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DESIGN AND PRODUCTION OF THE INJECTION MOULD WITH A CAX ASSISTANCE

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Abstract

This paper is focused on the process of designing the desired plastic component and injection mould by using the 3D CAD systems. The subsequent FEM analysis of the injection mould process was carried out in order to define shrinkage and deformation of the plastic material by CAE system. The dimensions of the mould were then modified to compensate the shrinkage effect. Machining process (milling and the laser texturing) of the mould was performed by using CAM systems. Finally, after the production of the plastic components by the injection mould technology, the inspection of the plastic component dimensions was carried out by CAQ in order to define the accuracy of the whole CAx chain. It was also demonstrated that CAx systems are an integral part of pre-production and production process.

Key words

Injection mould, FEM analysis, CAD model, CAM machining, CAQ inspection

INTRODUCTION

CAD systems are quite complex today; that include all the operation required for design of a component such as modelling operations, carry out various engineering calculations and analysis, enable the preparation of completely digitalized technical documentation and finally enable to visualize either a single component or even assemblies. These systems comprehensively deal with the whole development-design stage of the component. There are significant differences in individual types of CAD software these days. CAD software can be simply classified into several categories. Group 1 includes the small 2D modellers. Its biggest benefit is the low cost. The middle CAD software (f. i. AutoCAD) can be placed into the group 2. The final category is represented by big CAD systems which use of a series of modules with the latest integrated modeling as well as the imaging and information technologies to carry out the whole design and production process of a component (1).

Computer aided assistance is already widely extended in the field of designing the injected plastic components and the associated design of shape of injection mould. CAD systems enable to design a component shape in a very short time, generate its shell in next step and finally obtain the shape of injection mould by subtraction function of the component shape from its shell. Design of components by means of CAD software and its production through the CAM software has some advantages, since these processes are subjected to various analyses in the computer:

- In the CAD system, the model of the future component is visualized for the first time, and then the quality of component surface and shape can be assessed. The simplicity of solid modelling is given by the option of using the basic Boolean operation such as addition, subtraction or intersection of geometric bodies etc.
- By the use of the curvature analysis it can be easily assessed which cutting tool is supposed to be used for machining of a given surface. This is important in production of the mould cavity, especially when the mould as a negative to the component model shape is produced.
- The mould cavity has to be analysed in order to determine if it is possible to machine the cavity shape by the conventional methods. It is also checked if the tool can reach the required depth and whether the tool can be used for machining of the desired shape. Sometimes there is a situation that some surfaces cannot be machined by conventional methods only. Then the mould cavity is machined by the combination of conventional method and EDM (Electrical Discharge Machining) process (2).

Injection moulds used in the current machines are technically the complex and complicated devices. High demands in terms of quality, productivity, reliability and automation of production are put on them. From the methodological point of view, the injection moulds can be divided into two segments. The first segment is a shaped cavity of mould. It is a hollow space which is filled with the molten plastic material at high temperatures and pressures during the injection process. The plastic material is subsequently solidified to the shape and dimension of the final component. Mould cavities tend to be structurally very diverse; the design is affected by the function, shape and appearance of the final product. The second segment is the custom design of mould construction. It usually has significant elements of resemblance (3).

This paper describes manufacture of the simplest possible and the most accurate injection mould and to demonstrate the importance of CAx software in designing engineering activities. CAD software of Delcam PowerShape was used for generating a 3D model of the mould. The digital tool model was formed by a CSG method (Constructive Solid Geometry), using the basic geometric elements. Simplicity of the method of modelling is in using the basic Boolean operations such as addition, subtraction or intersection. The block was chosen as the basic object of the model, and was gradually modified to the desired shape by adding or subtracting the basic mathematical objects. The designed tool model has to satisfy all the construction principles placed on the injection moulds in order to final produced tool fulfils its function correctly. The following pages describe the procedure of the component production by the injection mould technology in the following steps: generating the CAD models of the components, FEM analysis of the injection process, generating the CAD model of the tool, production of the tool and the production of components.

A multiplicity of injection mould tool (Fig. 1) is given by several aspects. For instance, accuracy and the character of the products, the size and capacity of the injection moulding machine, a number of desired products and the economy of the machine must be taken into account. A compromise of all these requirements should be considered for the optimal tool multiplicity. In this case, the injection mould was produced with four cavities (one cavity for one product).

