Origami tubular structures with degree-n vertices for anisotropic stiffness properties

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Abstract

Thin sheets can be assembled into tubular origami structures, forming mechanically unique three-dimensional structures with broad engineering applications ranging from robotics to deployable structures. These tubular structures are dynamic by design, ideally allowing deployment along one axis while maintaining structural rigidity along the others. Most existing origami tubular designs rely on patterns incorporating degree-four origami vertices, as these single degree-of-freedom (DOF) vertices are well understood and relatively straightforward to design.

However, the design of tubular origami structures based on higher-degree origami vertices remains unexplored. The challenge lies in simultaneously managing deployability and stiffness properties, which makes achieving the desired anisotropic stiffness properties difficult. This paper addresses this gap by introducing a general design strategy for constructing tubular origami structures based on degree-n vertices. Through a combination of numerical simulations and experiments, we first characterize the stiffness properties of these structures. We then define a set of objective functions to evaluate their stiffness properties under large deformations and develop a numerical framework to study the impact of higher-degree vertices on stiffness characteristics.

Our findings, validated by experimental results, reveal two key outcomes. First, careful selection and optimization of degree-four vertices can yield a 20% improvement in anisotropic stiffness properties compared to state-of-the-art designs (1). Second, transitioning to higher-degree vertices as unit cells enables the design of tubular structures with significantly enhanced anisotropic stiffness (with a 17% improvement over degree-four designs). These results demonstrate the potential of multi-degree origami vertices in advancing the mechanical performance of tubular origami structures, providing a foundation for future applications requiring tunable stiffness properties. (1) Filipov E T, Tachi T, Paulino G H. Origami tubes assembled into stiff, yet reconfigurable structures and metamaterials(J). Proceedings of the National Academy of Sciences, 2015, 112(40): 12321-12326.

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