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COMPUTATIONAL MODELING AND EXPERIMENTAL TESTING OF A NEW FOAM- FILLED GRADED AUXETIC PANEL

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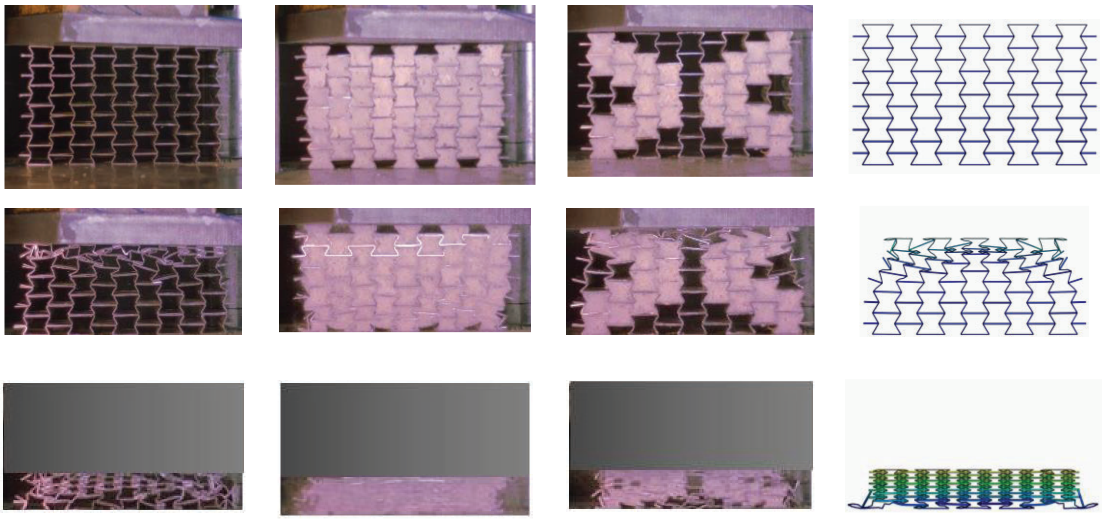
ABSTRACT
Auxetic topologies have superior energy-dissipation properties and can be employed as lightweight impact-energy absorbers. The objective of this work is to investigate the behaviour of new re-entrant auxetic graded aluminium panels filled with polyurethane foam in an auxetic pattern using both computational and experimental methods. The sandwich panel and its validated FE model showed high Specific Energy Absorption (SEA) providing auxetic response up to very large strains. The proposed panel could be a promising solution for modern crash absorption systems or blast protection elements.

INTRODUCTION
The lightweight nature and impact energy absorption of cellular structures have led to their widespread application in engineering [1]. Studies found that auxetic metamaterials (with negative Poisson's ratio) provide improved energy dissipation compared to conventional cellular topologies [2, 3]. Foam-filled sandwich panels are frequently used in building construction. Nevertheless, due to shear failure of the foam core or delamination between the face sheet and the core, this form of sandwich panel cannot withstand extreme impact [4]. As a result, the purpose of this work is to investigate the behaviour of a new re-entrant graded aluminium panel filled with polyurethane foam in an auxetic pattern. Performance is evaluated using quasi-static and dynamic drop tower experiments as well as advanced non-linear finite element modelling. This study looked at six distinct auxetic panels. Each panel has six re-entrant auxetic layers and is constructed by corrugating and gluing twelve aluminium sheets. The geometry of the fabricated auxetic panels was based on the numerical parametric study of Al-Rifaie and Sumelka [5] which was recently validated experimentally by Al-Rifaie, et al. [6]. The sheet thickness and PU foam content of the six auxetic panels vary. The first three non-graded auxetic panels feature uniform corrugated sheet thicknesses of 0.8 mm, 1.0 mm, and 1.2 mm throughout the whole panel. The fourth graded auxetic panel (Figure 1a) was made with varied sheet thicknesses (two layers of 0.8 mm, two layers of 1 mm, and two layers of 1.2 mm). The last two graded samples were filled with PU foam as a full-filled graded panel (Figure 1b) and an auxetic-filled graded panel (Figure 1c). The auxetic-filled arrangement was used to introduce multiscale auxetic behaviour to the panel, where filling may create additional auxetic effect.

Auxetic panels were tested quasi-statically using the universal testing equipment INSTRON 8801 at a position-controlled crosshead rate of 0.5 mm/s. The nominal stress-strain responses were estimated using the samples' original dimensions. In addition, drop tower testing was performed, which included a drop sledge with various masses guided by two 6 m tall columns. The overall weight of the impacting mass was 99.5 kg, and the loading velocity was 10 m/s, resulting in impact energy of 4975 J. Computational modelling was performed using LS-DYNA implementing 5 mm fully-integrated shell elements with 5 integration points throughout the thickness. The foam inserts were modelled with fully integrated 3D elements. The aluminium of the auxetic layers was modelled with an elastoplastic material model utilising strain hardening and rate dependence. Foam inserts were modelled with a crushable foam material model.

RESULTS AND CONCLUSIONS

The experimental and computational findings looked at stress-strain relationships, deformation patterns (Fig. 1), specific energy absorption, crash force efficiency, and Poisson's ratio. Foam-filled panels demonstrated better specific energy absorption and more stable deformation than non-filled panels. The numerical models successfully captured mechanical and deformation behaviour and may be utilized for future virtual testing of different combinations. The detailed results of this research are thoroughly presented in [7].



a) non-filled graded b) full-filled graded c) auxetic-filled graded d) numerical model

Fig. 1 Drop-Tower testing and numerical modelling of the auxetic panels considered in this study

REFERENCES

[1] H. Al-Rifaie, "Novel energy-absorbing auxetic sandwich panel with detached corrugated aluminium layers," *Vibrations in Physical Systems,* vol. 34, pp. p. 2023215-1-12, 2023.

[2] N. Novak, M. Vesenjak, and Z. Ren, "Auxetic cellular materials-a review," *Strojniški vestnik-Journal of Mechanical Engineering,* vol. 62, pp. 485-493, 2016.

[3] H. Al-Rifaie and W. Sumelka, "Improving the Blast Resistance of Large Steel Gates-Numerical Study," *Materials,* vol. 13, p. 2121, 2020.

[4] F. Usta, H. S. Türkmen, and F. Scarpa, "High-velocity impact resistance of doubly curved sandwich panels with re-entrant honeycomb and foam core," *International Journal of Impact Engineering,* vol. 165, p. 104230, 2022.

[5] H. Al-Rifaie and W. Sumelka, "The developement of a new shock absorbing Uniaxial Graded Auxetic Damper (UGAD)," *Materials,* vol. 12, p. 2573, 2019.

[6] H. Al-Rifaie, N. Novak, M. Vesenjak, Z. Ren, and W. Sumelka, "Fabrication and Mechanical Testing of the Uniaxial Graded Auxetic Damper," *Materials,* vol. 15, p. 387, 2022.

[7] N. Novak, H. Al-Rifaie, A. Airoldi, L. Krstulović-Opara, T. Łodygowski, Z. Ren*, et al.*, "Quasi-static and impact behaviour of foam-filled graded auxetic panel," *International Journal of Impact Engineering,* vol. 178, p. 104606, 2023.