FEM ANALYSIS OF THE INJECTION MOULD PROCESS

After designing the components in the required shape and dimensions and the whole gating system (gate, sprue and runners), FEM analysis of this process was performed. The analysis provided the information about the filling process of the mould cavities and the information about the shrinkage of the plastic material. Different plastic materials can be used for production of desired components. For produced components there is not necessary to acquire the high mechanical strength, but only low production cost. Polymers reinforced by glass fibers are not suitable for their abrasiveness. Therefore, components will be produced of polyolefin material. Its low viscosity can fill well the volume of the cavity; however, they are characterized by a semi-crystalline structure. Therefore, during the design of the mould, the shrinking effect of the material has to be considered.

***Fig. 1** Positioning of components in injection mould with sprue and runners*

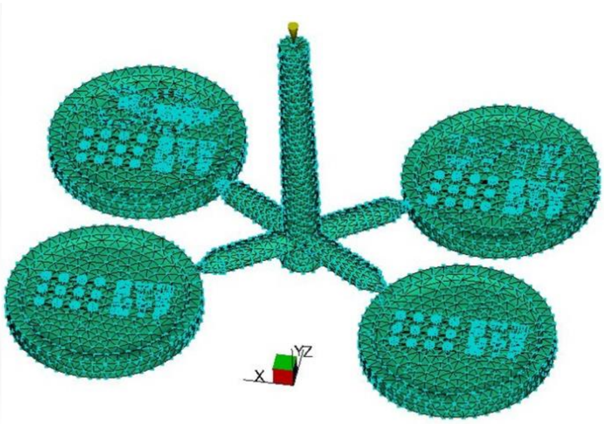

***Fig. 2** Sample after meshing process*

FEM computing analysis of injection moulding process requires a meshing of model (Fig. 2). Mesh of the sample consists of 208 671 elements. A tetrahedron was chosen as the basic element shape. The side length of one tetrahedron element is about 0.5 mm. The elements are bound by 38576 nodes.

PP (Polypropylene) with a melting temperature of about 290 °C was chosen as a plastic material. Viscosity of the material depends on parameters such as the shear rate and injection temperature used during the production process. Lower temperature and lower shear rate means higher viscosity of the material (Fig. 3). Specific volume of the plastic material depends on the used process pressure and temperature (this functionality is shown in Fig. 4). For PP material (such as other Semi-Crystalline polymers), the main transition occurs at T_m when the crystalline regions break down. This transition is marked in Fig. 4.

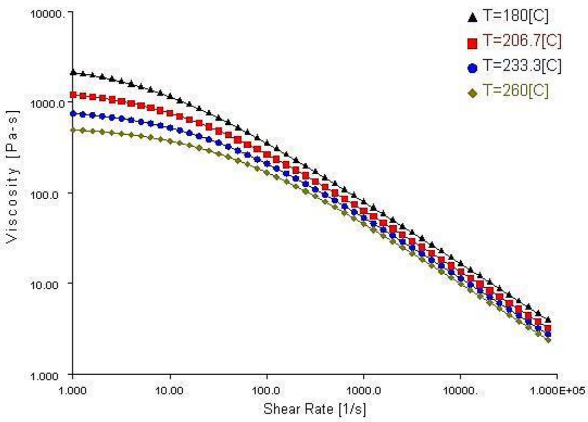

Fig. 3 *Viscosity- Shear rate plot for used PP*

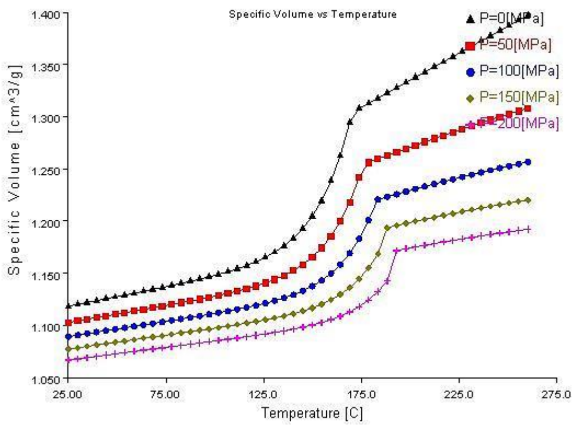

Fig. 4 *P-V-T diagram for used PP*

In the FEM simulation, the same process parameters were used as those applied subsequently during the production process using the injection machine. The injection parameters used during the production are as follows: injection pressure of 6 MPa with injection time of 2.5 s, holding pressure of 4 MPa with time of 4 s and cooling time of 10 s.

