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Compliant kagome lattice structures for generating in-plane waveforms

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ABSTRACT

This paper details the design, manufacture and testing of an adaptive structure based on the kagome lattice geometry – a pattern with well documented interesting structural characteristics. The structure is used to produce in-plane travelling waves of variable length and speed in a flat surface. The geometry and dimensions, as well as the location and compliance of boundary conditions, were optimized numerically, and a pneumatically-actuated working demonstrator was manufactured. Static and dynamic photogrammetric and force measurements were taken. The structure was found to be capable of producing dynamic planar waveforms of variable wavelength with large strains. The lattice structure was then surfaced with a pre-tensioned membrane skin allowing these waveforms to be produced over a continuous plane.

1. Introduction

Compliant structures can offer elegant engineering solutions to problems which are challenging or expensive to tackle with traditional engineering components. The movement typically facilitated by bearings and sliders can be replicated with prescribed structural compliance in an otherwise rigid assembly. With no complex moving parts, compliant structures can be easier to maintain and manufacture than the mechanisms which they emulate. They also offer a solution when manufacturing small sizes or large quantities of joints is impractical, or the cost prohibitive.

The work presented in this paper details the design, manufacture and testing of a compliant structure based on the kagome geometry. This optimal structure is then used to support and drive a pre-tensioned membrane skin. The surface – and therefore also the structure – have been developed to generate exclusively in-plane dynamic waves of variable length and speed which represents a challenging structural requirement. Futhermore, these in-plane travelling waves have a specific application as a flow control device, where their influence on a turbulent boundary layer has been shown to dramatically reduce skin-friction drag (Quadrio et al., 2009).

The kagome geometry has been investigated extensively as an infinite planar lattice. In this configuration, it has been shown to possess some unique and attractive properties which lend it to forming the basis of an active structure. When a member of the frame is elongated, the structural deformation is confined to a region in line with the actuation (Wicks and Guest, 2004), as illustrated in Fig. 1. The basis of the present work is the successful exploitation of this corridor of actuation in a practical setting. This trait is useful as the deformations are confined to a specific region and are also far reaching, allowing a single actuator to influence a large yet bounded area of the lattice.

The response of the infinite planar structure to actuation has been investigated previously in both linear (Wicks and Guest, 2004) and nonlinear (Leung and Guest, 2006) studies. In the linear case, the degree to which the actuation influences the structure is highly dependent on the stockiness of the members (Wicks and Guest, 2004) – the more slender the structure, the further the imposed displacement propagates through the repetitive framework. As the structure becomes increasingly slender, its response becomes similar to its pin-jointed equivalent, with modes of kinematic indeterminacy being inherited as modes of bending deformation in the rigid jointed case (Leung and Guest, 2007).

When large displacements are considered, and geometric nonlinearities become relevant, the response of the infinite kagome lattice is not as useful. Infinite frameworks, or those which are very large relative to their internal dimensions, can be formally statically determinate in terms of Maxwell's equation, but posses self-stress in practice.

In a large lattice frame with welded joints, the deformation imposed at the center will decay towards the perimeter (Leung, 2004), whereas if considered as a pin-jointed frame, the deformation will continue indefinitely. The zero displacement at the perimeter of the welded frame impacts the determinacy of

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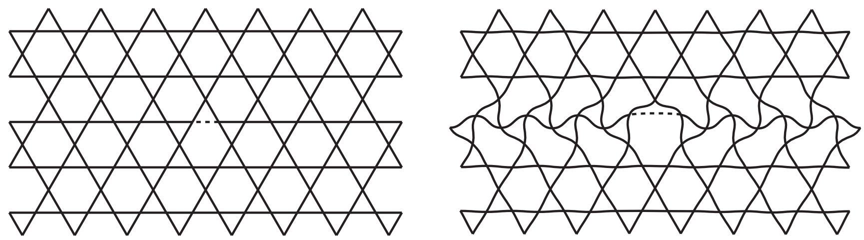
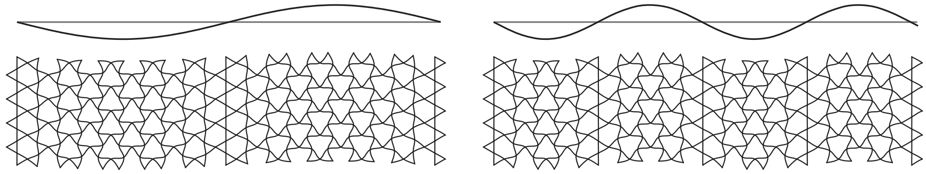


(a) Relaxed kagome lattice. (b) Actuated kagome lattice.

