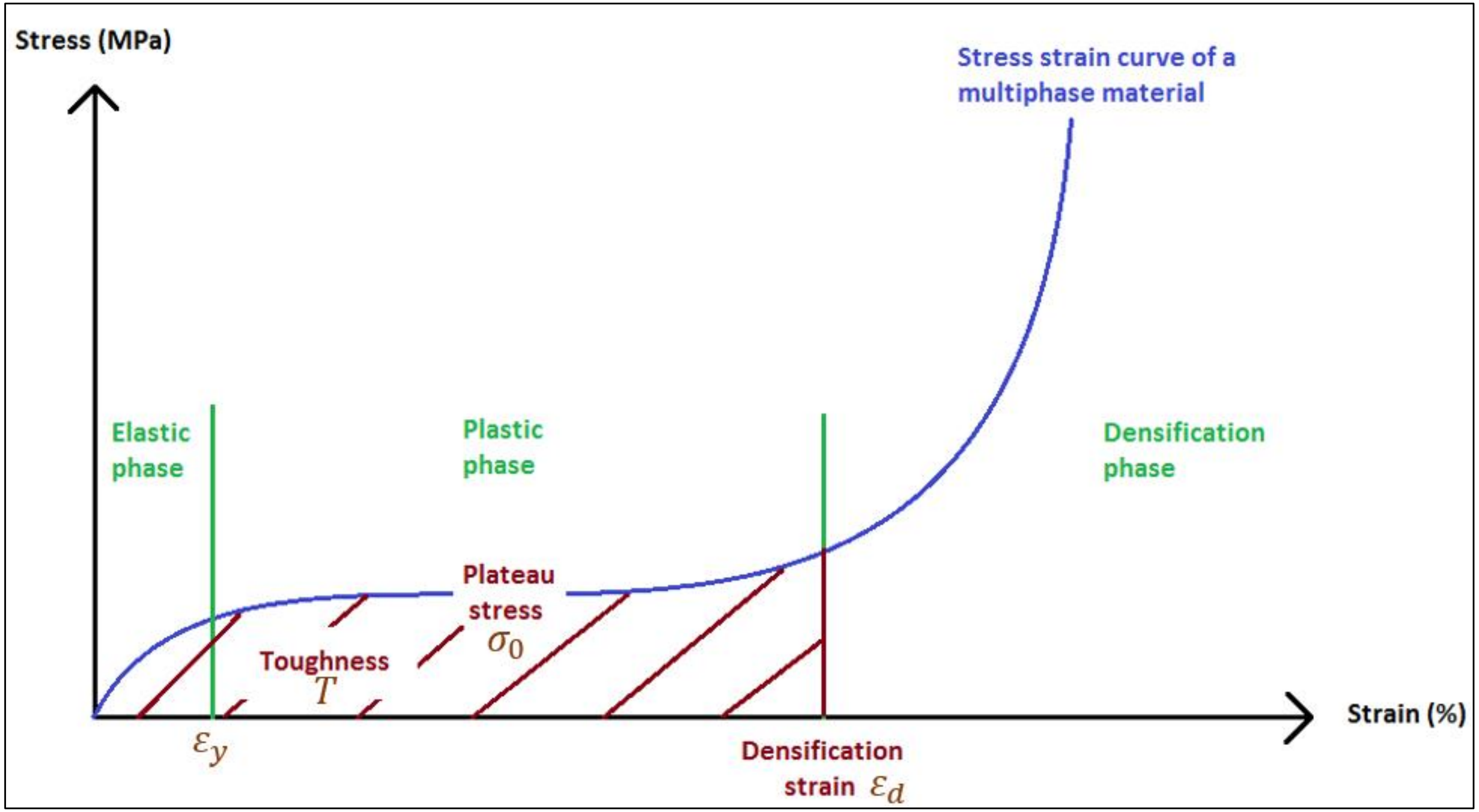
c) Core interaction with the rear plate: deformation of the panel and influence of imperfections and boundary conditions

a) Blanc, Lebaillif, Bufalo, Experimental analysis of fluid–structure interaction between a blast wave and a sandwich add-on armor, AIP Advances **12**, 055105 (2022)
b) Blanc, Jung, Diebels, Kleine, Sturtzer. Blast wave mitigation with galvanised polyurethane foam in a sandwich cladding. Shock Waves 31.6 (2021): 525-540.

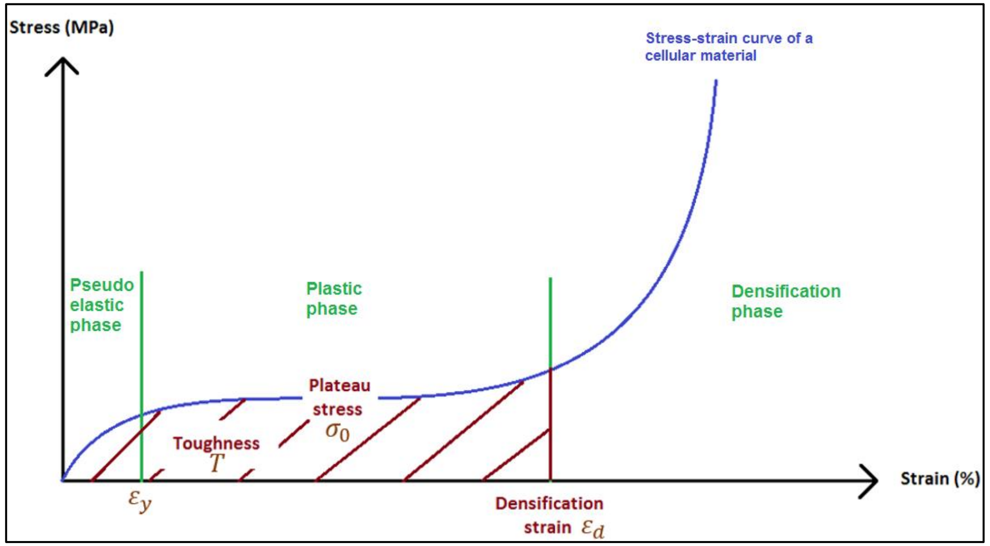
Introduction to the behavior of cellular materials

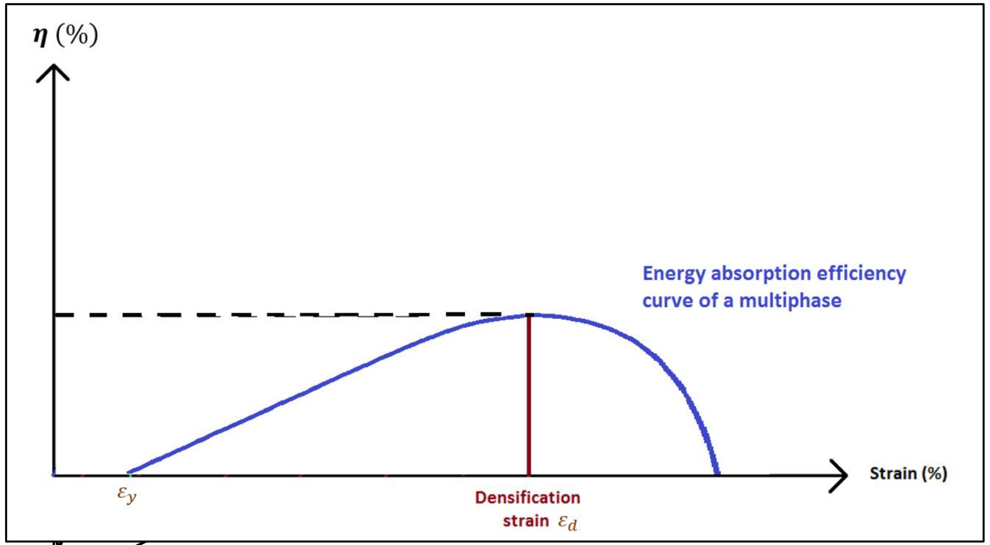


b) Front plate interaction with the core: load transmission, shock transmission and energy dissipation mechanisms



