FROM AN IDEA TO THE FINAL POLYMER PRODUCT

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Abstract: *Injection moulding process is one of the most important processes for the production of polymer parts. Effective tool for successful moulded part development is an approach of Rapid Product Development. This approach includes the application of Rapid Prototyping (RP) processes of obtaining physical models in an early stage of product development. Rapid Product Development also includes CAE approach with powerful tools such as computer simulation of the process of injection moulding. The paper presents phases of development from an idea to the final product in the case of a letter opener, which contains visual identity (logotype) of the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb (FMENA)*

Keywords: – plastic part product development
– Rapid Prototyping
– CAE approach

1. INTRODUCTION

Injection moulding process is one of the most important processes for the production of polymer parts. It is worth noting that 75 % of faults in the lifetime of injection moulded polymer parts are initiated in the process of developing and designing the parts. Moreover, in the conventional product development process, approximately 80 % of faults generated during early phases of product design are recognized during production or quality control (Fig. 1). In the later development process phases, it is very difficult and costly to correct these faults. This means that during product development process it is necessary to make correct decisions, and make them as soon as possible. [1]

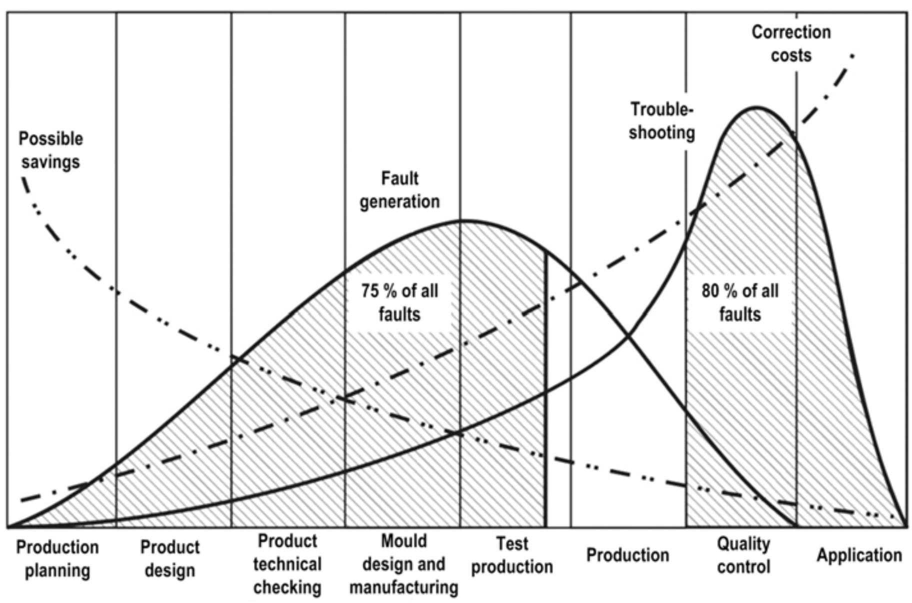

Figure 1. Magnitude of Faults generation and troubleshooting in the product lifetime [1]

One of possible, effective and already proven tools is the application of Rapid Prototyping (RP) processes of obtaining physical models in an early stage of product development [2]. These models can be used in order to prevent faults in product design and function and to maintain good communication between experts involved in product development and production [3].On the example of development of a plastic letter opener, all necessary steps of modern moulded part development process that includes additive manufacturing as well as CAE approach, will be described.

2. MOULDED PART DEVELOPMENT

2.1. Initial activities of moulded part design

In the initial phases of polymer moulded part development, it is necessary to have the information about requirements of the product, eventual limitations as well as the production process. Requirements are: FMENA logotype placed on the moulded part and the simplicity of product design which has to have practical application.

