BOARD # 183: MAKER – Recycling Post Consumer Waste Via Vacuum Forming Processes

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Vacuum Forming -A Method for Recycling Post-Consumer Waste

1.1 Abstract

Plastics are one of the most highly talked about materials in the conversation of recycling and waste management. However, plastic can be one of the most difficult post-consumer wastes to recycle. Many differing types of plastics, the cost of processing, low quality results, and dirty or contaminated plastic containers are some of the many issues plaguing the process of plastic recycling. That's not to mention the hundreds of millions of tons of plastic that go straight to the landfill each year. Discarded plastic waste is a large-scale issue in which everyone plays a part. As such, individual efforts to reduce waste can combine leading to a great impact in reducing the amount of plastic finding its way into a landfill or waterway. This paper documents efforts to establish a new way for the community at Texas State University to recycle and reuse postconsumer waste utilizing the process of vacuum forming. Using a vacuum forming device, students could quickly, easily, and sustainably recycle sheets of discarded plastics into something new. For example, a student may come into the makerspace one day with a cleaned-out milk jug, spend 5-10 minutes at the vacuum forming machine, and leave with star-shaped candle mold. This paper details the way the simple machines are made in the Ingram Hall Makerspace, products that can be made with the machines, and students' feedback on the making experience.

1.2 Introduction

Plastics are one of the most highly talked about materials in the conversation of recycling and waste management. However, plastic can be one of the most difficult post-consumer wastes to recycle. This research focuses on how vacuum forming can aid in allowing simple fabrication with recycled materials.

1.3 Early Exposure to Engineering in Education

Introduction to the world of STEM and engineering at an early age can play a key role in developing a passion for math and sciences in the hearts of younger students. Early exposure to the world of engineering through middle school and high school workshops, projects, and programs can help to make the amazing world of science and engineering far more approachable, knock down the *ivory tower of academia*, and make young students feel like they too can be a scientist or an engineer. Sadly, while programs such as these are invaluable to creating the next generation of engineers, the equipment and funding required to establish these types of workshops are oftentimes more than many school districts can justify spending. This project seeks to tackle this problem by creating an exciting and engaging, and creative way to teach principles of engineering and sustainability at a low cost.

With access to a 3D printer and optionally a laser cutter, the device developed through the completion of this project can be made at the material cost of $40. Additionally, to use the device

access to a heat gun and standard shop-vac or any other vacuum cleaner is required. Many school theatre departments or woodshops, as well as janitorial staff, often already have access to shop-vacs. A common $20 heat gun will suffice. Finaly, the consumable material for this project is recycled milk jug plastic, which comes at no cost to the school. Current research published at ASEE conferences with vacuum forming has been mostly focused on using vacuum forming to create an experiment or experience but little on making the vacuum form itself [1-5].

2. Vacuum Forming

2.1 The Process of Vacuum Forming

Vacuum forming is a process in which a thin sheet of plastic is heated to a temperature just below its melting point, in which it becomes malleable. This temperature varies slightly for each plastic and is called the plastic's Glass Transition Temperature (GTT). For recycled HDPE this temperature is close to 235°F but may vary. Once the plastic has reached its GTT, it is lowered over a buck or mold. A vacuum is then induced between the plastic and the buck, forming the plastic into shape of the buck. Typically, this vacuum is made by a vacuum table, on top of which the buck and heated plastic are placed. The vacuum table works similarly to an air hockey table, however instead of blowing air out of the table to make objects float, it sucks air into the table to create a vacuum.

While the concept of vacuum-forming is not new, the process, particularly as used in industry, often makes use of large, pre-processed stock materials. What makes this device unique is its ability easily and effectively re-use post-consumer waste instead of first-use stock plastics. Additionally, while many consumer level vacuum form devices do exist, nearly all these machines cost hundreds or even thousands of dollars to purchase. Assuming one already has access to a shop-vac and heat gun, this device can easily be replicated and used for roughly $23. With a much lower price and an easy-to-use form factor, this device intends to introduce the process of vacuum forming to users in a much more approachable and hands on way, while also teaching about the importance of reusing and recycling plastics.

2.2 Using the Vacuum Form Machine

The vacuum form machine has three main components shown in *Figure 2.1*: The vacuum table base, the vertical guide rails, and the square wooden clamp. In addition to the machine itself, you will also need a small air pump or shop-vac, a heat gun, and four binder clips.

