MECH 4V96.004, Individual Instruction

Shop Design

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Mechanical Engineering

Eric Jonsson School of Engineering and Computer Science

THE UNIVERSITY OF TEXAS AT DALLAS

Collapsed Lung Chest Tube Anchor

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Executive Summary

Dr. Phillip Jarrett – an emergency doctor at UT Southwestern Medical Center – requested molded parts to be designed and fabricated that are used to treat patients with a collapsed lung. An aluminum cast was milled using the Bantam CNC and the cast was used for injection molding via the Galomb injector tool. Many challenges were faced during the project including cast size, milling paths, and the manual portion of injecting. The team stepped up at every issue and the Collapsed Lung Chest Tube Anchors were successfully fabricated.

Figure 1 – Completed Female Cast

Figure 2 – Completed Chest Tube Anchor Part

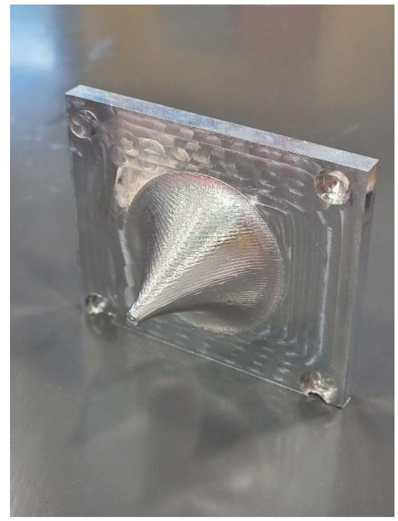


Figure 3 – Completed Male Cast

Section 1, Problem Identification

A *life anchor* part was designed by a UTD Senior Design team and patented by Dr. Jarrett. A press-fit mold was 3D printed to produce a sample for testing. A mold design must be constructed for use by plastic injection molding. 30 chest tube anchors must be fabricated for further testing using this developed mold design for further testing by Dr. Phillip Jarrett at UT Southwestern.

Section 2, Criteria and Goals

The **purpose** of this project is to create an injection mold to produce and replicate the *life anchor* part designed by Dr. Jarett and his team.

The **criteria** applied require that the device:

a.) **Be molded with TPE/TPU 60A pellets.**
b.) **Use of the Galomb A-100 molder.**
c.) **Replicate size and dimension via .step file provided.**
d.) **Be molded with limited to no voids or clashing.**

Goal – fabricate 15 parts as deliverables with another 2-3 parts for pre shipment testing.

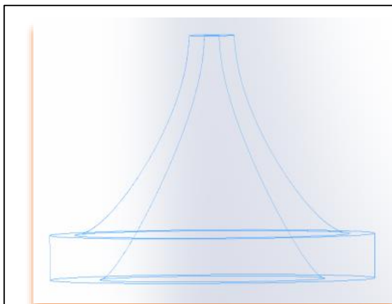


Figure 4 – View of .step file from Dr. Jarrett

Section 3, Research

Choosing a Mold Type

3D Printed Mold

While 3D printed molds allow for the design and production of complex mold designs, they are typically not used to mass-manufacture thousands of parts with consistent reliability. When the test mold below Chase Pearson (a member of the ECSW Project Workshop and Shop Design class) made who also participated in MECH 4V96 was tested, it fractured at the high temperature and pressure necessary to make the part.

Figure 5 – Example 3D Printed Mold designed by peer Chase Pearson

This 3D-printed resin mold was designed and manufactured by Chase Pearson, who wanted to experiment with 3D printing the mold design. Sample parts were produced with this mold, though parts of sufficient quality were not reliably produced. Note that the 3D printed mold fractured after several injection molds.

Press-Fit Molding

Press-fit molding depends on constant stress and friction and requires careful calculation of geometric tolerancing for the related interference fits between two mold halves.
While a press-fit mold currently exists for a larger-scale *life anchor* model, it's not suitable for large-scale production, particularly in a factory setting. As such, it has been determined that a plastic-injection mold will be utilized.

Hot Molding vs. Cold Molding

Hot molding requires the mold to be heated during the mold process. This reduces cycle time and potential waste, at a higher energy cost. On the contrary, cold molding manages the curing process at room temperature, leaving the heated thermoplastics to cool inside the locked mold, a more cost-effective production process.

For this project, cold molding will be utilized, as production is restricted to the Galomb A-100 Benchtop Injection Molder, which does not allow for the heating of the mold.

Figure 6 – Galomb A-100 Benchtop Injection Molder

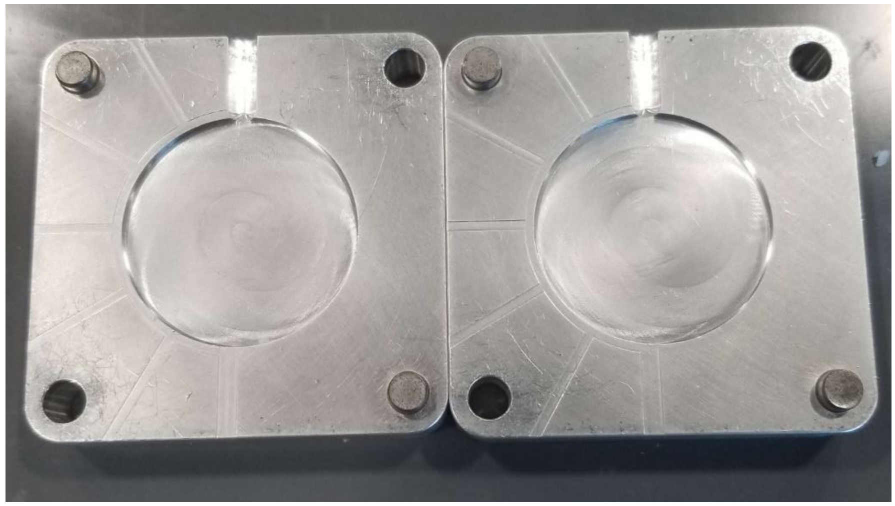


Figure 7 – Sample Cold Mold design provided by Galomb, available in ECSW Project Workshop

