# COMPRESSION PERFORMANCE OF CEMENTITIOUS MATERIAL-FILLED AUXETIC PANEL COMPOSITE STRUCTURES

**Mohammad Hajsadeghi [(1)], Emmanuel Owoichoechi Momoh [(1)], Amila Jayasinghe [(2)], Raffaele Vinai [(1)], Prakash Kripakaran [(1)], Ken E Evans [(1)], John Orr [(2)]**

(1) Department of Engineering, Faculty of Environment, Science and Economy, University of Exeter, Streatham Campus, Exeter, EX4 4QF

(2) Department of Engineering, University of Cambridge, CB3 0FA

Abstract ID Number (will be given by the scientific editors/organizers): *509095*.

**Keywords:** Auxetic Mesh, Cementitious Materials, 3D Printing, Confinement

## Author contacts


| Authors | E-Mail | Fax | Postal address |
|---|---|---|---|
| Mohammad Hajsadeghi | m.hajsadeghi@exeter.ac.uk | - | EX4 4QF |
| Emmanuel Owoichoechi Momoh | e.o.momoh@exeter.ac.uk | - | EX4 4QF |
| Amila Jayasinghe | jaas2@cam.ac.uk | - | CB3 0FA |
| Raffaele Vinai | r.vinai@exeter.ac.uk | - | EX4 4QF |
| Prakash Kripakaran | p.kripakaran@exeter.ac.uk | - | EX4 4QF |
| Ken E Evans | k.evans@exeter.ac.uk | - | EX4 4QF |
| John Orr | jjo33@cam.ac.uk | - | CB3 0FA |

**Corresponding author for the paper**: Mohammad Hajsadeghi

**Presenter of the paper during the Conference**: Mohammad Hajsadeghi

# COMPRESSION PERFORMANCE OF CEMENTITIOUS MATERIAL-FILLED AUXETIC PANEL COMPOSITE STRUCTURES

**Mohammad Hajsadeghi (1), Emmanuel Owoichoechi Momoh (1), Amila Jayasinghe (2), Raffaele Vinai (1), Prakash Kripakaran (1), Ken E Evans (1), John Orr (2)**

(1) Department of Engineering, Faculty of Environment, Science and Economy, University of Exeter, Streatham Campus, Exeter, EX4 4QF

(2) Department of Engineering, University of Cambridge, CB3 0FA

**Abstract**

Findings of the investigation on the compressive behaviour of 3D-printed auxetic panels filled with cementitious materials through experimental testing are briefly outlined in this extended abstract. Four different auxetic reinforcing structures including re-entrant, tetra-anti-chiral, missing rib, and double arrowhead made out of polyethylene terephthalate glycol, i.e. PETG, are examined. It is shown that the confinement effect of the auxetic mesh considerably enhances the compressive strength and ductility of the panels.

**Keywords:** Auxetic Panels, Cementitious Materials, 3D Printing, Confinement

## 1. INTRODUCTION

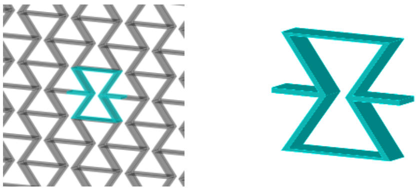
Auxetic materials, coined in 1990 by Evans et al. [1] shrink and expand transversely under axial compression and tension, resulting in a negative Poisson's ratio (NPR). They offer advantages like lower densities, high shear and indentation resistance, crashworthiness, energy absorption, damping capability, and better acoustic behaviour. Applications include crash barriers, breakwaters, sandwich structures, filters, base isolation, blast shields, reinforcement, seismic bracing, pipelines, shells, and fasteners [2].

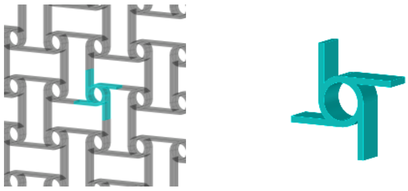
The fascinating potential of creating auxetic 3D-printed panels has gained attention. Using advanced manufacturing techniques like 3D printing, scientists can precisely control the structure and materials of these panels. This approach allows the creation of intricate auxetic patterns with exceptional mechanical properties. Auxetic 3D-printed panels showcase improved flexibility, strength, and durability, making them ideal for use in various fields like aerospace, automotive, and architecture. Engineers can precisely design these panels to meet specific demands due to their customisable geometry and composition, opening up new possibilities for tailored performance.