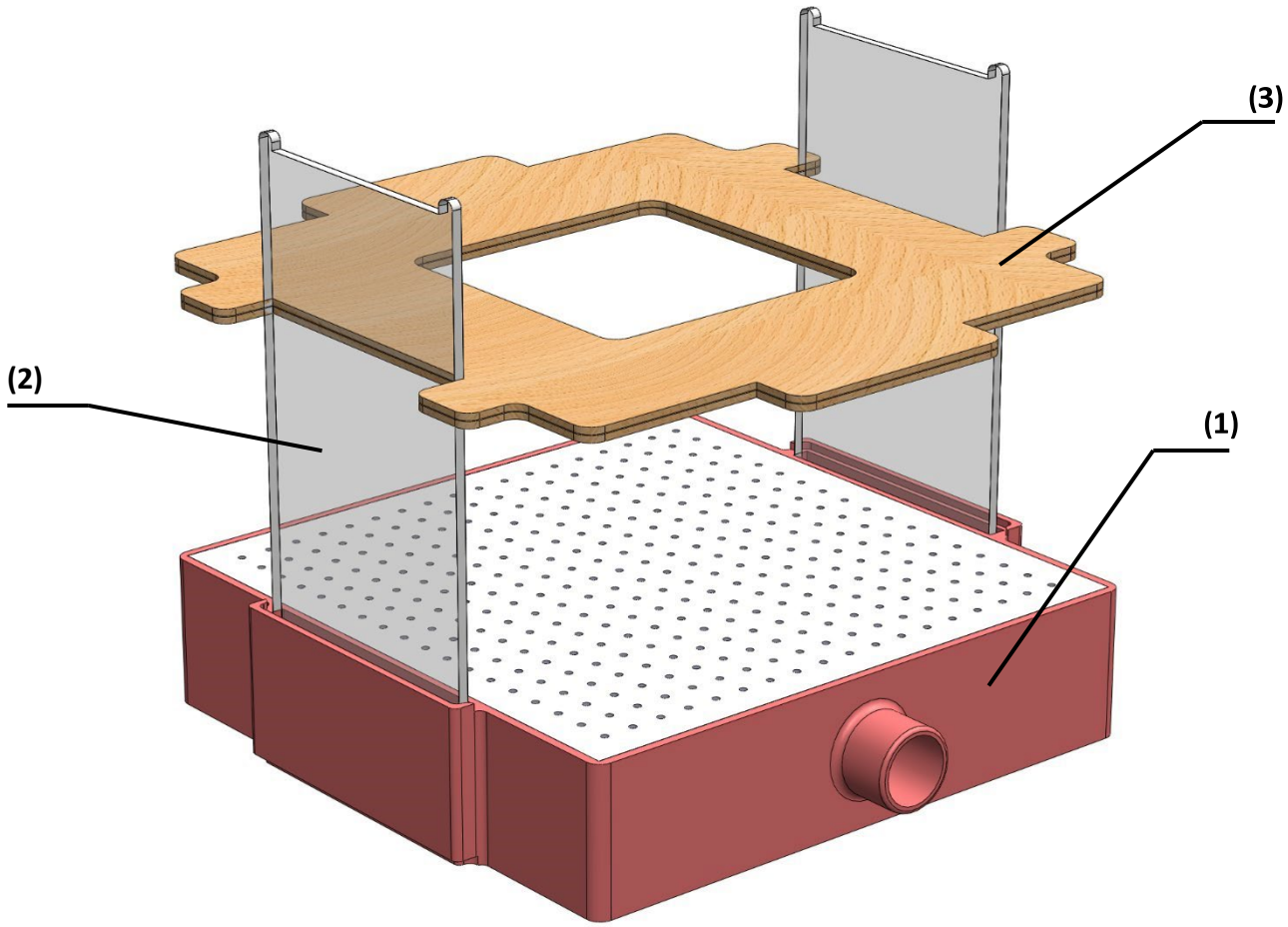

Figure 2.1. *Diagram of vacuum form machine designed through this project. (1) Vacuum Table base, (2) Vertical Guide Rails, (3) Square Wooden Clamps*

To begin, connect your vacuum to the nozzle on the side of the vacuum table, and place the buck with which you want to form your plastic around on the center of the vacuum table.
(See *Figure 2.2*)

