MEMS 5104 Small Project II: Topology Optimization & Casting Simulation using Altair Inspire and Altair Cast

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***Abstract*—Design of a product that is casted often goes over many design revisions before the final product is released. Recasting is time consuming and expensive because the design process will likely have to restart from the beginning. Topology optimization is used to find the optimal structure.**

***Index Terms*—Topology, Casting, Optimization, Altair**

I. Introduction

The design process often requires revisions to a component or group of components in a system. This revision is often after a final prototype has been made. So, the revision process is expensive.

Topology optimization for stiffness is used to reduce the weight of a material while keeping the necessary mass to maximize strength. A casting optimization is a simulation that will ensure that the component used is able to be manufactured without flaws. Issues like solidification before completion, or turbulent flow in a mold can be seen before the mold is even made. These processes together will reduce the amount of design and redesign time spent on a product.

II. Design Optimization

A. Objective

This analysis is inspired by a faux-hand pump handle from A Crafty Mix [1]. The handle they made is out of wood and full. The handle that will be optimized is made of cast iron and will have cut outs to reduce weight.

TABLE I: Material Proprieties of Cast Iron

Material Name	Youngs Modulus MPa	Poisson's Ratio	Density g/mm3	Yield Strength MPa	Part Mass kg
Cast Iron	6.6e10	0.27	0.01	65.5	1.096

Fig. 1: Unaltered model

B. Process

The existing component is filled to a uniform body.

Fig. 2: Existing Design Simplification Process

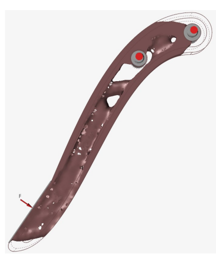
Below is the design space shown in brown. The non-design space is shown in the gray areas. The non design space is locations that cannot be altered due to their interactions with outside components. In this case, those components are bolts and the hand.

Fig. 3: Design Space and Non-Design Space

C. Optimization Concepts

Below are the various optimization simulations based on different control shapes. For this particular design, the best design is using the extruded control-shape which may be heavier than a the other options, but it gives a much better stiffness and castablity.

(a) Single draw



(b) Single draw no hole

(c) Extrusion

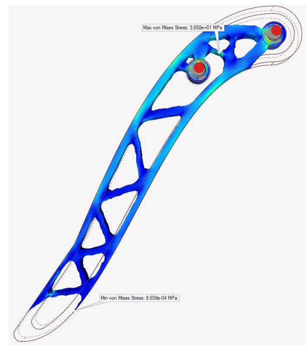
(d) Split Draw

(e) No constraint

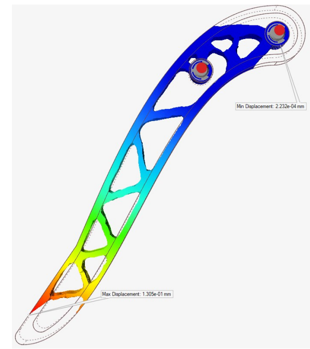
Fig. 4: Optimization Concepts with Different Manufacturing

D. Validation of Concept

An analysis of the extrude optimization shows that this is a viable selection to use for the handle. The end of the handle experiences 0.13 mm of displacement. The von Mises stress is at 36.5 MPa, which is greater than the unaltered model at 6.5 MPa, however, there is still a factor of safety over 2.1.



(a) von Mises Stresses

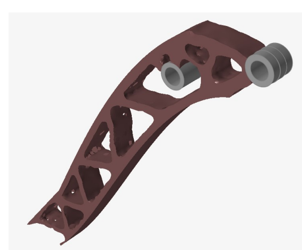


(b) Displacement

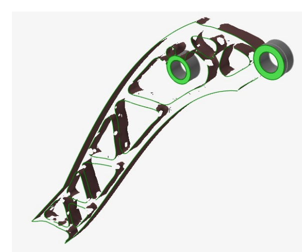
Fig. 5: Stress and Displacement Contours for the Optimized Design

E. PolyNurb Generation

The final optimized design is rough and requires smoothing. The PolyNurb function in Inspire allows for smooth contours that follow model surface. This is done using a “wrap” tool. There is a sectioned view and full view of the pre-PolyNurb and post-PolyNurb designs in Fig. 6. Following this process all geometry is filled, filleted, smoothed, and prepped for a casting simulation.