Researchers are studying the integration of auxetic materials into construction materials, such as mortar. The inclusion of auxetic elements such as fibres or panel structures into cementitious mortar makes the mortar stronger, tougher, and lighter than traditional mortar, making it useful in construction projects. Recent state-of-the-art research indicates that auxetic materials and structures have significant potential when application-specific materials are carefully selected and the bonding between the cement matrix and the auxetic phase is enhanced [3]. In this research, the application of 3D-printed auxetic structures as reinforcement of cementitious mortars is assessed experimentally [4,5].

## 2. EXPERIMENTAL TESTING AND DISCUSSION

Four different auxetic patterns including re-entrant (RE), tetra-anti-chiral (TAC), missing rib (MR), and double arrowhead (DAH) are investigated, as seen in Figure 1. The auxetic panels are all 200mm × 200mm × 30mm with weight of 240 grams (see Figure 2).


(a) Re-entrant


(b) Tetra-anti-chiral


(c) Missing rib

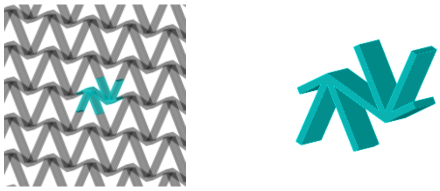

(d) Double arrowhead

Figure 1: Auxetic Structures

The tensile strength of PETG material and the mortar's compressive strength, $f_{ck}$, are respectively 37 MPa and 6 MPa. The unreinforced panels (with no auxetic mesh embedded) are also tested as a reference. For each auxetic structure, three specimens are prepared and tested on the 28$^{th}$ day after casting, where the average results are considered as the overall behaviour of each panel type.


(a) Re-entrant


(b) Tetra-anti-chiral


(c) Missing rib


(d) Double arrowhead

Figure 2: Cementitious Material-Filled Auxetic Panel Composite Structures

The specimens are statically loaded in a displacement-controlled manner at a loading rate of 1 mm/min. The specimens are pre-loaded with force of 50N to minimise any initial slack or movement in the testing setup. Hence, it is accurate enough to read the displacement from the movement of the cross-head.

The load-displacement graphs of the specimens are presented in Figure 3(a) to (e), where the average result of each auxetic pattern is also depicted. The average results of the plain, RE, TAC, MR, and DAH panels are shown in Figure 3(f). The peak loads, stiffness and the energy absorption up to the displacement corresponding to the 80% of the peak load are listed in Table 1.