The selection of injection mould process parameters was largely limited by the parameters range which can be set on the injection moulding machine, what is more, process parameters were affected by the material properties of the chosen plastic. These ranges were put into the FEM simulation, which subsequently defined the optimal parameters of the injection mould process. These parameters were consequently used in the production of the components.

The FEM simulation shown that the injection mould cavity has to be enlarged in order to the original dimensions of the components were achieved, that was due to the shrinkage of the plastic material. Therefore the distance between the gate centre and the far edge of the component is enlarged by + 0.9108 mm (Fig. 5).

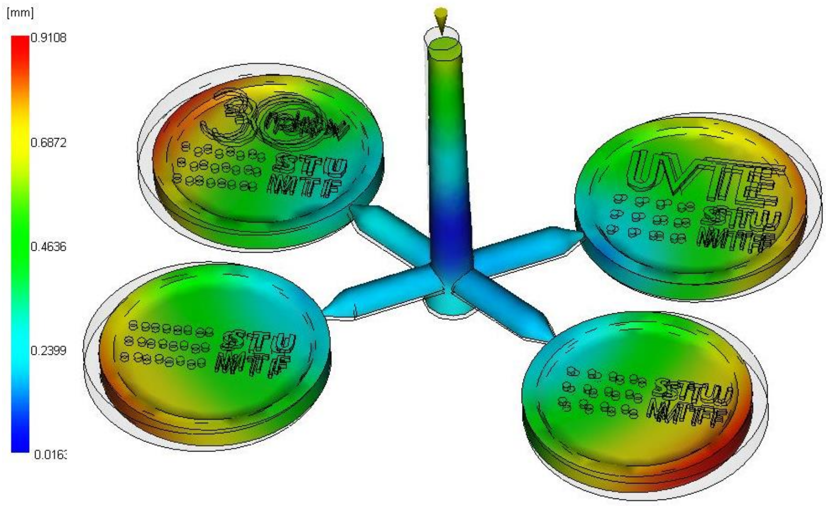

Fig. 5 *Total shrinkage of the components*

Jetting effect occurs when the molten plastic material fails to reach and fill the whole space of the cavity due to the high speed of the injection. As a result, the molten plastic material solidifies in state that shows some wavy folds on the surface of the injected components (4). To avoid this effect, the molten material is directed to the both rims and after then the filling of components cavities is initialized (5), (Fig. 6). To analyse the filling process of the injection cavities, the FEM simulation was carried out (Fig. 7).

