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MODERN APPROACH TO THE DEVELOPMENT OF A THINWALL PRODUCT FOR INJECTION MOULDING

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ABSTRACT

The benefits associated with decreasing wall thicknesses below their current values are still measurable and desired even if the final wall thickness is nowhere near those of the aggressive portable electronics industry. It is important to note that gains in wall section reduction don't always occur without investment, in this case, in tooling and machinery upgrades. Equally important is the fact that productivity and performance benefits of reduced material usage, fast cycle times, and lighter weight can often outweigh most added costs. In this work, various designs of thinwall plastic product were developed with usage of CAE tools. During development process special attention was put on the choice of material. Also, simulation of injection moulding was conducted in order to avoid potential moulding problems. Results gained from the simulation were used for the optimization of an existing product design, for mould development and for optimization of processing parameters.

Key words: injection moulding, thinwall parts, process optimization

1. INTRODUCTION

In today's production of consumers' goods, the production of polymer products has great share and the injection moulding as one of the most significant processing procedures of polymer materials occupies high position on the scale of the production of goods. One of the reasons why the injection moulding is the leading processing method of polymer materials is the possibility of economical production of a great number of complex mouldings of high-quality surface.

Often the question is raised regarding the justification of investing into the systemic development of a new product. However, it has been shown that the price of investing into the systemic development of products is justified and mostly not high regarding the price of the final product. It should be remembered that about 75 percent of defects on the products occur during their development. The cost of their elimination is the lowest in this phase. On the other hand, the analyses show that about 80 percent of all the defects are identified and eliminated during the production, quality control and the very usage of the product (Figure 1). The elimination of defects in those phases is always related with increased costs. [1]

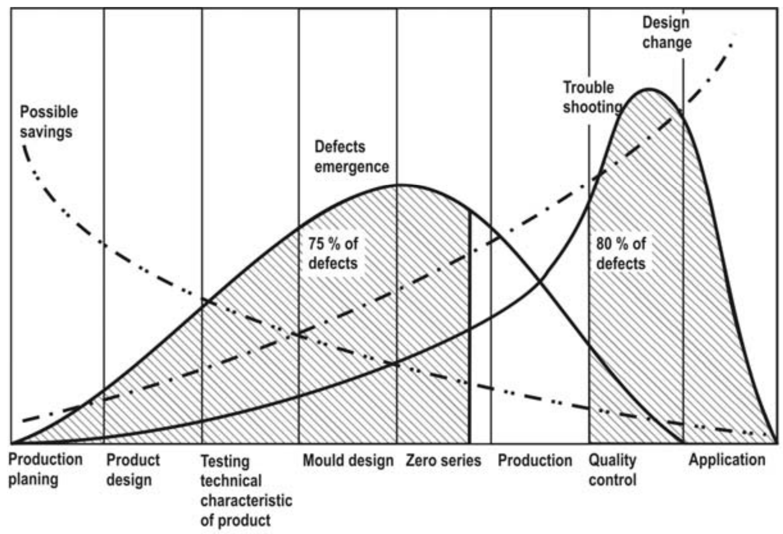

Figure 1 - Defects emergence and elimination during product life cycle [1]

2. TECHNOLOGICAL DESIGN OF PRODUCTS

Technological design means the development and the design of the product from the aspect of its technical, economic and sociological characteristics (Figure 2). Technological design can be divided into following phases: [2]

- initial procedures of design
- middle phase of design
- final activities of design.

2.1. Initial procedures of design

The initial phase of the product design starts with defining of all the product requirements. Since these are the initial activities of design, it is necessary to perform them in great detail and with great attention, since the product requirements represent the basis for the further development of the product. [1]

2.2. Middle phase of design

The middle phase of design is mostly characterized by the interconnection of three basic activities of shaping, dimensioning and selecting the material. In this phase of the moulding design, it is possible to observe high level of connectivity of the single phases, and their interactivity. Due to the need for the high level of synthesis and interactivity, computer assistance is almost indispensable today. [2]

