Perspective
Volume 14:1, 2023

Journal of Physical Mathematics

ISSN: 2090-0902 **Open Access**

Passive Topology Morphing Using Contact Connections for Stiffness Tailoring in Sinusoidal Lattice Structures

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Introduction

By rearranging their topology, structures with adaptive stiffness characteristics offer a chance to meet competing design requirements and increase efficiency. Planar lattice structures with rectangle-like unit cells may exhibit elastic buckling or bending of cell walls when subjected to longitudinal compression, which is investigated here as a means of achieving the desired adaptability. Cell walls have the ability to deform and come into contact with other cells when the load intensity is high enough. By utilizing this self-contact, the structure's topology is altered to that of a kagome-like lattice, resulting in the creation of new load paths and the individualized enhancement of the lattice's effective compressive and shear stiffness. We concentrate on macroscopic behavior (lattices of scale 200 mm), despite the fact that this phenomenon is unrelated to characteristic length scale [1].

Description

The analytical stiffness predictions for pre- and post-contact topologies and the finite element analysis of the experimentally observed responses of 3D-printed lattices are highly correlated. A parametric study examines how important geometric and stiffness parameters play a role in important parts of the design space. This topology morphing lattice structure's non-linear responses may provide designers with a new method for customizing elastic properties. Traditionally, structures are built with rigid parts whose deformations are designed to be small, i.e., to stay in the geometrically linear range. However, the use of non-linear, large-deformation components has recently gained traction as a reliable approach to performance improvement. Helical lattices, compliant mechanisms, architected materials, and helical lattices are just a few examples that can be found at a variety of length scales [2].

By allowing structural connectivity to reconfigure to meet operational requirements, the advantages of geometric nonlinearity can be enhanced. Alternate load paths within the structural system are created as a result, resulting in fundamentally different response modes, such as switching from high-compliance to high-stiffness behavior. A phenomenon distinct from the more conventional approach to adaptive design, which merely changes the geometric shape, is the emergence of new connections, which result in the establishment of a novel structural topology. Such contact between unit-cells is frequently linked to failure in architected materials.

However, a few recent metamaterials studies have attempted to program the structure into a different topology through the use of external actuators and materials, resulting in an increase in system complexity. On the other hand, we want to induce a passive topology change in a metastructure by establishing contact connections as applied load increases. This demonstrates a novel approach to the design of straightforward topology-morphing structures that are suitable for load-carrying and energy absorption applications. The structure is intended to remain elastic with non-linear responses that can be repeated and predicted.

The elastic planar response of cellular lattices with a nominally rectangular structure is the focus of this section. The lattice's components may flex or buckle under axial compression. The development of a kagome-like lattice structure as depicted in the effective stiffness characteristics of the structure if the loading is sufficient. Kagome-like lattice structures have a higher shear modulus for an intermediate density range than triangular-like (stretching-dominated) or hexagonal-like (bending-dominated) lattice structures. In addition, kagome-like lattices are easy to fabricate, have desirable transport and heat-dissipation properties, and are more mechanically strong [3].

A topology transformation of this kind is made easier by substituting curved elements for the lattice's straight columns and beams. The critical geometric and stiffness parameters that control the response of the cellular lattice are identified through a parametric exploration of the design space, and these predictions are contrasted with experimental observations made with 3D-printed PLA proof-of-concept demonstrators. The load that corresponds to the undesirable global buckling mode can be found even in a sinusoidal lattice may be less than the load at which contact between cells occurs. As a result, the lattice parameters ought to be chosen to encourage contact between cells.

As bending deformation of the vertical beams causes cell-to-cell contact, increasing the amplitude ratio will encourage this behavior. As a result, the amplitude ratio is emphasized as a crucial parameter that determines which of these deformation modes-global bucking and cell-to-cell contact through bending-happens. By inducing the desired deformation mode, as depicted the compression load required to initiate cell-to-cell contact (the "contact load") is evaluated using geometrically non-linear FE analysis. The material and geometric properties are identical to those of the rectangular lattice. From the top of the lattice down until the first cell-to-cell contact, an analytical rigid surface is used to control the displacement (compression).

Because increasing amplitude ratios decrease the bending stiffness of sinusoidal beams, compressive stiffness decreases with increasing amplitude ratio in the pre-contact regime. However, with the exception of the regime's beginning and ending points, the compressive stiffness does not significantly differ in the post-contact regime. The onset of global buckling causes the compression load to drop abruptly at the end of the post-contact regime. The maximum strain in the lattice during the deformation (i.e., up until post-contact buckling) was found to be lower than the material's yield strain, according to FE analyses. FE analysis and experiments revealed a linear response when unloading the lattice following global buckling after contact [4].

The lattice's compressive stiffness is only examined in the axial direction in this paper. Except when the lattice is based on a square grid, the stiffness in the lateral direction may be significantly different from the stiffness in the axial direction. However, square grids cannot be morphed using the proposed method of topology morphing. This is because the vertical sinusoidal beams in a unit cell cannot come into contact with one another during compression due to their insufficient lateral displacements under bending [5].

Conclusion

The shear stiffness of the lattice decreases with increasing compression prior to the topology change-that is, prior to the contact of sinusoidal beams, because the sinusoidal curvature of the beams increases as the compression increases, reducing their axial and shear stiffness. On the other hand, when the topology is changed, the shear stiffness goes up as the compression goes up, because the contact area between the sinusoidal beams increases with

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Received: 01 February 2023, Manuscript No. jpm-23-91406; **Editor assigned:** 03 February 2023, Pre QC No. P-91406; **Reviewed:** 15 February 2023, QC No. Q-91406; **Revised:** 20 February 2023, Manuscript No. R-91406; **Published:** 27 February 2023, DOI: 10.37421/2090-0902.2023.14.412

compression, making the connections stiffer. As long as the friction coefficient (between the vertical sinusoidal beams) increases with increasing compression, the experiment-derived load-displacement curves are very similar to those produced by FE analysis. The literature has documented the dependence of PLA's friction coefficient on normal load; however, whereas in it is reported that the coefficient decreases with increasing compression, here, the coefficient increases with increasing compression.

Acknowledgement

None.

Conflict of Interest

None.

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How to cite this article: Quintero, Mehrad. “Passive Topology Morphing Using Contact Connections for Stiffness Tailoring in Sinusoidal Lattice Structures.” *J Phys Math* 14 (2023): 412.