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SIMULATION STUDY TO EVALUATE THE USE OF FULLY 3D PRINTED INJECTION MOLDS OPTIMIZED BY TOPOLOGY

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Abstract. Nowadays the use of 3D printed molds is increasing. The reasons for the exchange from traditional tooling to 3D printed are the possibility of improvement on the conformal cooling design and building tool time in complex and detailed mold impressions. In this context and based on the perspective that the costs of metallic materials and time of 3D printing machines tend to continuously decrease with new technologies and companies, it is possible to see a variety of new possibilities of manufacturing metallic injection molds through 3D printing methods. Thus, the objective of this study is to verify the possibility of using 3D printing process to manufacture a whole injection mold, reducing weight and manufacturing time, without compromising its functionality and mechanical performance. In order to achieve the lightest possible 3D printed injection mold, it was performed in this study a topology optimization based on Finite Element Method (FEM). This optimization was carried out in a mold of cavities to inject two specimens of type tie tensile test (ASMI E8), because it has a simple geometry, and allows an easy positioning of its extractors, guides and bushings. As result of this optimization, it was achieved a weight reduction of 41,1% of the mold.

Keywords: 3DP, Mold, Injection, Optimization.

1. INTRODUCTION

Currently there is a tendency to manufacture parts made from polymers. For this, there are some processes that make it possible to convert the raw polymer into finished parts. Among them, it may be mentioned: extrusion, blowing, thermoforming, calendaring, rotomolding, compression, casting and injection (KANTOVISCKI, 2005). The last one is the most used to produce plastic parts. According to Michaeli (2000), "among the machines that are used in the processing of plastics, 60% are injection molding machines". Such machines can produce parts from a few grams to several pounds.

The injection process is performed in a semi or fully automated way which in turn makes the process and a final product with excellent quality, allowing the use of the manufactured part as soon as it is demolded. Mold is the main tool of the injection process, and its main function is to mold the liquefied polymer so that the molded part acquire the geometry and mold cavity dimensions. The mold cavity (responsible for shaping the piece) is manufactured by machining. According to Agudelo (2011), the injection molding cavities are generally made of tool steel (AISI H13, AISI P20 and AISI D13) and the base plates, support plates, spacer blocks and extractor plates are made of AISI 1045 steel.

Currently, with limited use and special low series viability, there are hybrid molds. In these molds the cavity is built by 3D printing using polymer resins by diverse 3DP techniques. (WYMAN, 2017). To support the 3D printed cavities standard mold plates made from steel have been used. (REDWOOD, 2017). The limitations from hybrid molds, as stated by Pomager (2015), makes them inviable for large and complex parts production, especially when using high temperature injection resins and too complex geometries with high surface quality and high tolerances.

Nevertheless, there are also hybrid molds which combine cavities made by 3D printing with metal alloys and standard mold base plates. The main technologies used in 3D metal printing are laser sintering and selective laser fusion. Basically, the two dominant processes bond layers of metallic powder through energy provided by a laser beam. The most relevant difference between the two is however, the higher degree of melting of the metallic powder provided

by the selective laser fusion. For this reason, this technology is able to melt a broader range of metals, such as: stainless steel, titanium, aluminum, cobalt-chromium, nickel alloys and brass alloys (HEWITT, 2017). Nevertheless, the 3D printing of metallic hybrid molds still not comparable in lifetime compared to traditional milled ones.

In this context, the replacement of the conventional process of manufacturing molds by metallic 3D printing process makes possible the design of more complex cavity geometries (POMAGER, 2015). In addition to that, metallic 3D printing process allows more efficient design of the conformal cooling system and reduction of the mold weight (no waste of material due to chip generation), energy usage (lighter parts to be moved) as well as manufacturing time. In addition, the costs with the metallic raw material and the time of 3D printing machines must decrease continuously with the evolution and implementation of new technologies, making this technology even more attractive.

In 3D printing process the time and cost depends on how much material the piece has, so that the lighter the mold the cheaper and faster it can be manufactured. Based on that, the objective of this study is verify the possibility of manufacturing an entire weight optimized 3D printed injection mold without compromising its functionality and mechanical performance.

2. METHODOLOGY

The methodology applied to this study takes into account modelling parameters and considerations as well as design concerns such as layout creation method and manufacturing feasibility as explained bellow.