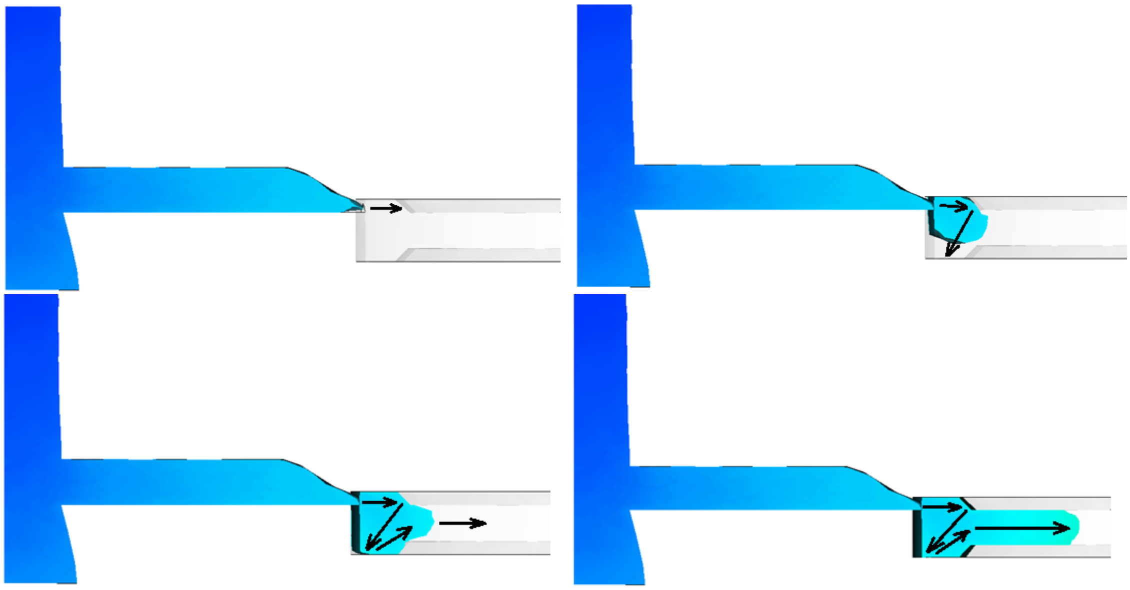

***Fig. 6** Filling the component the cavity gate during FEM simulation*

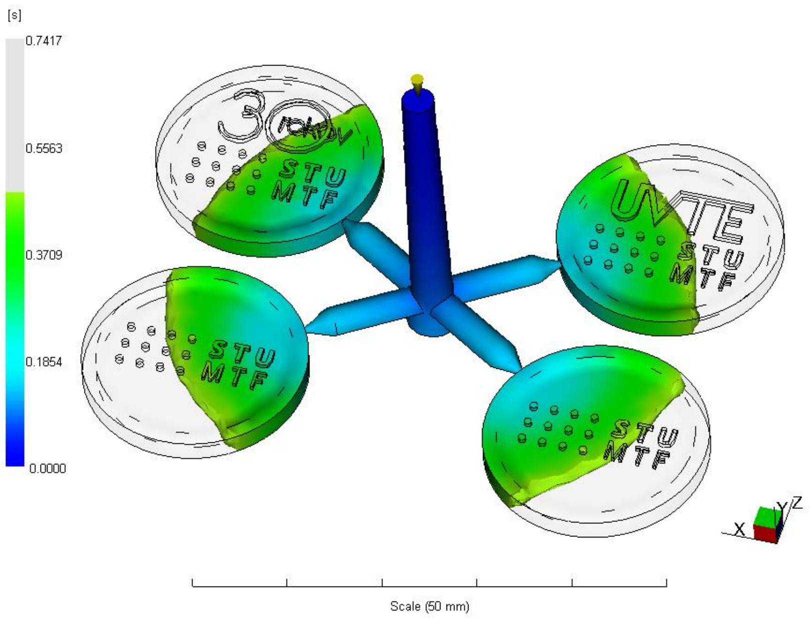

***Fig. 7** Filling the components in the middle time of the process (Time of filling)*

The simulation confirmed that undesirable Jetting effect was not observed. The reason is that the cavity of mould was designed with a non-symmetric location of the injection moulding gate and rims on each component. During filling the mould cavity, the molten plastic material enters the gate and hits the upper rim of the cavity and subsequently hits the bottom rim and then gradually fills the rest of the space (Fig. 6). This design prevents the Jetting effect and even ensures the full filling of the cavity.

Simulations shown that, after the dimensional modification and production of the injection mould, it is possible to initiate the production process, since the injection process parameters were proposed correctly.

PRODUCTION OF THE INJECTION MOULD

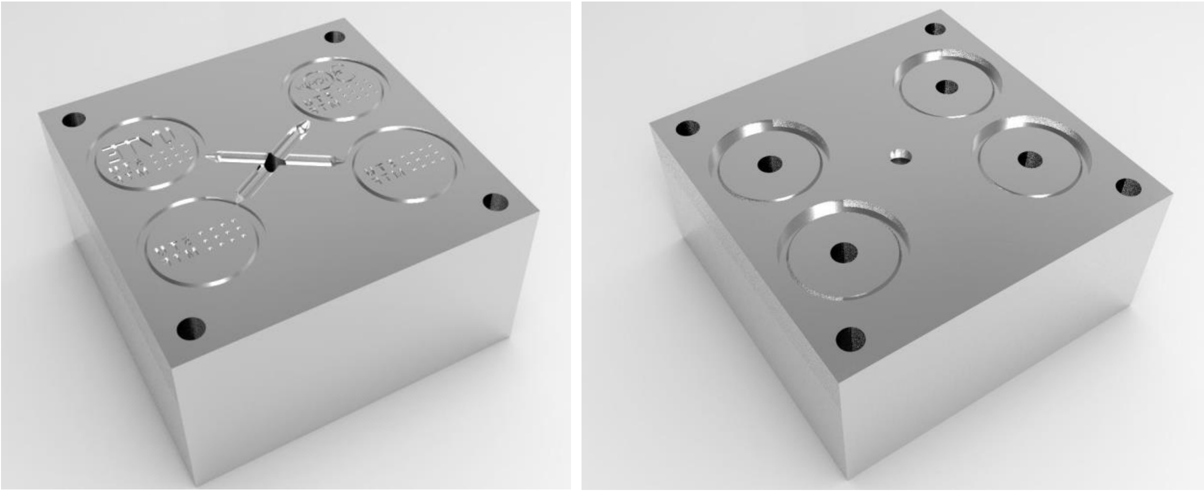

Fig. 8 *CAD models of injection mould*

The finished model of the injection mould (Fig. 8) was exported to CAM software called PowerMILL 2016, wherein CL data were generated for the machining of the proposed injection mould by a milling technology. Fig. 9 depicts an example of one of the used machining strategies (roughing model). Manufacture of the mould tool was carried out using a high speed 5- axis milling machine HSC 105 Linear of DMG (Fig. 10). The mould tool was machined from the AW 6082 material.

