

A Miura-ori based mechanical metamaterial with graded in-plane stiffness

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Abstract

Mechanical metamaterials are a kind of man-made materials whose properties are mainly defined by their structures. Origami inspired metamaterials have attracted great attention from physicists and engineers, due to their exotic behaviours such as negative Poisson's ratio and programmable stiffness. Currently, most origami metamaterials are made up of identical unit cells and thus show uniform mechanical behaviour, which makes it difficult for them to adapt to non-uniform environments. Inspired by the functionally graded structures in nature, here we propose a new Miura-ori based mechanical metamaterial (Fig. 1), referred to as graded Miura-ori, which has varying geometry over its volume and graded stiffness.

First of all, the geometric conditions of the graded Miura-ori are determined through a kinematic analysis. The folding process of the graded Miura-ori is also studied. It is found that a self-locking point exists, which divides the folding process into a rigid folding stage and a non-rigid one.

Secondly, physical samples of a graded Miura-ori metamaterial and a uniform one are manufactured, and quasi-static in-plane compression tests are conducted to investigate the mechanical properties of the new design. As can be seen in Fig. 2, the graded Miura-ori shows a four-level periodically increased reaction force, as opposed to the roughly flat force curve generated by the uniform model. Regarding energy absorption, the specific energy absorption of the graded model is 25.22% higher than that of the uniform model.

Finally, a parametric analysis is carried to study the effects of geometric parameters on the mechanical behaviours of the graded Miura-ori metamaterial, through a finite element modelling approach. The results show that the sector angle plays a major role in determining the graded stiffness and energy absorption capability, i.e., a bigger sector angle interval leads to more levels of graded stiffness and higher energy absorption.

In conclusion, we demonstrate both experimentally and numerically that the graded Miura-ori metamaterial can generate graded in-plane stiffness which is tuneable through geometric parameters. And the graded Miura-ori has superior energy absorption to the uniform one. Our work provides a new avenue in the design of origami structures and mechanical metamaterials that are tunable and adaptable to external loads.

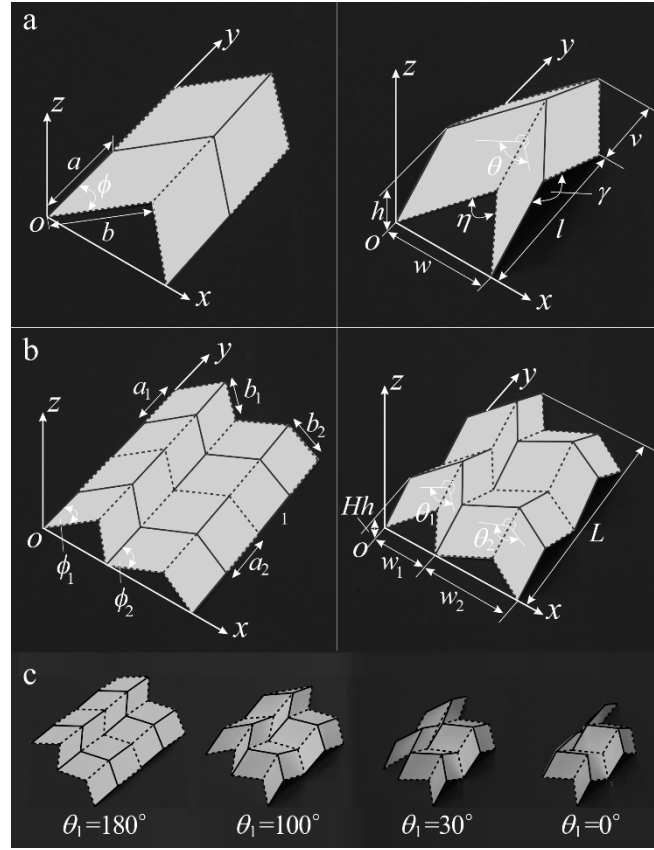


Figure 1: (a) A unit cell of the Miura-ori pattern; (b) A graded Miura-ori metamaterial; (c) Rigid folding process of the graded Miura-ori metamaterial.

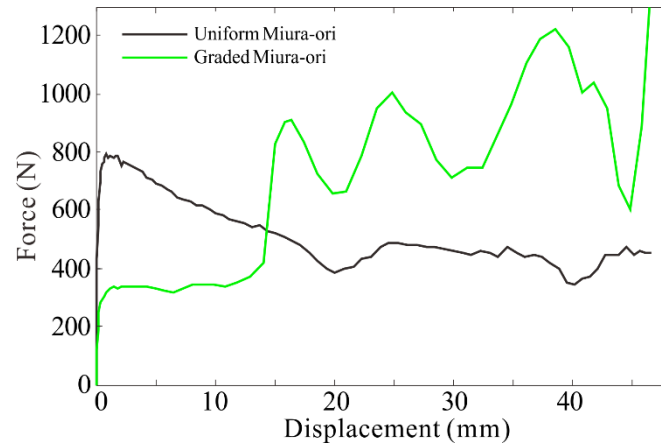


Figure 2: The reaction force vs. displacement curves of the uniform Miura-ori and the graded Miura-ori metamaterials.