Poisson's Ratio of Origami Tessellations

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Project Purpose

Determine Poisson's ratio of tessellation origami fold patterns. When a material is stretched in one direction, it normally compresses in another. Poisson's ratio describes this behavior.

Project Importance

Materials are selected for design applications based on specific characteristics, including weight, flexibility, thickness, compatibility with the use environment, and the availability of the material. These characteristics place limitations on design that are difficult to satisfy with conventional methods and materials in some circumstances, and so engineers are turning to origami to meet their design needs in these circumstances. Origami can have great flexibility or high bending stiffness. Desired strength can be added with minimal expense or weight. Materials can be folded into compact structures, or expanded over large areas. Currently origami is being used in deployable structures, medical stints, and energy absorption mechanics, among other applications [1].

Figure 1: The Muira-ori pattern is an example of origami tessellation.

One commonly used origami tessellation fold is the Miura-ori (Figure1). This fold pattern is interesting because it exhibits both positive and negative Poisson's ratios [2]. When a material is stretched in one direction, it usually contracts in another direction. This behavior results in a positive Poisson's ratio, which is defined as the negative ratio of the fraction of expansion over the fraction of compression [3]. When the Miura-ori is stretched, it expands instead of contracting. This gives a negative Poisson's ratio. The few materials that exhibit this behavior are classified as auxetics [4], and are used in many applications, including deployable structures and energy absorption mechanics. Engineers have studied the fold pattern extensively, and can now predict the behavior of the origami based on structure design and application conditions [5, 6].

This project proposes to extend that research to other fold patterns to determine whether or not a relationship exists between Poisson's ratio and origami tessellation fold patterns. If a relationship can be established, engineers will be able to predict the Poisson's ratio of an origami fold, and can select fold patterns based on their specific needs. This will save time and money in the design and test stages of product development.

Project Profile Body

The focus of this research will be on the fold patterns and Poisson's ratio of ten tessellation fold patterns. These patterns will be selected from original BYU tessellation folds (Figure 2) and patterns commonly used in engineering applications.

Figure 2: An example of original BYU origami tessellation

The research done on the Miura-ori pattern and its Poisson's ratio will aid the beginning stages of this project. Analysis will be done to determine the methods that have been used to relate the structure of the Miura fold to its Poisson's ratio. These methods will be applied to studying the unit cells of the ten tessellation fold patterns. The unit cells are the simplest, non-repeating element of a tessellation lattice.

Once a relationship has been determined at the unit cell level, the analysis will be extended to entire lattices of tessellation origami.

Anticipated Academic Outcome

It is expected that the results will be submitted for publication to an engineering journal or conference proceedings.

Qualifications

I currently am involved in research at the Compliant Mechanism Research Group (CMR) at BYU. The CMR has the resources to help me to succeed in this research, including expertise, software, hardware, and prototyping and testing equipment. The National Science Foundation, Air Force Office of Scientific Research, and NASA support the CMR research in this area. These organizations provide valuable resources for making this work successful.

My advisor, Dr Howell, has been extensively involved with engineering applications of origami. Additionally, the CMR also collaborates with Robert Lang, a world-renown origami expert, and his insight can be brought to the project.

I am a mechanical engineering student in my junior year. I have completed a math minor, which will aid me in completing this project. I recently returned from a full-term mission in Hong Kong. In addition to studying mechanical engineering, I am furthering my understanding of the Cantonese language. I also am a member of the University Orchestra.

Project Timetable

Selection of fold-patterns for research – October 2013
Research of unit cells – October 2013 – February 2014
Research of origami lattices – February 2014 – August 2014
Preparation of results for publication – August 2014 – December 2014
Submit ORCA final report – December 2014

Scholarly Sources

[1] Don Boroughs. Folding Frontier. ASEE PRISM, January 2013
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[3] G.N. Greaves, A.L. Greer, R.S. Lakes & T. Rouxel. Poisson’s Ratio and Modern Materials. Nature Materials, 24 October 2011
[4] Joseph N Grima. Auxetic Behavior from connected different-sized squares and rectangles. Proc. R. Soc. A 8 February 2011 vol. 467 no. 2126 439-458
[5] Z. Y. Wei, et all. Geometric Mechanics of Periodic Pleated Origami. Physical Review Letters, 110, 2013
[6] Mark Schenk, Simon D Guest. Origami Folding, A Structural Engineering Approach. 5OSME, 2010