Validation of design and ergonomics of a protective mask by creating a silicone replication in a 3D printed mold tool

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Abstract: The work presented aims to investigate the filling process of a protective mask for design validation and ergonomics by creating a silicone replication in a 3D printed mold tool for small series of production. The object of analysis is a protective mask with UV-C protection technology, which should ensure the sterilization of bacteria and viruses in inhaled and exhaled air using UV-C light. Applying additive manufacturing FDM technology to create a complex three-part mold tool improves the process of design and ergonomic parts which can be referred to cost effective method for small series. By creating a silicone replica of the mask, an assessment of accuracy and precision is made to validate design and ergonomics before proceeding to final tooling design.

Keywords: design, ergonomics, FDM, additive manufacturing

1 Introduction

1.1 Integral Role of Prototyping for Plastic Products

Prototyping is an integral part of the manufacturing cycle and is essential to the development of plastic products. In the development and validation process of such products, prototyping plays a key role in determining the functionality, ergonomics and quality of the final product [1]. Prototyping allows designers and engineers to test and validate different design concepts and technical solutions before the final production phase. It is important to emphasize that prototypes not only help in choosing the most suitable design, but also speed up the development process and reduce the risk of failure [2] [3]. Prototypes are used to validate various aspects of the product, including functionality, durability, ergonomics and appearance. They allow teams to make the necessary adjustments before the final production phase [4].

1.2 Limitations of 3D Printing for Elastic Elements

Despite the advantages of 3D printing, it has limitations, especially when it comes to elastic elements. This method cannot provide sufficiently accurate estimates of the ergonomics and functionality of such items due to the limitations of materials and processes. Creating a silicone replication in a 3D printed mold tool for small series of production is a method that allows designers to obtain realistic prototypes that can be used to evaluate the ergonomics and functionality of products, while maintaining the possibility of corrections and improvements before the final production phase [5].

1.3 Future Opportunities

Prototyping plays a key role in plastic product development, providing an opportunity for design validation and improvement prior to mass production. In the case of elastic elements, additive manufacturing of forming tools is the preferred method to obtain realistic prototypes and evaluate the ergonomics and functionality of the products [6] [7]. With the growing interest in customized products and rapid prototyping processes, new opportunities are opening up for innovation in the field of prototyping [8]. The development of new materials, including biodegradable and functional materials, will continue to change the way plastic products are developed and manufactured. The next stage in the evolution of prototyping is likely to be related to the integration of various technologies, such as artificial intelligence and the Internet of Things, to create more intelligent and functional products [9] [10].

2 The approach

The approach is developed that uses an effective method for design and ergonomic validation by creating a silicone replica in a 3D printed mold tool. This allows obtaining a realistic prototype that accurately reflects the shape and feel of the final product. Relevant possible adjustments and optimizations could be made before mass production, ensuring better functionality and comfort for users for low iterative costs.

2.1 Problem specifies

The product, which is the subject of analysis and development, is a protective mask with UV-C protection technology, which aims to ensure the sterilization of bacteria and viruses in inhaled and exhaled air using UV-C light. The subject of the work is the production of a prototype of a protective mask by gravity casting with compression of the material in a 3D printed molding tool and validation of the geometry with the aim of ergonomics and a tight fit on the user's face.

Validation cannot be done through 3D printing due to the fact that the source article will not correlate with the actual final product. Proceeding directly to mold plate production and the injection molding process would be a risky move that would be costly in case of errors in the virtual model.

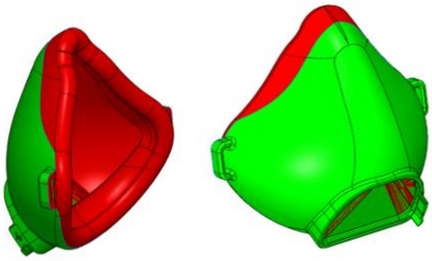
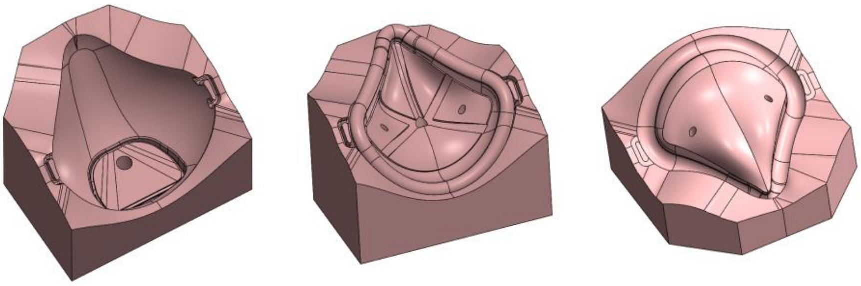