The visual identity of the Faculty for Mechanical Engineering and Naval Architecture (FMENA) by itself is determined by regulations. The sign is structurally demonstrated as a combination of shapes of the boat bow and wheel (Fig. 2). Proportions of the sign format are in accordance with standard ISO 5457, and sites are shaped in ratio: $A/B=\sqrt{2}$

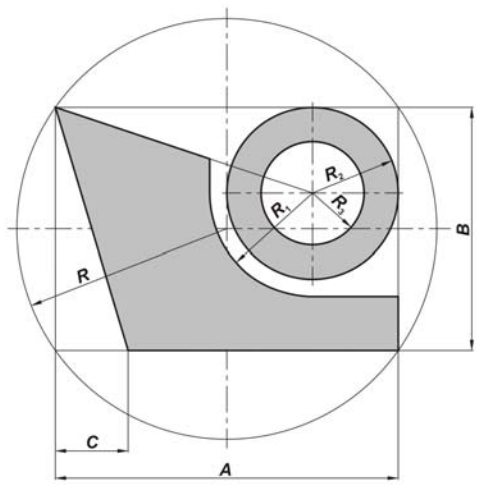

Figure 2. FMENA visual identity, University of Zagreb

Injection moulding was selected as a production process. With manufacturing process selection, some of the design limits are put on moulded part design. First of all, this refers to the moulded part wall thickness which preferably has to be under 4,0 mm. Otherwise it is a thick-walled moulded part which requires long injection moulding times. Also, there is a risk of void appearance. One of the general rules in injection moulded parts design is an effort to keep wall thickness as uniform as possible in order to avoid non-uniform shrinkage during moulded part cooling both in the mould cavity and outside the cavity, and the other is to avoid consequent unwanted warpage.

2.2. Product design – a letter opener

A letter opener (Fig. 3) is the product which clearly shows visual identity of FMENA. The product design is relatively simple and doesn't require special mould design for injection moulding. Wall thickness is 3,5 mm, which is close to the upper limit, but thinner walls can have unfavourable effects in product function because of the high elasticity of the opener during letter opening.

a)

b)

Figure 3. Computer model of the first version of the letter opener: a) with thin area between the bow and wheel, b) with uniform wall thickness

The only detail which is not solved in accordance with the general rules for moulded part design, is the connection between shape of the boat bow and wheel. This part of the moulded part is designed with smaller wall thickness (1,5 mm) than the rest of the moulded part. Computer simulation of injection moulding has shown that this kind of design exerts relatively little influence on the mould cavity filling and non-uniform moulded part shrinkage. Besides, moulded part with this kind of discontinuity (Fig. 3a) is visually more distinct than moulded part which has uniform wall thickness (Fig. 3b). Since this is a promotional product, visual characteristics of the product are at the top of the priorities.

Apart from the geometry of the product, it is necessary to select appropriate material during product development.

Acrylonitrile/butadiene/styrene (ABS) was selected, an amorphous thermoplastic material with a wide application area and excellent surface property, which is, in the case of the letter opener, one of the main requirements.

2.3. Prototype – the first version (FDM)

Following two sayings *a picture says more than thousand word*s and the newer one which is a kind of upgrade *but model tells a whole story*, it was decided to produce a prototype of developed letter opener geometry with Fused Deposition Modelling – FDM process.

The equipment for the FDM process is based on the NC machining principles. Polymer material in the wire form moves through the nozzle, controlled in all three axes by the computer (Fig. 4). The material is heated and leaves the nozzle in melted state, but it solidifies very quickly at room temperature. Therefore, the main request on FDM process is maintaining the temperature of the melted material just above the solidification temperature. During prototype building, material is extruded and deposited on necessary spots in very fine layers. For the production of complex prototype geometries, the support structure has to be used. In that case, the process is modified by using twin extruder head. One nozzle is used for build material and another for support material. Therefore, it is necessary to deposit a layer for separation so that at the end of the process a support material can be successfully removed from the prototype.

