Numerical modeling of MuCell® injection moulding process

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Abstract: The results of computer simulation of an injection moulding process with microcellular foaming were presented in this work. The methodology of preparing the simulation as well as the simulation results were described. The characteristic properties of the forecasted injection moulded part were shown. Finally, the microscopical investigation results of a real injection moulded part were presented and the comparison of simulation results and microscopical images was made.

Keywords: injection moulding, Moldflow, MuCell, simulation.

1. Introduction

MuCell® is a registered trademark of Trexel Inc. for microcellular injection moulding process. The concept of thermoplastics microcellular foaming was presented first at late 1980s. by Massachusetts Institute of Technology (MIT). At the end of 1995 Trexel Inc. started to develop and commercialize this idea. Atmospherical gases (mostly nitrogen and carbon dioxide) are used in MuCell to create microporous structure with closed pores. The dissolving of these gases in a liquid polymer is possible because they are transferred to in supercritical fluid (SCF) phase and then they reach high diffusion rate, high density (liquid like), low viscosity and low surface tension. The microcellular part are characterized by lower weight (density), and shorter injection moulding cycle time. This manufacturing process enables a significant cost reduction and real improvement of injection moulded parts quality [1].

1.1. MuCell injection moulding

The dissolving of a gas in a polymer occurs when injecting supercritical fluid (SCF) created from an atmospheric gas (N_2 or CO_2). The supercritical fluid is injected directly to the injection unit of the injection moulding machine where it is mixed with the polymer. In order to enable the rapid dissolving of a SCF in a polymer, a special design of the reciprocating screw as well as using the SCF injectors is required. A big number of nucleation points is created in the polymer - a whole order of magnitude bigger than in conventional foaming process. The cell (bubble) growth is controlled by the processing parameters - temperature and pressure. After material injection into the mould the material shape is controlled by the mould shape which is usually not modified in comparison to the classical mould shape, however, it is sometimes to introduce some modifications to use the advantages of this process more.

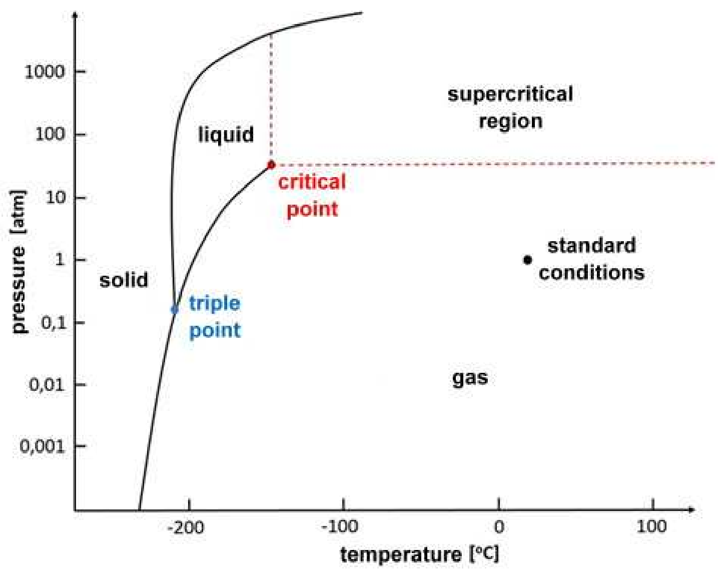

Fig. 1. Phase transitions of nitrogen

The rate and effectiveness of cell growth depends on the processing conditions (mainly from temperature and pressure) but also on the kind of polymer and gas and on the gas content andsitr solubility in the polymer, For example, carbon dioxide solubility to polymers is better than nitrogen, but nitrogen is better to control the process and cell quality so nitrogen is more common in MuCell [1]. The phase diagram of nitrogen is shown in Fig. 1. Supercritical fluid is when a substance is over its critical pressure and critical temperature which for nitrogen are: 34 bar and -147 °C.