Fig. 1. 3D model of protective mask. Parting line

The mold tool for making the product consists of a cavity and core, where the core is composed of two parts for easier cleaning of the channels after casting. The forms are built using 3D print additive technology - FDM (Fused Deposition Modeling).



a) Cavity b) Core

Fig. 2. 3D printed mold tool

The whole tool is assembled by two self-tapping screws (fig. 3).

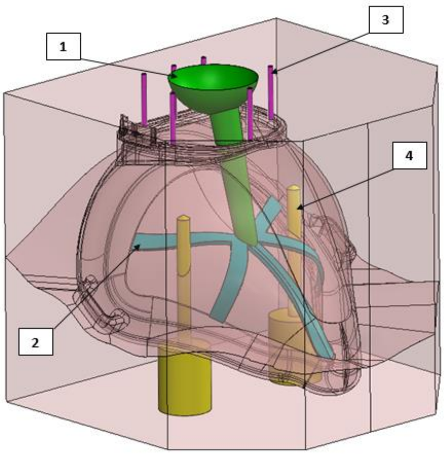


Fig. 3. 3D visualization of assembled mold tool

The molding tool consists of a sprue (1), which serves to pour the silicone into the mold. After the material enters the sprue, it reaches the distribution channels (2), which misleading the material to the different parts of the mold. During the filling of the mold, the air pushes the silicone to the surface, where the ventilation channels (3) expel the air out of the mold and it is completely filled. The screw holes (4) serve to hold the whole mold tool.

2.2 Virtual flow simulation analysis

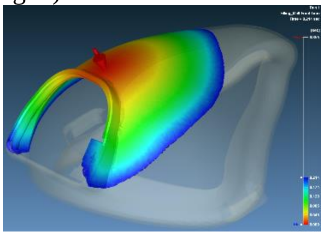
The purpose of injection molding simulation analysis is to check if there are areas of the part that cannot be subsequently filled due to an error in the construction of the 3D model in the CAD environment. This step will prevent future physical optimization costs.

Table 1. Process parameters

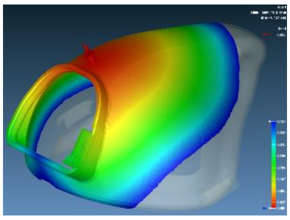
Parameter	Unit
Filling time	0.8 sec
Melt temperature	245 ºC
Maximum injection pressure	140 MPa
Maximum packing pressure	70 MPa
Fill to pack switch time	98%

Results

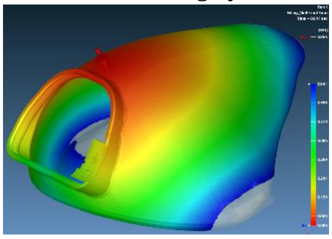
Simulating the process of filling the mold gives basic information about the behavior of the melt flow - uniformity of the flow, cooling time, filling factor, formation of air traps, etc (fig. 4).



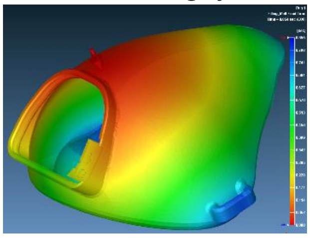
25% of filling cycle



50% of filling cycle



75% of filling cycle



100% of filling cycle

Fig. 4. Mid stages of the filling process.

From the results shown in fig. 4 and it can be concluded that the product can be cast via silicone and there are no existing wall thickness issues (fig. 5.) The average wall thickness is 1.35mm.

