MAKER: Fabricating a Flat-Pack Portable Display Using Laser Cutting and Kerf Bending

Mr. Riley S. Booth, University of Calgary

I'm a biomedical engineering MSc student at the university of Calgary. My research interests include haptics, rehabilitation, mobile and wearable technology, engineering education and educational software. I'm currently developing a wearable device for blind and/or deaf users to interface with a computer.

Prof. Peter Goldsmith P.Eng., University of Calgary

Peter Goldsmith is an Associate Professor in Mechanical Engineering at the University of Calgary. He holds a PhD in Mechanical Engineering from the University of Toronto. His research interests are in human-computer interfaces, control theory, robotics, mechanism analysis and design, applied and pure mathematics, and engineering education.

MAKER: Laser cutter hinge bending to create a portable flat pack curved display case

Abstract

A machine familiar to the maker community is the laser cutter. Unlike 3D printed products, most projects made with a laser cutter are flat, or assembled out of flat components. A technique called kerf bending, also called lattice hinging, allows flat pieces of material to be cut and then curved, opening up a much greater range of opportunities. This method combines mechanics of materials, subtractive manufacturing, and design. As well as being very useful, creativity and artistic flare make this technique quite ascetically pleasing.

In this paper, we showcase this method by applying it to the fabrication of a portable display case for the Petri Picasso group to create an exhibit for painting with fluorescent bacteria. For an earlier exhibit, a case was machined from clear, thick acrylic. The laser cut case was made at a much lower price, is equally functional, and is more visually appealing. The fabrication method is described here as it applies to the construction of the display case, and the benefits of the method are discussed.

1. Introduction

A laser cutter is a common subtractive manufacturing tool that is simple enough to be used by hobbyists but has professional looking results. Laser cutters direct a high power beam perpendicularly to the face of a workpiece and cut the piece along some path by moving the laser head, the piece or both. Materials can be cut through or engraved, with the quality of either depending on the cut speed, laser power, laser focus, and the material properties (e.g. thickness). Laser cutters are excellent for making finely detailed cuts or engravings, for replicating many small parts, and for most 2D manufacturing.

Although laser cutting is faster than 3D printing and provides a finer finish, construction of 3D products requires assembly of several 2D parts. Another way to produce a 3D shape is to bend a 2D laser-cut part. While some materials, such as aluminum, can be easily bent after cutting without risking fracture, others, such as wood or plastic, cannot. This maker project will outline a technique which allows almost any material to be bent into a curve after laser cutting, essentially by cutting slots into the material to make it more flexible.

2. Theory

Uncut sheets of rigid material, such as wood or acrylic, don’t bend easily. If a maker desires a curved product, then a design must have multiple parts or a single part that is able to bend into the desired shape. The part must be able to bend without breaking, either through inherent flexibility or via some other process (such as heating.) Permanent deformation must be avoided though, if the part is to be returned to its original shape for disassembly and transport. Both of these goals require that certain strain limits (usually known for the material) are not exceeded. Without hinges, the maximum bending curvature allowed depends simply on this strain limit and the thickness of the material.

Hinges fundamentally change the geometry of the piece, which changes the mode of bending, and hence the strain in the material, and hence the amount of bending (i.e. curvature) allowed before the strain limit is reached. For example, suppose the flat part in Figure 1A must be bent about a vertical axis. Figure 1B shows a typical hinge cut into the part to increase its flexibility about that axis. When the part is bent, almost all of the deformation occurs in the red strips in Figure 1C, which are in torsion. This torsion yields a significant relative rotation angle (about the vertical axis) between the bottom and top of each strip. If the hinge pattern is repeated a few times horizontally, these rotations can accumulate into a large total bending angle.

