TAILORED WRINKLE PATTERNS ACHIEVED BY A MICROSTRUCTURED MEMBRANE

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ABSTRACT
This work reports a straightforward method to achieve tailored wrinkle patterns of a membrane by designing its microstructures. To quantify this idea, the wrinkle pattern and the manipulation of a two-end clamped membrane with holes are examined by experiment, numerical simulation and analytical method. The effect of holes on the wrinkle pattern of the membrane is analysed and the underlying mechanism is revealed. Tailoring of wrinkle pattern can be achieved by designing the position, radius and distribution of holes. The novel wrinkle patterns of membranes with microstructures may have emerging applications in various disciplines.

Keywords: tailor, wrinkle pattern, microstructure, membrane.

INTRODUCTION
Wrinkle patterns induced by surface instability of soft materials have received intense attention in recent years owing to their important applications in flexible electronics, biomedical science and even aerospace engineering (Li, 2012). The soft materials tend to wrinkle instead of uniform deformation due to inhomogeneous deformation or constrained swelling/growing. A simple example is the wrinkle formation of a stretched membrane with clamped boundaries (Cerda, 2003), however this method provides less flexibility to control wrinkle pattern on the membrane. In order to meet the demands of applications, much effort has been made toward controlling the wrinkle patterns (Bowden, 1998), but no study has been reported on the control of wrinkles on a stretched membrane with clamped boundaries.

Here, we report a straightforward method that achieves this controlling by introducing simple microstructures into the membrane (Yan, 2014). To demonstrate this idea, we consider a two-end clamped membrane with holes under tension and different kinds of wrinkle patterns are observed by varying the position, radius and distribution of holes in experiment. The underlying mechanism is revealed by eigenvalue buckling analysis and stress analysis. Several novel wrinkle patterns are obtained by designing the position, radius and distribution of holes.

RESULTS AND CONCLUSIONS
The wrinkle patterns of the membrane with a pair of holes at different positions are shown in Fig. 1. Three kinds of wrinkle patterns can be obtained by designing the position of holes, as well as the radius of holes as shown in Fig. 2. The eigenvalue buckling analysis and stress analysis reveal the underlying mechanism: Microstructures change the distribution of stress field in the membrane, resulting in variations on the buckling mode and wrinkle pattern. The
phase diagram of wrinkle pattern related to the position and radius of holes in Fig. 2 shows the ability to tailor the wrinkle pattern.

The wrinkle patterns achieved by designing periodic arranged microstructures are shown in Fig. 3. The holes are arranged in square and hexagonal patterns, and some local wrinkles form near the holes with the same pattern as the arrangement of holes. The wrinkles of the microstructured membrane with periodic-arranged large holes can be regarded as the collection of the wrinkle pattern of a single hole. Hence, wrinkle pattern of the membrane would have a significant dependence on the distribution of holes.

In this study, an effective method to generate tailored wrinkle patterns by microstructured membranes is proposed. The designed microstructures can make the membrane display a desired wrinkle pattern. The mechanism is due to the modification of stress field and buckling mode. The observed novel wrinkle patterns will have potential applications in various disciplines.

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