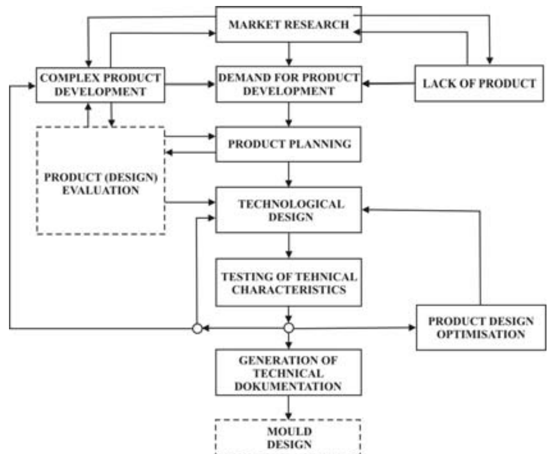

Figure 2- Technological design [2]

In the process of developing a product from the idea to the prototype, one of the critical steps is also the material selection. Wrong material can mean failure of the product on the market or may cause great problems during production. The selection itself can be compared to the procedure of elimination. Based on the required properties expected of a moulding part, the material that best meets these requirements is selected. It is therefore obvious that detailed knowledge of the material characteristics is needed as well as of its behaviour in the environment for which the moulded part is intended. [3]

The production requirements set on the material and the usage requirements are often in inverse proportion so that it is necessary to rank the importance of fulfilling single requirements. Regarding the necessity of meeting the requirements the following are distinguished: [3]

- invariant, requirements that have to be met
- variant or variable requirements – these can be met within certain tolerable limits.

The invariant requirements serve for the a priori elimination of unsuitable materials during the pre-selection phases, whereas the variant requirements are used as the basis for looking for, evaluating and selecting the optimal variants. In the phase of elaborating the variant solutions – in conceiving, designing and construction analysis, each variant is assigned those materials which best satisfy the special requirements related to the given solution - functional, production, exploitation and economic ones. [3]

In any step during the product development, the intermediate result of selection can be several groups or types of suitable materials requiring optimisation to be carried out by means of the known methods and defined criteria which result from the analysis of the tasks. [3]

When subjected to the action of external mechanical loads, every real body gets deformed. At the same time certain state of stress occurs in the body. The value of stress and deformation depends on the method, size and directions of load, shape of the body, and type of material. The procedure which connects the optimal usage of materials with the restrictions on the design shape of the product under load is in general called dimensioning. [2]

There are significant restrictions in dimensioning the engineering polymer products. This is the consequence of the unavailability of data about the properties for a number of polymers under different load conditions, insufficient knowledge about the behaviour during deformation and uncertainty in determining the allowed stresses and/or deformations. Product dimensioning can be carried out in four basic ways, depending on the method of performing the calculation of stresses and deformations: [2, 1]

- based on experience (empirical)
- experimental (use of adequate prototype)
- conventional (analytic)
- numerical methods (*FEM, FEA*).

Production shaping is the shaping regarding the planned production procedures. In the world the focus is on two trends used in shaping regarding the production procedure (*DFM*) and the shaping regarding the assembly procedure (*DFA*). [1, 4]

The shaping phase of the product requires co-operation of several experts or expert teams (material producer, moulding designer, mould designer, production engineer), which indicates the justification of the application of the simultaneous engineering concept. The cooperation with the mould designer, who has significant share in the decision-making in the moulding shaping based on the acquired experience, mould calculations (rheologic, thermal and mechanical), and simulations of mould cavity filling is of great importance. [1]

2.3 Final activities of design

Testing of the technicality of the product includes testing of the functionality and the producibility of the product, and the consideration of technical characteristics of ecology [2]. By checking the functionality of the product, its capability of fulfilling the functions for which it has been planned, that is, its usability is checked. The functionality can be checked by means of simulation or through experiments. Checking of the producibility of the injection moulded polymer product includes checking of the possibility of moulding fabrication, as well as the testing from the processing standpoint, that is, the capability of producing the material at the same time with the given dimensions of mouldings. [1]