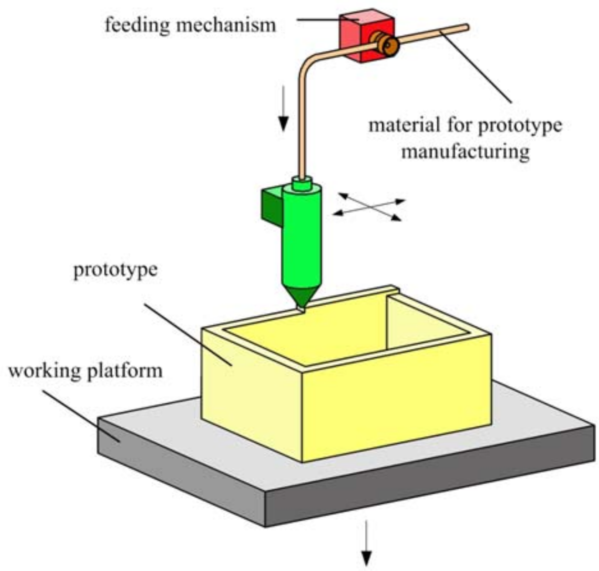

Figure 4. Fused Deposition Modeling equipment [3,4]

The surface quality is relatively rough, and prototypes are porous. With additional filler infiltration, it is possible to raise a prototype density. Materials for prototype production with FDM process are wax, PE, PA and ABS [3,4]. Since the prototype can be made of the material which was originally chosen as the material for the final product (ABS), the choice of FDM to create the first version of the letter opener (Fig. 5) was justified.

Figure 5. Letter opener prototype made by FDM process

2.4. Letter opener redesign

The need for a redesign of the letter opener appeared to mark the 90^{th} anniversary of FAMENA. In order to commemorate the anniversary, a special visual identity of the 90^{th} anniversary *FSB 90* was introduced. This new logotype had to be put at the forefront of the existing geometry of the letter opener (Fig. 6).

Figure 6. Computer model of the letter opener with incorporated logotype FSB 90

It was also necessary to adapt the new model to the requirements of injection moulding process. These requirements include necessary draft angles on the moulded part in the mould opening direction and moulded part ejection from the cavity. Thus, a general position of the moulded part and respectively the position of parting plane in the mould were determined. In the case of the letter opener, the position of the parting plane is at half moulded part height.

2.5. Prototype – the second version (PolyJet)

When the letter opener had been redesigned, a new prototype was produced. During Rapid Prototyping process selection, possibilities of achieving better surface quality and of producing transparent prototypes were considered.

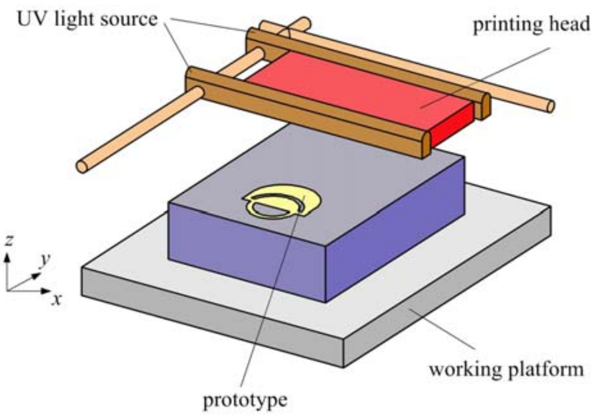

Figure 7. Equipment for the hybrid PolyJet process [3,4]

In the final selection, a *PolyJet* process (Fig. 7) was recognized as optimal for the prototype production of the redesigned letter opener.

PolyJet is a hybrid procedure which combines good characteristics of *Stereolithography* (SLA) and *3-dimensional printing* 3DP).

During *PolyJet* process of prototype production, the first step is 3D printing of photo sensible polymer material layer by means of nozzles. In doing so, it uses a built and support materials that allow for the printing of complex geometric shapes. After printing one layer, in the next step, under UV light action, the layer is curing and thus solidified. Before starting to produce the next prototype layer, the working platform is lowered by the thickness of the next layer, and the process is repeated until the production of the final layer. The basic advantage of *PolyJet* process compared to the SLA process is the possibility to solidify a whole layer at once (simultaneously, not selective as by SLA), which leads to shorter times of prototype production. [3,4]

After final layer production, support material has to be removed. As this is a very precise process (layer thickness is 16 μm), there is usually no need for additional finishing. Moreover, there is no need for additional solidification of prototypes. Depending on the type of the material for prototypes production, the prototypes with different mechanical properties, colours and surface quality can be obtained. For production of letter openers, a partly transparent material *FullCure 720 Transparent* was selected (Fig. 8), an acrylate based photopolymer.