Methodology

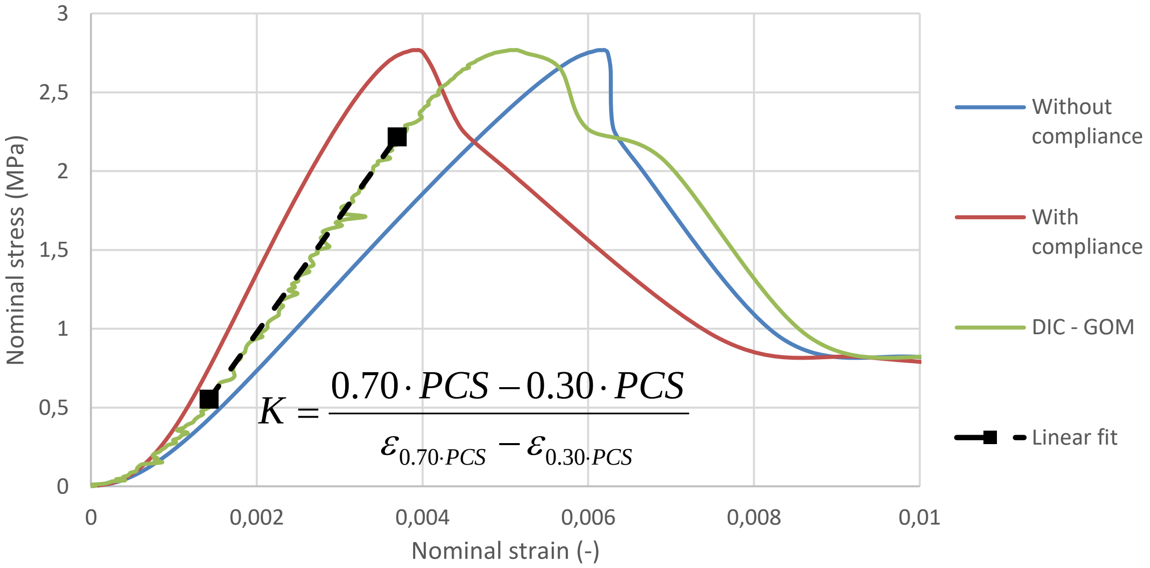




Li Q.M., Magkiriadis I., Harrigan J.J., 2006, *Compressive strain at the onset of densification of cellular solids*, Journal of Cellular Solid 42, Issue 5, pp. 371-392

$$\eta(\varepsilon) = \frac{1}{\sigma(\varepsilon)} \int_{\varepsilon_y}^{\varepsilon} \sigma(\varepsilon) d\varepsilon \qquad \sigma_0 = \frac{\int_{\varepsilon_y}^{\varepsilon_d} \sigma(\varepsilon) d\varepsilon}{\varepsilon_d - \varepsilon_y} \qquad T = \int_0^{\varepsilon_d} \sigma(\varepsilon) d\varepsilon \approx \sigma_0 \cdot \varepsilon_d$$

Bulk modulus computation is chosen following this methodology



Cellular materials

Introduction: cellular materials and absorbers

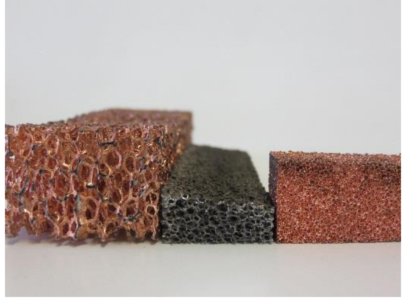
A) Granular Materials: chunks of a material

Perlite

Hydrated potassium polyacrylamide

B) Stochastic Materials: irregularly organized

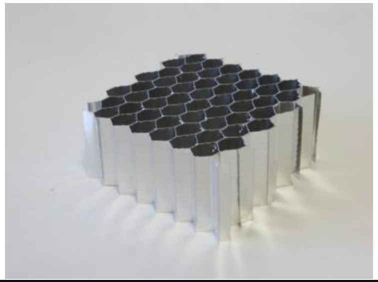
Concrete foam



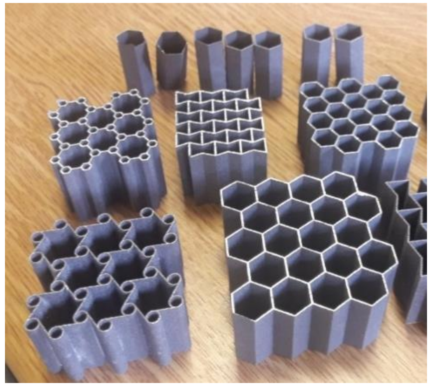
Galvanized foam

Aluminium Metal foam

C) Prismatic structure: regularly organized (1D)

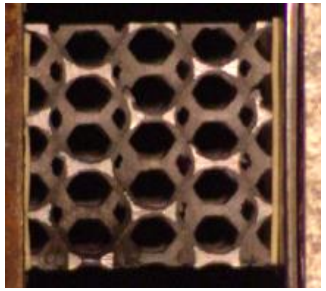


Honeycomb (Alu, Aramid, cardboad)



3d Printed material

D) Lattice structure: regularly organized (3D)

