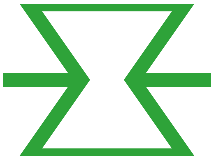
(In)efficacy of Architected Auxetic Materials for Impact Mitigation

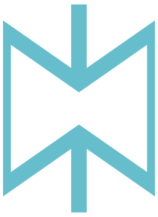
Investigations of Energy Absorption and Force Distribution

T. Gärtner[*†], L. Amaral[†], R. Dekker[†], A.M. Diederen[†], A. Niessen[†], D. van Veen[†], and S.J. van den Boom[†]

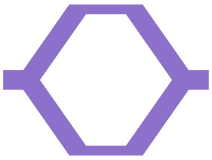
[†]*Netherlands Institute for Applied Scientific Research (TNO)* [*]*Delft University of Technology*



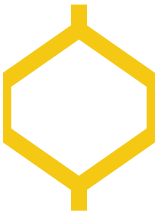
$E_y = 2.49\,\mathrm{GPa}, m = 5.5\,\mathrm{g}$



$E_y = 2.49\,\mathrm{GPa}, m = 5.98\,\mathrm{g}$



$E_y = 2.48\,\mathrm{GPa}, m = 3.99\,\mathrm{g}$



$E_y = 2.49\,\mathrm{GPa}, m = 4.12\,\mathrm{g}$

Figure 1: Investigated unit cells

Background

Auxetic materials are claimed to offer beneficial capabilities for impact mitigation, such as higher indentation resistance and energy absorption. However, the efficacy of lattice meta-materials as protective layer is not only defined by the global resistance properties, but also by the peak loads transmitted to the protected structure. These load-transmission characteristics w.r.t. the material architecture are the target of this investigation. We chose to compare an auxetic re-entrant honeycomb, a rotated by 90° variant, a conventional honeycomb (W), and a conventional honeycomb (L) (Fig. 1), with the same equivalent Young's modulus.

Physical Modeling

The unit cells form structures of approx. 130 mm × 65 mm with a strike-face of half the width (∼ 65 mm) on top and a solid base at the bottom. The strike faces are impacted by a plunger weighing 1.2 kg at $70\,\mathrm{m\,s^{-1}}$. Images of the samples after the test are shown in Fig. 2. The rotated re-entrant structure shows a distinct peak at 0.7 ms in Fig. 3. The re-entrant structure shows a less distinct peak at 0.9 ms. Both conventional honeycomb structures (**W** and **L**) do not show distinct peaks and spread the loading out over a longer impact time.

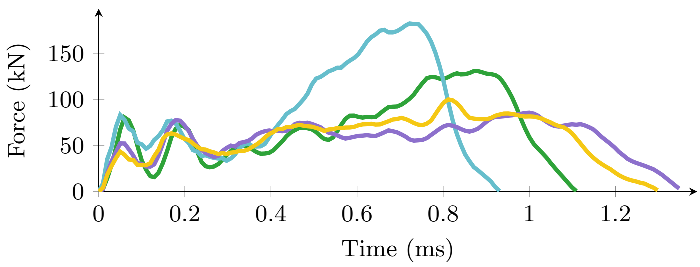


Figure 3: Force on the back-face over time from experiments

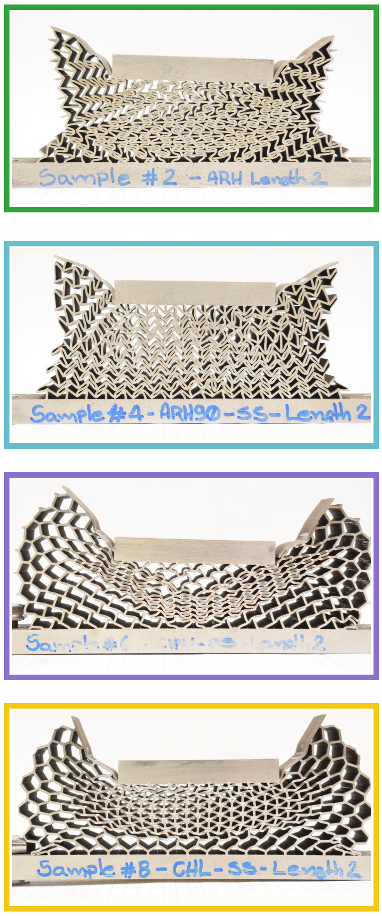


Figure 2: Test samples after the experiments

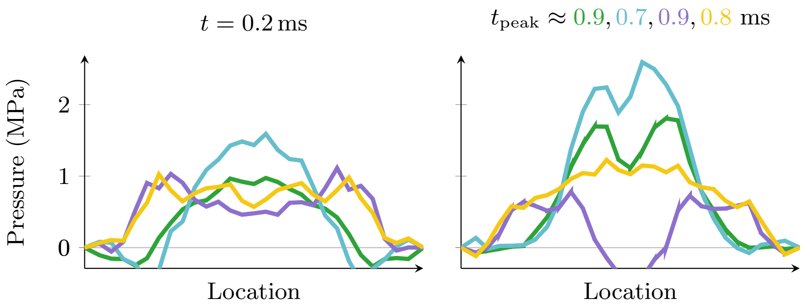


Figure 4: Pressure over the back-face from simulations

Numerical Modeling

For a better understanding of the processes in the material, the experimental setup was remodeled using plane-strain elements in a commercial FE code. Using numerical experiments, loads can be extracted at arbitrary locations. Looking at the pressure distribution at the bottom of the samples (Fig. 4), we can see, that the material densification of auxetic structures also leads to a load densification on the side facing the protected structure. This effect is both observable at time of equal force transmission and at time of the highest peak load.

Discussion

The auxetic structures (both re-entrant and rotated re-entrant) show a higher peak-load in time (Fig. 3) and location (Fig. 4) compared to the conventional honeycombs (**W** and **L**). These results show that the efficacy for impact mitigation is not solely determined by the initial configuration of the lattice, but requires a deeper understanding of the processes inside through time and space.

Further Investigations

To quickly model different loading scenarios at different patch configurations further numerical experiments are conducted using nonlinear Timoshenko beams in a custom FE framework. Initially results showcasing the purely elastic case are available. Further investigations, including material nonlinearities, are being conducted.

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