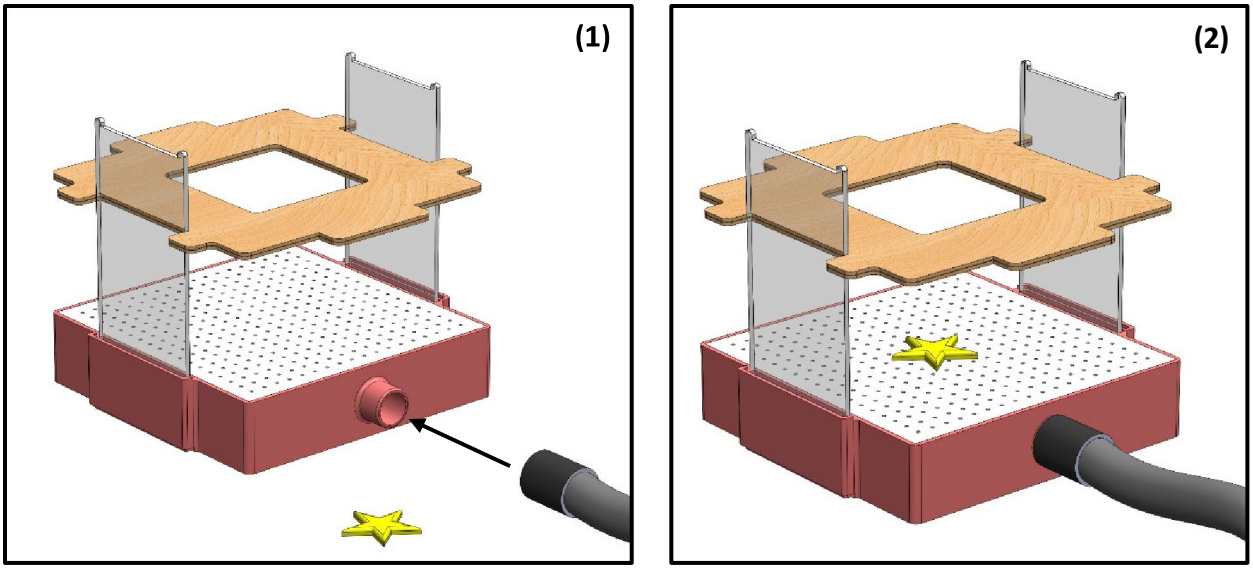

Figure 2.2. *Buck placement and attaching hose to vacuum table.*

You can then cut out a clean sheet of HDPE (#4 plastic) and lay it flat between the two square wooden clamp pieces. Then take four binder clips and use them to securely clamp the plastic sheet between the square wood clamps. (See *Figure 2.3)*

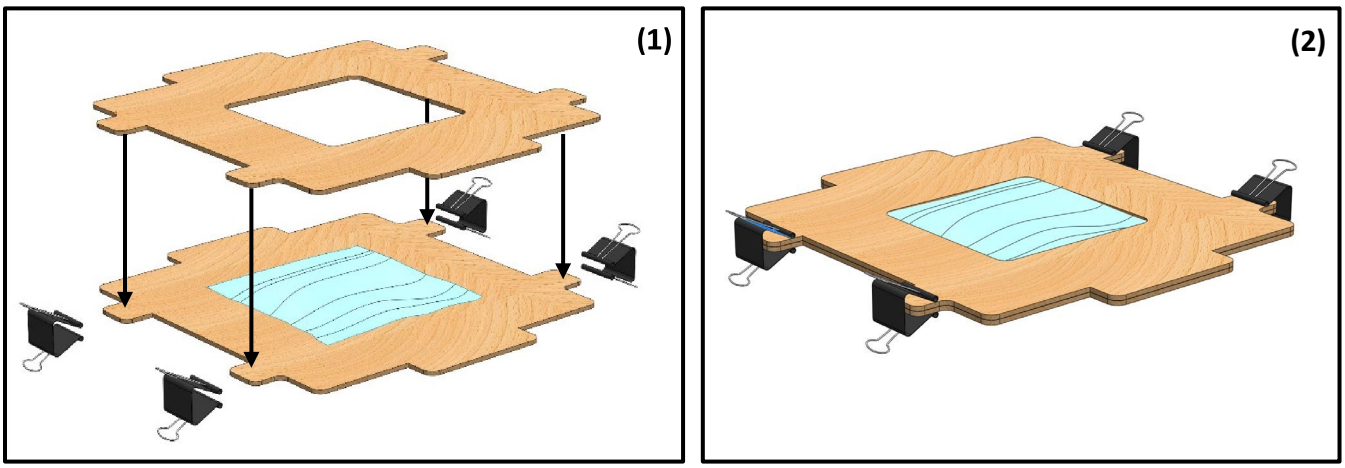

Figure 2.3. *Securing HDPE sheet in wooden clamps.*

For this step make sure to cut your plastic sheet out roughly half an inch larger on all sides than the hole in the wooden clamps. In the later steps when the plastic is heated it will shrink some, so it is important that there is extra material to clamp fully onto.