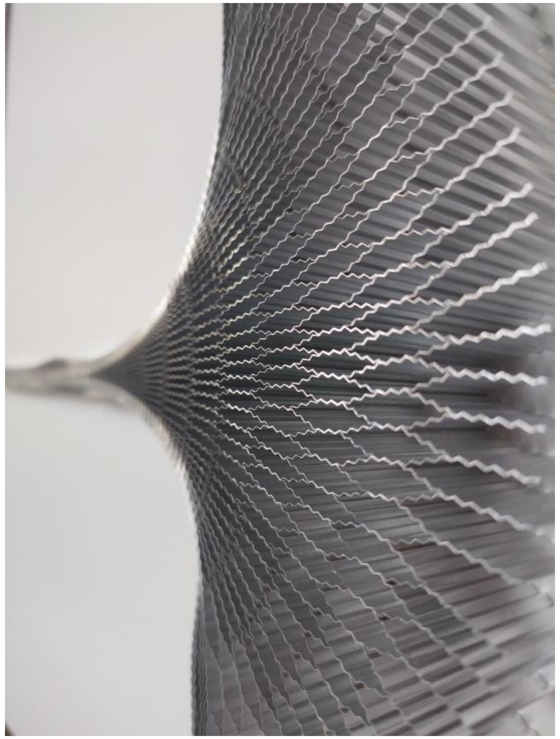


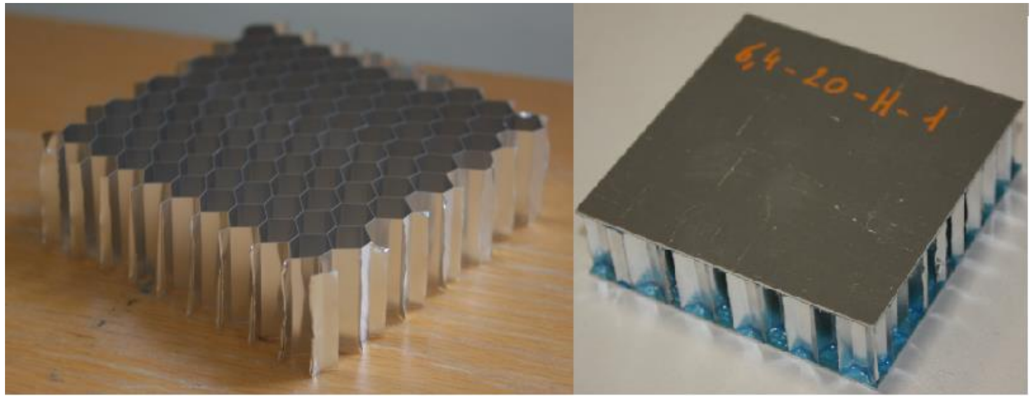
Casted lattice

Honeycomb samples

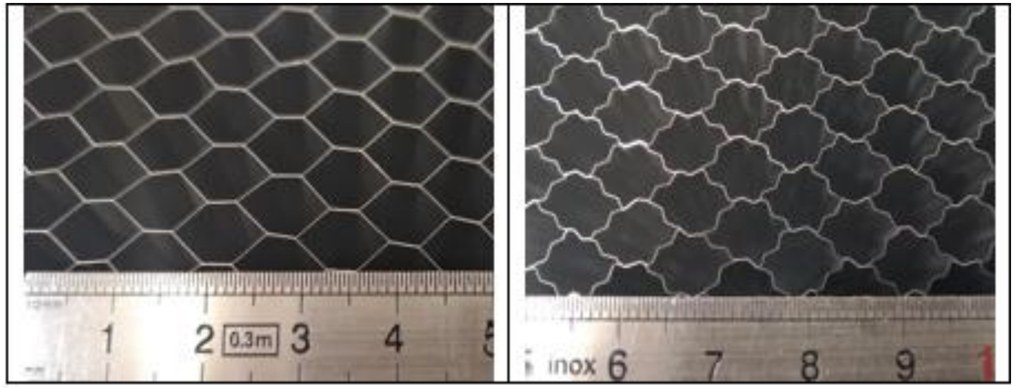
Parameters of the honeycomb :

- Squared area : 75 x 75 mm^2
- Height: 20 / 60 / 100 mm
- Cell size: ϕ6.4 / ϕ9.5
- Sheet thickness: 40 / 60 µm
- Density: ≈ 42 kg.m^{-3}
- Stabilization: Half of the samples, with two 0.8 mm thin aluminium sheets glued with “prepreg epoxy Hexcel Redux 609”
- Cell topology: Hexagonal, Modified





Stabilisation: none (left), 0.8 mm sheets (right)

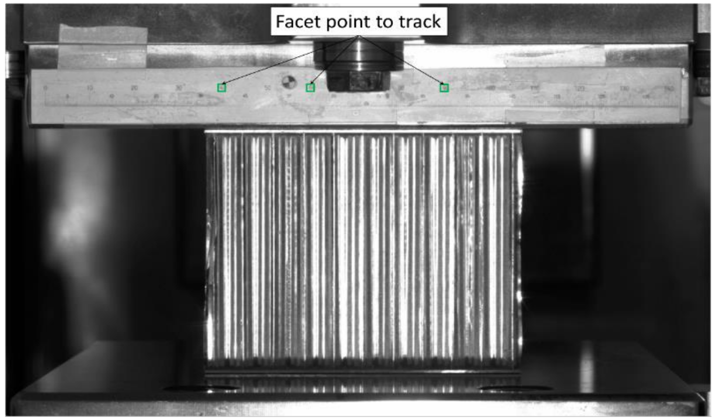


Cell topology: Hexagonal (left), Modified (right)

Experimental set-up: Quasi-Static

<u>Quasi-static tests : INSTRON 250kN 5985</u>

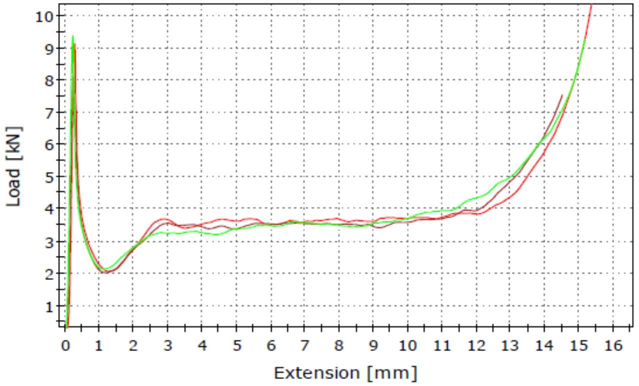
- Measurement through traverse displacement
- Strain-rate: 0.5 mm/min to compute the bulk modulus K (Norm ASTM C365M)
- Strain-rate: 25 mm/min to compute the platau stress σ_0 (Norm ASTM D7336M)
- Automatic change in strain-rate once the stress decreased to 80 % of the ultimate force prior to failure
- Compliance test performed and included in the analysis



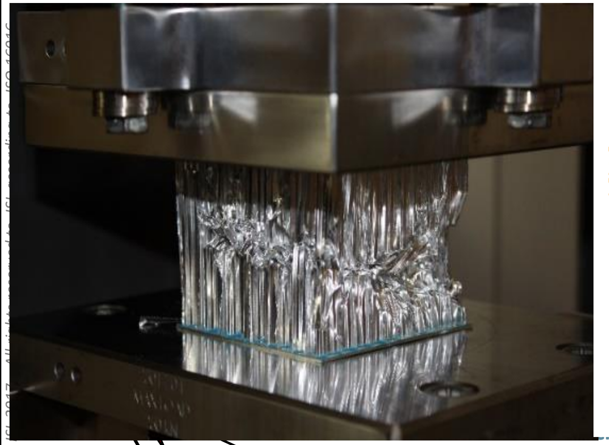
Experimental and numerical set-up

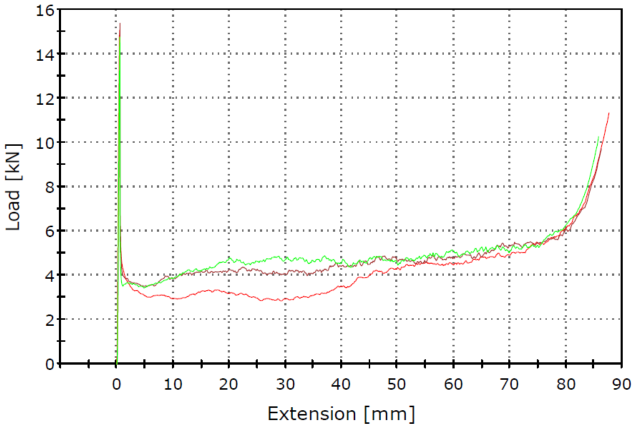
Experimental :

- Repeatability and Dispersion of the results :
  - Low dispersion < 5%: Influence of the structural default on the measured Plastic Collapse Stress



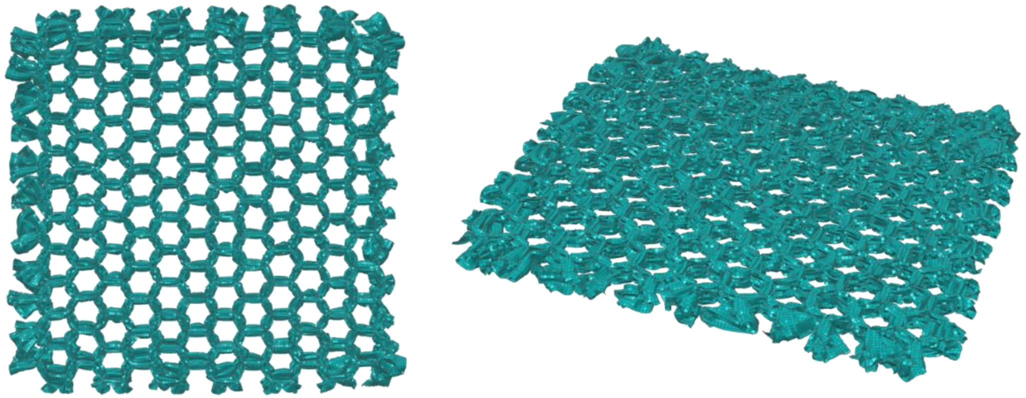
  - High dispersion = 10 %: Catastrophic failure and its influence on the toughness of the sample

