Multi-point hinge displacement characterisation in a 316L additively manufactured re-entrant auxetic

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Abstract. Auxetic structures are metamaterials characterised by a negative Poisson's ratio (NPR) effect [1,2]. In particular, the NPR of re-entrant honeycomb structures arises from coordinated hinge rotation at discrete strut junctions, and applications in fatigue-resistant structures [3] exploit this collective behaviour. Laser powder bed fusion (L-PBF) has emerged as the principal enabling manufacturing technology for these topologies [4]. What matters mechanically is the deformation at these junctions: it is the local hinge motion, not the global load–displacement response, that defines the auxetic behaviour. A bulk load–displacement record captures almost none of this, and finite element models calibrated against the bulk response alone remain poorly constrained. What is needed is simultaneous displacement measurement at many discrete junctions across the gauge section.

Introduction

Standard full-field strain measurement techniques map poorly onto this class of specimen. Conventional digital image correlation (DIC) assumes a continuously patterned surface through which a rectangular subset can be tracked, and for the present lattice (2×2×10 unit cells, inclined-strut thickness $t = 0.625$ mm) that assumption fails on several fronts. A typical DIC subset is 21–41 pixels wide, larger than a single strut at this magnification, so a subset placed on a junction covers both struts and the gaps between them, and the correlation would fail. Individual ligaments also rotate out of the focal plane during loading, violating the planar-deformation assumption of DIC and producing apparent strain artefacts even where subset correlation is nominally successful. A contact extensometer is not a viable fallback either: clip-gauge attachment onto ligaments of this slenderness perturbs the hinge response being measured, and at best yields a single gauge-length extension with no hinge-level resolution.

Methodology

This work uses a different approach, implemented with OpenCV. In the first frame, a small 25×25 pixel template (≈0.98×0.98 mm) is placed on each hinge junction. Each template is small enough to fit entirely within material, so it never spans a void as a DIC subset would. Normalised cross-correlation then locates the same template in every subsequent frame, with sub-pixel refinement of the position. At every frame the match returns a correlation score between 0 and 1, where 1 is a perfect match. By checking this score frame by frame for every junction, tracking quality is monitored throughout the test, and any frame where tracking has been lost can be flagged. As a result, the displacement of each hinge junction is captured individually in both in-plane directions.

Results and Discussion

Re-entrant honeycomb specimens were fabricated from AISI 316L by L-PBF and tested in quasi-static tension (5 kN load cell, 1.0 mm/min crosshead rate). A 5 MP monochrome camera fitted with an 80 mm telecentric lens acquired images at 1 fps at a calibrated spatial resolution of 0.039 mm/pixel. Fig. 1 shows the specimen at the start and end of loading, with zoomed views of a representative tracked hinge junction indicated in red; the lateral expansion characteristic of the auxetic response is directly visible between the undeformed and deformed frames.

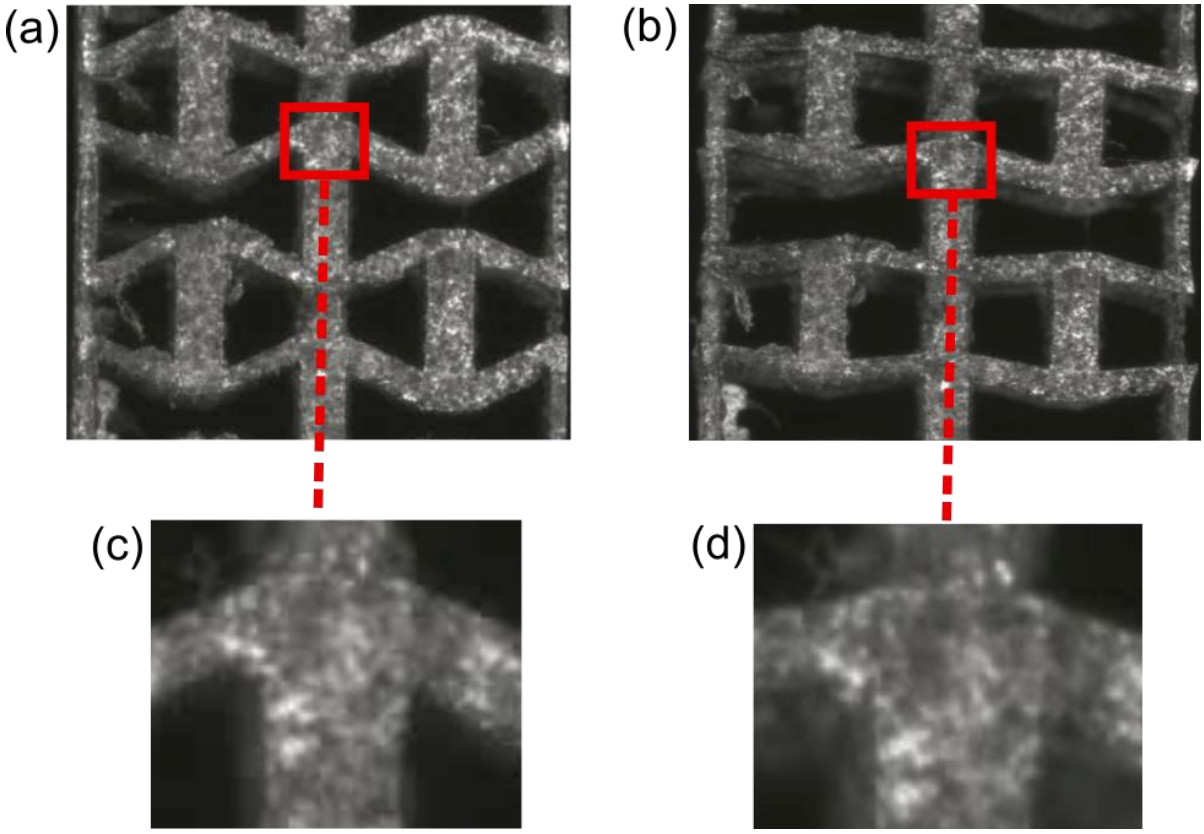

Figure 1. *Image-based hinge tracking before and after tensile loading: (a) first frame of the undeformed specimen and (b) final frame at peak applied displacement, with zoomed views of a single hinge junction in (c) the first frame and (d) the final frame.*

Conclusion

All visible hinge junctions on the specimen front face were tracked simultaneously across the full loading history, yielding coupled axial and lateral displacement records at every junction. The hinge-resolved dataset enables validation of finite element predictions at a resolution inaccessible from global force–displacement records alone, and is used in the associated paper to benchmark beam- and continuum-element formulations of the lattice against per-junction displacement histories. The technique is directly extensible to cyclic and fatigue loading, and its independence from an applied speckle pattern makes it attractive for small or geometrically complex additively manufactured specimens more generally.

References

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