The gas content in microporous parts impacts the part weight but also some mechanical properties [2]. Tensile strength, tensile modulus decrease with gas content but the part weight drops in case of glass fibre reinforced polyamide [3].

An important disadvantage of microcellular injection moulding process is poor surface quality, beacuse the pores can get into the part surface which are not smooth. It is possible to decrease surface roughness by rapid heating of the mould with the use of induction heating elements in InduMold process [4].

The MuCell technology has several advantages from the processing point of view, for example it requires lower mould clamping force, shorter cycle time. Some of the part properties are better when compared to the conventional moulding process. Flatness of injection moulded parts is improved and the parts weight lower. All these factors contribute to important saving during mass production of plastic part [5].

Mucell process is also used for reinforced polymers, for example to produce glass fibre reinforced parts from polyamide, where decrease in product weight is especially important. The structure of the part in the cross-section is different across the part thickness [6,7]. The size and concentration of the pores can be controlled first of all by the polymer pressure, but also by the speed of injection [8]. When controlling the plastic pressure it is important to limit the counter pressure because this parameter can block the generation of pores [9]. The pores can be larger in the center of the wall thickness because several pores can join and create bigger features of irregular shape [10].

2. Simulation of microcellular injection moulding

The results of modeling of the injection moulding process by MuCell technology used to manufacture a channel for drain water are presented.

2.1. Preparing the simulation

A view of the investigated part is shown in Fig. 2. The geometrical model was prepared in a CAD software and exported as STP file. In the next step it was imported to Autodes Simulation Moldlfow Insight software and finite element mesh was generated on this model - Fig. 3.

Fig. 2. The investigated part - a channel used to transport a drain water

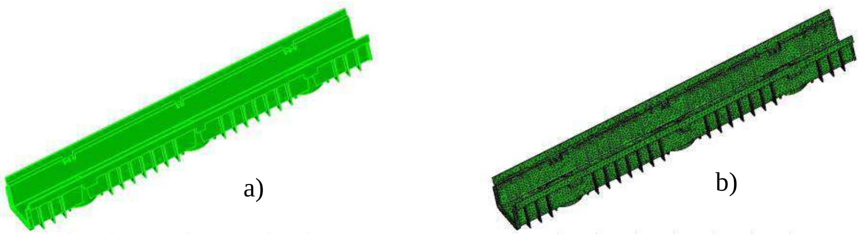

Fig. 3. The model of the part, imported to the simulation software (a) and mesh model (b)

After preparing model and mesh the simulation was made in two options: as a classical (conventional) injection moulding process and as MuCell process. The processing conditions were as follows:

For the conventional process only:

- Melt temperature: 240 °C,
- Mould temperature: 40 °C,
- Holding time: 10 s,

- Cooling time: 20 s,
- Holding pressure: 15 MPa,
- Injection time: 2.5 s.

The additional parameters for MuCell technology:

- the assupmted decrease in the part mass: 10%,
- initial bubble diameter: 0.001 mm
- Initial estimative bubble concentration $2 \cdot 10^5$ 1/cm^3

The processed plastic was polypropylene reinforced with glass fiber (30%) - Hostacom PP 2062.

2.2. Simulation results

Some selected results of microcellular injection moulding simulation are presented, for example in Fig. 4 and 5 - the forecasted mechanical properties in different regions of the part. The results are presented in a form of coloured maps and plot referred to some selected points.