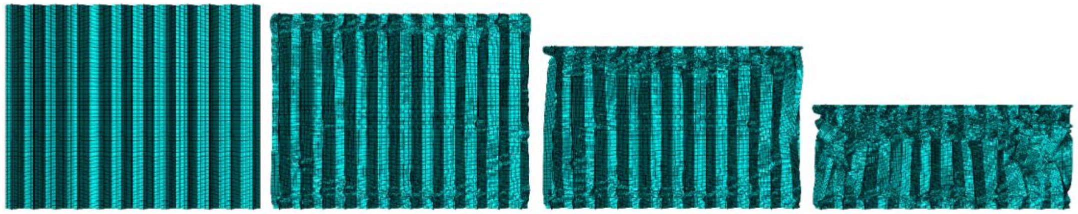




Numerical:

- Full modelization with a 0.5 mm mesh
- Stabilization modelled through boundary conditions





Quasi-static analysis

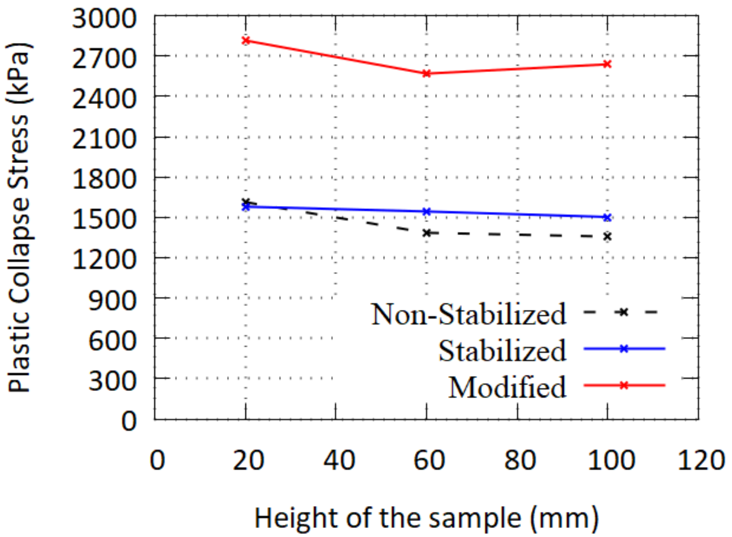
Plateau stress, plastic collapse, densification and toughness

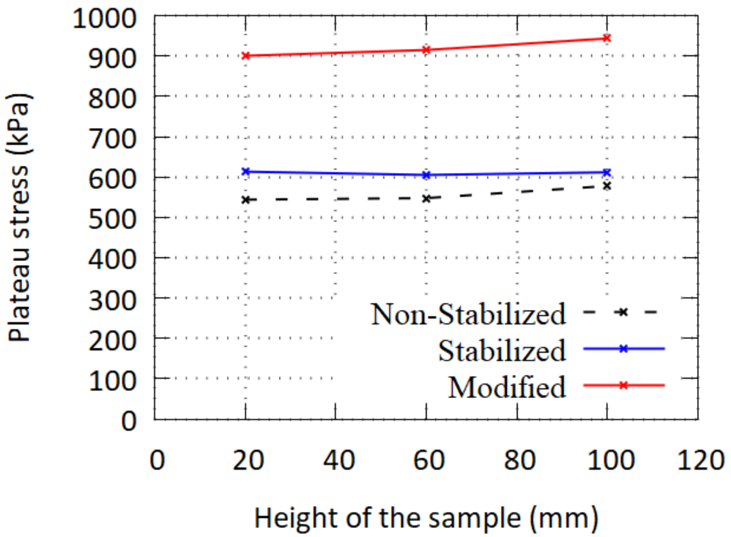
<u>Influence of the stabilization process :</u>

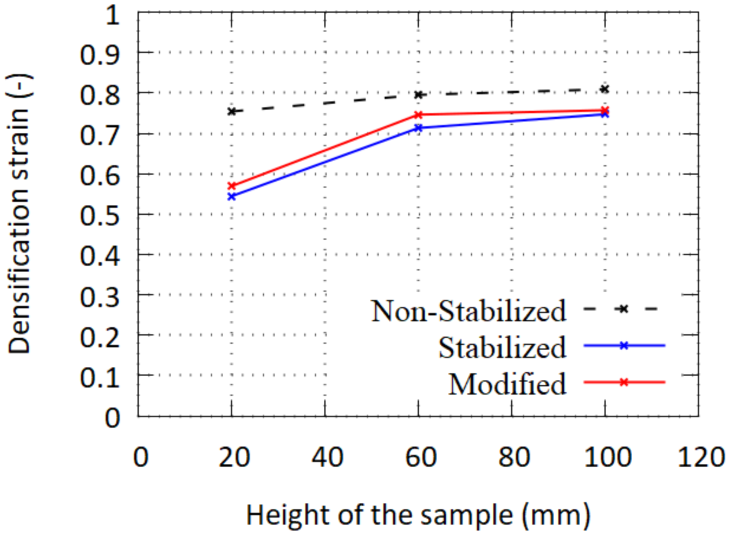
- **Higher plastic collapse stress** except when the height is low enough to have similar boundary conditions with or without the glue
- **Higher plateau stress**
- **Lower densification strain**, simply because the material has less room to deform with the glue. The difference decreases when the ratio height of glue over Height of honeycomb decreases
- **Lower toughness**, because of its definition and how the densification strain is influenced.

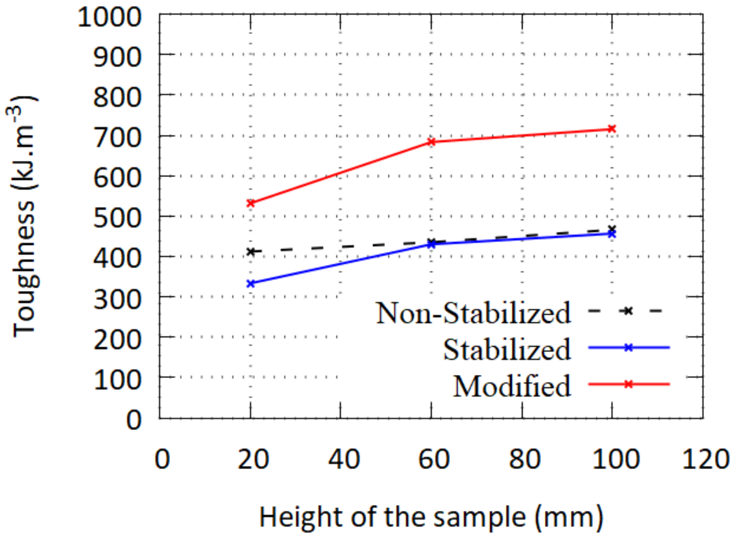
<u>Influence of the height of the Honeycomb :</u>

- **No influence on the plastic collapse** stress BUT … … as the height increases, we are more likely to find default in the material
- **No influence on the plateau stress**
- **Influence on the densification strain**, especially on stabilized sample.
- **Influence on the toughness** following the trend found for the densification strain.