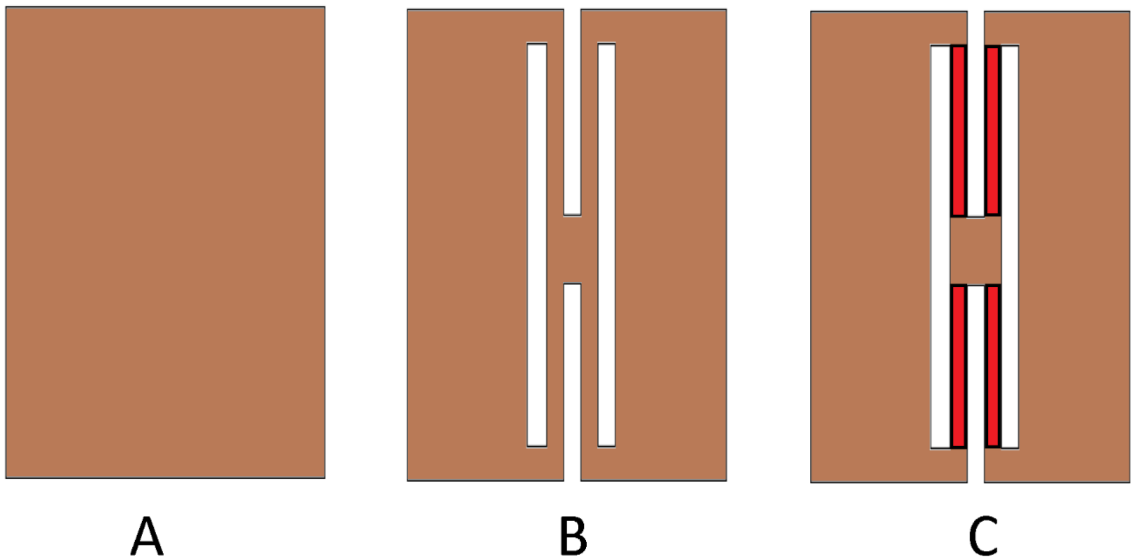

Figure 1. A. plain sheet of material for laser cutting. B. Single symmetric hinge cut into the material. C. Torsion strips highlighted in red.

In contrast, if the uncut part in Figure 1A is bent about a vertical axis, the mode of deformation is not torsion, but rather simple beam bending (i.e. tension and compression). The curvature limit before permanent deformation or failure (for a given thickness and material) is relatively small, so a desired total bend angle (e.g. 90 degrees) must be distributed over a long horizontal distance. Hence, the fundamental principle behind hinge bending is that it transforms the mode of deformation from bending into torsion.

Besides avoiding permanent deformation or failure, another effect of the hinge is that it reduces the required force or bending moment required to bend the part. This makes it easier to fasten the part to itself or another part when in its bent position. For example, the display case we fabricated is assembled using only plastic tabs that were laser cut into the material, avoiding the need for screws or other external parts. However, a potential drawback of the flexibility created by hinges is that it not only lowers the strength of the parts in the direction of bending, but in other directions as well.

3. Prototyping

The amount of bending achievable can be determined analytically, using solid mechanics theory, for the pattern shown in Figure 1. Other patterns can be designed that add a more artistic flare or allow the material to bend in more than one direction. Some potential patterns are shown in Figure 2. However, these alternate designs require a more complicated analysis to determine the achievable bending allowed prior to fracture. The number of potential designs is limitless, so determining the ideal combination of artistic design with freedom to bend would be a complicated problem without rapid prototyping and testing capabilities. Thanks to the ease of use of the laser cutter, many prototype hinge designs can be made, even from the same piece, and then tested, prior to making a final product. As illustrated in Figure 3, each hinge design can be bent until failure, and the failure angle recorded.

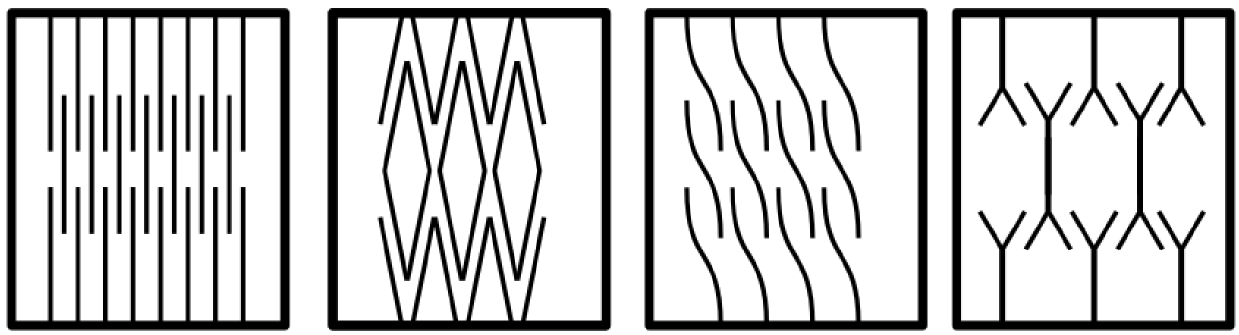

Figure 2. Possible hinge cut patterns for creating curved laser cut surfaces.