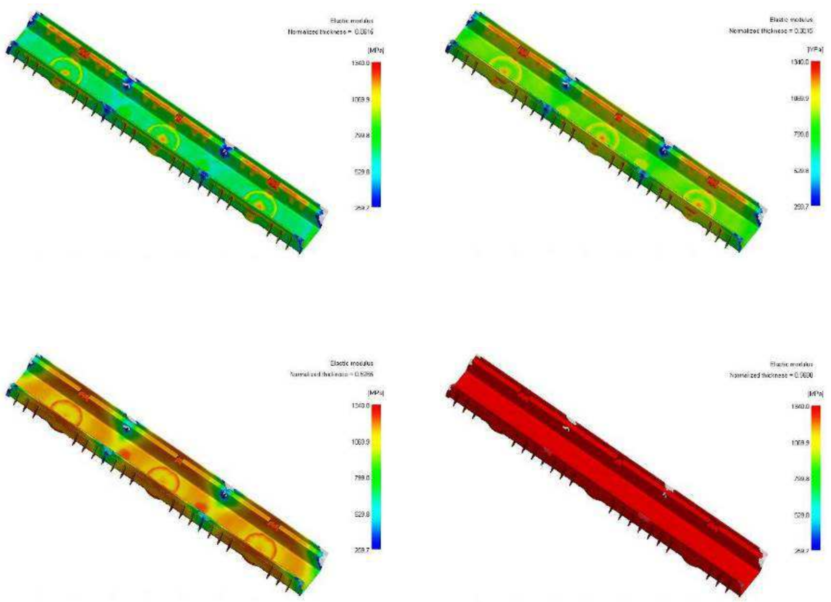

Fig. 4. Youg's modulus at different depth in the part wall thickness.

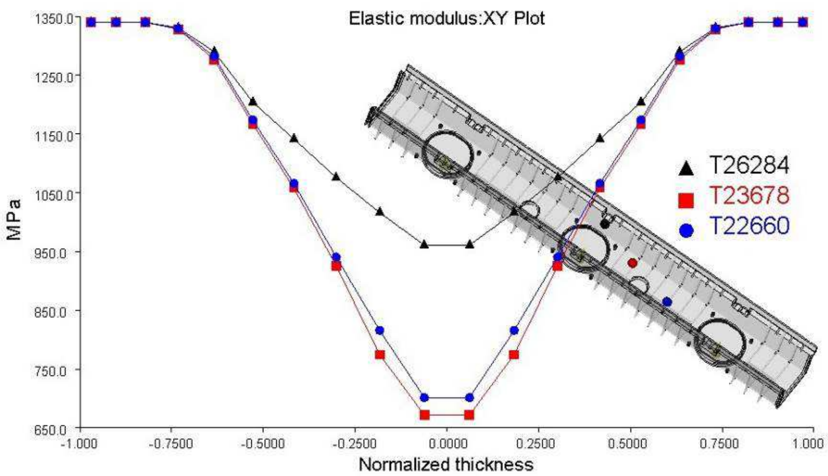

Fig. 5. Young's modulus dependence on the depth in the wall thickness. 0 - the middle of the wall thickness, 1 - part skin.

In figure 6 the comparison of estimated sink marks values on the part surface, conventional injection moulding and microcellular injection was presented.

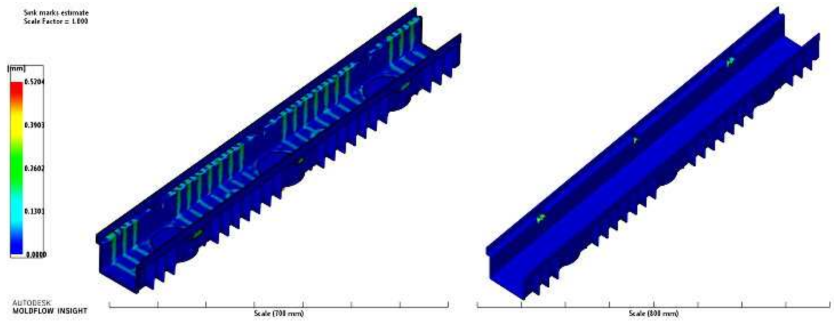

Fig. 6. The comparison of estimated sink marks values on the part surface, a) conventional injection moulding, b) microcellular injection.

The results of bubbles growth simulation in different areas of the parts are presented in Fig. 7, 8 and 9. On the linear graphs (Fig. 7 and 8) the results in the microscopical samples collection areas are shown. Significant differences in bubble diameter, depending on the distance from the sprue as well as depending on the coordinate in the wall thickness direction were stated.

