NASA-Missouri Space Grant Consortium

Apr 22nd, 12:00 PM - 1:10 PM

Analysis of Laser Cut Living Hinge Pattern Design

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Introduction

Living hinges are flexure bearings that consist of one material which makes up both the hinge and rigid end connections. They are typically made of plastics that can naturally bend without causing permanent strain. Plastic living hinges usually consist of a flat, thin strip of material connecting two ends, and have a wide range of commercial applications. The function of these living hinges can be replicated in plywood samples through subtractive manufacturing. Laser cut patterns produced in plywood samples reduce the flexural rigidity of the material, and are popular amongst hobbyists.

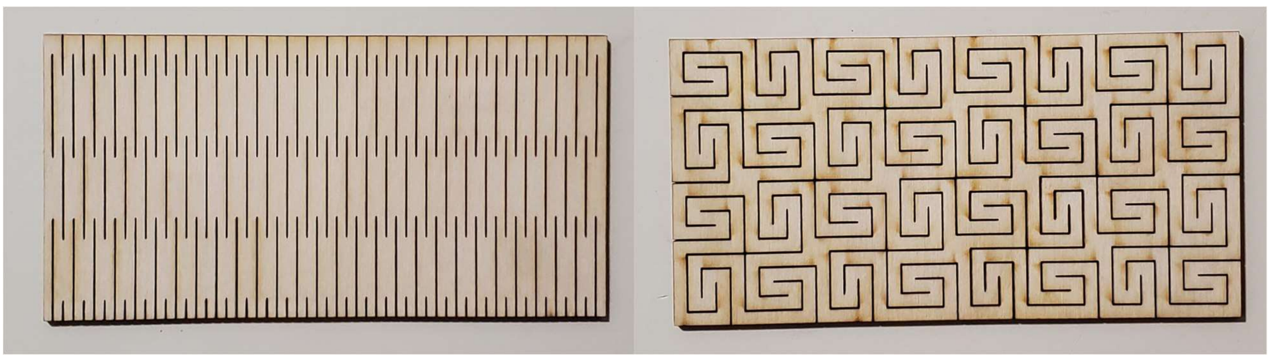

Figure 1: Laser cut plywood samples of two common living hinge patterns.

The applications of these patterns have been limited to art and woodworking projects, and their potential applications have not been thoroughly investigated. The aim of this project is to quantitatively analyze the effect of these living hinge patterns on the effective material properties of plywood samples. The results of this analysis will be used to create a methodology for designing optimized living hinge patterns that reduce flexural rigidity whilst preserving favorable material properties. The end goal of this project is the creation of a database of living hinge patterns, and a computer program capable of generating optimized patterns for provided geometric contours.

Analysis

Past analyses of plywood living hinges, such as (Fekiac, 2020), have focused on the influence of the plywood material itself, with less focus on the patterns cut into the material. Fenner (2020) implemented trial and error design to create variations of a common pattern and create a mathematical model for more precise design. Both of these studies focused on physical data collection from variations of preexisting and popular living hinge patterns. Rodriguez *et al.* (2022) developed a computational design method for varying the parameters of a pattern to modulate the bending stiffness of a sample. This was done to fabricate structures that could mimic an input 2D geometry path when force was applied to the structure.

Analysis in this project will investigate the laser cut patterns applied, with focus on the effects of geometry rather than sample material. Living hinge patterns commonly used in the hobbyist realm will be studied to form a baseline for design optimization methodology. The variety of patterns under study and the amount of parameters that must be varied for each necessitates the use of computational modeling. This modeling will be done with the open-source computing platform FEniCSx, using a representative volume element (RVE) analysis.

The smallest section of the laser cut pattern that repeats to form the overall 3D geometry will be modeled in CAD software. This unit cell geometry will be imported into the FEniCSx software and a representative 3D mesh will be generated. The nodes of this mesh representing the outer faces of the unit cell geometry will be subjected to periodic boundary conditions. This will simulate the behavior of a continuously patterned sample and reduce the processing time of the program. Boundary conditions will enforce strain in the axial and shear directions of the coordinate system. The resulting stress at the mesh nodes will be evaluated and used along with the strain values to solve the Hooke's Law stiffness matrix. The Elastic moduli, Poisson's ratios, and shear moduli provided by the calculations will be recorded for variations in pattern parameters.

The accuracy of the computer modeled material properties will be calibrated with physical data collection. Samples of varied parameters for the selected cut patterns will be created using a CO2 laser cutter. The samples will be subjected to three-point bending testing to provide the actual material properties resulting from the living hinge patterns. These physical results will be used to improve the results of the computerized model, and the verified results will be recorded in a database of living hinge patterns.

Application

The results of the unit cell analysis will be applicable regardless of sample material or dimensions. This allows for the scaling of the unit cell geometry to modify the local bending stiffness for targeted regions of a sample. Desired 3D contours can be produced by assembling a varying map of unit cells that produce the necessary flexure at points on a sample. Computer software utilizing the recorded living hinge pattern database can be used to generate these maps. This would provide a new method of manufacturing a desired surface geometry on a material using subtractive manufacturing.

Acknowledgements

Guidance for this project was given by Dr. Hussein Nassar (University of Missouri - Columbia). Funding for this research was provided by Dr. Frank Feng (University of Missouri - Columbia) and the NASA-Missouri Space Grant Consortium Grant Award number 80NSSC20M0100 and by the NSF under CAREER award No. CMMI-2045881.

Biography

My name is Andrew Weber and I am from Mexico, Missouri. I am a graduate student in the Mechanical and Aerospace Engineering Department at the University of Missouri - Columbia. I am pursuing a master's degree in mechanical engineering with a focus on the elastic behavior of structures.

References

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