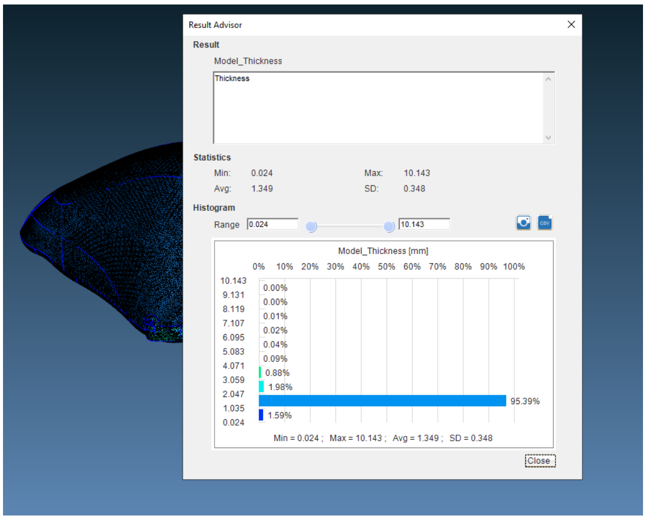


Fig. 5. Wall thickness analysis

2.3 Physical tests

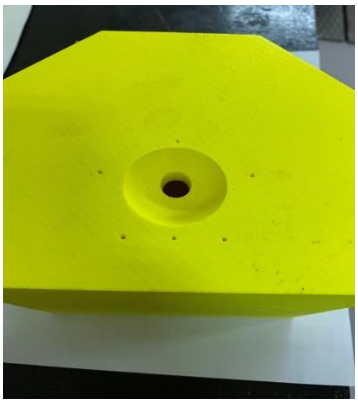
The core and cavity are made by 3D FDM printer Stratasys Dimension Elite, shown in Fig. 6.

Fig. 6. FDM Printer Stratasys Dimension Elite

a) left view

b) front view

c) right view



d) top view (air vents and sprue shown)

