Topology Optimization & Casting Process Simulation

Himanshu Singh, Prashant P. Hiremath, Subir Roy, John Brink, Andrew Stankovich; Altair Engineering Inc.

ABSTRACT

Oftentimes, in the design of a casting, suboptimal structural concepts are developed which at the same time are not castable, requiring multiple and time-consuming design iterations. This paper describes a process to generate both structurally efficient and also castable parts, while reducing the overall design cycle time. The optimal structure is determined by topology optimization, reducing component mass while maintaining performance requirements. This step is followed by a design smoothing operation and then by a casting simulation to check for casting defects. To demonstrate this software driven product design and process validation, solidThinking Inspire is used to develop the concept design and Click2Cast for casting process validation. Both software are part of Altair's product suite and available through solidThinking and HyperWorks licensing.

KEYWORDS

Topology, Optimization, Manufacturibility Constraints, Casting Simulation, Inspire, Click2Cast, Weight Savings, Validation

INTRODUCTION

During the design of components of a system, engineering's main focus is meeting structural product performance requirements. After a time-consuming manual design optimization process, if it is discovered that the part cannot be manufactured, the entire design cycle effort is wasted. Repeating the whole process is a waste of time, money and effort.

Topology optimization is a proven approach for developing structurally efficient parts in a fraction of the typical design cycle time. To ensure manufacturability, casting simulation has become a powerful tool for analyzing the mold filling, solidification and the cooling process. It guides the design from casting defects like air entrapment, porosity, cold shots etc.

For the case study reported in this paper, a robot arm has been considered. Concept level optimization is carried out using solidThinking Inspire with real field loads & manufacturing constraints. Several optimizations have been performed considering different manufacturing options with a final design selected meeting all the performance targets. This final design is analyzed with Click2Cast to investigate the casting process and any potential defects.

INSPIRE solidThinking®

CLICK2 CAST™ solidThinking®

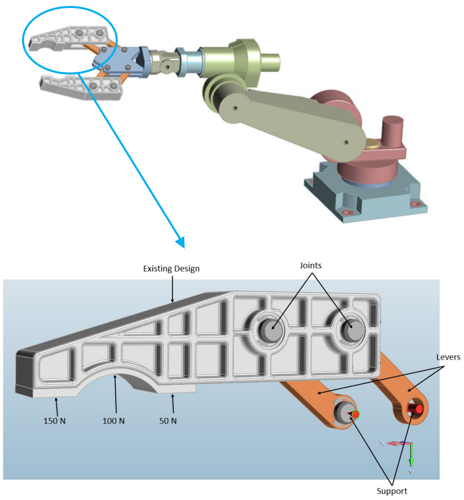

Figure 1: Existing design with applied loads and boundary condition

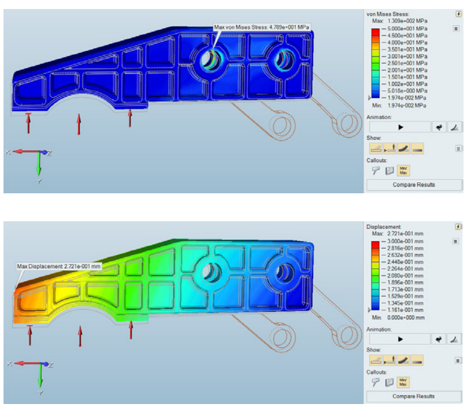

Figure 2: Stress and Displacement Contours for Robot Arm—Existing Design

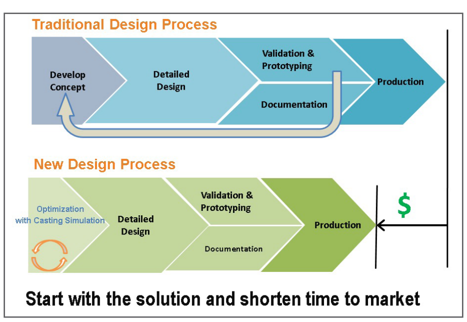

Figure 3: Design Processes

DESIGN OPTIMIZATION

The existing design of the robot arm in an assembled condition with all the loads and boundary conditions are shown in Figure 1. A total force of 300 N is applied on the face of the arm while the lever ends are constrained, with one end being free to rotate. The part material and its details are provided in Table 1.

Material Name	Young's Modulus (MPa)	Poisson's Ratio	Density (t/mm^3)	Yield Strength (MPa)	Part Mass (kgs)
Aluminum (A380)	71000	0.33	2.76E-9	159	0.364

Linear static analysis is performed in Altair's Inspire software. The model is analyzed for static equilibrium to find the stresses and deflections (Figure 2).