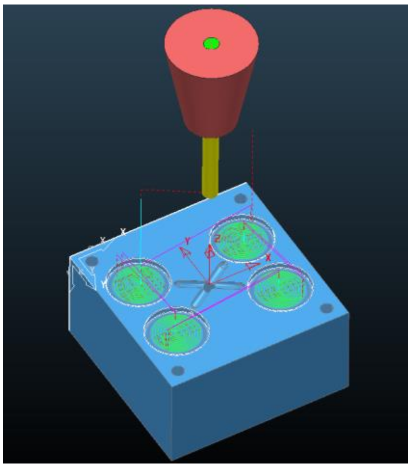

Fig. 9 *Roughing the mould cavity in CAM software*

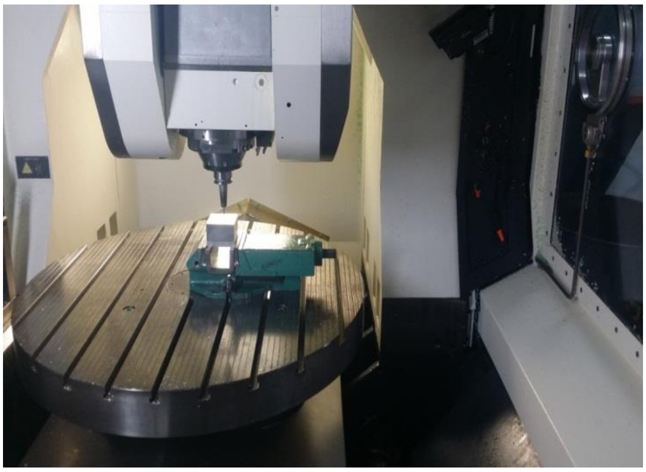

Fig. 10 *Manufacturing the mould in CNC milling machine DMG HSC 105 linear*

After the milling process of the moulding cavity, the tool was moved to a 5-axis laser machining center called LaserTEC 80 Shape for the final shape completion. The machine (Fig. 11a) is equipped by the nano-second pulsed fibre Nd:YAG laser with a wavelength of 1064 nm. It was used to produce the Faculty (MTF) and Institute (UVTE) emblems in the cavities of the injection mould.

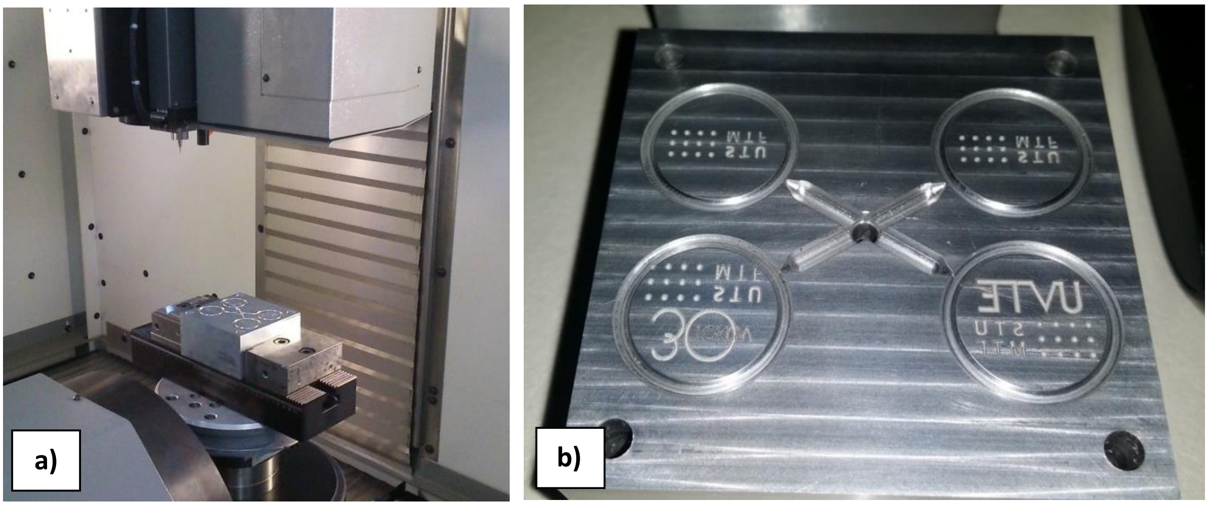

Fig. 11. *Laser machining process*
a) Injection mould clamped inside the laser machine, b) state after the ablation process