Mold Material

Aluminum stock will be utilized for the construction of the mold. An industrial standard, aluminum is relatively inexpensive, easy to mill with the available tools and machines, and produces reliable molds. The heat dispersion factor of aluminum is even higher than that of steel, making it ideal for plastic injection molding with molten plastic. The mold walls can be designed to be extremely thin, at a thickness of approximately ~ 2-4 mm.

Air Vents

Air vents in some form will be utilized to remove the possibility of trapped air within the mold during the plastic injection process. Trapped air can lead to the formation of air bubbles or a deformed surface, and even cause burning in the molded part.

During tests with the manufacturer-provided disc mold and the procured TPE pellets, the existing air vents on that mold were deemed to be sufficient at removing any trapped air, though earlier prototypes contained some air bubbles. Air vents with a width of 0.05 inches and a depth of 0.005 inches were designed on the parting line as those are the dimensions of the air vents in the example mold from Figure 7.

Draft Angle

Draft angles are typically employed in molds to facilitate the process of removing the finished product from the mold. Draft angles are typically 1-2 degrees relative to the face in the mold cavity; They can be modified by 0.1-0.4 degrees for the desired texture thickness. For this mold, a draft angle will not be utilized, as the parts are easily removable from the mold after injection molding.

Process

Per the criteria given, the part is to be hot injection molded with the plastic provided so research focused on the tools and peripherals needed to meet the goal.

a.) Converting the .step file to a casting block.
b.) Implementing injection molding properties to the block. i.e.: vent ports, injection port, mirroring one half and adding set pins.
c.) CNC router for the injection mold cast and how to convert the file to mill the block properly.

Section 4, Brainstorm

Brainstorming Injection Point Geometry

The geometry of the gate used for the entry of the melted plastic needs to be determined. The gate is the geometry of the input hole used to feed the molten plastic into the cavity of the rest of the mold

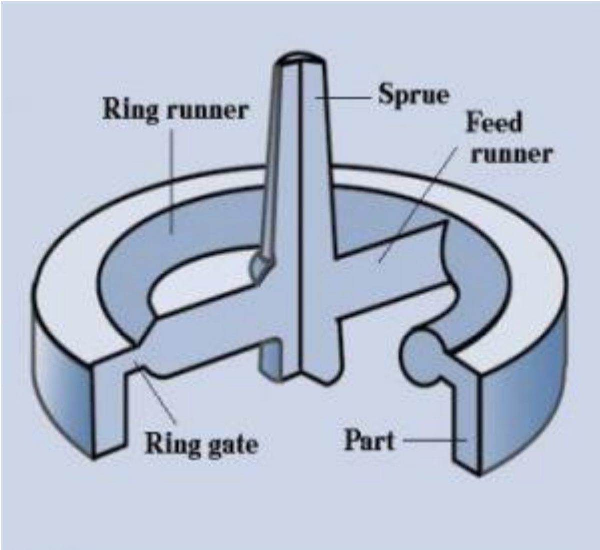


Figure 8 – Example Ring Gate (Mechanicaleng Blog, 2018)

Figure 9 – Example Tapered Pinpoint gate (Fischer, 2019)

The gate used in the sample design shown in Figure 7 resembles a Tapered Pinpoint gate, albeit with no runner. A ring gate such as the one shown in Figure 10 was also considered with the pros and cons written below.

Pros of Ring Injection Gate

- Promotes even flow of molten plastic into part
- Allows uniform use of gravity to make short shot defects (i.e., the entire void is not filled) less likely

Cons of Ring Injection Gate

- It is believed that the milling functions required are outside the abilities of the Bantam milling machine
- Any flash defects placed at the ring of entry would be nearly impossible to remedy

It was determined that the use of a simple hole to mimic the tempered pinpoint gate would be drilled as that is easiest design to use and any excess material formed using the gate is easily removed using scissors as this material is quite flexible.

Brainstorming Injection Point Location

An Injection point must be determined before the mold is designed.