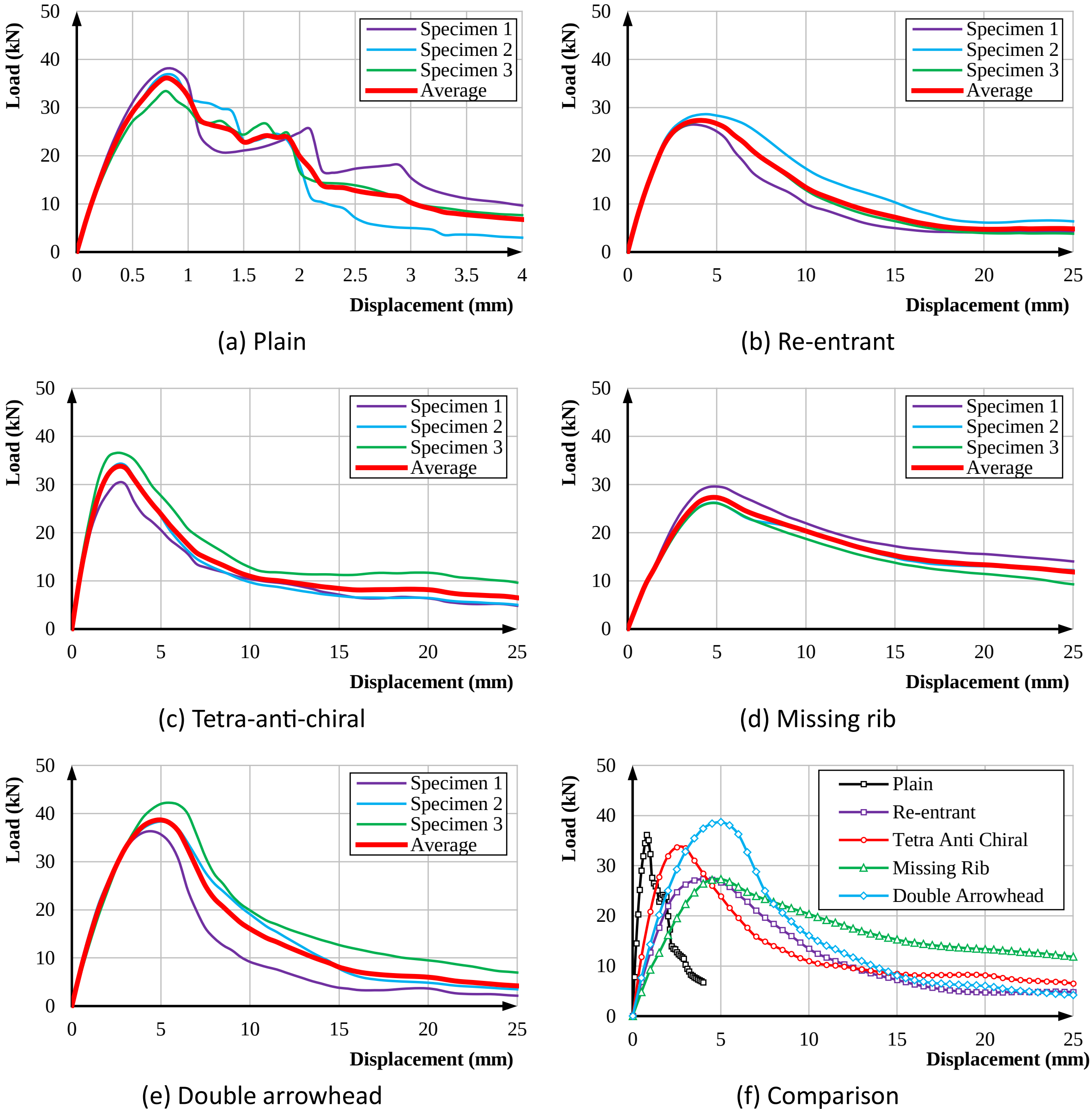


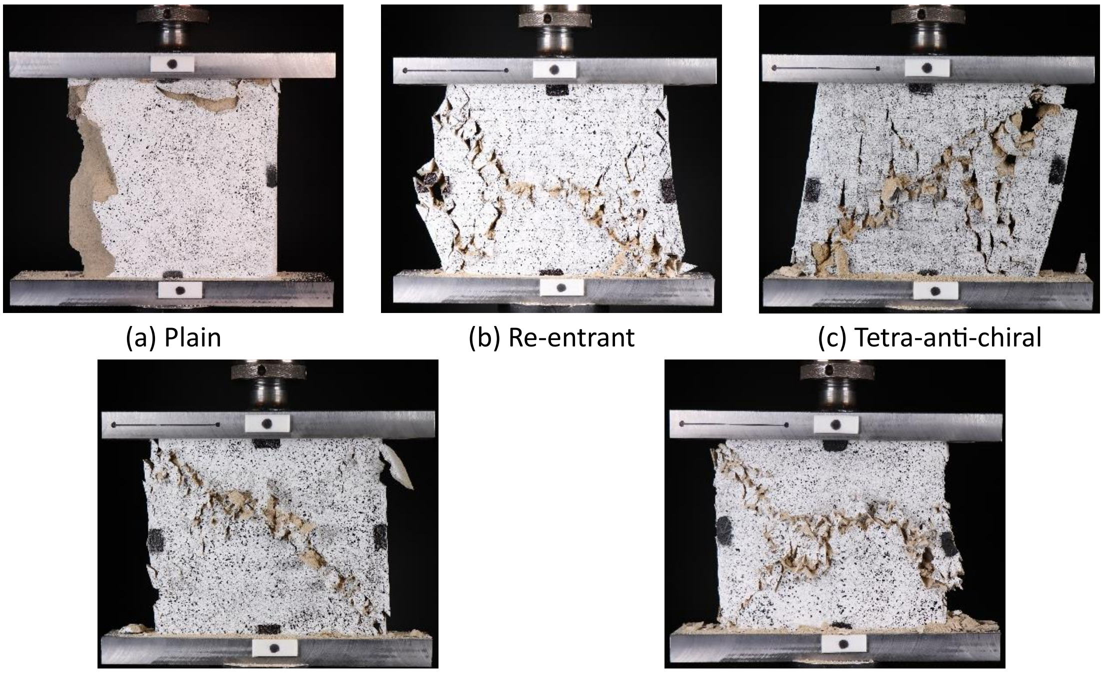

Figure 3: Compression results

Table 1: Peak load, stiffness and toughness

| Parameter | Peak Load (kN) | Stiffness (kN/m) | Toughness* (kN.mm) |
|---|---|---|---|
| Plain | 36.1 | 58026.7 | 27.2 |
| Re-entrant | 27.3 | 9893.3 | 145.9 |
| Tetra-anti-chiral | 33.7 | 13461.2 | 110.9 |
| Missing rib | 27.3 | 7808.5 | 179.4 |
| Double arrowhead | 38.7 | 11696.0 | 191.7 |

* It is calculated up to the corresponding displacement to the 80% of the peak load.

Figure 4 depicts the failure of a specimen from each of the auxetic panel composite structures and plain concrete panels.



(a) Plain (b) Re-entrant (c) Tetra-anti-chiral

(d) Missing rib (e) Double arrowhead

Figure 4: Failure of the specimens

As observed from Figure 3 and Table 1, the embedment of the 3D-printed auxetic mesh within mortar panels generally results in a reduction of their compressive strength, with decreases of 25% for the re-entrant and missing rib patterns and 6% for the tetra-anti-chiral pattern. However, the double arrowhead structure exhibits a slight increase in strength, approximately 7%. Additionally, the auxetic mesh significantly diminishes the stiffness of the panels, with reductions of 82%, 77%, 86%, and 80% for the RE, TAC, MR, and DAH patterns, respectively.