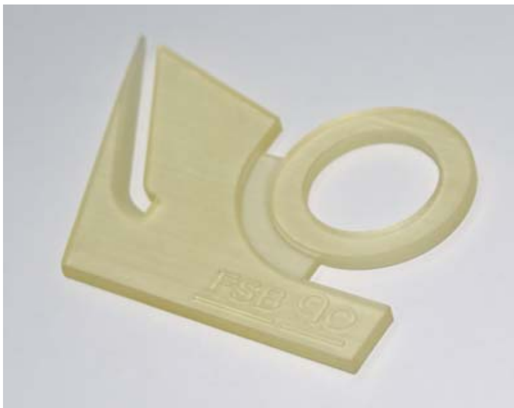

Figure 8. Letter opener prototype made by PolyJet process

2.6. Moulded part technical checking

Based on the analysis of the prototype of the redesigned letter opener, it has been concluded that moulded part geometry is acceptable. The next phase was a technical checking of the moulded part – computer simulation of injection moulding.
Before computer simulation of injection moulding of the letter opener, a number of mould cavities and their arrangement were determined as well as the type of mould runner system and the gate. Based on economic estimation of mould production costs and the planned number of products, it has been decided that the mould with two mould cavities shall be made. In addition, the mould shall be produced with cold runner system and with fan gates. Figure 9 shows a model of two moulded parts and a runner system (material output from the injection moulding process).

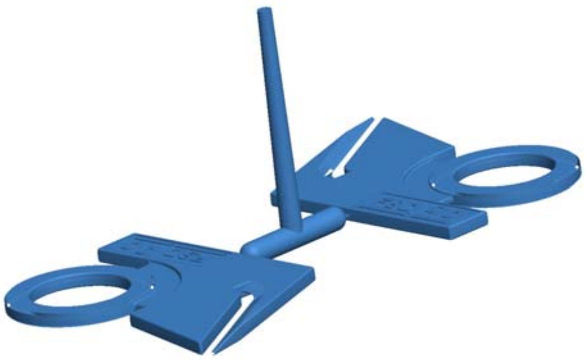

Figure 9. Injection shot – two letter openers and runner system

Computer simulation resulted in sets of different initial and adjustable processing parameters of injection moulding of the letter opener.

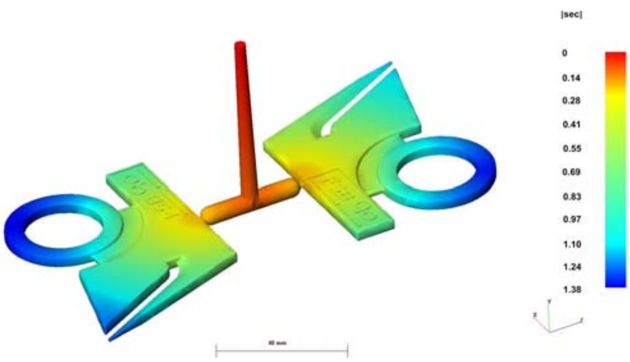

Figure 10. Mould cavities filling time

Some of the simulation results are: mould cavity filling time, (Fig. 10), necessary injection and pressures, polymer melt temperatures range, estimation of injection moulding time, probability of complete mould cavity filling etc.Apart from the information about injection moulding parameters, injection moulding computer simulation enables an insight into potential moulded part faults, such as appearance of the weld lines or air traps (Fig. 11); it also facilitates the estimation of the quality of the moulded part.