2.1 Model Parameters and Considerations

Initially, a tie-type test body with dimension defined by ASTM E8 was chosen as “part” to be injected. The injection molding material used for the test was standard rheological ABS polymer. Although the maximum injecting pressure and temperature considered were 120 MPa and 200 °C. They occur in the injection sprue which is usually able to support even more severe conditions (MENEGUELLO, 2016). In fact, pressure and temperature drop down when the melt polymer start to flow into the mold cavity. Thus, based on information provided by Manrich, (2005) it was calculated that during the injection process the pressure in the mold cavity is around 78 MPa, and the temperature is approximately 90 °C. In addition, the force required to hold the mold closed is also a critical parameter that must be taken into account the mold design. In this case, it was used a calculated clamp load of 630 kN.

The raw material used in the mold design was the 316L stainless steel. The choice of this material is based on the fact that it is one of the most accessible alloys to be used in parts manufactured by 3D metallic printing. Moreover, it is composed of cobalt and nickel which confers to it substantially high yield and ultimate strengths. (ALL3DP, 2016). According to data extracted from the stainless steel suppliers Baker Industries Inc (316L) and Stratays Direct (3DP), this alloy has the mechanical properties shown in Fig. 1.

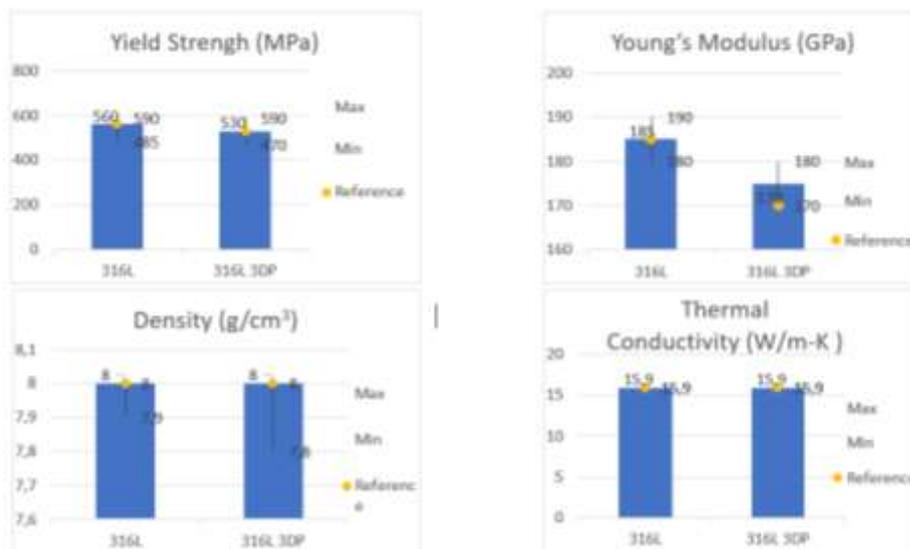


Figure 1. Database used in the topology optimization analyses. The 316L stainless steel alloy data are on the left side of the charts whereas the 316L stainless steel alloy data are on the right side.

2.2 Method of Creating a Layout for the Injection Mold

In order to manufacture a weight optimized mold preserving its mechanical performance and functionality, it is necessary to choose a problem-solving method which is able to create a layout that matches the design requirements.

For this purpose, it is employed topology optimization. Based on a numeric approach, using the finite element method, this method was applied to optimize the layout of material, by the modification of mass distribution, within a given designable space, ensuring that the obtained concept matches a prescribed set of objectives and optimization constraints.

2.2.1 Modeling

The metallic 3D printed mold proposed in this study accomplishes some commonly requirements adopted in conventional mold designs, such as: the cavity plate, the spacers and the support plate. The design of these components was previously defined. Then they were grouped into a set of non-designable parts. In order to allow the finite element (FE) software to freely optimize the rest of the mold shape it was divided into two designable parts (upper and lower sets), as shown in Fig. 2. It also shows that the upper part is in contact with the injection bush whereas the lower one acts support the extractor plates. moving together with the moving plate during the cycles of injection molding.