Figure 3. A visual representation of the testing required to determine the amount of bend each hinge design can achieve.

4. Design and Fabrication of a Display Case

For this maker project, a display case was desired for the Petri Picasso to present their fluorescent bacteria at the University of Calgary's 50th anniversary gala, as a combination art and science piece. A design was envisioned that used the described technique of laser cut hinge bending. Figure 4 includes a 3D rendering of the display case previously built for a previous display using a different technique. Since the display is a six-faced column, six individual parts were made, and each edge bevelled and glued for the final manufacture. This was a time-consuming (and thus costly) manufacturing method, as the clear acrylic was machined to create the circular cuts and angular bevels, and required skilled practice in gluing to assemble the final design. The final design, rightmost image of Figure 4, was functional and solid. The thick material, precision machining, and high quality glue made the display very sturdy, and easy to use. However, the drawbacks were that the display was permanently assembled and somewhat heavy.

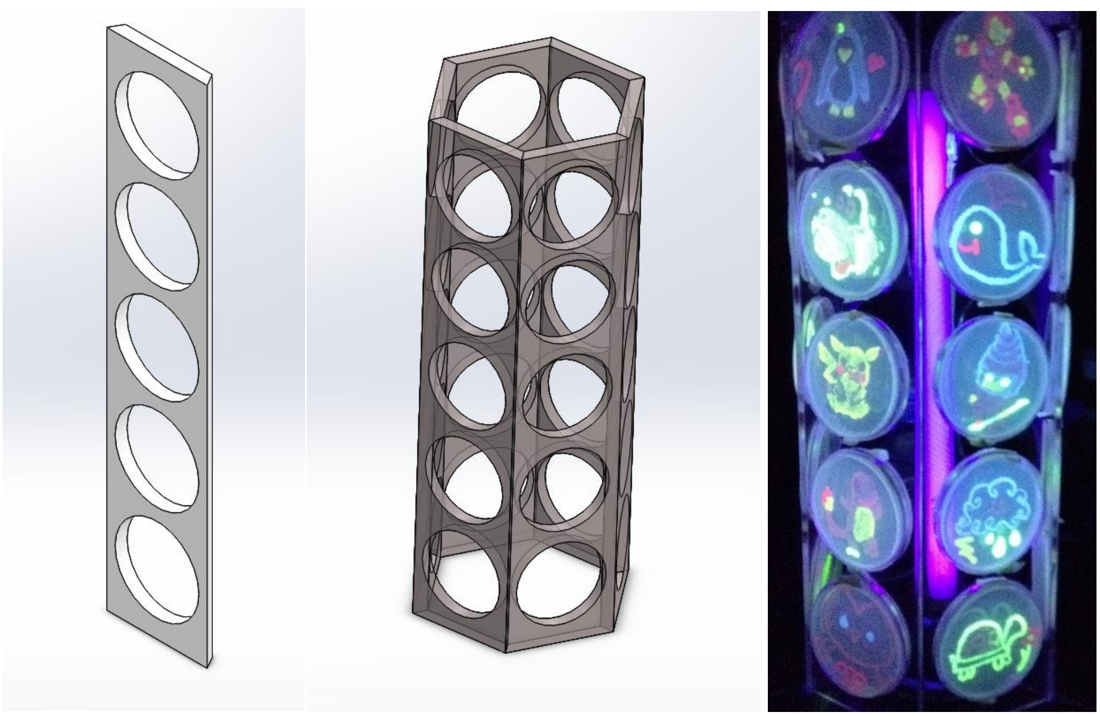

Figure 4. A 3D rendering of a single face, and the final six-sided column that was previously manufactured for an art display case, followed by a photograph of the display in use, holding petri dishes with fluorescent bacteria paintings.

