Optimal perforation of bending-active sheets

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Abstract

Perforated thin sheets morphing into three-dimensional structures are inspired by the kirigami paper technique that allows the placement of cuts and holes on the initially flat surface to create a wide range of possible deformations of the paper. This method has many applications, such as wind-steering devices (1) and space-structures (2). Typically, curved shapes are created by parallel cuts, resulting in strips that move out of the plane by buckling. By determining the location of the cuts and holes using inverse design, it is possible to deform the surface into prescribed shapes (3-4).

Here, we investigate one rectangular, bending-active sheet perforated by rectangular holes as the simplest example of the phenomenon. The sheet is supported at two ends and loaded by the self-weight, and a concentrated vertical force acts in the middle. On the one hand, the perforation weakens the cross-section of the sheet, and it can reduce the rigidity of the structure. On the other hand, higher curvatures can develop at weakened cross-sections, which can result in a structurally preferable overall shape. It was shown that the global porosity, that is proportional to the area of the holes, and the local porosity, describing the distribution of the holes, affect the structural rigidity in the same order of magnitude (5).

It follows from the previous findings that for a given level of global porosity, it is possible to improve the structural rigidity by changing the local porosity. Holes located closer to the center increase both the height and the rigidity of the structure. However, the structures do not allow for an arbitrary weakening of the cross-section without failure. In this work, we seek for the optimal perforation pattern, and for a given level of global porosity, we determine the maximum achievable structural rigidity. The structure is modeled using a nonlinear beam model that we solve using numerical continuation. The results are validated using laser-cut PET sheets with a thickness of 0.5 mm.

References:

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