In this study, a mold of cavity is chosen due to its simple geometry, easy positioning of its extractors, guides and bushings. In addition to that, this type of mold enables a qualitative analysis of the specimens after being manufactured. In this case, the mold cavity has the shape of two specimens for tensile testing.

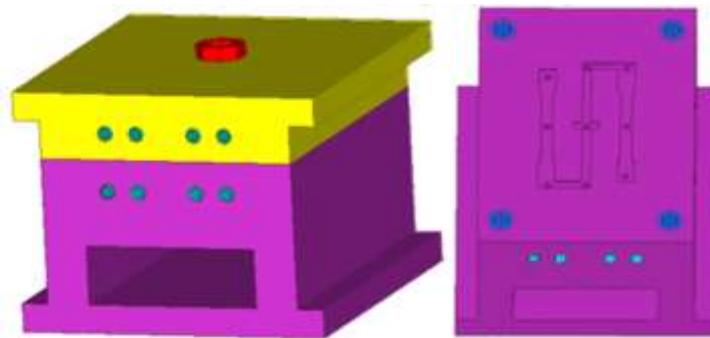


Figure 2. On the left side of the figure are the two sets of the mold (the top in yellow and the bottom in purple), the conformal cooling channels (light blue) and the sprue (red). On the right side of the figure is the mold cavity, the conformal cooling channels and the guides (in dark blue).

To build the 3D model the CAD software SolidWorks™ was used. Then, the geometry was imported into FE-preprocessor SimLab™ to generate the tetrahedron mesh of the designable part (the purple and yellow set shown in Fig. 3) as well as non-designable ones (all components are blue and green). After that, the mold material (316L stainless steel), the loads (pressure in the cavity, closing force, temperature, clamping claws that have the function of fixing the mold in the injector and gravity), the boundary (the upper part is fixed in all directions and the lower in the z direction.) and the contacts among all the components were set, see also Fig. 3.

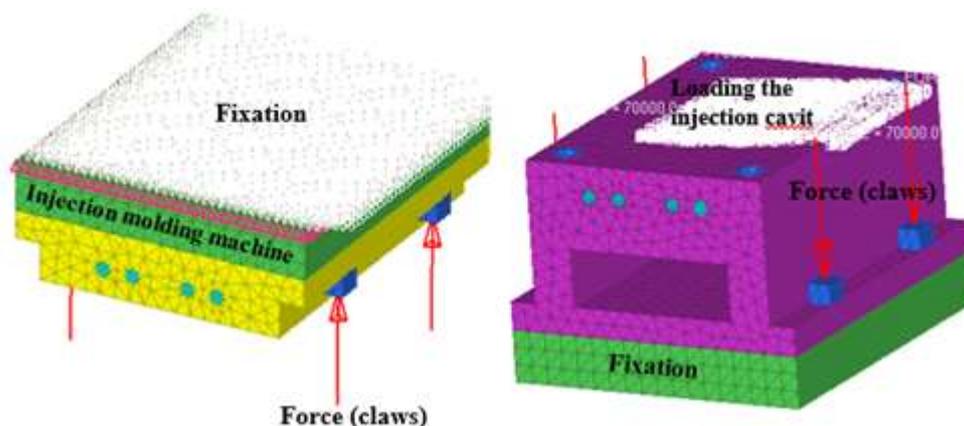


Figure 3. In this figure, it is possible to see all the loads to which the mold was submitted.

After the first stage, the discretization of the mesh in SimLab™, the model was imported into the FE-Software HyperMesh™ in order to define the topology optimization parameters. In this case, it was set an objective function of a 50% reduction of volumetric fraction of the designable regions and an optimization constraint in which the displacement should be within a range 0.04 mm and 0.4 mm (values obtained from a displacement pre-analysis of the standard mold cavity). They both, objective function and optimization constraint, were defined based on the assumptions of weight optimization as well as the mold functionality and mechanical resistance preservation. Once, the

optimization parameters were set, the analysis was then sent to be solved in Optistruct™ and finally the results were visualized in the Hyperview postprocessor™, as presented in the next topic.