A. Objective

The goal of this study is to demonstrate how to reduce the manufacturing cost and the time to market. By optimizing the component upfront while also simulating the casting process, the design cycle time is reduced and the cost is minimized, Figure 3 shows the traditional design process compared to the new design process. In the traditional design process there are many cycles of design iterations before finalizing a design. In contrast the new design process utilizing topology optimization software Inspire followed by casting simulation Click2Cast delivers a solution which very closely meets the design parameters—i.e. Stress, Deflection and Frequency—while also being manufacturable.

B. Process

A maximum design/package space is created around the component considering all the adjacent components. Normally, designs using concept optimization fall into two cases;

a. Start from scratch
b. Use a carryover design

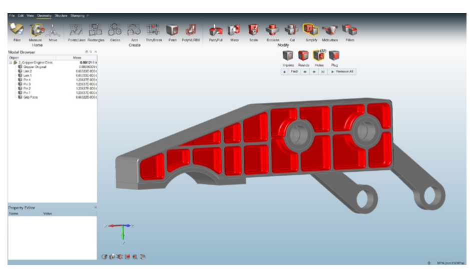

Figure 4: Existing Design Simplification Process

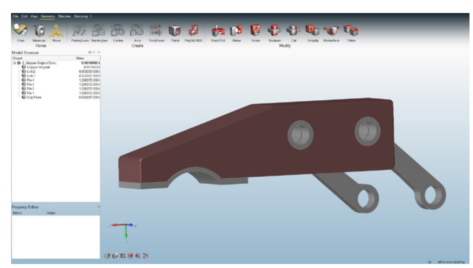

Figure 5: Design and Non-Design Space

In this case the carry over design is used, and a design/package space is created using the "simplify geometry" feature within Inspire (Figure 4). The design/package space is the volume within which Inspire can carve away material to arrive at an efficient concept (in Figure 5 the region in maroon is set as design/package space). The locations where forces and constraints are applied are set as non-design space (in Figure 5 these regions are gray).

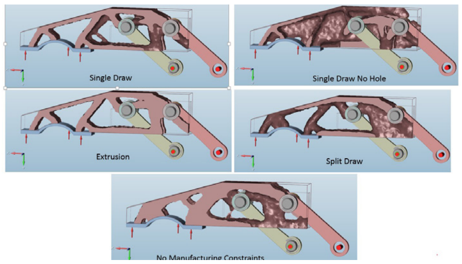

Figure 6: Optimization Concepts with Different Manufacturing Constraints

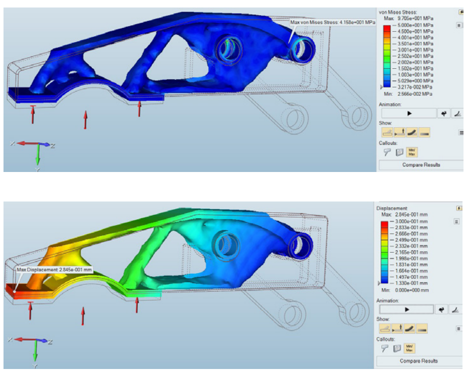

Figure 7: Stress and Displacement Contours for the Optimized Design

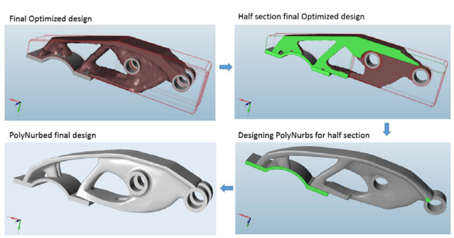

Figure 8: Polynurbs Process Flow

C. Optimization Concepts

An Inspire optimization was run with "maximize stiffness" as objective, while retaining 30% material of the design space. Different concepts were explored by varying the manufacturing constraints: single draw, single draw with no-hole, split draw, extrusion and with no manufacturing constraints at all. The concept with no manufacturing constraints was found to be the stiffest as expected, but as it could not be manufactured, the next stiffest concept was selected for further study—split draw (Figure 6).

D. Validation of Concept

The split draw concept which was selected was further analyzed to check the stresses and displacements, which were found to be within the performance targets (Figure 7).

E. Result Comparison

The optimized design was found to be 46.5% lighter than the existing design while the stresses were lower and the displacements were almost the same. Table 2 shows the results comparison between the existing design and the optimized design.