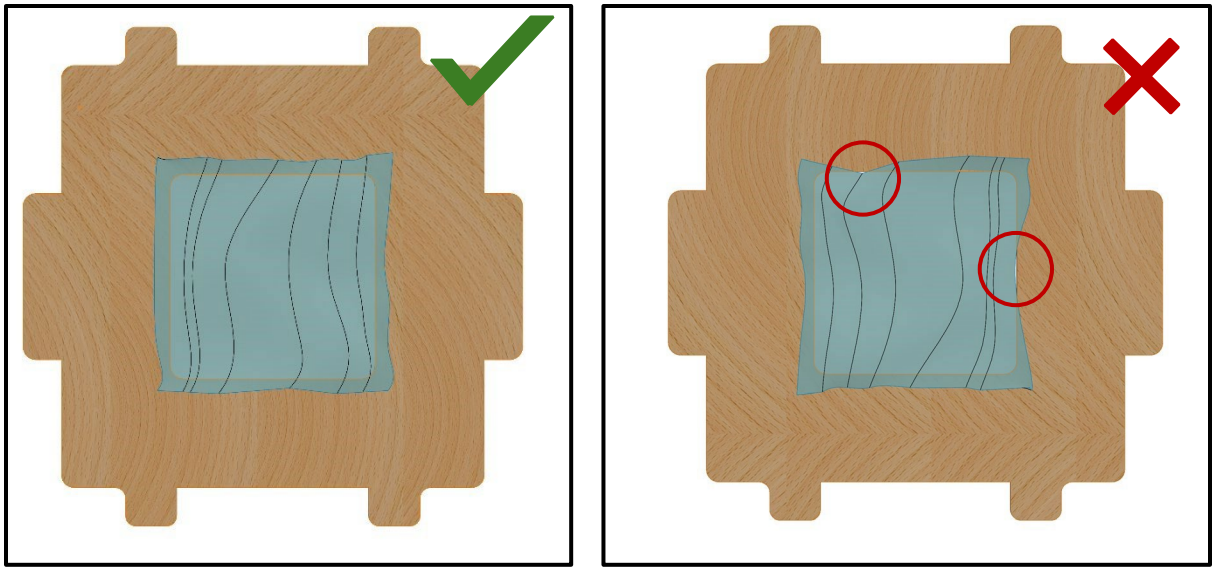

Figure 2.4. *Proper and improper HDPE placement.*
(shown on left and right respectively)

Now place the handles of the wooden clamps on top the vertical guide rails. These rails will act like standing, holding the plastic up while it is being heated to its GTT.

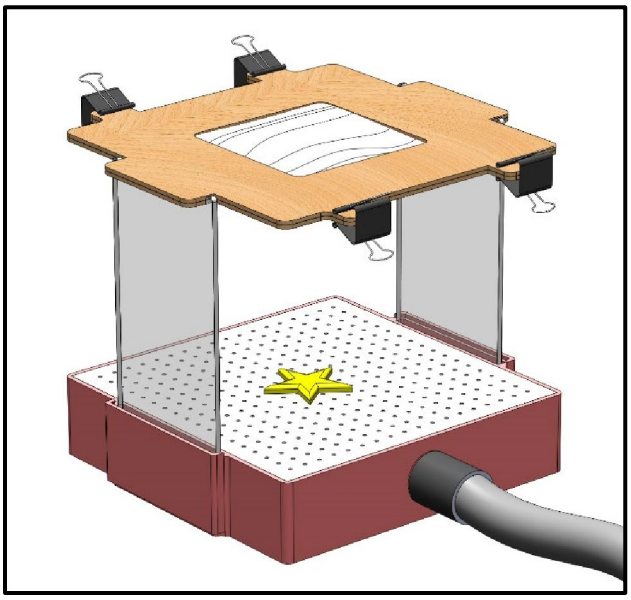

Figure 2.5. *Using the vertical guide rails as stands to hold wooden clamps.*

Now with a heat gun, evenly heat the plastic in the clamp until you notice it becomes flexible, almost like a taught fabric. You may also notice any folds or wrinkles in the plastic disappear as it gets taught. Once the plastic becomes taught and moves or deflect slightly from the air coming out of the heat gun, the plastic will have reached the optimal temperature.

