

Kirigami fabrication of shaped, flat-foldable cellular materials based on the Tachi-Miura polyhedron

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Abstract

In [Miura and Tachi \(2010\)](#) and [Tachi and Miura \(2012\)](#), several rigid-foldable origami cylinders are proposed and analyzed. One example, the Tachi-Miura polyhedra, is a rigid, bidirectionally flat-foldable cylinder which is tileable. Such foldable, space-filling cylinders open the possibility of constructing cellular materials with rigid folding mechanisms. The mechanical properties of cellular materials based on the Tachi-Miura polyhedron have been analyzed in several studies, including [Yasuda et al. \(2013\)](#), [Yasuda and Yang \(2015\)](#), and [Yasuda et al. \(2016\)](#). As these materials are rigidly flat-foldable, they can be used to create objects that undergo large reversible strains, with Poisson ratios determined by the Miura angle used to create the underlying polyhedra. This capability is a powerful tool for engineering compliant structures.

Physically constructing such cellular materials by simply joining many cylinders is difficult to implement at scale, but we can adapt strategies that were developed to efficiently construct origami honeycombs [Nojima and Saito \(2006\)](#) [Saito et al. \(2011\)](#) [Saito et al. \(2014\)](#) [Wang et al. \(2017\)](#). These works show how a single sheet can be cut and folded to create a straight-walled honeycomb filling the space between two bounding functional surfaces. This research extends these methods to fabricate honeycombs with Tachi-Miura polyhedra instead of hexagonal prismatic cells. These cellular materials are efficiently constructed by cutting and scoring a flat sheet which rigidly folds into the cellular material. By specifying locations of cuts, these cellular materials acquire a desired shape, just as with hexagonal honeycombs.

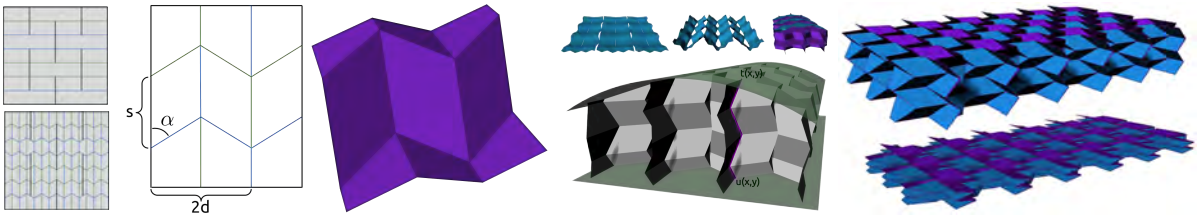


Figure 1: A) Cut-and-fold patterns for hexagonal and Tachi-Miura honeycombs, B) Unit cell of Tachi-Miura folding pattern, C) Folded unit cell, D) Tachi-Miura folding mechanism with shape determined by bounding surfaces, E) Cellular material undergoing flat folding mechanism.

In this work, we first describe our construction for these cellular materials, parameterizing a folding pattern and calculating the required parameters to create a cellular material filling the space between two bounding surfaces. We design a prototype utilizing both the large compliance of the folding mechanism and the shape control offered by the honeycomb construction: a running shoe sole. We laser cut, fold ([video](#)), and test ([video](#)) this prototype. To validate the application of these cellular materials to engineer compliant materials, we measure the



Figure 2: A) Digitally designed geometry for shoe sole, B) Cut pattern for shoe sole, C) Laser cut polypropylene prototype, D) After initial folding, E) Testing the shoe sole at running speed.

mechanical response of samples under compressive loading. By varying the Miura angle of the underlying Tachi-Miura polyhedron, we can tune response to match a range of common engineering foams. Finally, we present work towards automating the folding of our patterns.

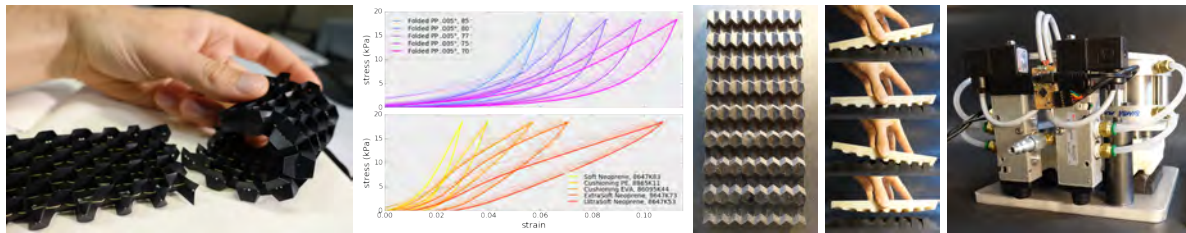


Figure 3: A) Samples for mechanical testing, B) Loading curves of Tachi-Miura polyhedra compared with those of engineering foams, C) Incremental forming die for automated folding of creases, D) Incremental forming mechanism, E) Pneumatic press prototype for incremental forming.

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