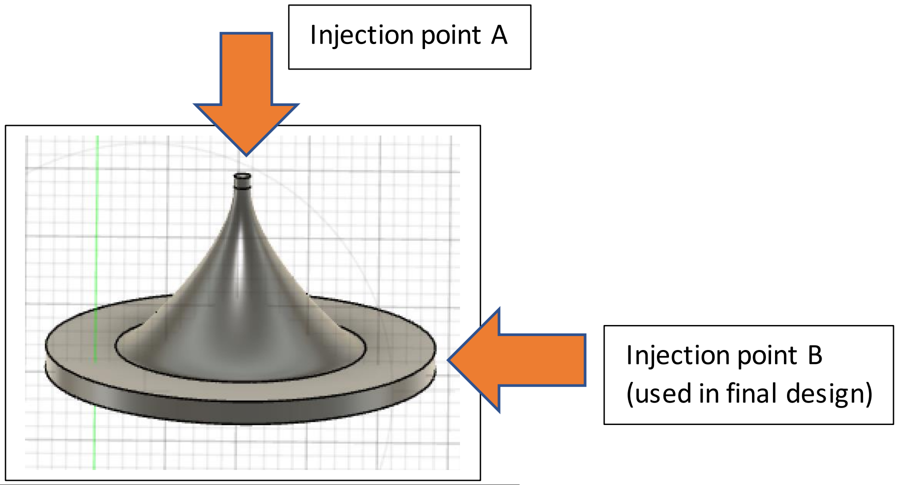


Figure 10 – Illustration of Points A and B

Pros and Cons of Point A

- Potential flash defects do not affect an area of geometry critical for part functionality
- Milling the runner and gate would require difficult hole drilling

Pros and Cons of Point B

- Easier to mill, remove material at the boundaries of the blocks
- Flash defects are more likely to form and become more difficult to remedy as a result of placing the injection point onto a curved surface

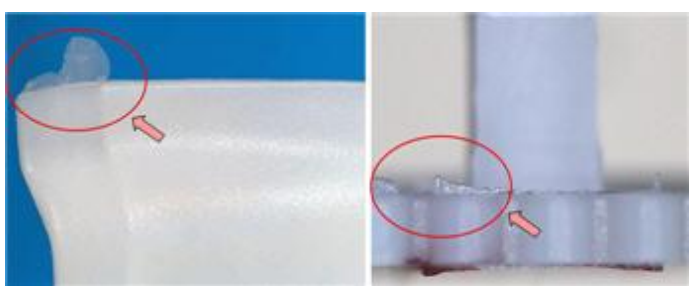


Figure 11 – Examples of flash defects found when using injection molding. (Paulson, 2012)

Point B was chosen as the injection point as this type of defect would be best placed in an area not crucial for product functionality

Brainstorming Vent Design

The Original Vent Design intended to be used is inspired by the mold design provided shown in Figure 7. Testing with the example mold produced proper parts.

The decision was made to drill a tiny hole at the bottom of the mold rather than engraving the slits as the drilling a single hole is determined to be a significantly easier operation with the available drill bits. This design change still yields proper parts.

Decision Tree

#	Consideration	Result 1	Result 2	Result 3
1	Material of Mold	Aluminum	3D Printed	
2	Drill bit usage	2 flute drill bits	3 flute drill bits	
3	Gate type	Ring Gate	Tapered Pinpoint Gate	Simple Hole
4	Gate Location	Point A	Point B	
5	Keep Dowels	No	Yes	
6	Vent Design	Single Hole	One Hole at point A plus a hole opposite point B	Engraved slots
7	Injection Temperature	200 ℃	250 ℃	300 ℃

Section 5, Analyze Solutions & Develop Requirements

Requirements for the Injection Mold and the Produced Part

#	M/P	Requirement	Pass/Fail	Proposed Modification / Additional Notes
1	M	Fit within the Galomb A-100 Injection Benchtop Injection Molder	Pass	
1.1	M	Height of mold must be no greater than 2.63”	Pass	The given height is dependent on the orientation of the block during injection molding. This height is likely oriented with the point of plastic injection.
1.2	M	Depth of mold can be no greater than approximately 2.75”	Pass	
2	M	Remove trapped air pressure within the mold during the process	Pass	Holes drilled on the female base and bottom will allow sufficient air flow
3	M	Facilitate removal of the finished part upon finishing the molding process	N/A	A draft angle is currently not being employed, as current removal is sufficient.
4	M	Ensure proper alignment of the two mold halves	Pass	A dowel fixture is being employed.
4.1	M	Allow only one orientation for the two mold halves	Pass	One mold half must have 3 extruded dowels, and one insertion point. The opposite will be milled for the other half.
4.2	M	Manufacture alignment feature(s) to be precise	N/A	Due to milling issues, all dowel pins have been removed. The mold is currently aligned manually.
5	M	Manufacture with aluminum stock	Pass	3 in. x 3 in. x 2.63 in. aluminum stock will be utilized
6	P	The produced part must be an accurate representation of the original geometry	N/A	
7	P	All 15 parts must be identical	Pass	Visually inspected
8	P	Parts should not have any air bubbles or burns	Pass	
9	P	Parts should be relatively smooth	Pass	
10	P	Parts should have a reasonable elasticity	N/A	The desired elasticity has not been quantitatively measured, only qualitatively by Dr. Jarrett

Requirements are categorized as relevant to the mold, or to the produced parts.

Section 6, Develop & Test Models

Developing the Mold Design

Displayed below are the completed models of the two mold halves, designed with Fusion 360.

