

# Mechanical Properties of Flexible Tachi-Miura Polyhedron-based Cellular Structures Fabricated by Additive Manufacturing

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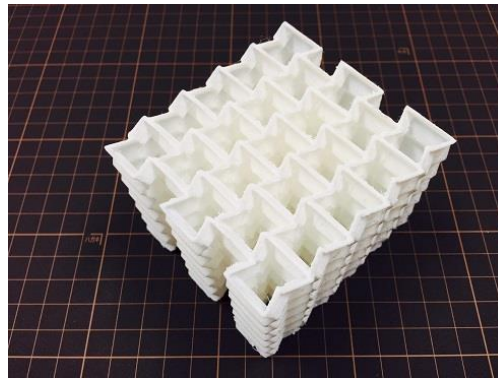
## Abstract

We study origami-based mechanical metamaterials composed of the Tachi-Miura Polyhedron (TMP) cells<sup>1,2</sup>. We fabricate the physical prototypes of the TMP structure by leveraging an additive manufacturing technique (i.e., 3D printing) to demonstrate the unique properties of the TMP, specifically negative Poisson's ratio under axial compression. The TMP is a bellows-like origami structure, and the recent study has reported that the TMP unit cell exhibits tailorable negative Poisson's ratio depending upon its geometrical design parameters<sup>3</sup>. Although this unique kinematics of the single TMP made of paper sheets has been studied analytically and experimentally, the multi-TMP cellular structure has not been investigated experimentally. This is due to the technical challenge in manufacturing such complicated three dimensional structures.

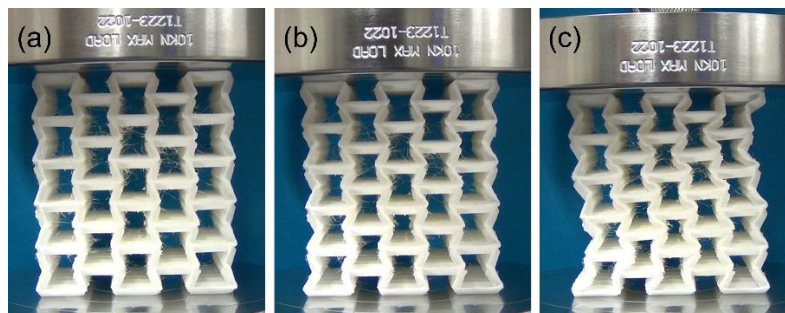
In recent years, rapid development of additive manufacturing has enabled us to fabricate complex structures drawn by computer-aided design (CAD) with various kinds of materials such as polymers, ceramics, metals and alloys. In this study, we examine the mechanical properties of multi-TMP cellular structures fabricated by additive manufacturing. First, we design and analyse the TMP cellular structures under rigid origami model in which we assume that structural deformations take place only along the crease lines. From this kinetic analysis, we observe that the multi-TMP cellular structure shows positive/negative Poisson's ratio by controlling the design parameters (e.g., angle between creases). Based on this analysis, we determine the design of the cellular structure, and then the physical prototypes are fabricated by fused deposition modelling (FDM) which is one of the most common additive manufacturing techniques. In the FDM, a nozzle melts the polymer filaments and extrudes them onto a build platform. A polyurethane filament having a 1.75-mm diameter is used in this study. The prototype made of polyurethane materials, especially crease lines, shows rubber-like flexible deformation so that we obtain smooth folding/unfolding motions of the TMP. A 3D printed multi-TMP structure is shown in Fig. 1.

To investigate the negative/positive Poisson's ratio and force-displacement relationship of the 3D printed prototypes, we conduct the compression tests by using a universal testing machine. Figure 2 shows the sequence of the folding motion of the multi-TMP structure and we clearly observe the shrinkage of the cross-section, i.e., negative Poisson's ratio. Also, we find that the prototypes show strain-softening effect. Recent studies have suggested that a one

dimensional chain of origami unit cells with strain-softening interactions can be highly efficient in mitigating impact by leveraging the unique dynamics of nonlinear waves formed in it<sup>4</sup>. Therefore, this rapid additive manufacturing technique can be utilized for the development of new types of engineering devices which can deal with vibration or impact in an efficient way.



**Figure 1:** 3D printed multi-TMP structure.



**Figure 2:** Compression tests for the 3D printed multi-TMP structure having negative Poisson's ratio.

## References

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