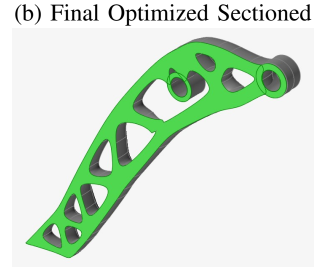


(a) Final Optimized Design



(b) Final Optimized Sectioned

(c) PolyNurbed Final Design

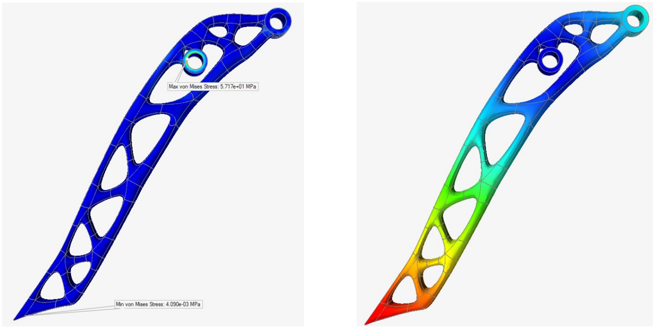


(d) PolyNurbed Sectioned

Fig. 6: PolyNurb process

F. PolyNurb Analysis

An analysis below shows the displacement and von Mises stresses in the PolyNurb design. The displacement and stress vary slightly from the pre-PolyNurb Design. However, all of the geometry is kept the same.



(a) von Mises Stresses (b) Displacement

Fig. 7: Stress and Displacement Contours for the Optimized Design with PolyNurbs

G. Result Comparision

The optimized design was found to be 30.5% lighter than the existing design. The stress is in the existing design was higher but the displacement was lower. Table II, shows the comparison of the two designs.

TABLE II: Comparison of the two designs

Design	Stress MPa	Displacement mm	Mass kg	% Mass Reduction
Existing	6.52	36.8 mm	1.097	
Optimized	57.2	0.130 mm	0.7616	30.5%

H. Casting Simulation

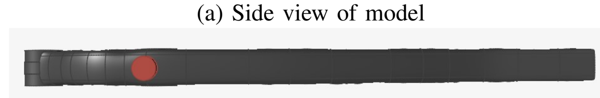
Figure 8 shows the optimized PolyNurbed model in Inspire Cast. This program is used to generate a simulation for casting. The simulation is most helpful in understanding turbulent flow throughout the model, solidification, and porosity. These can create failed models due to incompleteness or warping. The model was finely meshed with element size of 3 mm.

Fig. 8: Modeled in Inspire Cast

The material used is Cast-Iron GJS-500-7 at 1521.15 K. The model is green-sand. The part volume is 10,670 mm^3 with an ingate area of 113.1 mm^2.

There is only one iteration of this simulation because there were no failed molds. This is due to the location of the ingate. It's at the top of the part, but oriented so that the cast-iron will flow into both sides of the part. This will reduce the chances of warping and ensure the entire mold is filled.

(a) Side view of model



(b) Top view of model

Fig. 9: Gate location

I. Final Casting Simulation Results

The solid fraction contours shown in Fig. 10 displays very little material close to solid fraction of 1. Therefore this has input parameters that will give good casting behavior.

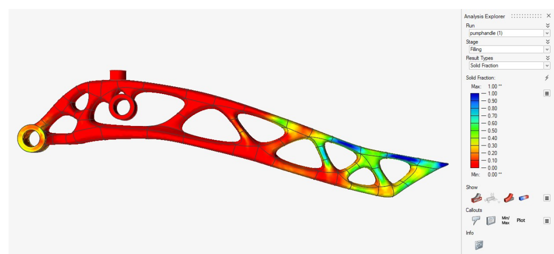


Fig. 10: Solidification Result

The temperature contours in Fig. 11 show a relatively uniform distribution throughout the part. The exception location being near the ingate, which is expected. Therefore, cold shots and blemishes will not be a problem.

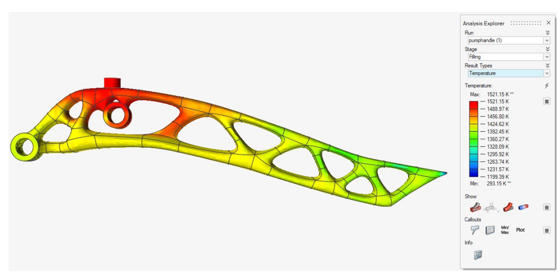
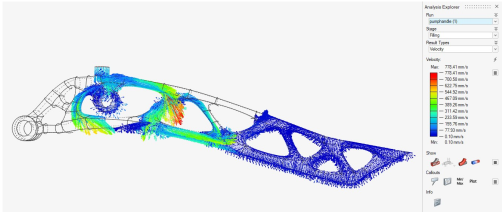
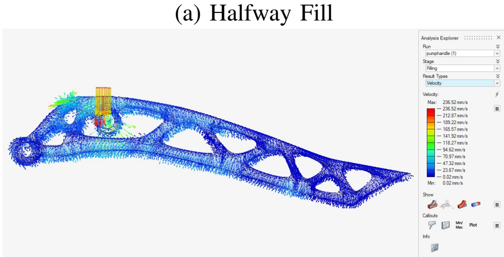


Fig. 11: Temperature results

The velocity vectors in Fig. 12 show the behavior of the cast iron as it flows into the mold. Half way through the pour, displayed in Fig. 12a, there is some turbulent flow. This means that there will be greater wear on the mold. However, due to the low solidification, there should not be any concern for blemishes or an uneven finish.