[More about the mold design itself, in relation to the stock (and other *constraints*)]

Mold Halves

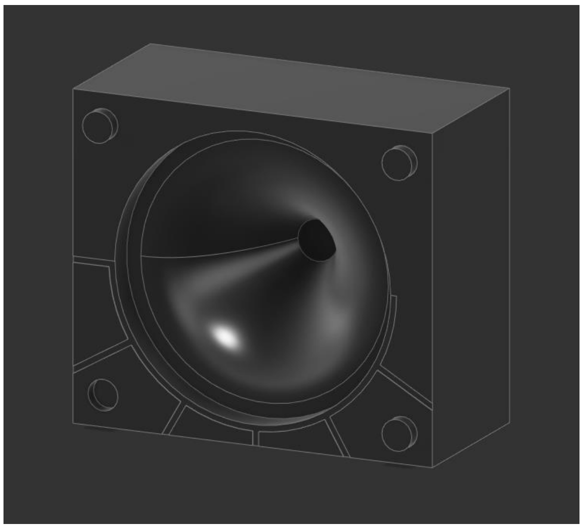


Figure 12 - Female Mold

The entirety of the *life anchor* part will fit within the insertion half of the negative mold.

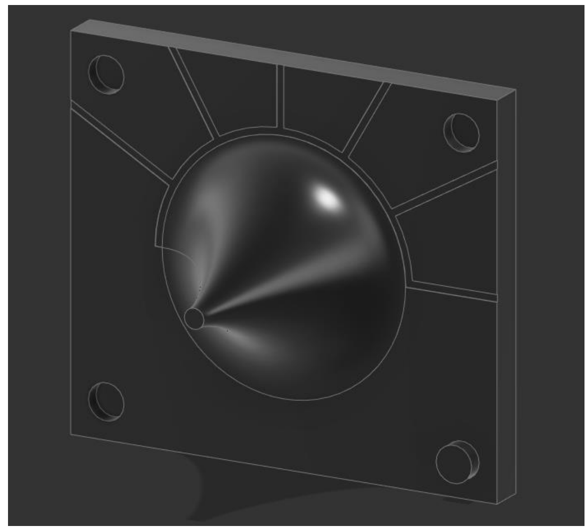


Figure 13 – Male Mold

The receiver half of the mold serves as the base for the entire mold and defines the inner cavity of the *life anchor* part.

Air Vents

Air vents are designed to be of 0.05 inches in width and 0.005 inches in depth, replicating the air vents for a previous disc project. Sample testing with the disc molds shown in figure 5 have proved to have reasonable control over removing any potential trapped air pressure with the TPE 60A pellets.

Note that these air vents were not used in the final prototype of the mold. The Bantam Mill did not offer the precision and tools required to mill the air vents in such a fashion.

Dowel Pin Arrangement

Dowel pins are arranged on a 3:1 ratio on both the insertion half and receiver half of the negative molds to allow only one alignment. The insertion half has 3 extruded dowels, which will be milled from the stock for precision, and 1 dowel insertion point. The receiver half will have 3 dowel insertion points and 1 extruded dowel to fix the molds together during the injection molding process. Note that this process will ensure that the air vents on both mold halves will be uniformly spread across the parting line.

Due to milling issues, the dowel pins have been completely removed, and the mold is to be manually aligned. While each individual dowel pin has been appropriately milled and tolerance, their relative distances to each other are inaccurate, thereby not allowing a flush fit.

Manufacturing the Mold

Clear Excess Material from Stock

Currently, a toolpath has been generated to clear the excess material of the provided stock to the desired height of 2.63 inches.

A 2D pocket operation was used for this, to extend the boundary of the toolpath to the stock diameter. A face operation or 2D Adaptive Clearing may also be used if appropriate precautions are taken.

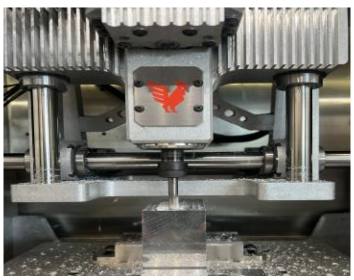


Figure 14 – Bantam Mill in operation

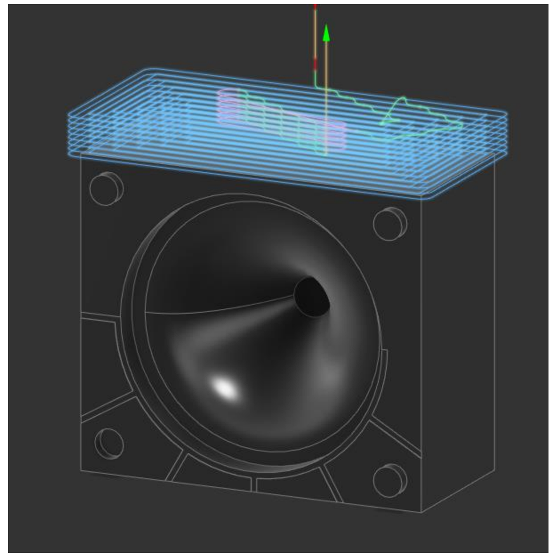


figure 15 – Toolpath used to trim excess material

2D Adaptive Clearing for Dowels

2D Adaptive clearing operations were used to quickly clear excess stock material and create the dowels from the stock material. A stepdown size of 0.05” was initially used, but later tests revealed that smaller stepdown sizes are much more time efficient.

The 3-flute ¼” square-end mill was used for these adaptive clearing operations, but later milling procedures were done with the Helical 00150 (2-flute ¼” square-end mill) as two flutes are better suited towards milling aluminum and are more efficient at clearing greater amounts of material.