3. THINWALL MOULDINGS DESIGN CONSIDERATIONS

Design is a key component of successful product development. When working on applications with thinner walls, depending on the market and the application, three main issues will typically be of concern to the engineer:

- impact
- stiffness
- manufacturability. [5]

As engineers move to increasingly challenging designs with wall thicknesses of less than 1.2 mm, many classical design guidelines change. Achieving required design features may be more challenging as wall thickness decreases. Figure 3 reviews some of the design issues and options that are considered. [5]

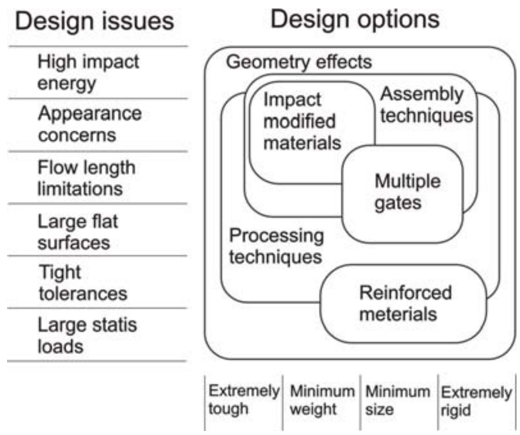

Figure 3 - Thinwall design issues and options [5]

4. TESTING OF TECHNOLOGICAL CHARACHERISTICS

With usage of injection moulding simulation it is possible to predict most of problems which could occur during the process of injection moulding, so that they could be solved in virtual – computer environment. With usage of this software it is possible to analyse influence of mouldings geometry, characteristics of polymeric material, mould material and injection moulding parameter settings. Most of new injection moulding simulations consists of four different numerical calculations (analysis): fill analysis, pack analysis, cool analysis and warpage analysis. [6]

Fast development of computers and the required software's has brought about an increasing application of numerical methods in injection moulding simulations. One of the most frequently used methods is the *Finite Elements Method (FEM).* This method is most used when analytical solving of exact problem equations is complex or impossible. It should be noted that the finite elements method is only approximate, therefore, in order to obtain acceptable results it is necessary when solving certain tasks to have also database with accurate data necessary for the calculations. This means that the results obtained by this method have to be considered critically. [7]

The majority of computer programs for injection moulding simulations include rheological and thermal mould calculation, and the calculation of the moulded part deformation after demoulding (shrinkage and warpage). The numerical rheological mould calculation includes calculations of pressure gradient in the runner system and mould cavity while filling it with thermoplastic melt. Based on the calculated pressure gradient optimal dimensions of the runner system are determined. The rheological calculation also gives insight into the occurrences happening in the mould cavity during the filling, i.e. the basic parameters of the injection moulding process are determined: pressure and temperatures distribution in the mould cavity, values of shear rates and share stresses in the thermoplastic melt and structure orientation. [8]

Thermal calculation of the mould for injection moulding of thermoplastic includes calculations of duration of the injection moulding cycle (duration of hardening and auxiliary times) and important parameters during injection moulding (temperature of thermoplastic melt, temperature of cavity wall, temperature and rate of the cooling/heating medium, ...). [9]

A great number of calculations in mechanical mould calculation consist of dimensioning of given mould elements. This refers primarily to the cavity walls. The pressure in the cavity presents active load on the cavity wall, based on which the stresses and deformations of mould plates are calculated. Computer programs which can apply allow simulations of stresses and deformations of mould cavity walls. [10]

5. EXAMPLE OF THE TECHNOLOGICAL DESIGN OF FOOD PACKAGING

The development starts with considering the requirements and limitations on the product, which are defined by the very setting of the task. The requirements regarding functionality, producibility, ergonomy and aesthetics of the product are to be considered concurrently and in dependence.
The material of the product polypropylene (*PP*), volume 202 cm^3, series of 1,000,000 items and of general dimensions - length 100 mm, width 65 mm, height 50 mm, are the only input data of the product development.

The first step is to adopt the wall thickness of 0.6 mm based on the dimensions of the similar products available on the market. The selection of the material for the product is limited to polypropylene that has to be suitable for application in food industry and for thin-wall injection moulding. *BJ 360MO* (*PP*) of the manufacturer *BOREALIS* was selected.