Designs	Stress (MPa)	Displacement (mm)	Mass (kg)	% Mass Reduction
Existing design	47.8	0.27	0.364	
Optimized design	41.5	0.28	0.195	46.5

F. PolyNurb Generation

The final optimized design consisting of iso-density contours remains bumpy and needs to be converted into smooth surfaces, using the PolyNurbs functionality within Inspire. Smooth surfaces are created directly on the optimized concept using the "wrap" tool. The process flow of PolyNurbs generation is shown in Figure 8. PolyNurbs were initially created only on the half section considering the symmetry and later mirrored through the symmetry plane to generate a full PolyNurb model. Proper fillets and curvatures have been provided to the final design to make it smoother and ready for casting simulation.

G. Casting Simulation

Click2Cast is a casting process simulation software within the solidThinking suite which allows the user to enhance and optimize their manufactured components by avoiding typical casting defects such as air entrapment, porosity, cold shots etc. Click2Cast offers an innovative user experience allowing the complete simulation to be done in 5 simple steps, through a user-friendly interface.

Casting simulation has been performed on the final design in Click2Cast (Figure 9). The model has been finely meshed with 1 mm element size, having 84,692 total number of nodes and 378,963 tetrahedral elements.

Aluminum A380 L2630 is used for part material and Steel X40CrMoV is used for mold material taken from the Click2Cast material data base. The gravity is in the negative Y direction for filling simulation refer Figure 10. The first iteration is performed with filling time as 5 seconds. Results were requested for both filling and solidification with an assumed gate location based on engineering judgement.

The first iteration revealed that the gate location selected was introducing unwanted turbulence in the part (Figure 11). Also, the filling time of 5 seconds was too high as material in some regions were seen to be solidified while others were still liquid. Figure 12 shows material with solid fraction close to 0 (liquid) and 1 (solid).

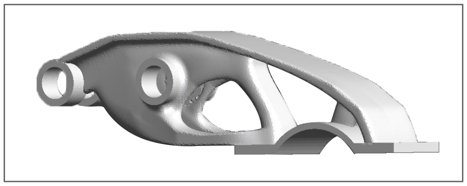

Figure 9: Model in Click2Cast

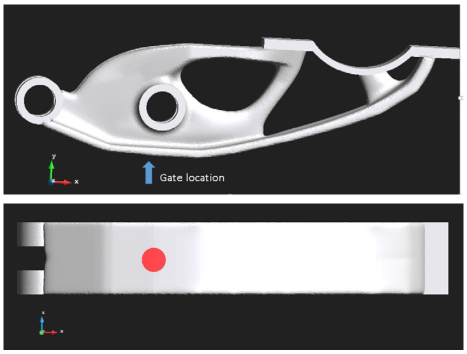

Figure 10: Iteration 1 Gate Location

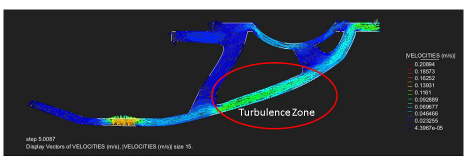

Figure 11: Iteration 1 Velocity Distribution

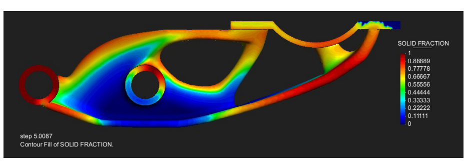

Figure 12: Iteration 1 Solidification Result

A second iteration was performed by changing the filling time to 2.5 seconds and shifting the gate location in the X direction to reduce the turbulence (Figure 13).

Results were drastically improved showing the material flowing smoothly without any turbulence (Figure 14). The reduced filling time of 2.5 seconds also had a very good impact on the results, as there was less material close to solid fraction 1 (Figure 15), and hence, this iteration was finalized with the input parameters giving good casting behavior.

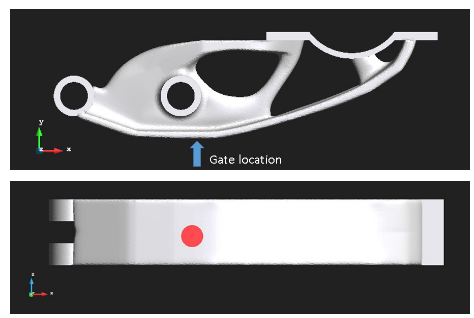

Figure 13: Iteration 2 Gate Location

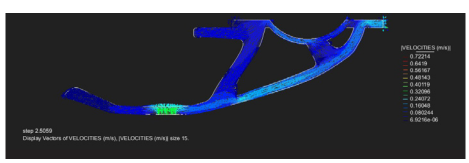

Figure 14: Iteration 2 Velocities Distribution

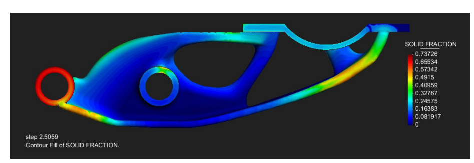

Figure 15: Iteration 2 Solidification Result

H. Final Casting Simulation Results

Temperature contours in Figure 17 show uniform distribution, hence it can be concluded that cold shots and blemishes will not be a problem.