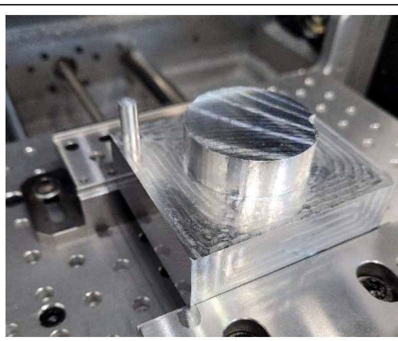


Figure 16 - 2D Adaptive Clearing Operation for Male

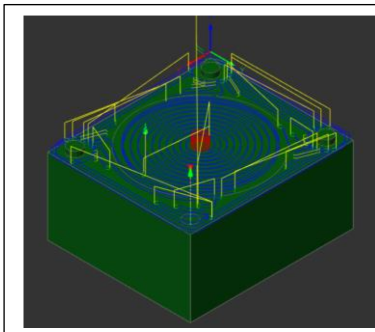


Figure 17 - 3D Adaptive Clearing Toolpath for Female (2)

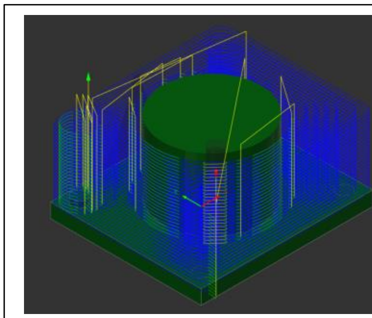


Figure 18 - 2D Adaptive Clearing Operation for Male

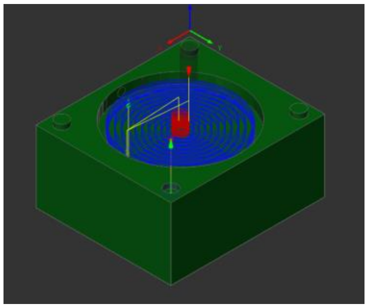


Figure 19 - 2D Adaptive Clearing Toolpath for Female (2)

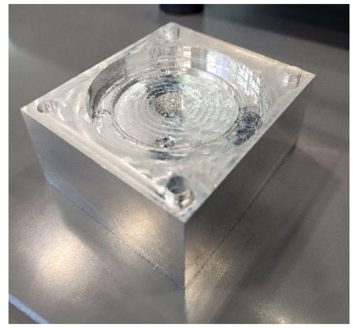


Figure 20 - 2D Adaptive Clearing Operation for Female

3D Adaptive Clearing for Pockets

To clear the remaining material in the conic geometry, 3D adaptive clearing operations were used with the Helical 00150 end mill (1/4" square-end mill, 2 Flutes). Certain settings were optimized during the construction of the toolpath to allow a smooth and efficient milling procedure, primarily the stepdown size, retraction height, and shallow stepdown specifications.

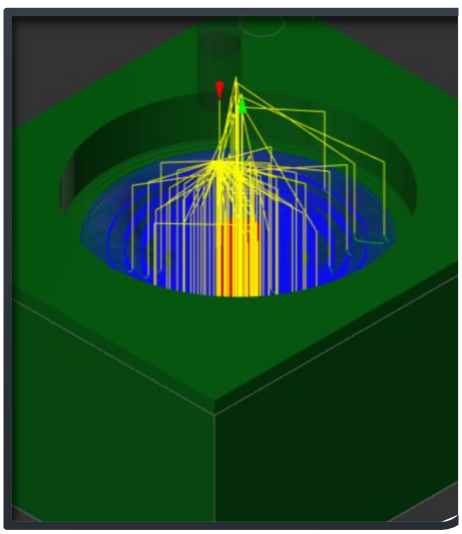


Figure 212 - 3D Adaptive Clearing Toolpath for Female

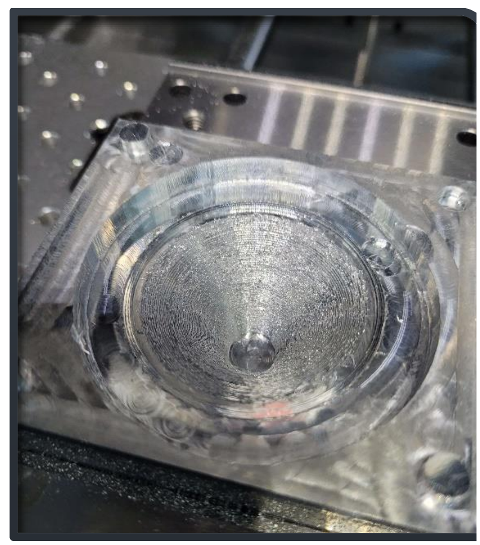


Figure 22 - 3D Adaptive Clearing Operation for Female

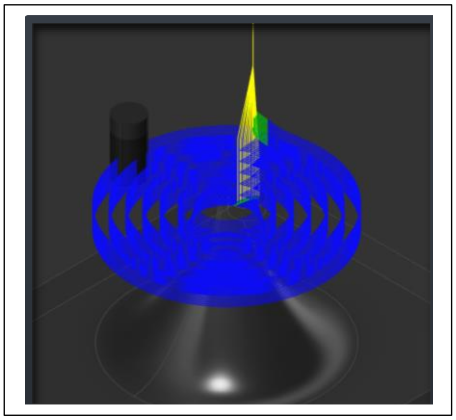


Figure 23 - 3D Adaptive Clearing Toolpath for Male

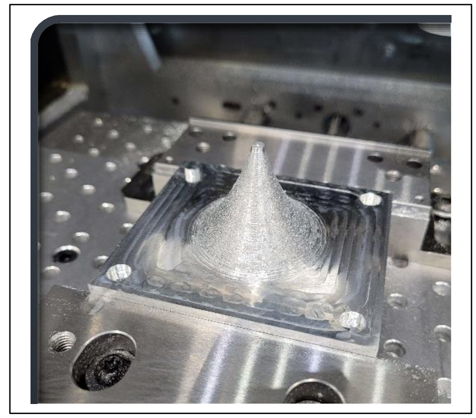


Figure 24 - 3D Adaptive Clearing Operation for Male

Smoothing Operations

For the smoothing operations, a parallel operation was run with the ¼” ball-end mill. A contour operation was also run for the female mold half, for an even smoother finish.