The ergonomic requirements on the moulding refer primarily to the roundness of the edges, soft transitions between surfaces, comfortable handgrip, etc.

The moulding has to be rigid enough to withstand the possible impact loads which may occur e.g. during transport, storage or in some other way. However, the objective of the container ending in this way is not only to increase the rigidity, but also to enable good clinging of the cover and good connection between the container and the cover.

The appearance often sells a product, and therefore the aesthetic requirements should always be considered as well. In this case, this is the avoidance of sharp edges, the quality of the surface and the colour of the product. One of the frequent problems during storage is the turning over (rolling). Slippery surfaces slide easily and no great force is needed to make them tumble e.g. when the containers are stacked one upon the other. In this case the possibility of tumbling over would be reduced by an indent on the cover that exceeds by a small amount the dimensions of the container bottom.

The case made of PP can be considered as a flat plate moulding with a wall thickness of 0.6 mm. Beside moulding wall thickness for cooling time calculation (equation 1) the following data are required:

- wall thickness $s_o = 0{,}6$ mm
- shape coefficient $K_o = 1$
- inside coeffiient $KU2 = 8/\pi^2$
- melt temperature $T_T = 533$ K (260 °C)
- mould wall temperature $T_K = 343$ K (70 °C)
- freeze temperature $T_{PO} = 373$ K (100 °C)
- thermal diffusivity *PP* $a_{ef} = 6{,}2 \cdot 10^{-8}\ m^2s^{-1}$

$$\bar{t}_{\mathrm{h}} = \frac{s_{\mathrm{o}}^{2}}{K_{\mathrm{O}} \cdot a_{\mathrm{ef}} \cdot \pi^{2}} \cdot \ln\left[K_{\mathrm{U2}} \cdot \frac{T_{\mathrm{T}} - T_{\mathrm{K}}}{\bar{T}_{\mathrm{PO}} - T_{\mathrm{K}}}\right] = 0.96\,\mathrm{s} \qquad (1)$$

The technological characteristics of the moulding have been tested by computer simulation of the mould cavity filling. The analysis of the mould cavity filling for the simulation parameters presented in Table 1 was carried out using the *Part Advisor* software of the *Moldflow Company*. The results obtained by the analysis are presented in Figures 4-7.

Table 1. Simulation parameters

Material trade name	*BJ360MO* (*Borealis*)
Mold temperature	60 °C
Melt temperature	260 °C
Max. injection pressure limit	250 M Pa
Actual injection pressure	167.68 M Pa
Actual injection time	0.40 s
Weld lines	Yes
Air traps	Yes
Shot volume	10.65 cm^3