Using the technique described in this paper, a new display case was built from a single flat piece of acrylic. Figure 5 depicts a first draft 3D model for the new display case design. Finalizing the design required the addition of the hinges, to allow for bending; fitted tab slots, for the assembly; and a base and lid to support the electronics housed within the display. An iterative design and testing process revealed design considerations needed to complete the display case. In fact, from the first CAD model in Figure 5, it was clear that bending could not be allowed to occur around the circular dish supports, as they would deform into ovals and no longer fit the dish shapes.

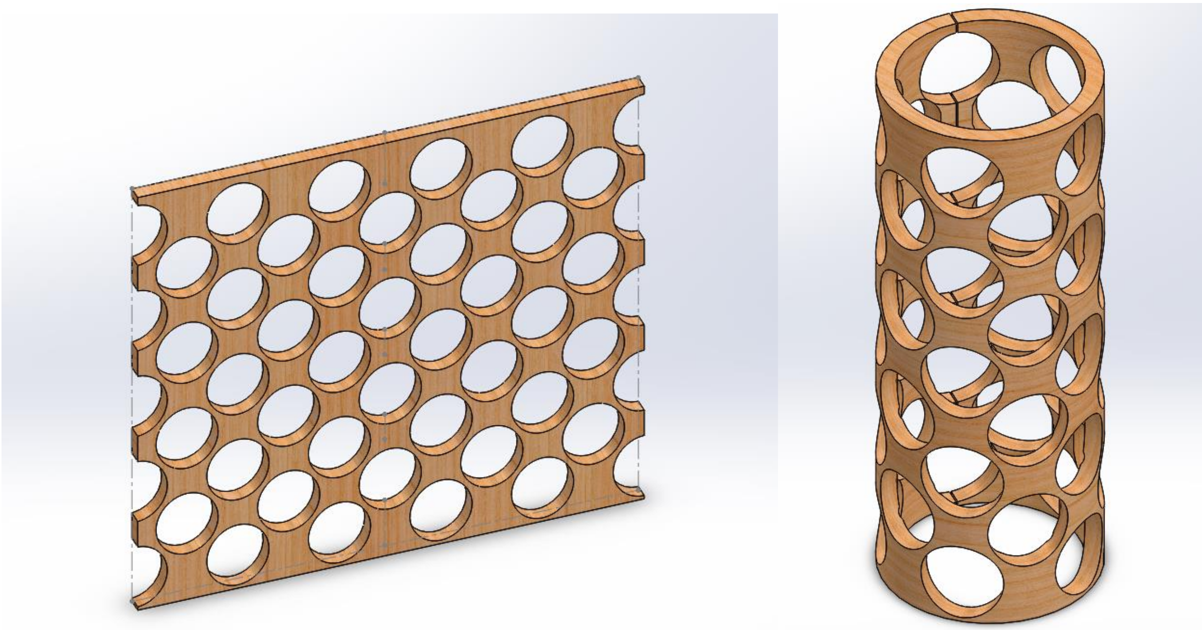

Figure 5. A 3D rendering of an initial design, cut from a single 2D piece, and able to be stored as such, but capable of bending into the desired final state.

An improved design was created and laser cut out of cardboard. This was a comprehensive test on the concepts within the design, such as the hinge-bending, fitted tab slot assembly, laser-cut parameters and petri dish display fitting. Following the cardboard test, further iterations were completed using white acrylic. The most pressing test was determining a hinge design that would allow sufficient bending without risking structural failure, while maintaining a small display case size. The first hinge pattern shown in Figure 2 was chosen for its simplicity and ease of modification. Increasing the frequency of the pattern and the height of the spring hinges allows for greater bending. However, the proximity of the hinge is limited by the precision of the laser. During the cutting process, material is vaporized by the heat of the laser. Since the laser is a beam of light being focused to a point (ideally), there is a minimal thickness of the width cut by the laser, called laser kerf. The sharper the focus, the smaller the width of the cut. The cut edges aren’t perfectly flat either. The laser focus causes the cut edge to be convex, as when the focal point is directly at the center of the material thickness the top and bottom faces are cut slightly wider, due to the less focused beam.