The laser beam parameters were optimized so as a depth of cut of 5 μm per a layer was achieved. The laser beam tracking distance parameter (the distance between the two parallel paths of the laser beam on the workpiece surface) was set to 5 μm. The overall depth of produced emblems was set to 0.5 mm (100 layers per emblem).

The preparation of machining program consists of importing a given emblem (in *.bmp format with no colour information) into the CAM software LPSwin. After entering all necessary parameters (overall depth of depression, layer thickness and track distance), the machining program in .L4D format was generated for all types of emblems. Fig. 12 represents the trajectories of laser beam movement during the ablation process generated for each type of emblem. Injection mould was subsequently clamped into the jaw vice of laser machine and the micromachining process was initiated.

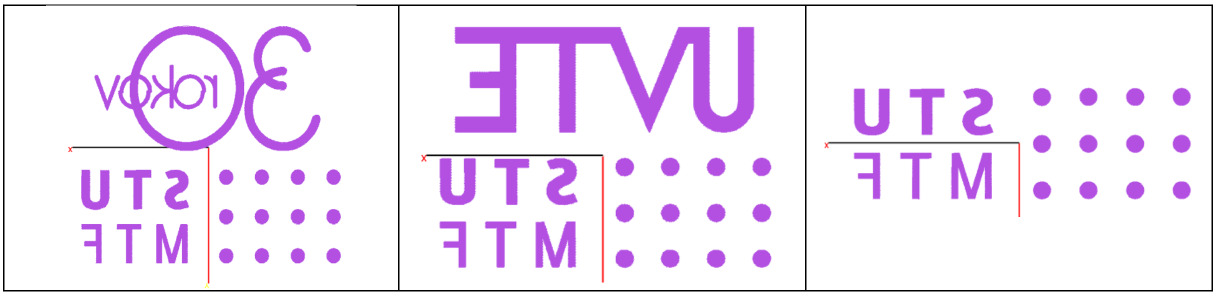

Fig. 12 *Laser beam trajectories generated by LPSwin software*

The final shape of the injection mould is depicted in Fig. 11b. The tool manufactured by the above mentioned machining process is ready for a first real injection test now.

PRODUCTION AND DIMENSIONAL INSPECTION OF THE COMPONENTS

For the purpose of real production of the plastic components, a horizontal injection moulding machine called Babyplast 6/10p was used with the process parameters as described above.

Table 1 Dimensional comparison of CAD model with the plastic component and injection mould

Parameter	Value (mm)			Dimensional change	
	CAD model	Injection mould	Component	CAD / Injection mould	CAD / Component
Diameter	24.0	23.985±0.009	23.32±0.014	-0.06 %	-2.83 %
Thickness	2.40	2.390±0.003	2.357±0.021	-0.42 %	-1.79 %

Subsequently, the dimensions of three chosen plastic components (diameter and thickness) and the chosen cavity were measured three times by a digital caliper to identify the percentage change in dimensions of the component compared to its CAD model. These findings are stated in Tab. 1. It can be seen there, that the diameter of the component is smaller than the diameter of the CAD model; the difference is -2.83 %. This similarity can be found in the values of thickness too, since the difference of the component thickness is -1.79 % compared to the CAD model thickness. This dimensional change is caused by the shrinkage effect of the plastic material during its solidification in the cavity of the mould. Comparison of the dimensional change of the CAD model cavity with the real injection mould cavity shows that these differences can be neglible, and we can therefore say that the injection mould tool was manufactured in a high dimesional and shape accuracy.