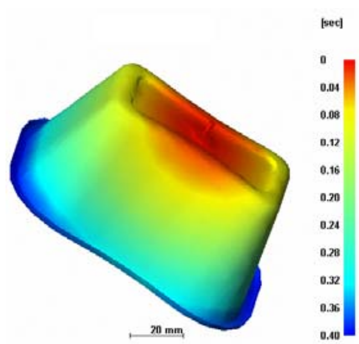

Figure 4 - Fill time

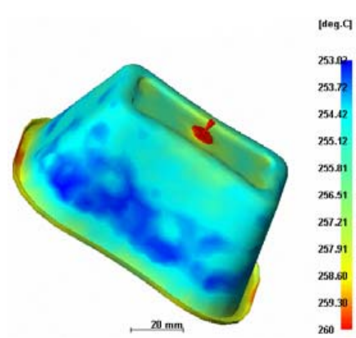

Figure 5 - Flow front temperature

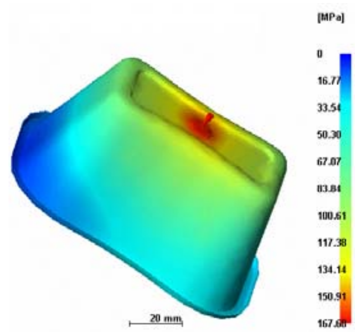

Figure 6- Injection pressure

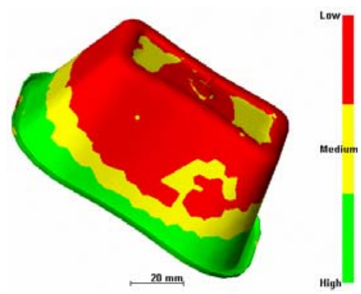

Figure 9 - Quality prediction

The analysis of the anticipated quality of the moulding surface has shown poor results. The shear rate and the shear stress exceed the allowed values. However, it should be stressed that the selected software package does not take into consideration the type of gate, mould plates material, characteristics of the temperature regulation system, and a number of other data that influence the moulding quality, and therefore the results in this case are not credible. It should be mentioned that one more great disadvantage of this software package is that there is no possibility of generating the finite element mesh. If it could be set, more accurate results might be expected. Nevertheless, an attempt was made to improve the moulding quality by changing the position of the gate and by changing the injection parameters. Thus, the nozzle was moved 3 mm outside the moulding centre in the existing plane towards the axes x and y, and the moulding wall temperature value was raised from 60 ^{o}C to 80 ^{o}C, and the temperature of the thermoplastic melt from 260 ^{o}C to 270 ^{o}C. The moulding quality improved, the mould cavity filling time remained approximately the same, the temperature distribution of the melt front also remained approximately the same, the injection pressure and the pressure fall in the mould cavity were reduced. The results of raising the temperature of the thermoplastic melt and the mould cavity wall temperature can be explained by easier flow of the polymer melt through the feed system and the mould cavity. However, raising these temperatures would mean uneconomical production or additional investments in the tools and the accompanying equipment, since then a great amount of heat should be supplied to the mould by the heat exchange system. There would also be the danger of degradation of the polymer material in the nozzle cylinder and the mould cavity.

6. CONCLUSION

The advancement of civilization from its very beginnings has been closely related to the development of new products with which humans tried to improve their lives. In spite of great differences in the methods of obtaining, i.e. manufacturing new products from the Stone Age to the modern, let us call it, Polymer Age, the first and the final phase of production have not changed. The beginning was always the idea, and the finish was always the production. All the rest in between was changing and was improving during history.

The modern approaches to the product development and the application of advanced engineering tools which facilitate the work of the engineers have significantly shortened the period between the idea and the finished product. In this way it is possible to provide fast solutions to meet the whimsical market requirements. The use of computers in the development of the product has become an imperative, but it should be mentioned that the engineer's experience cannot be replaced by computers or expert systems, at least not yet, and the engineer is the one who accepts or rejects the results obtained by computer simulations.

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SAVREMENI PRISTUP U RAZVOJU TANKOZIDNIH DELOVA ZA INJEKCIONO PRESOVANJE

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REZIME

Debljina zida predstavlja jedan od najbitnijih činilaca u procesu injekcionog presovanja i kao takav direktno utiče na izbor parametara procesa i kvalitet gotovog proizvoda. Smanjenje debljine zida nekog proizvoda je u većini slučajeva poželjno, iako u prvom trenutku to znači povećanje troškova proizvodnje zbog neophodnih prepravki na alatima ili samim jedinicama za injekciono presovanje. Naime, beneficije koje se postižu na ovaj način, a to su pre svega smanjnje utroška materijala, skraćenje vremena brizganja, manja težina proizvoda itd, mogu u velikoj meri nadmašiti uvećanje troškove proizvodnje zbog neophodnih korekcija.

U ovom radu prikazan je razvoj različitih tankozidnih plastičnih delova korišćenjem CAE aplikacija. U toku razvoja ovih proizvoda posebna pažnja bila je posvećena izboru materijala, a sama simulacija procesa poslužila je da se uklone moguće greške i izbegnu problemi u procesu injekcionog brizganja. Takođe rezultati dobijeni simulacijom iskorišćeni su za optimizaciju postojećeg dizajna delova, unapređenje procesa brizganja i optimizaciju parametara procesa.
Ključne reči: injekciono presovanje, tankoyidni delovi, optimizacija procesa