Kerf thickness was determined by cutting a square of known dimensions from the acrylic, and comparing the inner and outer dimensions of the cut piece, using calipers. Once the kerf was known, dimensions within the final CAD model were adjusted such that the exact final product matched the desired dimensions. Figures 8-10 show the final manufacture of the display. Kerf width is very important for cutting hinges into a material, and is also key for assuring that fitted pieces are proper sizes. For example, the tab slots and their counter-parts shown on the edges of the final design (Figures 6 & 7) are not identical dimensions, as due to a kerf of approximate 0.2 millimeters, identical dimension shapes would fit much too loosely. As such, an extra 0.2mm width must be added to the external shape so that it fits tightly into the internal shape.

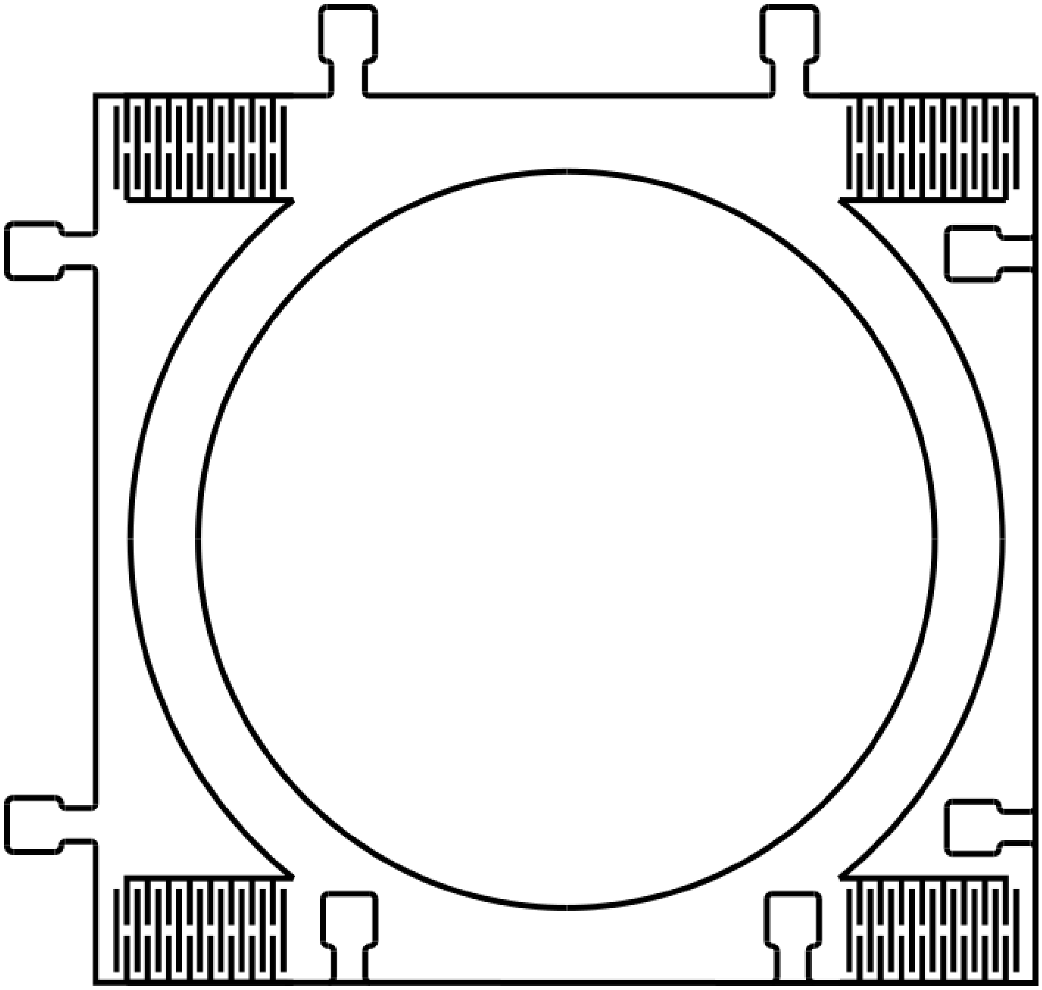

Figure 6. Test laser cut path for display case design. Design allowed for petri dish mounting and tab slot fit tests, as well as bend angle tests.