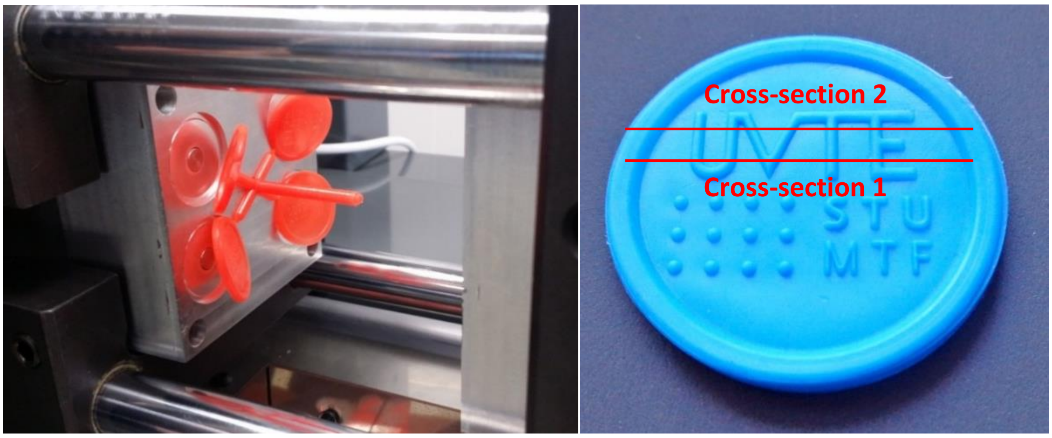

***Fig. 13** The production cycle of the real plastic components*

Based on the tests in a real injection process, it was found that the injection mould process (shape and dimensions of the tool cavity and the production process parameters) were proposed correctly (Fig. 13), which was also confirmed by the FEM simulation. Components were produced in the required shape and dimensions with no deformations or material defects. It was also demonstrated that CAD/CAM and FEM software is an integral part of the pre-production and production process.

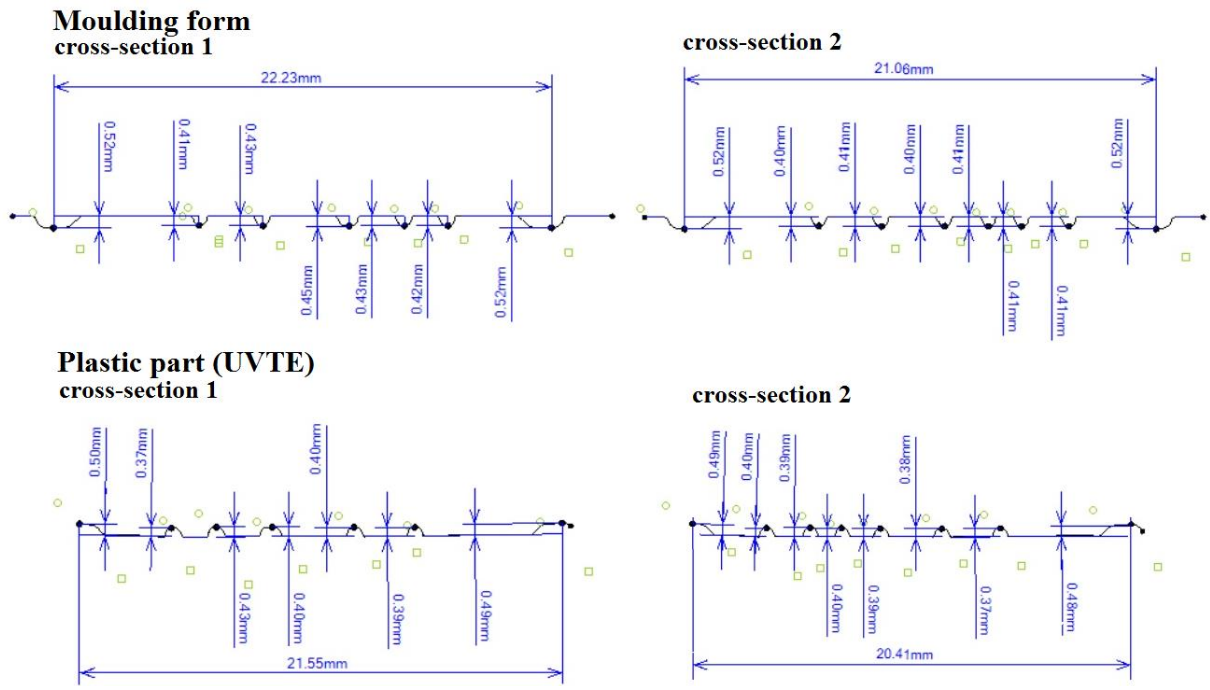

Fig. 14 *Real depth of the emblem (UVTE)*

In order to verify the dimensional accuracy of the injection mould and subsequently the dimensional accuracy of the plastic component, the dimensional inspection was performed using the measuring device of Surfcom 5000. Obtained results of the profile dimensions (mould and the plastic component) are depicted in Fig. 14. Measurements were performed in two cross-sections, as shown in Figure 13.