Fig. 1. The response to the kagome lattice to actuation. A bar of the structure, indicated by a dashed line, is replaced with an actuator and a displacement is imposed. The deformation, confined to a 'corridor' of the structure, was calculated with a linear finite element analysis (Leung, 2004).



(a) Large wavelength (b) Short wavelength

Fig. 2. An illustration of how the planar kagome lattice can be used to discretise waveforms of varying length.

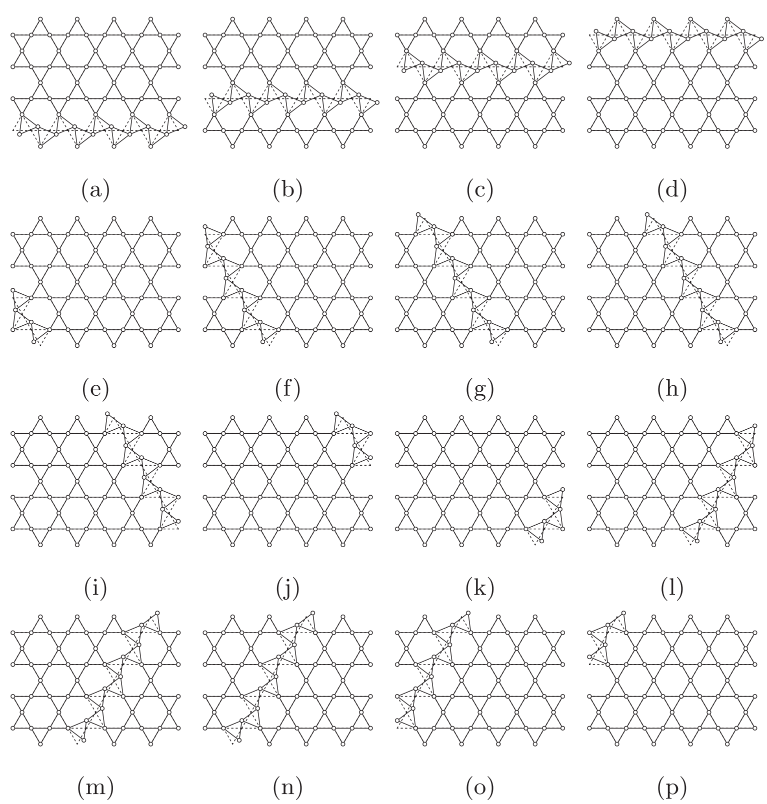


Fig. 3. The sixteen modes of kinematic indeterminacy for a finite pin-jointed planar kagome lattice.

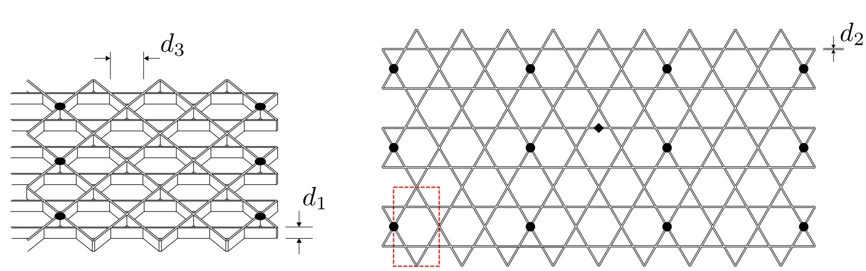


Fig. 4. A finite kagome lattice structure, with a fixed number of unit cells, parametrised with dimensions d_{1-3}.

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