3. RESULTS

The results of the topology optimization showed that it was obtained a mass reduction of the mold of 41.1% (initial mass of 131.1 kg and the final mass is 77.2 kg), as can be seen in Fig. 4. At the top of the mold (yellow) the material was concentrated in the middle and on the sides. The middle mass concentration occurred in this case due to the effect of pressure in the mold cavity whereas the lateral mass concentration due to the closing load. In the lower (purple) mold component, the majority withdrawn mass was from the region between the mold cavity and the location of the extractor plates. It was also noticed in this case, a mass concentration on the mold base.

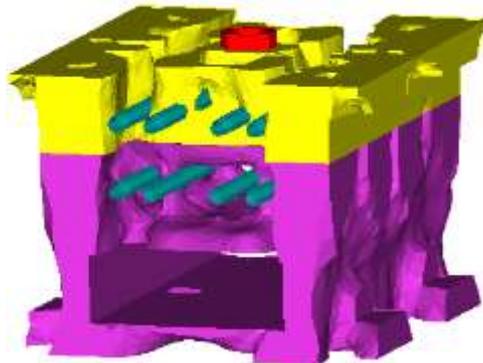


Figure 4. Mold after topology optimization.

In addition to that, it can be seen that the functionality, mechanical strength of the mold and the displacement constraints has been maintained or are within allowable values. In Fig. 5, it is possible to notice that the critical displacement has undergone few changes; however, the column between the cavity plate and the base plate has experienced a greater displacement, and this is justified by the reduction of material in this area. Nevertheless, the displacement magnitudes are acceptable since the model of the optimized mold has the similar displacement in the region of its cavities, so that there is no geometric and dimensional distortion of the injected parts.

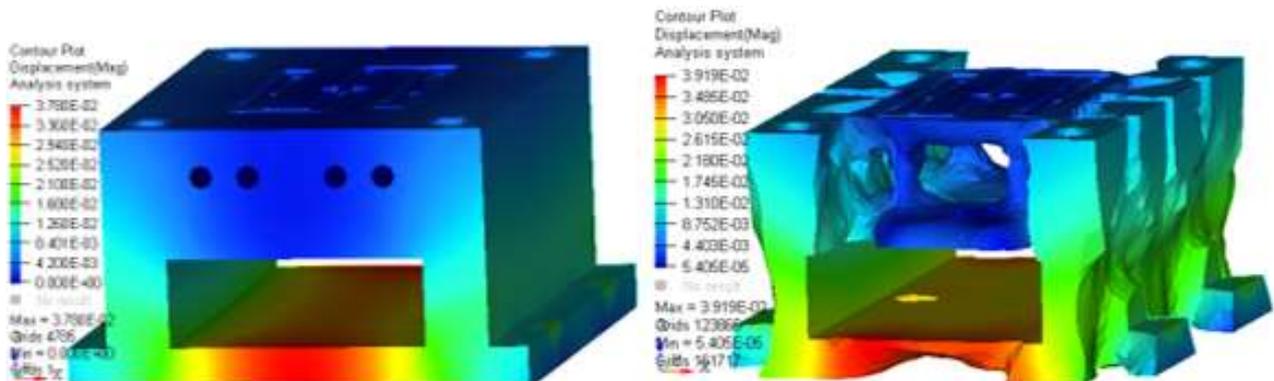


Figure 5. Displacement comparison between the regular design model (the left) and the optimized model (the right) with a slight increase in displacement.

In Fig. 6 it is possible to note the stress level on the mold "The lower part of the optimized mold has experienced a maximum stress increase of 20.53%. On the other hand, in the case of the upper part, the maximum stress of the optimized mold has undergone an increase of 8.01%, see Fig. 7.