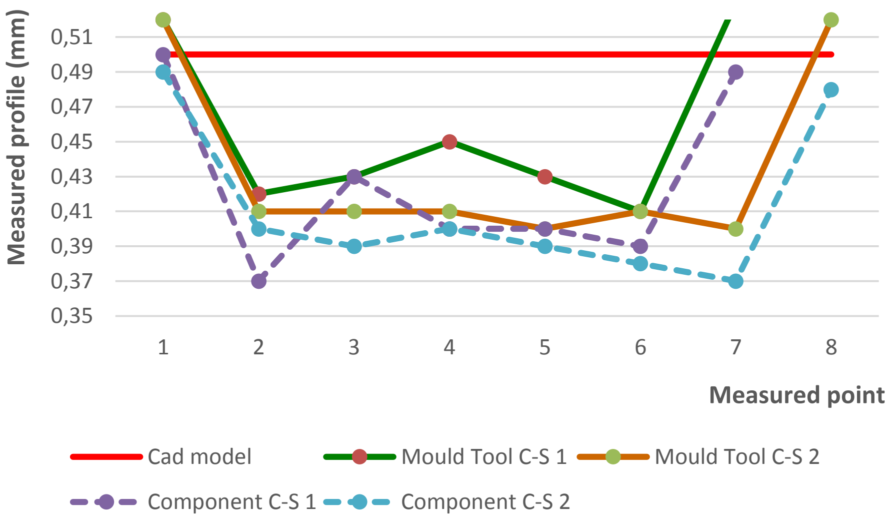

Fig. 15 *Graphical comparison of measured profiles of CAD model, mould tool and component*

It can be seen in the Fig. 15 that the biggest dimensional differences of the profiles are between the CAD model (which represents the reference value of the profile depth of 0.5mm) and the grooves produced by the laser micro-machining; the difference is equal to 20 %. This difference could be avoided by the optimization of the laser beam parameters. The plastic component was relatively precisely produced; the dimensional difference between the mould tool profile and the component profile is equal to 3.7 %.

CONCLUSION

The objective of the research described in this paper was to design and manufacture the injection mould for production of plastic components based on the latest knowledge in the field of CAD-CAE-CAM-CAQ systems. During the design process of the injection mould tool, it was necessary to respect all the rules and principles of successful service of the mould tools. The most important element in the design was a suitable and correct location of parting plane. The parting plane was in this case placed parallel to the top edge of the products. The next step of the injection mould design was choosing the multiplicity of the tool, design of an ejection system and an intake system and other elements. The 3D design of the plastic components and the injection mould was carried out in PowerSHAPE software, and the preparation of the NC code necessary for production of this tool was prepared using the PowerMILL software.

It was demonstrated that the dimensional changes of the plastic component and the mould tool cavity were caused by the shrinkage effect of the plastic material, since the semi-crystalline polypropylene was used as the component material. Formation of crystalline phases has the greatest influence on the plastic material shrinkage. It would be appropriate to use an amorphous plastic material such as ABS to avoid the effect of material shrinkage.

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References:

1. KURIC, I., KOŠTURIAK, J., JANÁČ, A., PETERKA, J., MARCINČIN, J., 2002. *Počítačom podporené systémy v strojárstve. (Computer aided systems in a mechanical engineering).* Žilina: ŽU, 351 p. ISBN 8071009482.
2. FABIANOVÁ, J., 2006. *CAD/CAM systémy pri návrhu tvaru a výrobe plastových výliskov. (Using CAD/CAM systems for design and production of the injection moulded components).* [cit. 2014-10-05]. Košice, TU SF. [online]: <http://www.sjf.tuke.sk/transferinovacii/pages/archiv /transfer/9-2006/pdf/88-90.pdf>
3. JANČUŠOVÁ, M., 2010. *Formy na tvárnenie plastov. (Moulding tools for forming plastic materials).* Žilina: ŽU, 155 p. ISBN 9788055401911.
4. AKAY, M., 1992. Jetting and fibre degradation in injection moulding of glass-fibre reinforced polyamides. *Journal of materials science*, 1992, **27**(21), 5831-5836. ISSN 0022-2461.
5. WANG, X., ZHAO, G., WANG, G., 2013. Research on the reduction of sink mark and warpage of the molded part in rapid heat cycle molding process. *Materials & Design,* Volume 47, 779-792. ISSN 0261-3069.

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