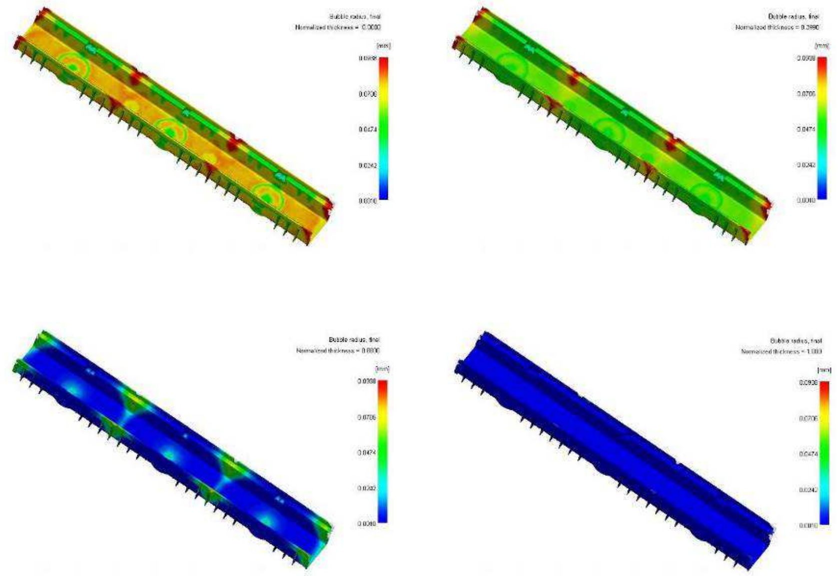

Fig. 7. Bubble radius at different depth in the part wall.

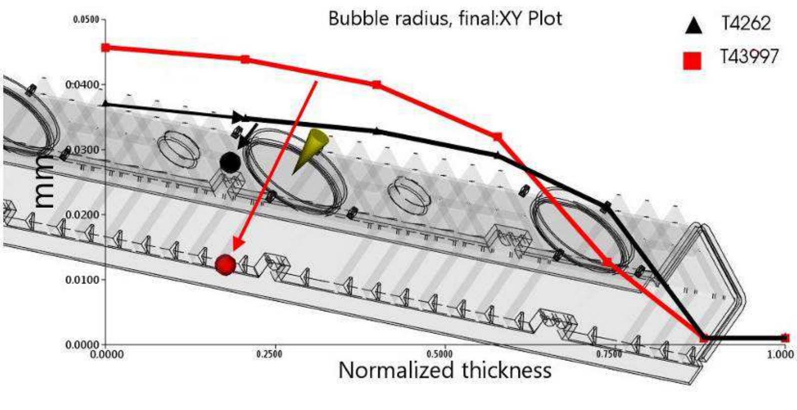

Fig. 8. Bubble radius near the sprue at different depth inside the wall thickness. 0 - in the middle of the thickness, 1 - part skin

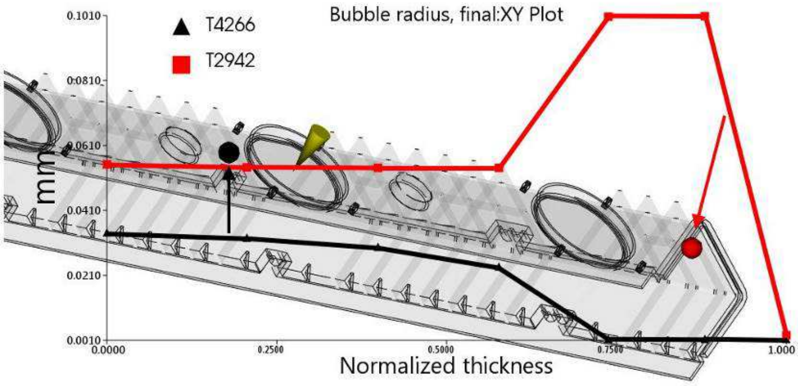

Fig. 9. The comparison of bubble radius near the sprue and at the flow end at different depth inside the wall thickness. 0 - the middle of the thickness, 1 - part skin