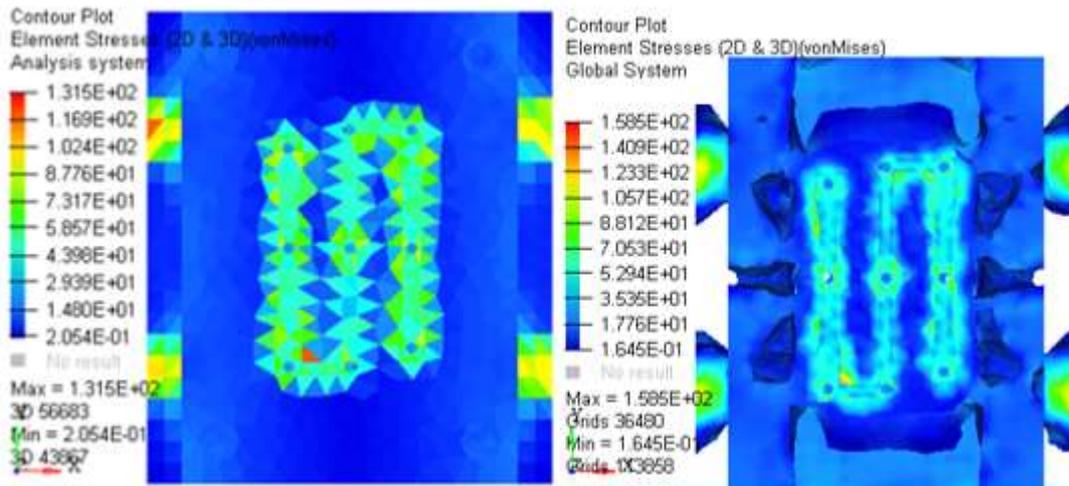


Figure 6. Von Mises stress comparison between the regular design model (the left) and the optimized model (the right) on the lower part of the mold.

Also, it is possible to notice in Fig. 6 and 7 that there is a small quantity of material connecting the central part of the mold and the central part of the cavities. That was caused by the pressure considered during the injection molding of the component.

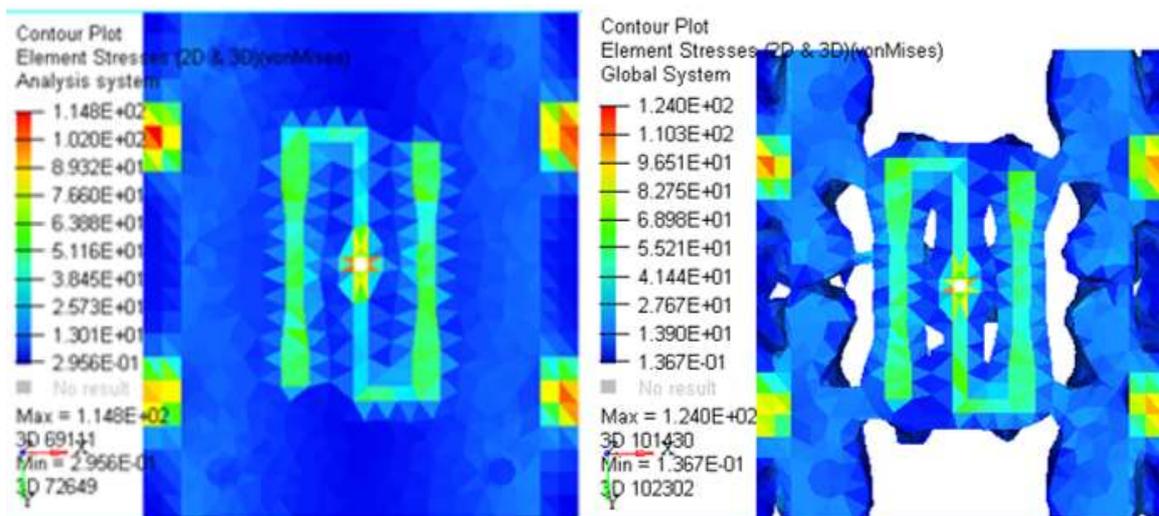


Figure 7. Von Mises stress comparison between the regular design model (the left) and the optimized model (the right) on the upper part of the mold..

4. FINAL CONSIDERATIONS

Based on the results presented, it is possible to reduce the mass during mold making without compromising the functionality and mechanical performance of the mold. Leaving the mold lighter makes it possible to save on the raw material, shorten the manufacturing time and the energy expended to inject a part. In addition to the mass reduction manufacturing via additive manufacturing possibility also optimize the cooling system to decrease the cycle time per part. However, the existing technology does not provide the necessary support to achieve such a project yet. The manufacturing cost is still high and the quality of the processed parts does not have the same mechanical characteristics that a conventional manufacturing process offers. However, all the advantages of additive manufacturing indicate the need for advances in 3D printing technology, and this work serves as a reference for further experiments.

5. ACKNOWLEDGMENT

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7. RESPONSIBILITY NOTICE

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