Despite the decay in peak load and stiffness, the auxetic mesh considerably enhances the toughness of the panels. The toughness increases by 4.36, 3.0, 5.6, and 6.0 times for the RE, TAC, MR, and DAH specimens, respectively compared to the unreinforced counterpart.

## 3. CONCLUSION

Results reveal that mortar panels reinforced with 3D-printed auxetic mesh generally possess lower strength and stiffness compared to those of their unreinforced counterpart. However, it dramatically improves toughness of the mortar making it suitable for applications where ductility is needed.

## REFERENCES

[1] Evans, K.E., Nkansah, M.A., Hutchinson, I.J. and Rogers, S.C., 'Molecular network design', Nature 353 (1991) 124.

[2] Xu, Y., Schlangen, E., Lukovic, M., Savija, B., 'Tunable mechanical behavior of auxetic cementitious cellular composites (CCCs): experiments and simulations', Constr. Build. Mater. 266 (Part B) (2021), 121388.

[3] Momoh, E.M., Jayasinghe, A., Hajsadeghi, M., Vinai, R, Evans, K.E., Kripakaran, P., Orr, J., 'A state-of-the-art review on the application of auxetic materials in cementitious composites', Thin-Walled Struct. 196 (2024), 111447.

[4] Guo, M.F., Yang, H., and Ma, L., 'Design and characterization of 3D AuxHex lattice structures', Int. J. Mech. Sci. 181 (2020), 105700.

[5] Jiang, W., Ren, X., Wang, S.L., Zhang, X.G., Zhang, X.Y., Luo, C., Xie, Y.M., Scarpa, F., Alderson, A., and Evans, K.E., 'Manufacturing, characteristics and applications of auxetic foams: a state-of-the-art review', Compos. Part B: Eng. 235 (2022), 109733.