Velocity results can be observed in Figure 18. By visualizing the velocity vectors, it is clear that the behavior of the material during the filling is smooth. The velocity vectors show the speed and direction of the material flow helping the user identify areas of turbulence during the filling of the part.

The material flow can be observed in Figure 19, where the flow is divided into two colors. The light gray color represents the material in contact with the mold wall, and the red color represents the material in contact with air. Click2Cast uses a biphasic solver, thus it considers the liquid plus the air inside the mold.

Shrinkage porosity is also plotted to determine the size of the porosities by comparing the color of plot nodes with the legend (Figure 20). It was observed that the max was 7.5 mm3 which is quite low and also the location of the porosity seems to be in the top surface, which can be easily eliminated by adding a riser.

Further % porosity is plotted at a value of 5%, which means 5 % of what we see would be a void, which seems to be very low (Figure 20).

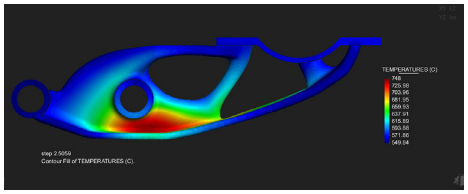

Figure 17: Temperature Results (°C)

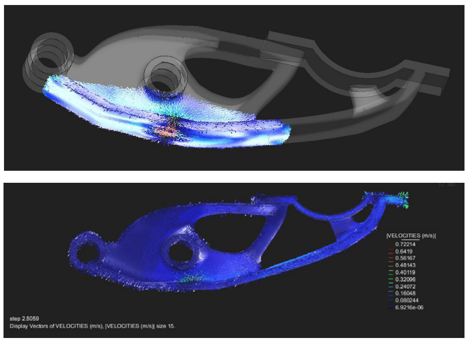

Figure 18: Velocity Results (m/s)

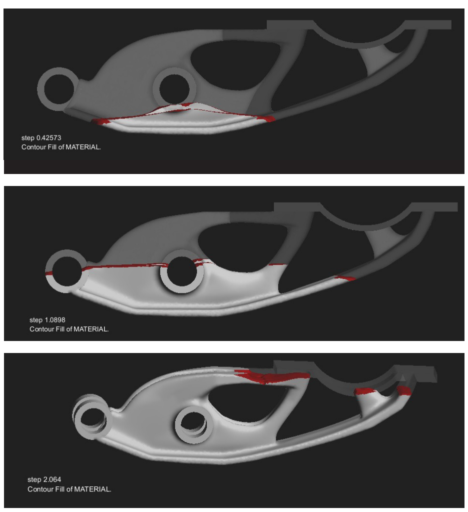

Figure 19: Material Flow

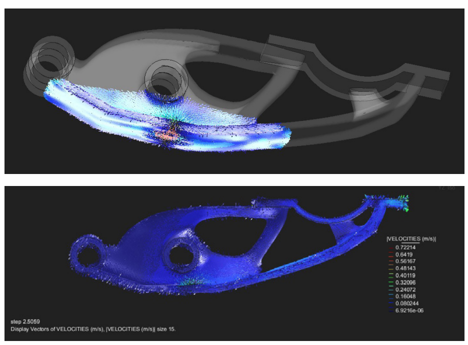

Figure 20: Shrinking Porosity (mm^3)

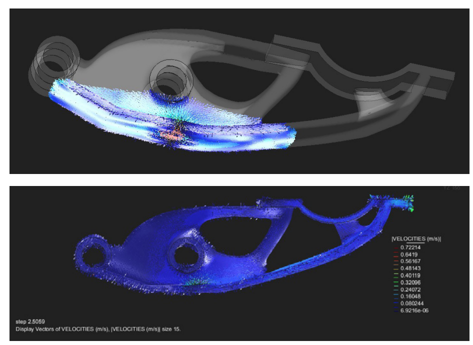

Figure 21: % Porosity

CONCLUSION

In this study a design methodology is presented using an upfront design optimization and casting process simulation to reduce design cycle time and significant cost. The tools used–Inspire and Click2Cast—are very intuitive & easy to learn. Also the seamless modelling environment with finite element solver, optimization engine, and a high performance compute cluster makes it possible to run multiple design iterations very quickly.

REFERENCES

http://www.altairhyperworks.com/product/solidthinking-Inspire

http://www.solidthinking.com/ProductOverview.aspx?item=Inspire Overview&category=Products

http://www.solidthinking.com/click2cast_land.html