Additionally, milk jug plastic is great for this because in addition to becoming taught, the plastic will also go clear as it reaches GTT.

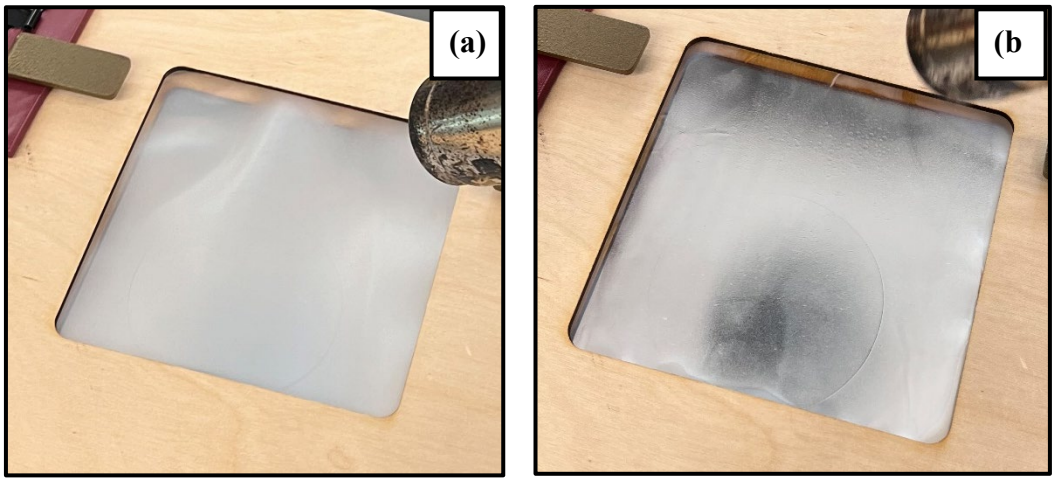

Figure 2.6. HDPE from a milk jug (a) before and (b) after reaching GTT

(Note: be careful not to overheat the plastic, as it can cause the plastic to become too thin or burn a hole through the sheet, making it impossible to form with. This may take some practice and a few tries to get right.)

Once the plastic has reached GTT, turn on your vacuum and carefully pick up the wooden clamp with the handles. Rotate the wooden clamp 90 degrees and firmly lower it over the buck and onto vacuum table, using the vertical uprights as a guide.

(NOTE: if the frame is too hot, it may be necessary to use oven mitts for this portion of the device operation)