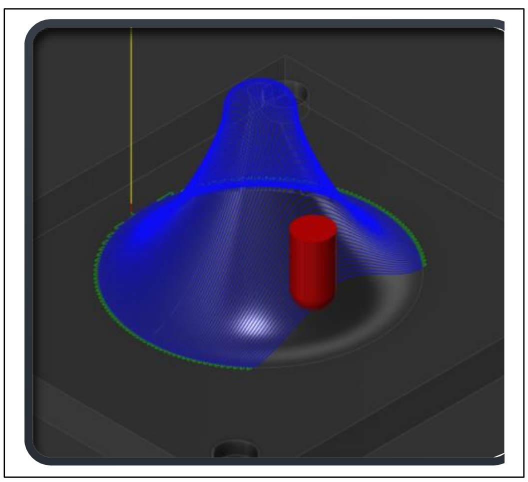


Figure 25 - Parallel Toolpath for Male part

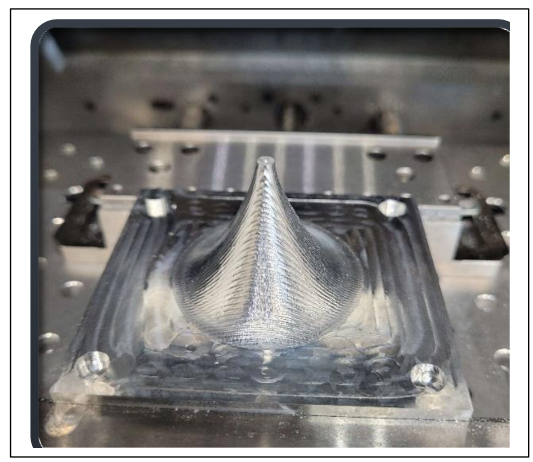
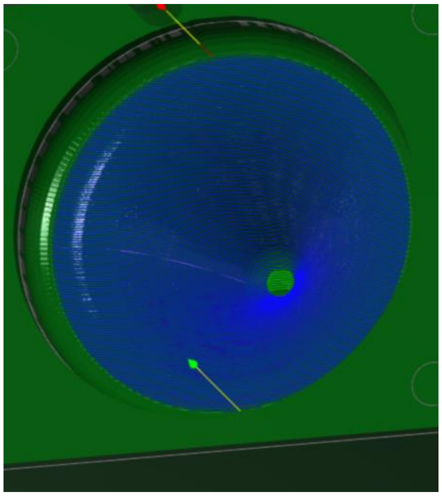


Figure 26 - Parallel Operation for Male part



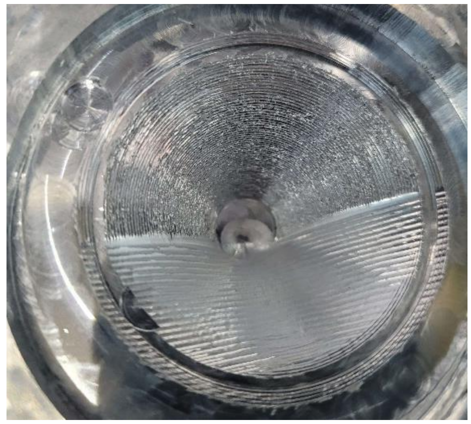


figure 27- Parallel Operation for Female

Figure 28 - Parallel Operation for Female

Figure 29 - Contour Operation with Female

Section 7, Make a Decision (CDR Presentation)

As the objective for this project was pre-determined by the sponsor of the project, both the design and the materials, a CDR is not required. An alternate presentation has been scheduled for November 16, during which the course of the project, issues encountered, and lessons learned will be discussed.

Meeting Comments/Responses:

- A 3D printed mold may be used instead of an aluminum mold, at least for testing purposes. These 3D printed molds can be reinforced with aluminum to improve reliability and heat dispersion rates.
    - A 3D-printed mold has been tested by peer Chase Pearson, which fractured after several injection molds. Reinforcing such a mold with aluminum, or selecting a stronger material may circumvent this issue, and can be tested.
    - 3D-printed molds are efficient for testing more complex geometries, or even experimenting injection points for testing optimal melt flow. As such, 3D printed molds can be utilized to improve the reliability and function of the final mold, whether they are traditionally milled or additively manufactured.
- While a hole was drilled in the base of the conic cavity (of the female mold) for air flow, this hole was blocked by the vice grip of the Galomb A-100. As such, the effectiveness of this hole as an air vent cannot be accurately estimated.
    - Using an injection molding machine that allows for the use of a different injection entry point, the effectiveness of this hole for air flow can be tested.
- Additional documents related to this report will be provided later.
    - A more detailed analysis on the milling procedure

    - This document will detail to future students the intricacies of milling with the Bantam Mill, as to promote the development and production of future projects in the ECSW project workshop.
  - The experiment details for potential leakage in the life anchor (when applied with a medical adhesive)
    - A secondary report detailing the specifics of this experiment is being written and will be provided to Dr. Phillip Jarrett upon completion. Following this, different adhesives and alternative methods will be tested.