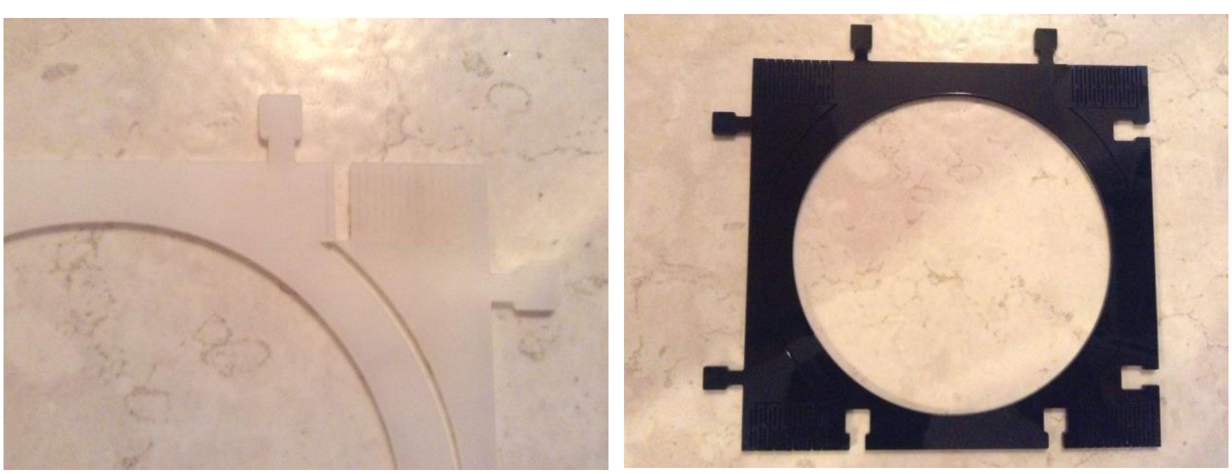

Figure 7. Test cuts performed prior to final design manufacturing. Left image shows close up of bend joint on white acrylic test bent to breaking. Right image shows successful black acrylic design.

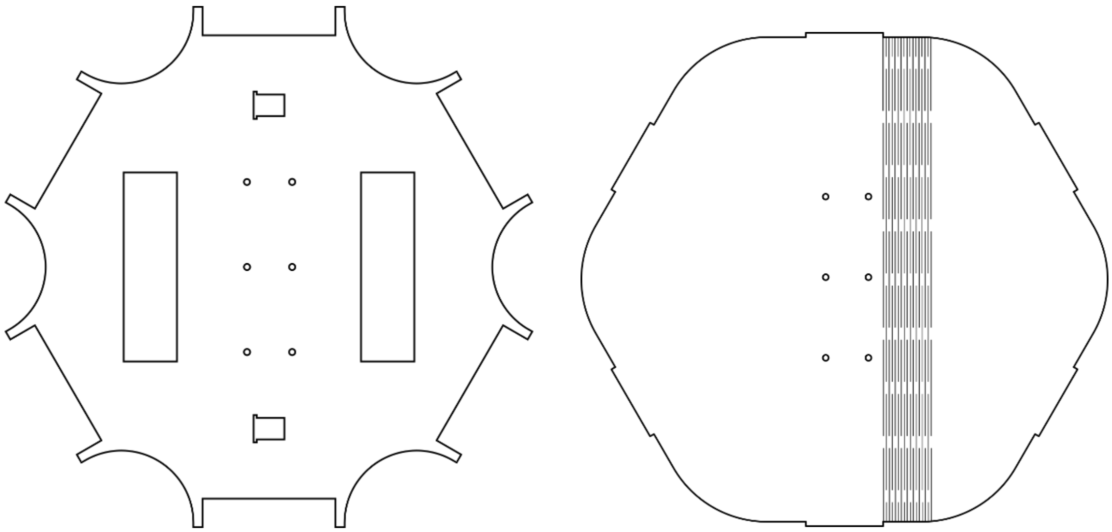

Figure 8. Final laser cut path for the display case internal horizontal supports. Left image shows bottom support for holding black light fixtures, electric converter box and switches, while allowing space for wiring. Right image show top support with complete enclosure, identical slots for black light fixtures, and elongated hinges for very flexible bending to allow opening the cover.

