Design and modification of a pressure vessel produced by injection molding

Introduction

BlueEye is a company originated from AMOS at Norwegian University of Science and Technology (NTNU), who aim to develop and provide the world's best underwater drone for the global consumer market.

The BlueEye P1 prototype have just been manufactured and tested. Feedback have been promising, but in order to mass produce the complete vehicle a different production methodology must be used. Injection molding is an efficient process to manufacture a large quantity of thermoplastic products, and using this methodology will be a essential step towards reducing the total vehicle cost below the NOK 20 000 price limit.

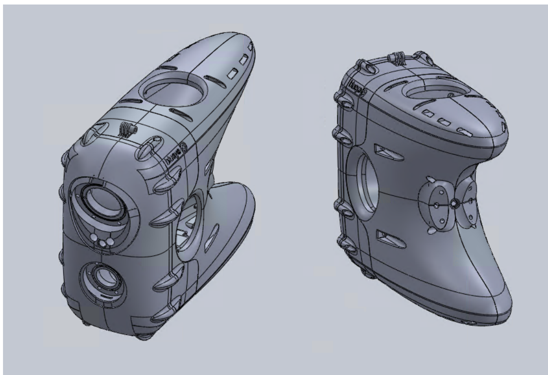

Figure 1. BluEye P1 without thruster system[1]

Objectives

The purpose of the thesis is to investigate the possibility for mass producing the current P1 prototype by injection molding. Different suitable materials for this type of production must be evaluated and the entire pressure hull must be modified with respect to design constraints connected to manufacturing of an injection molded part.

Main objectives in this thesis are:

1. Evaluate polymers that can be used in injection molding and select an appropriate material.
2. Investigate the possibilities of producing the current prototype by injection molding, with basis in the design aspects and requirements connected to the production process and mold design.
3. Address challenges connected to the P1 design and propose future modifications.

Methodology and Results

Material Selection

Selecting a polymer with the right properties required a strict decision gate and good control over the end-use aspects of the vehicle. The main selection criteria was based on the:

- Thermal behavior
- Density
- Manufacturability
- Mechanical properties
- Water absorption
- Price

Polyamide (PA) 66 with 30% glass reinforcements possess a good combination of properties and is applied in all analyses. As polyamide absorbs a significant amount of water the analyses were done for both dry and conditioned.

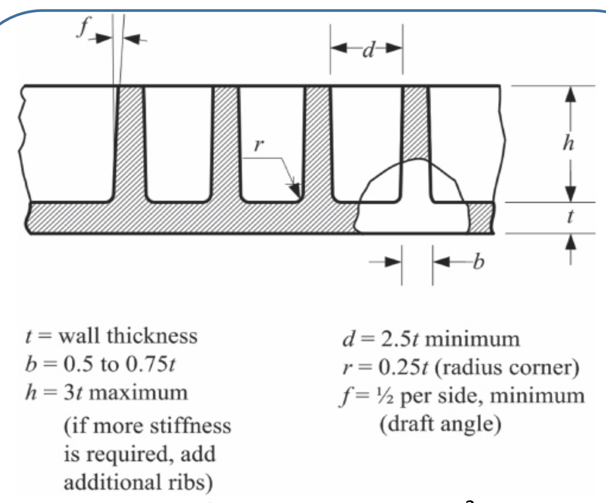

Figure 2. Rib design restrictions[2]

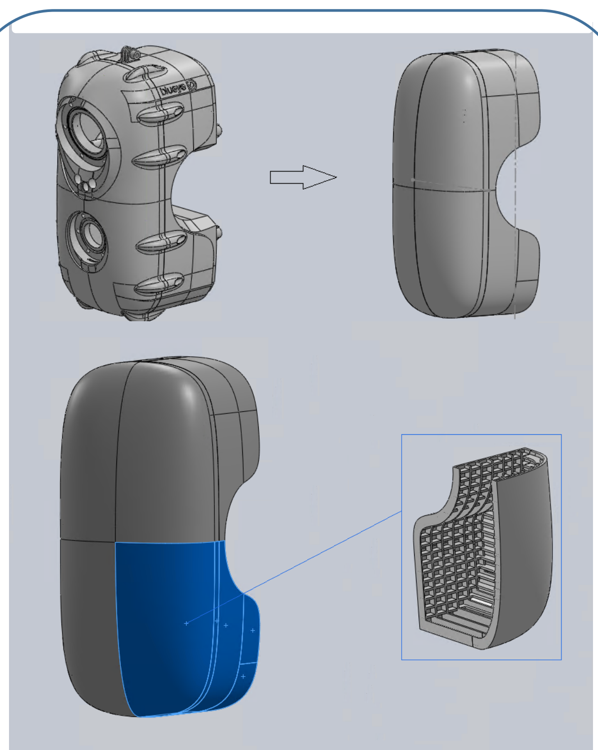

Figure 3. Simplified geometry and rib system

The injection molding process include heating of the polymer and further inject the melt into a mold before cooled. Hence, the different polymers have their own design criteria and limitations to avoid improper shrinkage, warping or sink holes. There will be restrictions connected to the

- Wall thickness and thickness transitions
- Rib design
- Corners, undercuts and filets

Figure 2 shows the relation between nominal wall thickness and a proper rib design, which is the basis for stiffening the pressure vessel. Figure 3 is the simplified geometry used in the analyses, with the complete rib design applied.