Section 8, Communicate & Specify

All costs for this project were handled by Dr. Phillip Jarrett, who provided four blocks of aluminum stock and a twenty-kilogram bag of TPE 60A pellets.

Of the four aluminum blocks, only two blocks were used to manufacture the male and female halves of the mold, due to early milling limitations.

The remainder of the TPE pellets will be given to Dr. Jarrett for further individual testing.

Beyond the stock and materials for this project, additional and spare end mills were procured for backup during the project. They also serve as a future resource for the Bantam mill and the shop.

Section 9, Implement

3D Adaptive Clearing with a Square-end mill

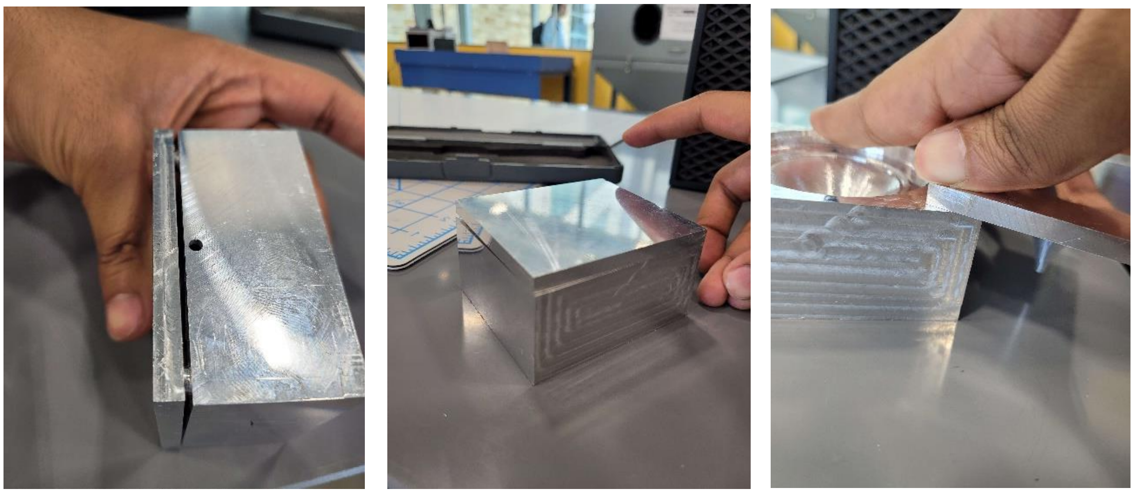
The square-end mill is not designed to ramp during the milling operation. As a result, the initial 3D adaptive clearing for the female mold crashed, given the 0.005” stepdown size.

After discussing with machinists about milling optimization and specifications, the stepdown size was reduced to 0.0015”. The proceeding milling operations were successful, ran with no interruptions, and allowed for a faster federate.

Dowel Misalignment

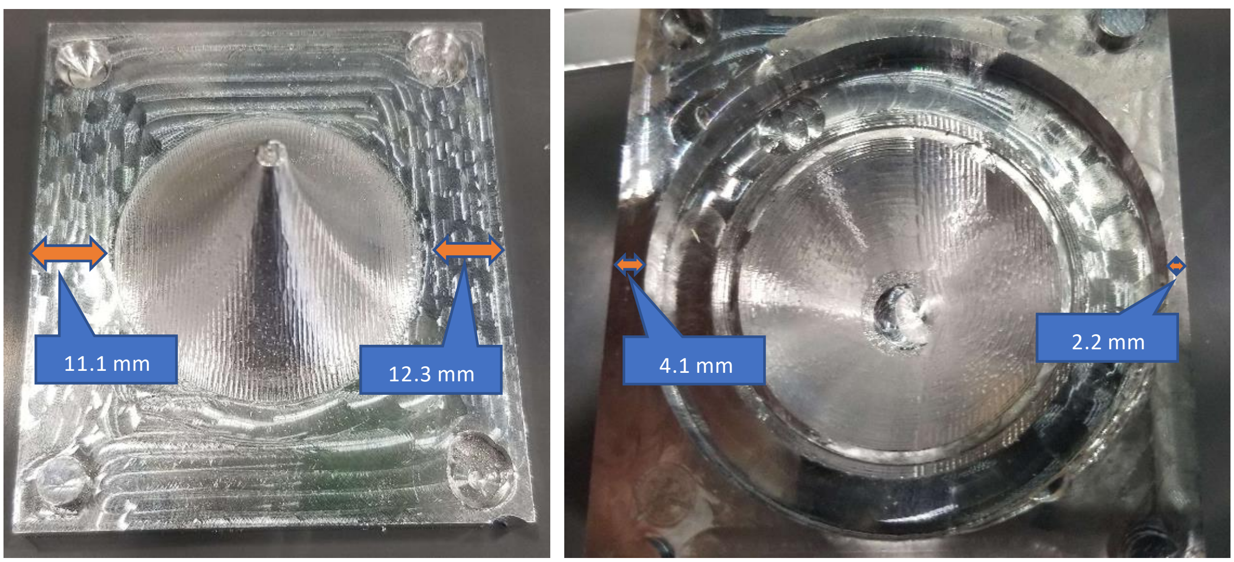
Due to a milling error in the initial milling process, the dowels of the developed mold halves did not align, to create a flush, aligned fit. To address this issue:

1. An appropriate tolerance was applied to the dowel pins – 0.005” for a clearance fit
2. The dowel pins were entirely removed – The dowels facilitate alignment, a process that can be manually done for this project.