Figure 9. Final display case assembly. Left image shows display without black lights or petri dishes. Right image shows display case in use (during daylight.)

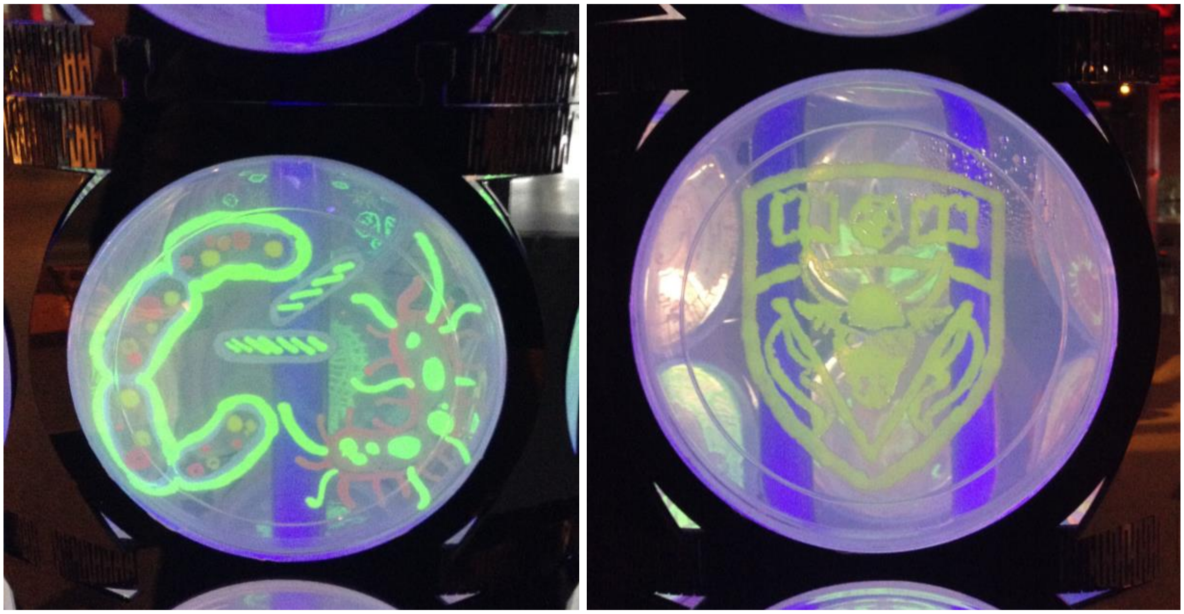

Figure 10. Sample petri dishes that were painted using fluorescent bacteria for the display case.

5. Role in Engineering Education

The maker technique described in this paper provides an excellent tool for students to design and prototype projects in a design course. Laser cutting is a relatively low cost and time effective technique that can be made available to large numbers of undergraduate students. Cutting specifications can be generated by students using CAD software and implemented on the cutter with little or no technical support, allowing rapid prototyping and the possibility of several design iterations and testing cycles. The design of the hinges is an excellent exercise in mechanics of materials, since students can apply their basic knowledge of stress, strain, bending, and torsion to design and analyze different hinge patterns to predict their strength and flexibility. Hence, design, analysis and testing of hinges could provide a hands on laboratory component for a course in mechanics of materials that would highlight the usefulness of solid mechanics theory. Finally, the construction of 3D objects from 2D components is an excellent exercise in geometry and visualization, as well as a window into the field of manufacturing and automation.

6. Summary

Hinge bending adds an extra dimension to the laser cutting design process. Laser cutting is very rapid, which allows makers to design and test potential hinge designs very quickly and effectively. The solid mechanics of simple hinge designs is fairly straightforward, while analysis of more complex designs can be done through experimentation. Anyone experienced with the use of a laser cutter could implement this technique, and hinge designs can be created easily through CAD software. A useful application of this method is to build projects that can be assembled and disassembled easily, and stored in a flat pack manner.