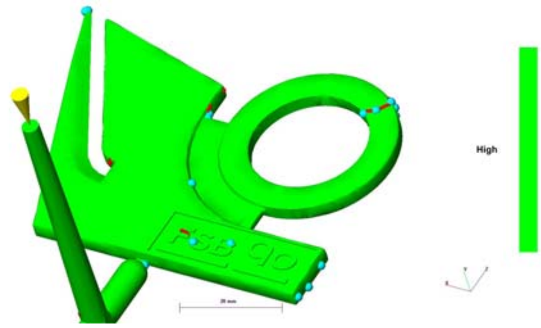

Figure 11. Welding lines and air traps spots

Based on the results of computer simulation, it was concluded that under determined moulded part geometry and selected material (ABS), no difficulties during injection moulding are to be expected.

3. MOULD FOR INJECTION MOULDING OF THE LETTER OPENER

The mould for injection moulding of a letter opener was designed with mould cavities in both movable and fixed mould inserts. On fixed mould insert, it is necessary to create FSB 90 logotype (Fig. 12).

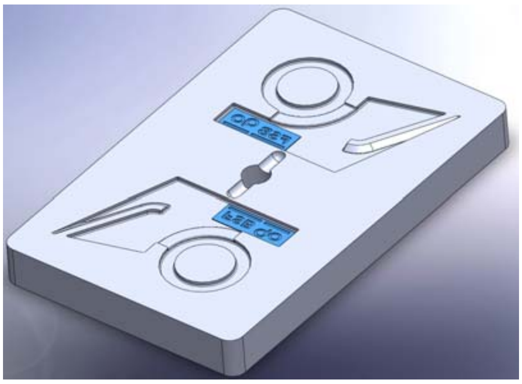

Figure 12. Computer model of fixed mould insert

The possibility of logotype changing was taken into account as well. Therefore, additional changeable inserts with logotype were built in the fixed mould insert.
Mould inserts are made of high-alloyed steel X38CrMoV5 1, which were thermally treated by hardening. Based on the selection of the mould with two cavities, a standard mould base with dimensions 190 x 246 mm (Fig.13) was selected. The runner system was performed as a cold runner system with fan gates. Moulded part ejection from the cavity has been performed with pin ejectors. Temperature regulation of movable and fixed mould side was adjusted with cooling channels in both mould cavity plates.

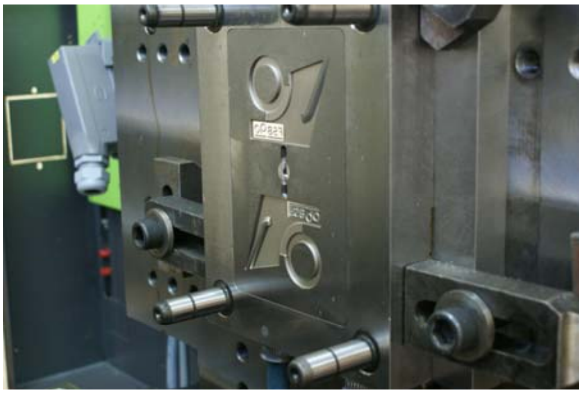

Figure 13. Mould for injection moulding of the letter opener

4. INJECTION MOULDING OF THE LETTER OPENER

Final products were produced on injection moulding machine ENGEL Victory 330/80. Apart from ABS (Fig. 14), the materials from which the letter openers were produced were SAN and PS.

Figure 14. Final product - letter opener (FSB 90)

Prior to injection moulding of ABS, it was necessary to dry material at higher temperatures in order to achieve satisfactory moulded part quality. Moreover, during injection moulding, it was necessary to maintain the mould cavity wall temperature at the level of 60 °C, which requires the application of temperature regulation device. Injection moulding cycle was set at 22 s.

5. CONCLUSION

The paper briefly describes the development process of commemorative thermoplastic moulded part – a letter opener, from an idea to final product (production). During the process, knowledge areas of modern polymeric moulded parts design and methodical design of mould for injection moulding process were applied. In each phase of moulded part development process, an appropriate mould, modern tools and procedures improving development process were used, reducing thus the chance of growing faults on products and again raising quality levels of the product. CAE approach (computer design and simulation) and Rapid Prototyping processes were used in the process of the product part development.

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