Figures 30, 31, and 32 – *Showing initial misalignment issues*

After extensive troubleshooting, it was determined that the root cause of the misalignment was a result of a misplacement of the conic geometry used in the molds. This is when the decision was made to remove the dowels altogether and find an alternate method to secure the two sides of the mold.



Figures 33 and 34 – Measurements of misaligned geometry

Milling Restrictions in the Conic Cavity

In the female part, the smoothing operation is unable to cover the entirety of the conic surface, specifically the sharp corner near the base of the cavity. This is due to the limitations of the ball-end mill, the curvature of its tip makes that section unreachable.

To account for this, a design modification will need to be made at the base of the cavity, a rounded surface correlating to the curvature of the ball-end mill. Alternatively, a different end mill or CNC machine must be used to effectively clear and smoothen this area.

Injection Molding

- The molding process was found to be a very manual process that took multiple attempts to find the right cast alignment, temperature, and injection pressure.
- Besides the temp. (200 °C) there's not any documented takeaways for this process as it is completely manual.
- Trials and experience are the best options to learn a good technique for each new mold/part.

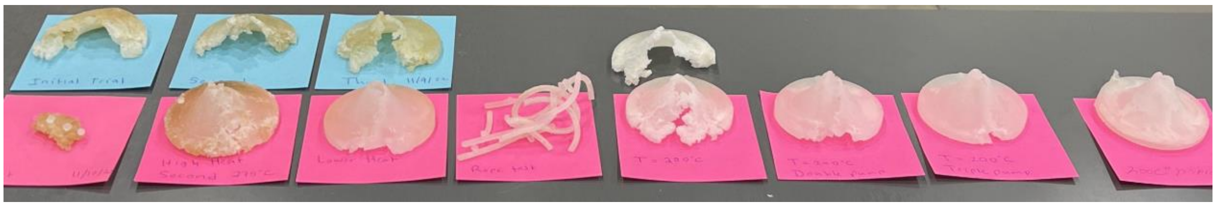


Figure 35 – Process changing injection parameters to achieve final product

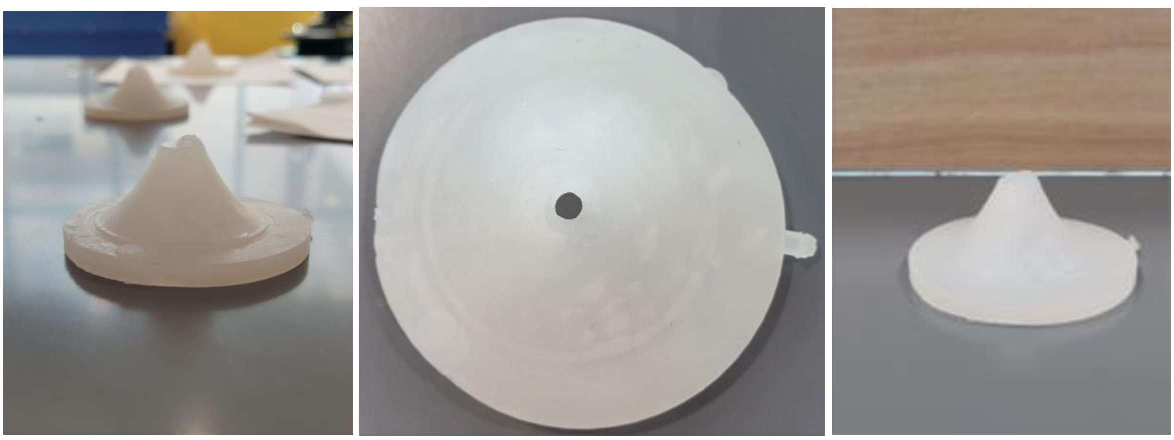


Figure 36 – Final Product

Section 10, Review and Assess

Here is a brief list of obstacles that needed to be addressed.

- Multiple iterations of the part file were provided by Dr. Phillip Jarrett to accommodate the size of the available area used by the Bantam A100 machine. Specifically, the original block was too wide to fit inside the staging area used to hold the mold. The width of the mold had to be reduced from 3 inches to 2.63 inches, and consequently required the part to be scaled down to fit inside the new width.
- October 5th: The Bantam tool library Chase Pearson (a member of the ECSW Project Workshop and Shop Design class) provided does not include the helical square end mill used as part of his documentation given to operate the mill.
  - The CAM Tool Library provided by Helical tools was used to acquire the data for the necessary end mills.

- A second experiment was conducted to test the effectiveness of this injection-molded prototype for pressure leakage. A secondary report will be written and provided later.
- A cadaver study at UT Southwestern Medical Center will be conducted with these molded samples.

References

Fischer, N. *Torsten's Training Tips: Mold Design — Pin-Point Gates*. Retrieved from Kruse Training: https://krusetraining.com/2019/02/08/torstens-training-tips-mold-design-pin-point-gates/

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