Quasi-static analysis

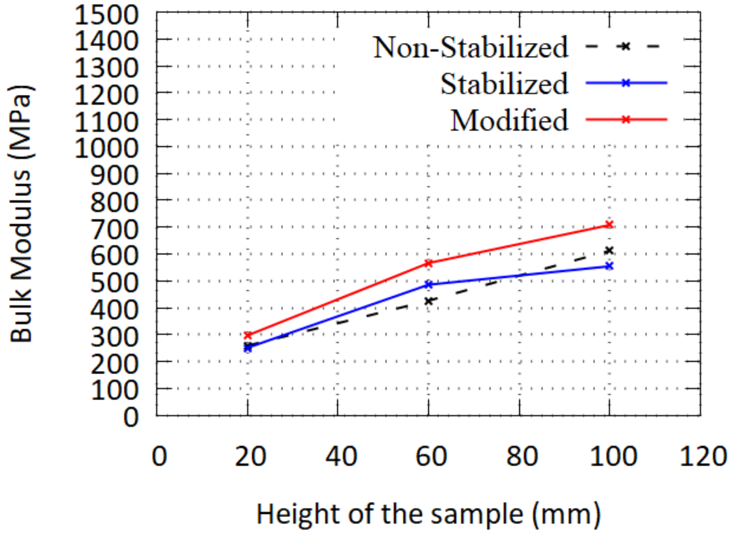
Bulk modulus and cell diameter

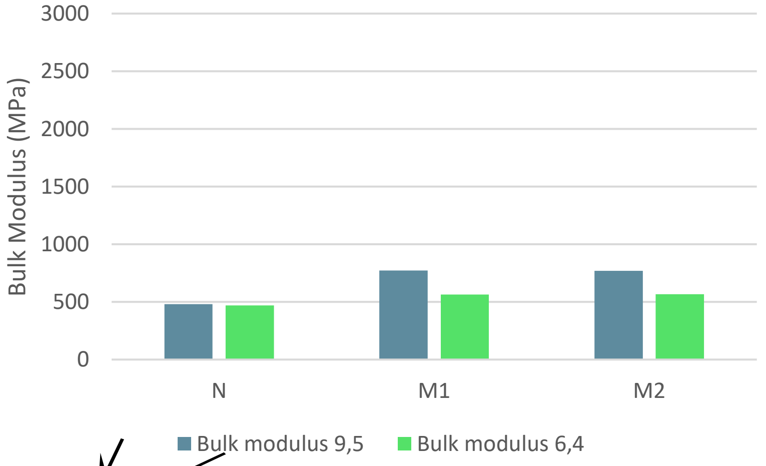
Bulk modulus of the Honeycomb :

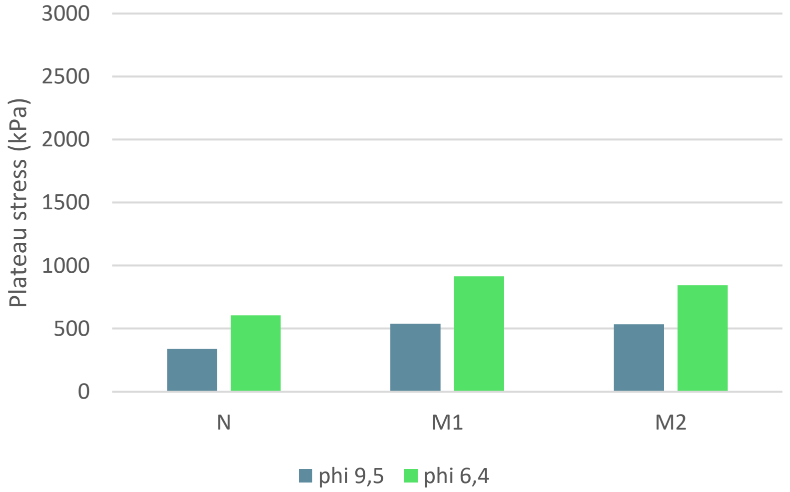
- Increase with the height of the honeycomb, since the ratio F/Δl is known to be constant.
- Be careful if the material is homogenized in a numerical model using the bulk modulus
- Be careful when using the Bulk modulus of a material in application (safety coefficient,…)
- The influence of the stabilization process is unclear yet on the bulk modulus

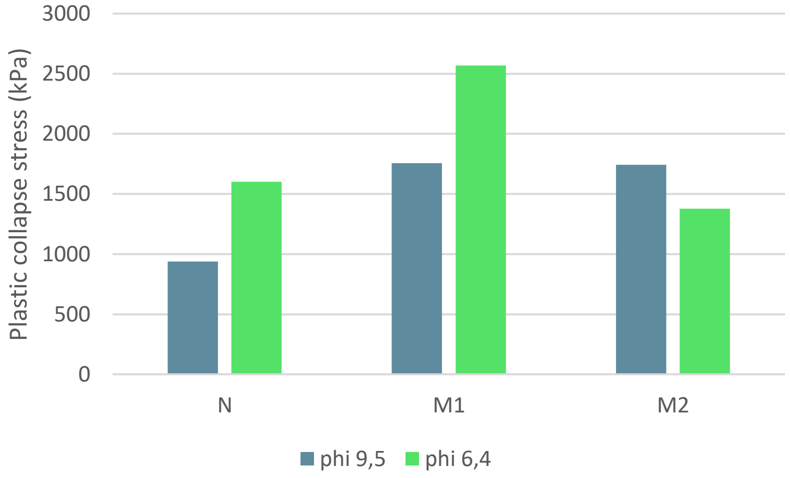
Cell diameter of the Honeycomb :

- A higher cell diameter increases the bulk modulus, while decreasing the plateau stress and plastic collapse stress





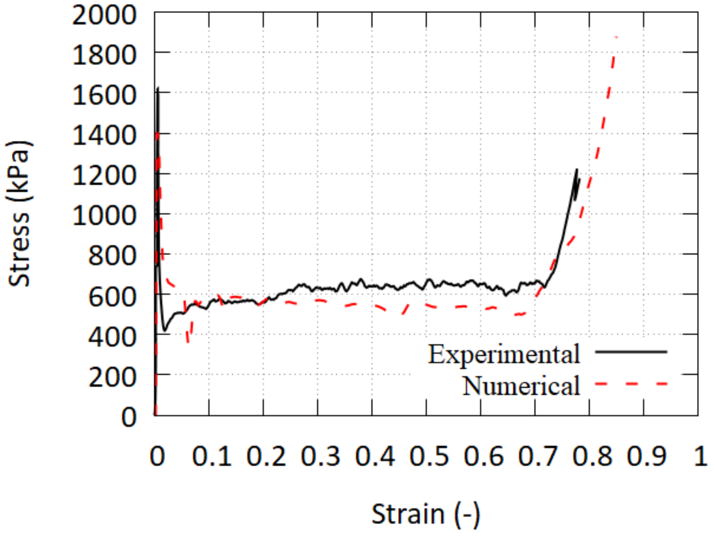


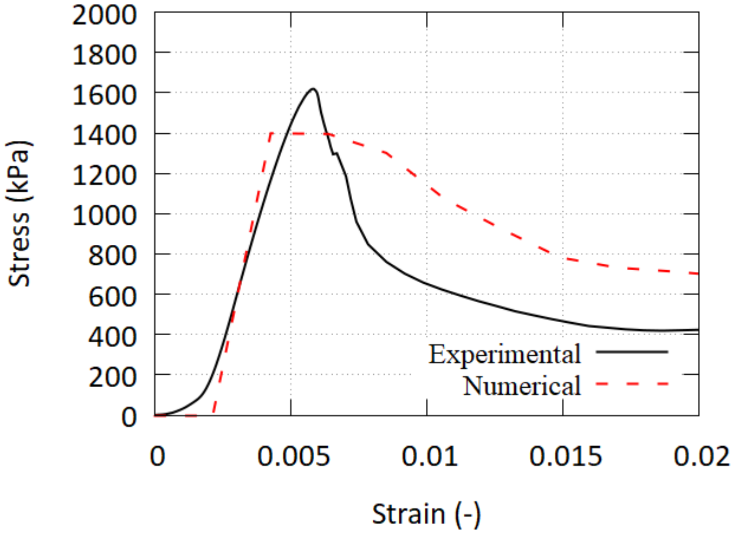


Comparison experimental/numerical

<u>Stabilized Honeycomb (h = 60 mm) :</u>

- Good description of the crushing behavior, including the plastic collapse stress, the plateau stress, the onset of densification and the toughness.
- Good description of the bulk modulus, but not of the rate of collapse