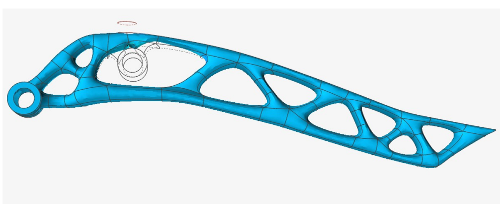
(a) Halfway Fill



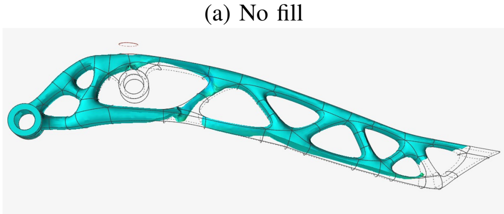
(b) Complete fill

Fig. 12: Velocity results [m/s]

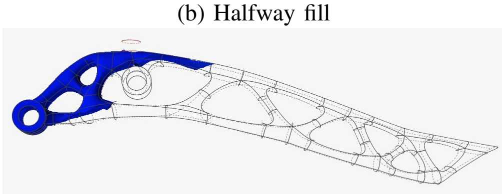
In the images below, blue depicts air inside of the model. As the cast iron is poured into the mold, the air is shown existing. There are no air gaps left when the mold is complete.



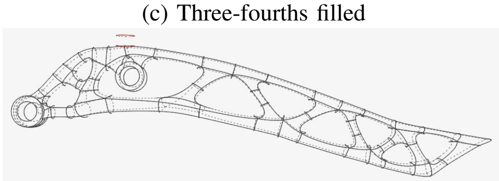
(a) No fill



(b) Halfway fill



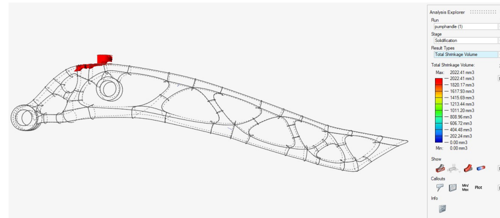
(c) Three-fourths filled



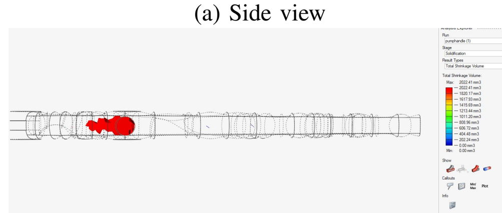
(d) Filled

Fig. 13: Material Flow, blue represents air in model.

The porosity experienced is at 40%. The locations that expereince this is evenly distributed throughout the model as shown in Fig. 15.

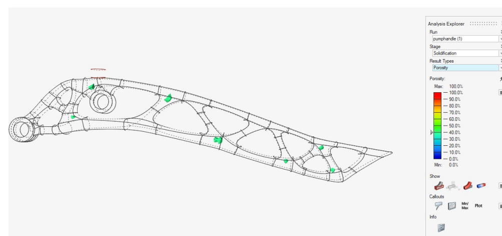


(a) Side view

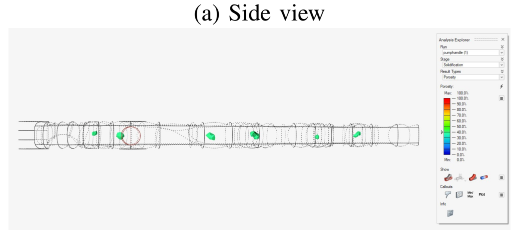


(b) Side view

Fig. 14: Shrinkage porosity [mm^3]



(a) Side view



(b) Top view

Fig. 15: % Porosity

III. Conclusion

This design study shows how topology optimization and casting simulation can be beneficial to reducing the total time spend in revising a part. This saves costs two-fold through using less material in reducing the weight by 30.5% for this part and ensuring that the casting model will not have failures. The tools used were Altair Inspire and Altair Cast. It was possible to efficiently run multiple simulations and models.

References

[1] Acraftymix, “How to make your own faux hand water pump,” A Crafty Mix, 04-Sep-2021. [Online]. Available: https://acraftymix.com/blog/faux-hand-water-pump/. [Accessed: 10-Nov-2021].

[2] Altair Engineering Inc., ”Topology Optimization & Casting Process Simulation using Altair Suite of Products”, Himanshu Singh, Prashant P. Hiremath, Subir Roy, John Brink, Andrew Stankovich.