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2D Lattice Materials for Low Energy Actuation

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2D Lattice Materials for Low Energy Actuation

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In the last two decades, lattice materials have received considerable attention as a means to design adaptive (shape morphing) structures [1-5]. Similar to foams, lattice materials are lightweight, but can be much stiffer and stronger depending on their microarchitecture. Externally triggered lengthening or shortening (actuation) of one or more members in a lattice material can be used to achieve significant macroscopic shape change.

The three main attributes sought in 2D lattice materials to be suitable for actuation are in-plane isotropy, high specific elastic moduli and limited energy requirement for actuation. No infallible topological criteria have yet been discovered that determine which micro-architectures meet these requirements. The Kagome micro-architecture yields the best-performing lattice material for actuation known to date. It has the highest possible isotropic macroscopic elastic moduli [6], while bending- dominated deformation results when it is actuated, limiting the energy required [1,2,5].

In our recent work [7] we have proposed that for an n-dimensional (n = 2, 3) in-plane isotropic lattice material to be suitable for actuation, its pin-jointed equivalent must obey Maxwell's rule, and must possess $3(n-1)$ finite kinematic mechanisms. These mechanisms must be *non strain-producing* and thus be comprised of internal rotations of lattice members. Therefore, they cannot be triggered by any remote stress state. In this study, in light of this criteria, we search for micro-architectures that perform similar to Kagome lattice material, or even outperform it.

The four novel micro-architectures depicted in Fig.1 are contrived in light of criteria proposed in [7]. Matrix analysis [2,8] is performed on repetitive pin-jointed trusses with these four micro-architectures to reveal the states of self-stress and infinitesimal mechanisms of the structures. Macroscopic elastic properties of the rigid-jointed lattice materials are determined by performing finite element (FE) analyses with periodic boundary conditions. FE models comprising thousands of unit cells are employed to determine actuation energies associated with the four different micro-architectures.

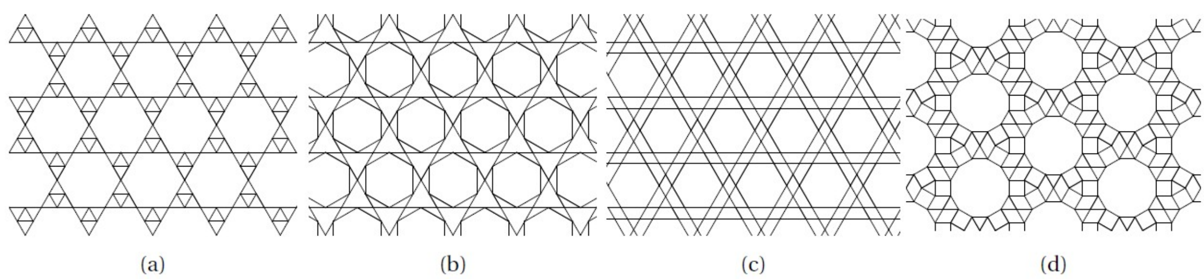

Fig 1. Lattice micro-architectures investigated: (a) Kagome with concentric triangles (KT), (b) Kagome with concentric hexagons (KH), (c) Double Kagome (DK) and (d) the 'modified dodecagonal structure' (MD).

These models also allow the effects of actuation to be quantified by the distance from an actuator at which the deformations vanish. Each of the new micro-architectures is verified to constitute a stiff (i.e. stretching-dominated) isotropic lattice material. Still, not all of them result in optimal elastic moduli.

One of the proposed designs does perform identically to the Kagome structure in terms of elastic moduli. Moreover, it requires less energy for actuation in the range of relative densities of interest. On the other hand, its attenuation distance is shorter; actuation deformations damp out within a shorter distance in comparison to the Kagome lattice material.

We have found that there are lattice topologies that can compete with the Kagome architecture in terms of suitability for actuation. Three out of four proposed repetitive micro-architectures comply with the simultaneous requirement of high, isotropic elastic moduli and limited resistance to actuation. They combine stretching-dominated deformation behaviour with linearly scaling actuation energy. The DK structure unprecedentedly outperforms the Kagome lattice, combining the same optimal isotropic elastic moduli with a lower actuation energy.

Moreover, the criteria for a lattice material to be suitable for actuation proposed by Pronk et al. [7] are further refined, as lattice materials with a statically indeterminate micro-architecture do not necessarily have a high actuation energy. Also, it is found that although the KH micro-architecture meets the current criteria, it has an anomalously large resistance to actuation. The latter will be further investigated [9].

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