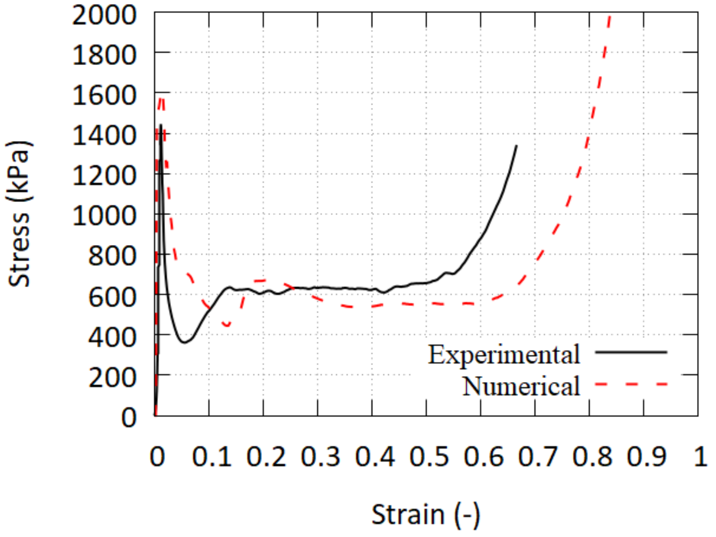


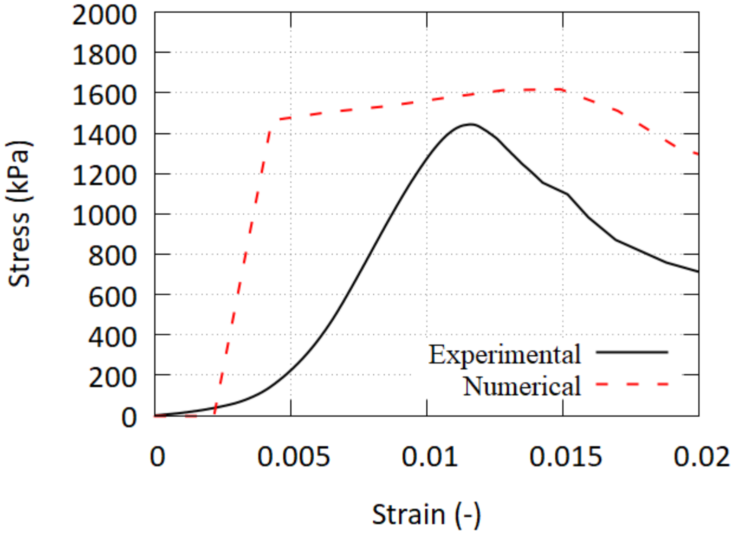


<u>Stabilized Honeycomb (h = 20 mm) :</u>

- Bad description of the crushing behavior, especially the elastic and densification phases

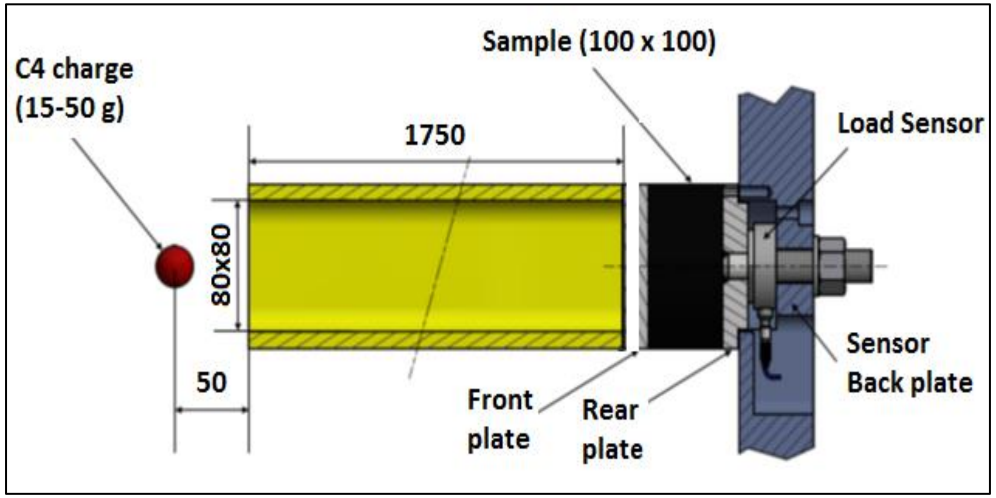
→ Low height stabilised honeycomb needs to be improved in numerical simulations (influence of the glue not negligible anymore on the bucking process)

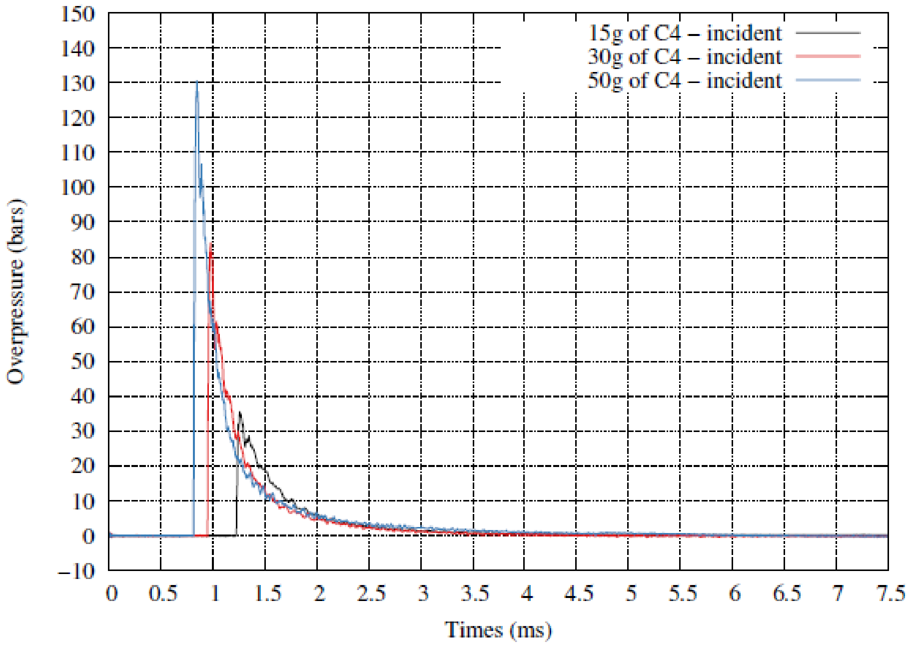


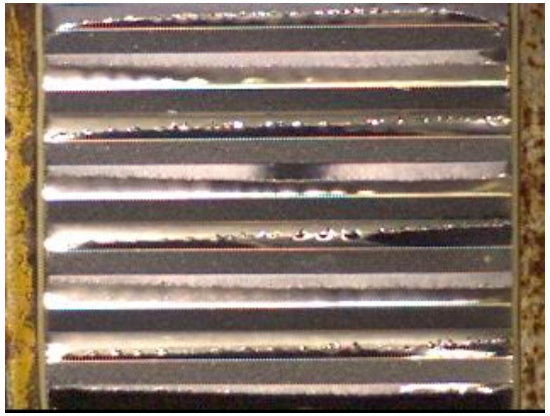


Experimental set-up: Dynamic

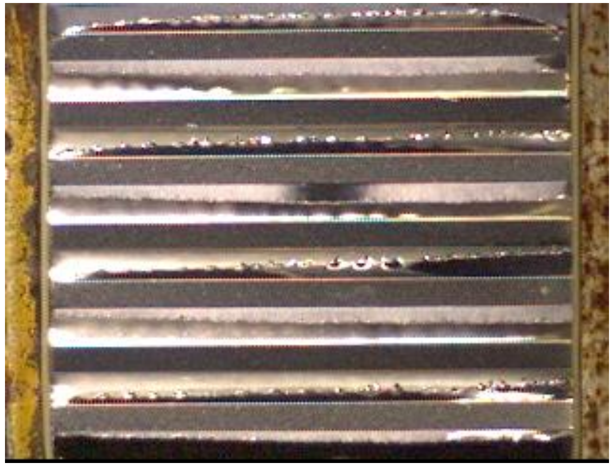
Dynamic tests : Explosive Driven Shock Tube