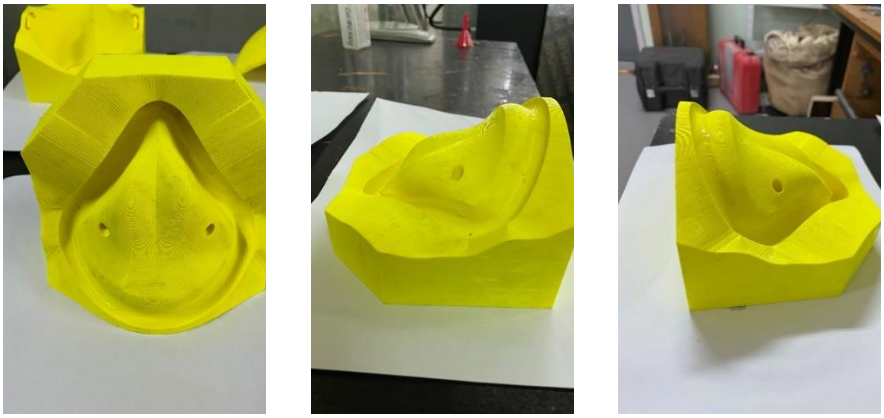
Fig. 7. Physical 3D printed cavity

a) back view

b) left view

c) right view

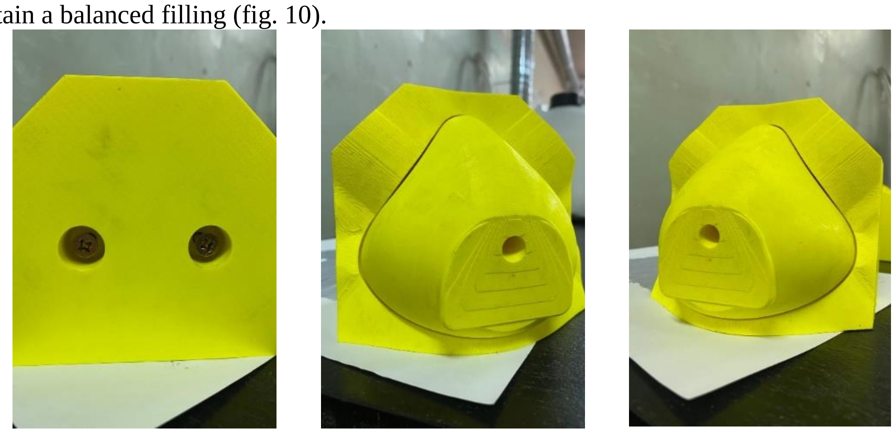
Fig. 8. Physical 3D printed mid core



a) top view b) left view c) right view

Fig. 9. Physical 3D printed core

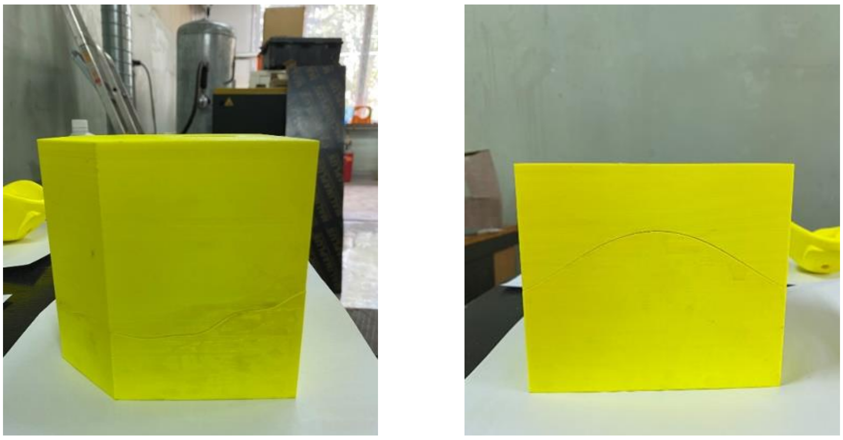
Two cores are assembled by two self-tapping screws that center the two inserts, and when tightening it is important to consider the clearance between the two half-forms to obtain a balanced filling (fig. 10).



a) bottom view b) left view c) right view

Fig. 10. Cores assembly

The chosen material for the process is silicone, in this case it is chosen “Zhermack”, with the aim being to make the prototype as soft as possible to be easily removed from the tool and to achieve a tight fit to the face. The total volume needed to be filled is 60 grams while mixing ratio between base and catalyst is 1:1.



a) side view b) front view

Fig. 11. 3D assembled printed tool

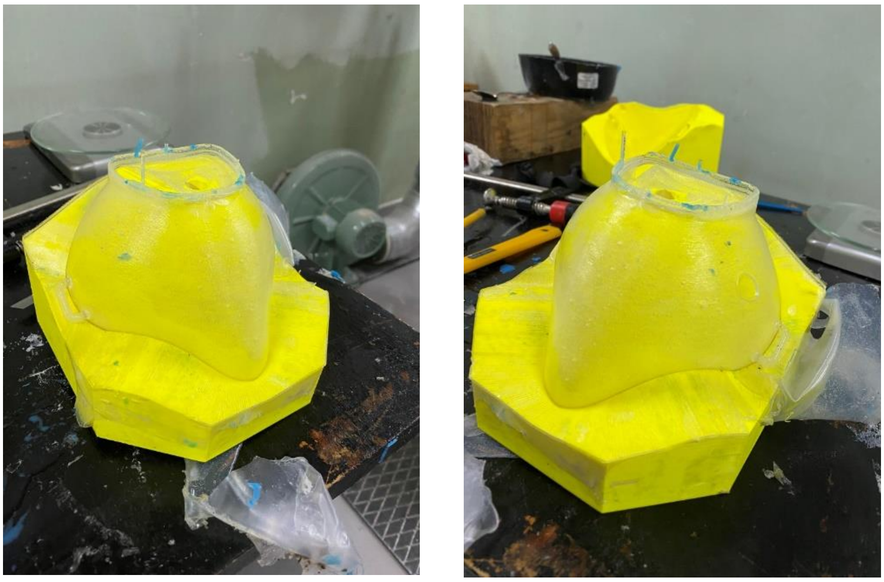


Fig. 12. The final product after casting

The prototype product validation conforms to the shape of the face and the resulting result fulfills the purpose of the study, ensuring air penetration only through the UV-C light air filtration device.

Fig. 13. The final product validation

3 Conclusions

The developed approach and the results analyzed, it can be concluded that:

- Injection molding virtual analyzes provide important information about whether the part will fill completely and evenly at all points, and whether there is a problem in the virtual model in the CAD environment;
- By performing virtual injection molding analysis, it would save expense costs by working parameter and model optimizations;
- Physical prototype replicates virtual showing balanced and entirely filled cavity;
- Product fits the facial structure well where the quality assessment is made to verify the steps for mass production.

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