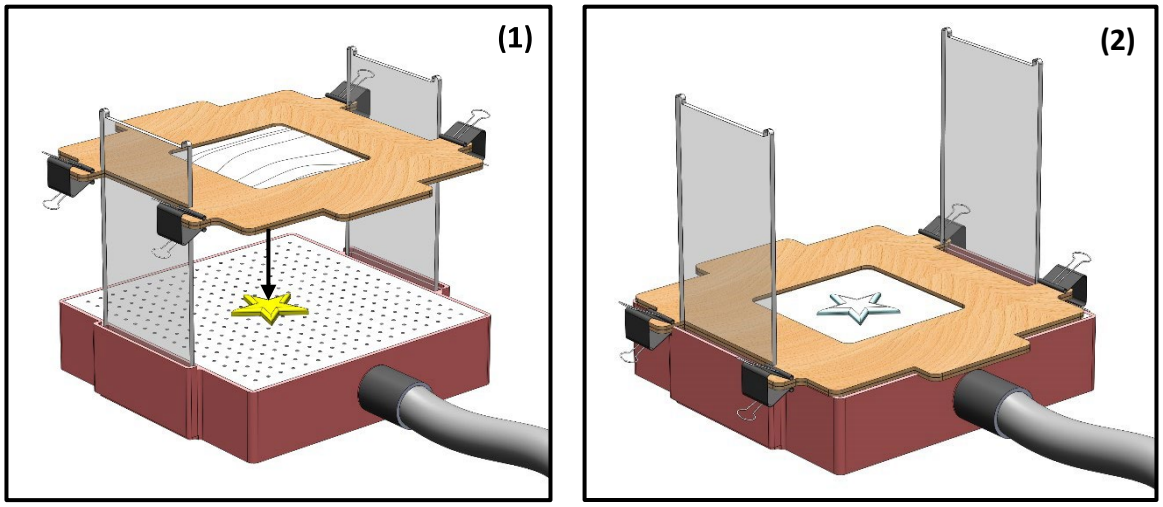

Figure 2.7. *Lowering HDPE over buck to form a part.*

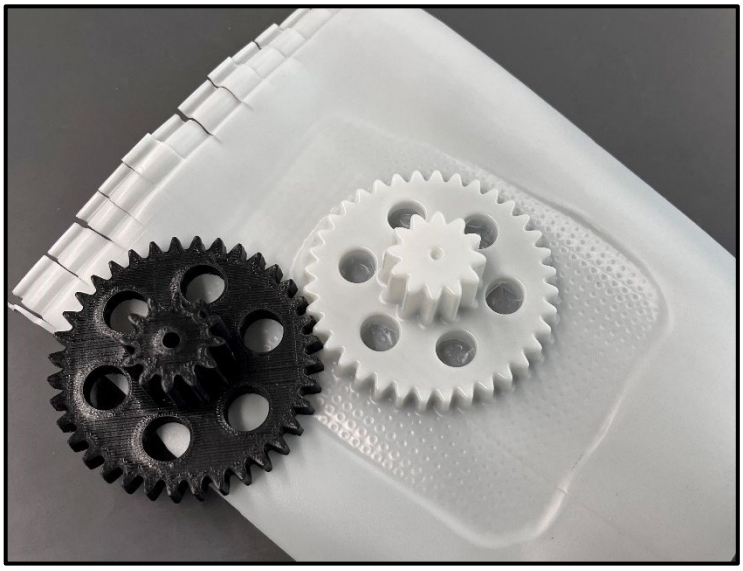

Figure 2.8. *Buck and Vacuum Formed Part*
(Shown on the Left and Right Respectively)

When the wooden clamps are lowered over the vacuum table, a seal is made creating a vacuum between the table and the hot plastic. This vacuum causes the plastic to form to match the shape of the buck beneath it. If the plastic doesn't seem to form to the buck beneath it, check to make sure there is nothing preventing this seal from being made and try again.

2.3 Making the Vacuum Form Machine

The purpose of this project was to develop a method to recycle/reuse post-consumer waste that was easily accessible to as many users as possible. The primary target markets for this product are on campus makerspaces at Texas State University, schools with STEM programs, and any hobbyist makers. With this in mind, three primary design targets were identified. First, the device must be easy to quickly pick up and use. Second, the device must be small enough to easily store when not in use. And third, the device must be easily replicated by those who wish to make their own. To this end, the vacuum form machine was designed to be made using a tabletop 3D printer and CO2 Laer cutter.

The vacuum form machine has three main components (Reference *Figure 2.1)*: The vacuum table base, the vertical guide rails, and the square wooden clamp. The machine's vacuum table is made of two pieces, the Base Piece and Top Piece.