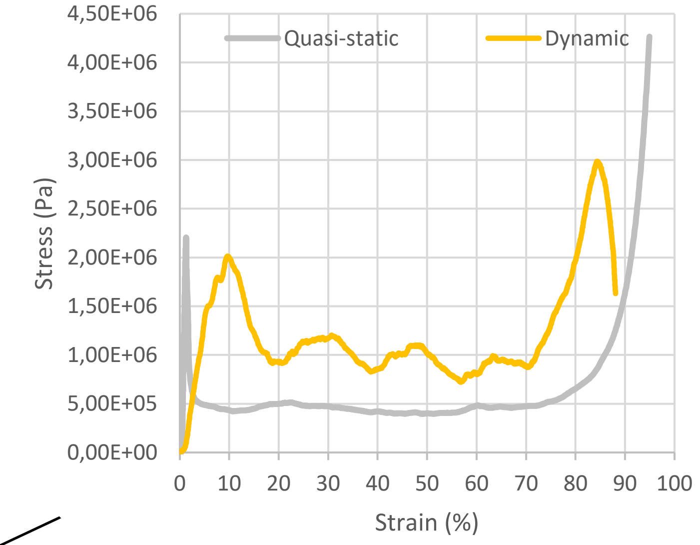


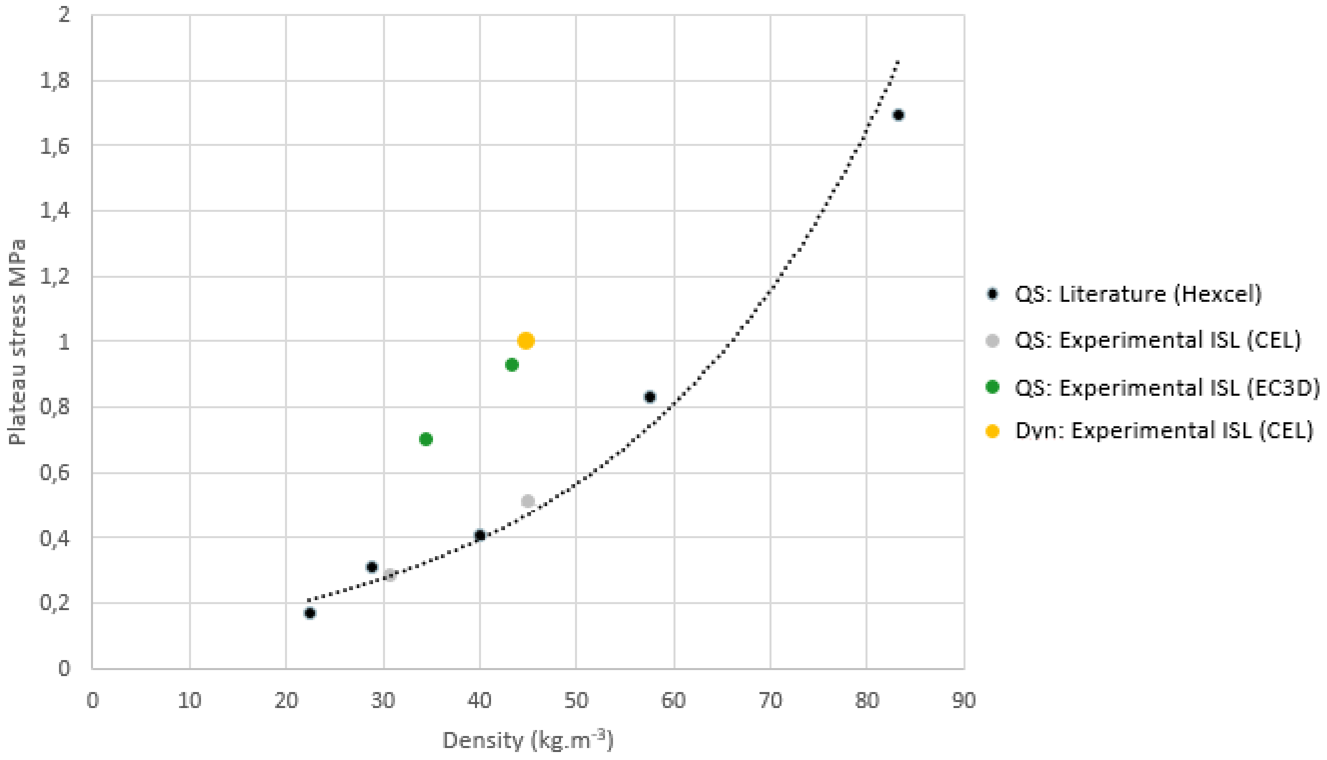




Dynamic testing of Honeycomb

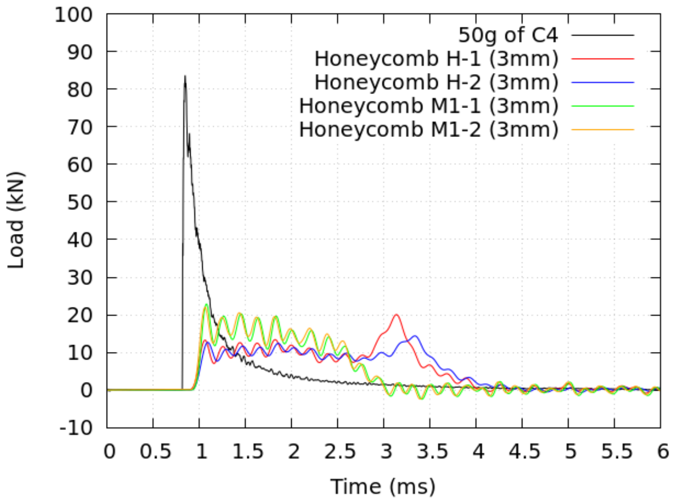


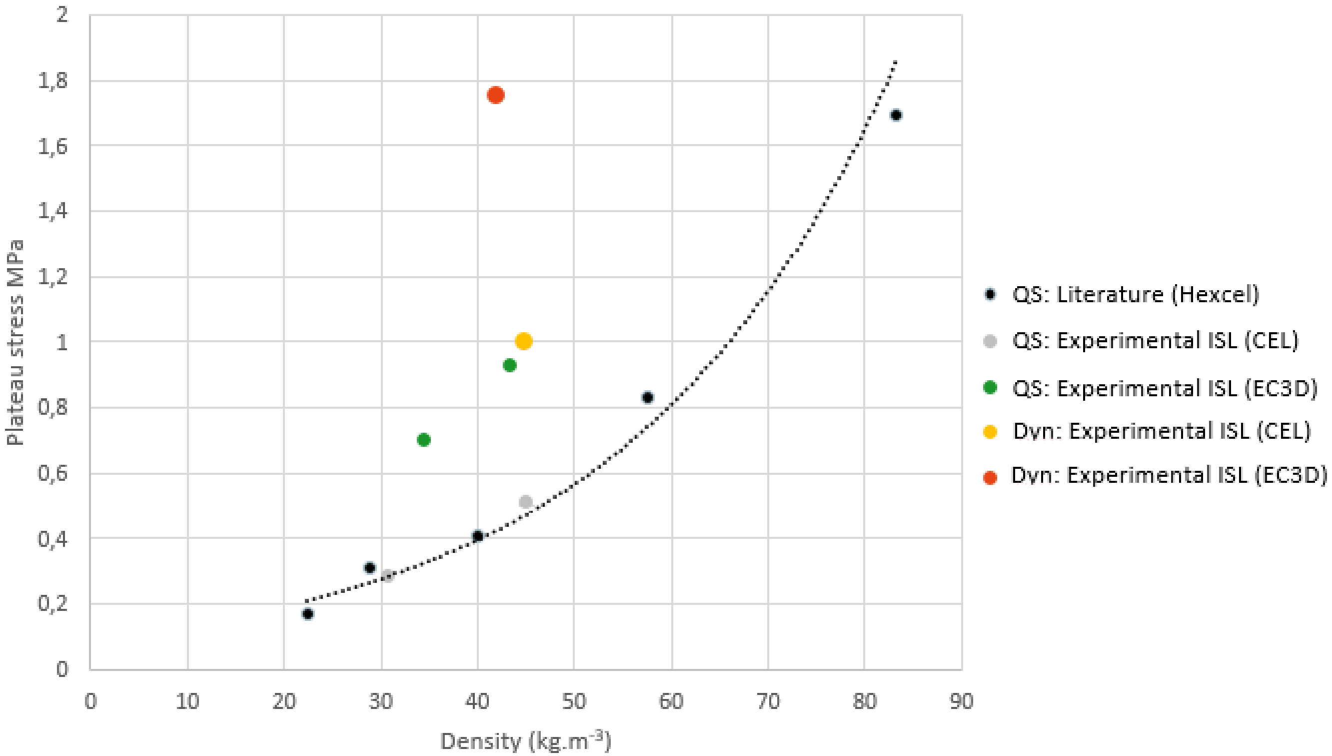




Quasi-static and Dynamic crushing test comparison between hexagonal honeycomb (CEL/HEXCEL) and modified honeycomb (EC3D)