The pressure vessel is designed to withstand pressure forces down to 100 m depth. In all analyses the connections between compartments was assumed perfect to get an indication whether the material and stiffening was sufficient. Linear static and buckling analyses were done by using SolidWorks Simulation, and the failure depth for the dry and conditioned polymer are shown in the table below.

Failure mode	PA 66 30% GF Dry	PA 66 30% GF Conditioned
Stress limit	36 m	24.5 m
Buckling failure	53 m	37 m

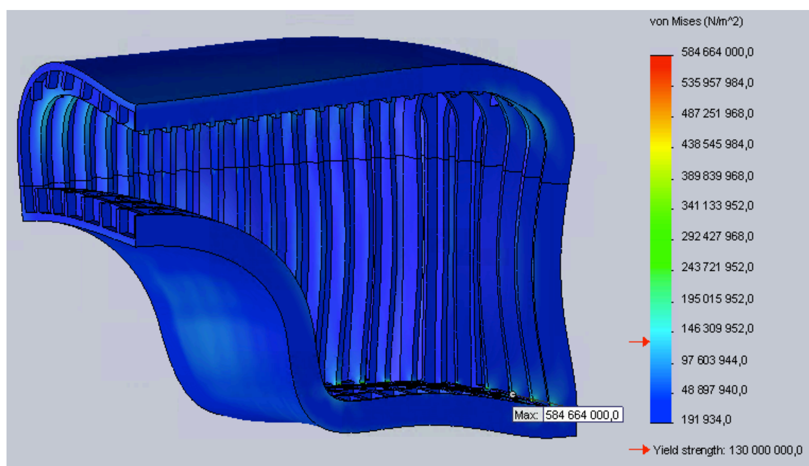

Figure 4. Stress distribution

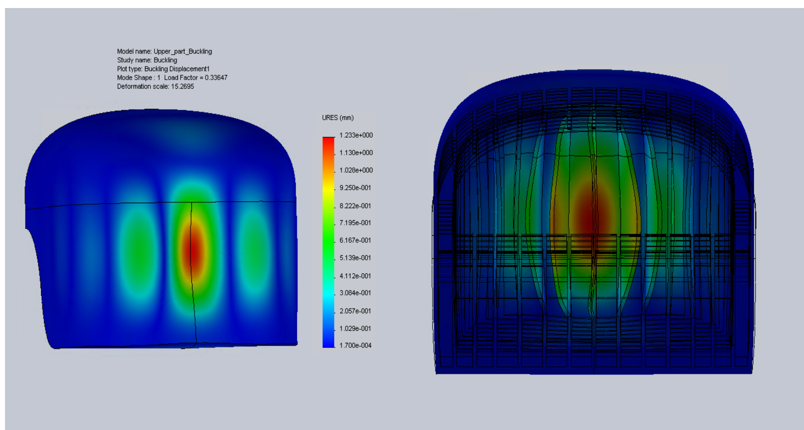

Figure 5. Buckling mode and shape

Sharp corners in the global geometry create large stress concentrations in the model. These filets and corners follow the recommended radius for injection molded parts and cannot be adjusted without special equipment. The center of the geometry have large displacements, which leads to a loss of effective volume and interactions with internal equipment.

Buckling occur in the side wall and is a result of insufficient stiffness. Also here additional equipment are needed to produce horizontal stiffeners, which will further complicate the entire production and manufacturing process

Conclusion and Future Work

The results from all analyses clearly indicated that the pressure vessel geometry are not fit for injection molding at this point. Sharp corners created stress concentrations and generally the displacements was too large. By selecting a stronger material the stress limit will be increased and displacements reduced, but buckling would occur before reaching the design depth of 100 m. Due to production considerations there are no cross-stiffeners at the side wall of the pressure vessel. Creating stiffeners at the side walls would improve the buckling capacity, but will require additional tools for production. Also, the connection between the top and bottom compartment will become a challenge, even if the design is stress and buckling resistant.

The current mechanical connection will not be applicable for a polymer with wall thickness of 3 mm, and both the design and connection method must be adjusted. Before the next generation prototype could be produced by injection molding BluEye have to consider the benefits of investing in new tools compared to changing the entire global geometry. To achieve a pressure resistant design the following should be re-evaluated:

- Global design and shape of the pressure vessel
- Connection solutions and the need for additional surface area for strong bonding
- The need for additional tools to create a proper stiffener design and internal arrangement

References

[1] Prototype P1 designed by BluEye in cooperation with EGGS design

[2] Zhou, H. (2013). *Computer Modeling for Injection Molding : Simulation, Optimization, and Control*. John Wiley and Sons, Somerset, NJ, USA.

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