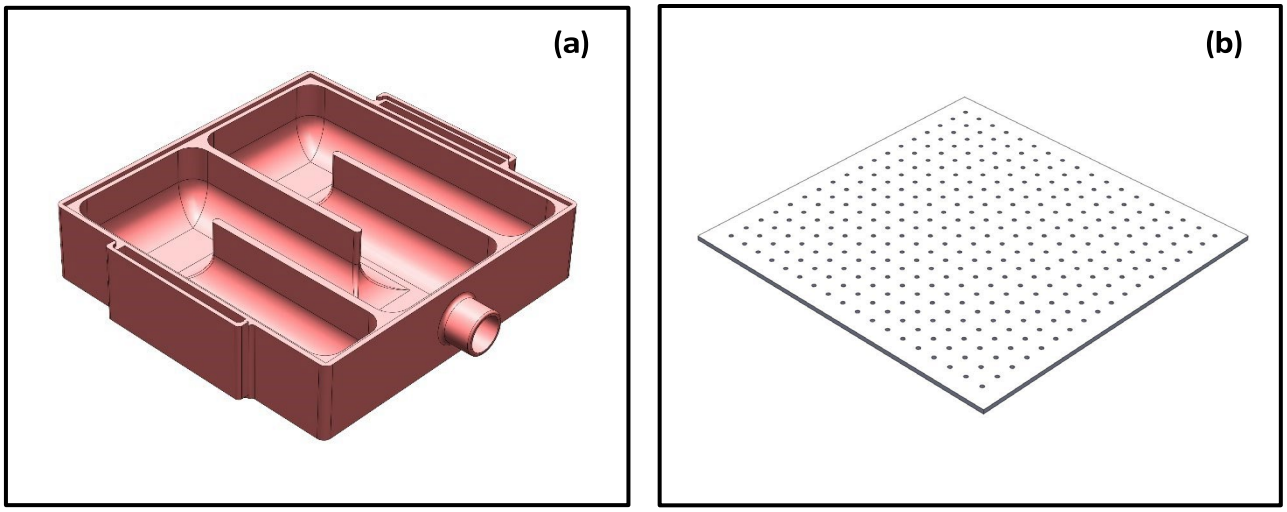

Figure 2.9. *Vacuum Table Base Piece (a) and Top Piece (b)*

The base piece was designed to be 3D printed on a Bambu Carbon X1 Printer using the Bambu Slicer. Using PETG on the Bambu CX1, the base piece took 8 hours in total to print. The top piece was designed to be cut out of a 1'x 1' x 1/10" acrylic sheet on a VLS CO2 Laser Cutter. Both vertical rails were designed to also be cut out on a VLS CO2 Laser Cutter, using a single 1'x 1' x 1/8" acrylic sheet. The wooden square clamps were designed to be cut out of two 1'x 1' x 1/10" laminated wood sheets. All laser cutting operations took between 5-25 minutes to complete.

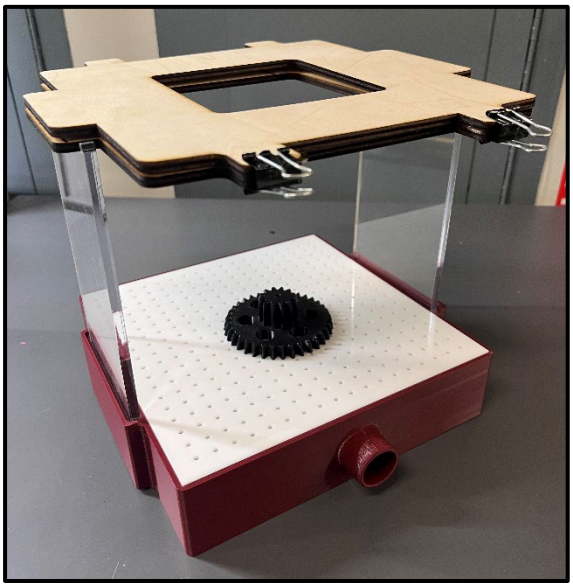

Figure 2.10. *Final Device*

3. Trial Workshops and User Feedback

For this project a workshop was created to teach participants how to use the device, as well as introduce the world of engineering and sustainability to these participants in a hands-on and exciting way. Through this workshop, participants were able to mold and create custom candles or crayons. Each participant would create their own unique buck using play-doh or modeling clay, which they would then use with the vacuum form machine and a piece of reused HDPE, to form a mold. The participants could then place the mold in a cool water bath and fill it with melted wax or crayons to create a uniquely shaped candle or crayon.

A trial workshop was conducted at the Ingram Hall Makerspace with three student members of Engineers for a Sustainable World, a student organization at Texas State University. This workshop lasted for roughly one and a half hours, within which students were able to complete the entire process of creating their own custom wax candles as outlined previously. After a brief introduction and a short two-to-three-minute demonstration of how the vacuum form machine worked, the students were easily able to use the device to make their own molds for the workshop, with little additional support. After an initial successful attempt, users saw an average success rate of 80% when forming with recycled HDPE. Additionally, due to the nature of of the vacuum forming process, several attempts may be made using the same piece of stock material, so long as it is not sufficiently overstretched, or if there is not a tear or hole appearing in the plastic. The molding takes on average between five to ten minutes to complete. This includes machine, stock, and buck setup, heating of plastic, forming/molding, and time it takes for the part to cool. In a verbal interview with participants after the workshop, students stated that the device was “easy to use” and was an interesting and engaging experience. They also expressed that they would be interested in attending another workshop with this device in the future.