Dynamic testing of Honeycomb





Quasi-static and Dynamic crushing test comparison between hexagonal honeycomb (CEL/HEXCEL) and modified honeycomb (EC3D)

Conclusion

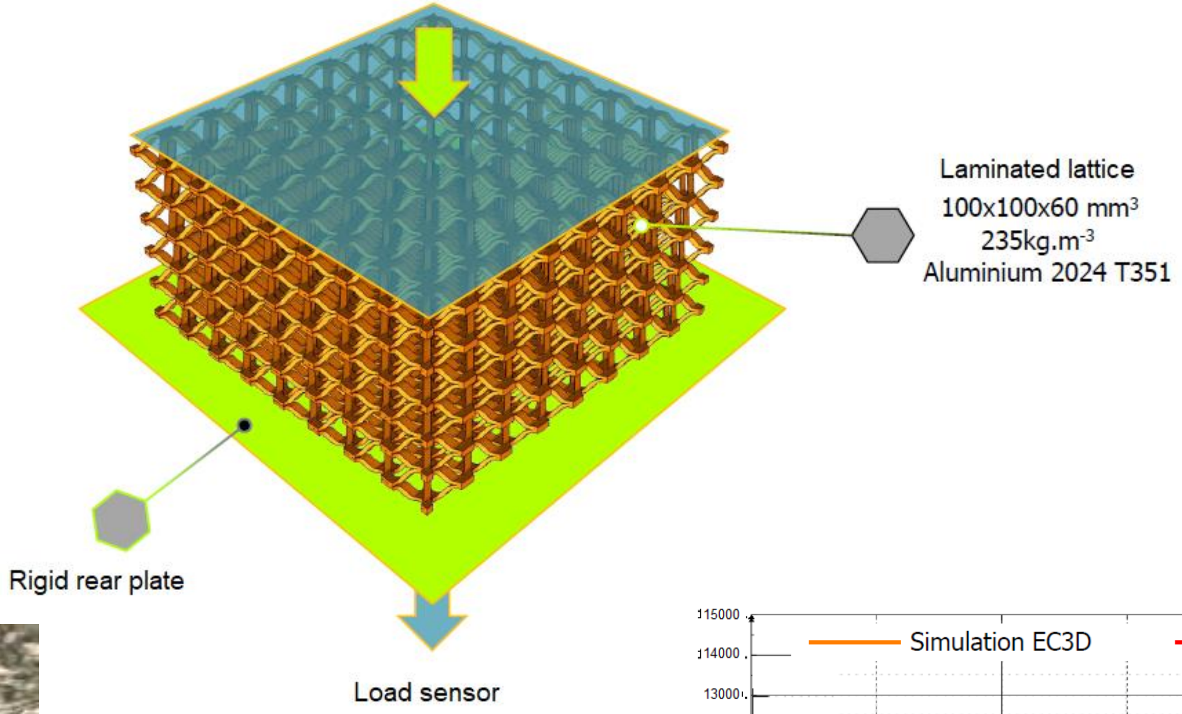
Modified Honeycomb:

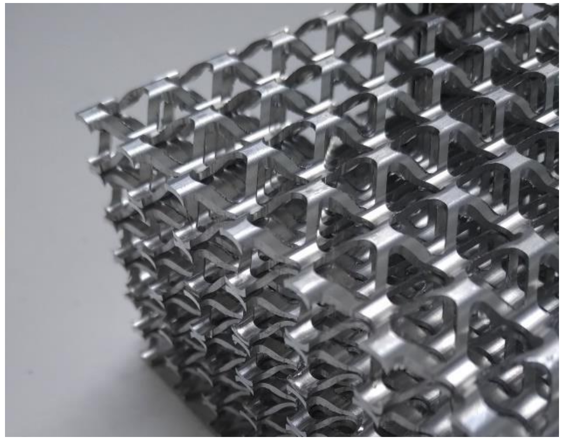
- New parameters are necessary to describe the cells : angle and period of folding.
- At equivalent density, equivalent aluminium, and almost without increasing the price of the manufacturing process, the modified honeycomb is significantly higher on a mechanical point of view than the hexagonal/classic honeycomb
- This also means that at equivalent efficiency, a material saving close to 30 % is expected.

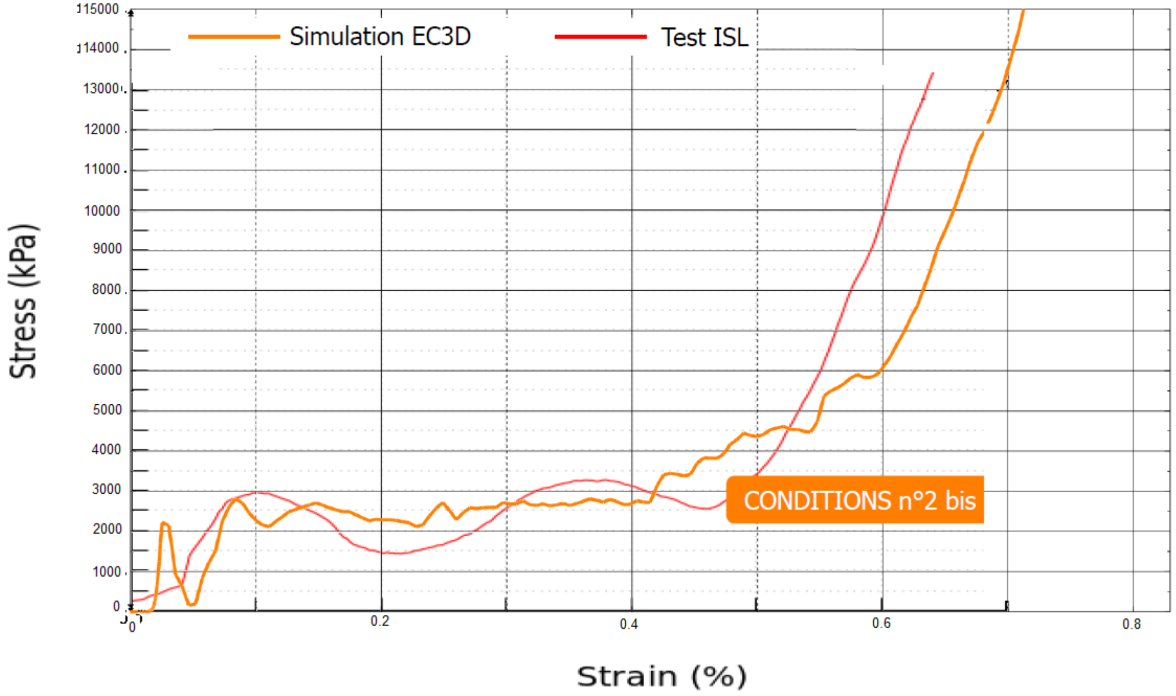
Stabilization and height of the honeycomb:

- Structural aspect are already known, but honeycomb users should be careful with the manufacturer datasheet, for which tests are performed in normalized conditions

Perspectives







Thank you for your attention

Many thanks to all my colleagues for their help:

Researchers: T. Schunck, F. Rondot, M.-O. Sturtzer
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Group leader: J.-F. Legendre