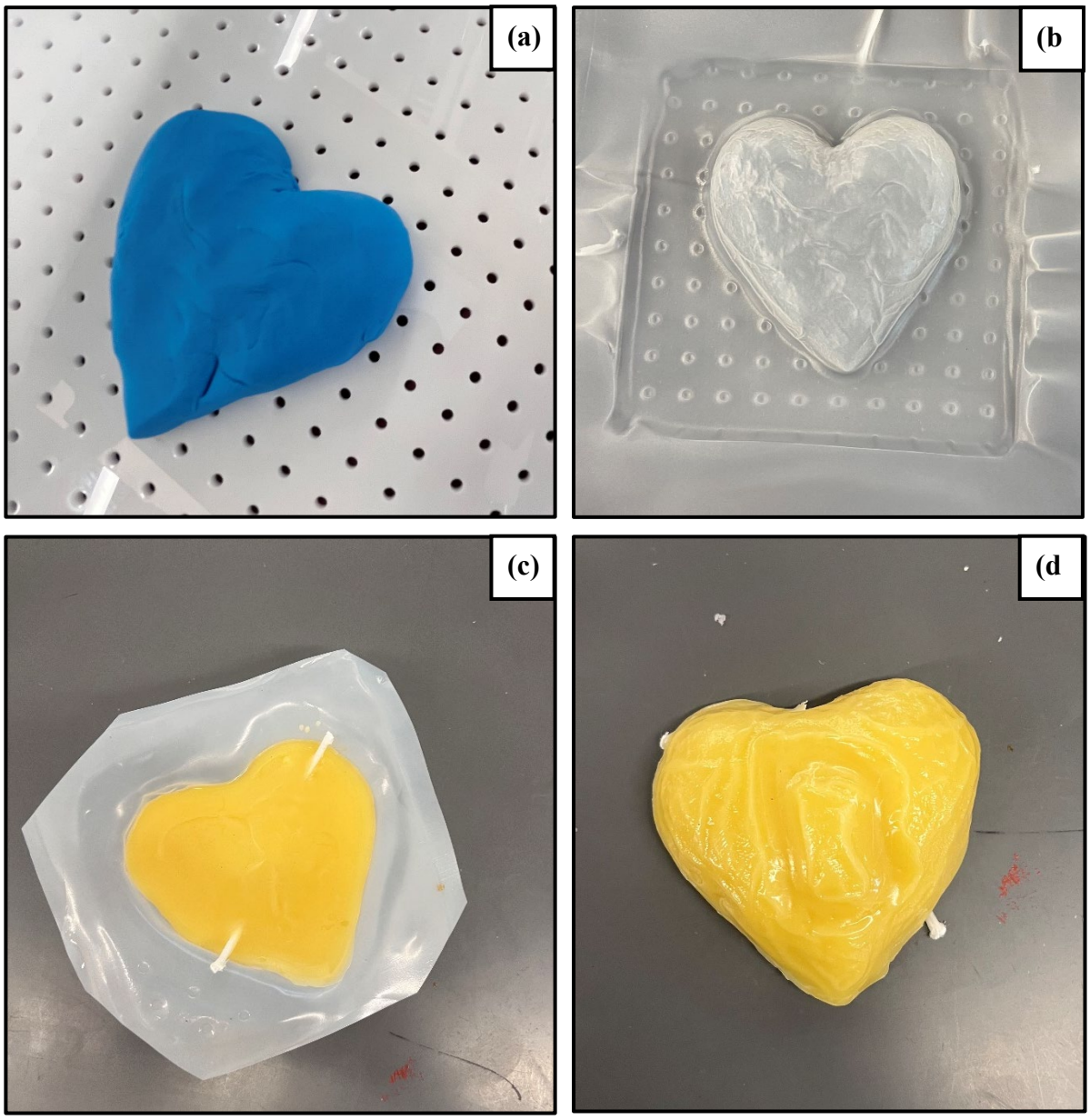

Figure 3.1. *(a) Play-doh buck, (b) vacuum formed mold, (c) candle wax in mold, (d) final product*

4. Project Aspirations

As previously mentioned, the end goal of this project is to provide a device that is readily and easily accessible to as many people as possible, so that they may be able to more easily make

new things and contribute to a more sustainable world. As such, upon the completion of this project, it is planned that all files and documents related to creating a vacuum form device like the one outlined in this document will be redistributed on online maker forums and websites such as thingiverse and/or makerworld, for anyone to be able to recreate and make their own device. Additionally, several more workshops will be designed to highlight the type of products that can be made through the process of vacuum forming. Finaly, I'd like to reach out to several local school districts and work with them to host several workshops with their students and provide them with their own vacuum form device so that they may continue to educate youngers students about the world of engineering and sustainability.

5. Acknowledgements

We would like to acknowledge the Texas State Undergraduate Research Quanta Services Fellowship for the funding to do the research.

6. References

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