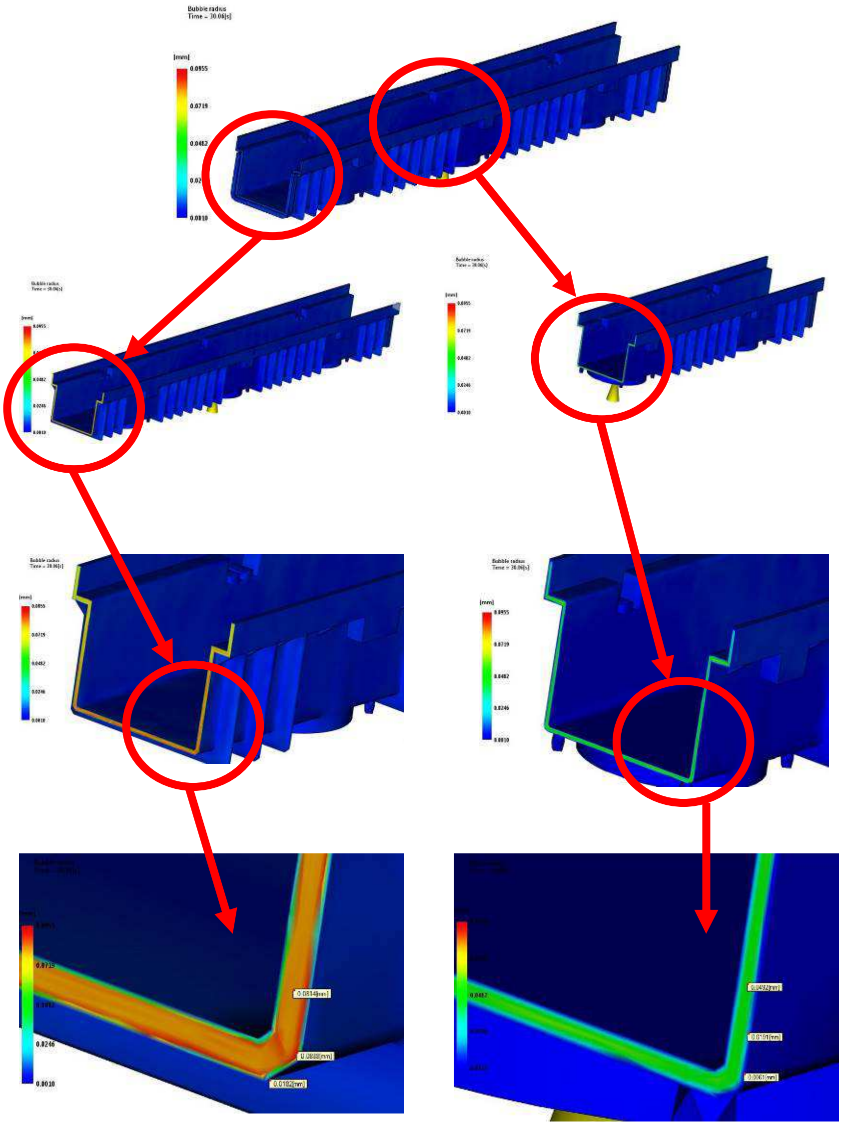

Fig. 10. The comparison of bubble radius near the sprue and at the end of the dlow at different depth across the wall thickness.

3. Microscopical investigation results

The verification of the microcellular injection moulding computer simulation was made by the microscopical investigation in the part cross-section in different part areas. Both conventional and MuCell parts were investigated in the areas marked on the photography shown in Fig. 9. The investigation was made using Nikon SMZ800 microscope to observe the microtomed surface in the reflected ligjt and Nikon Eclipse E200 microscope for microscopical slides observation in the transmitted light.

Microtomed flat surfaces of the parts were observed as well as microtomed slices were used to prepare microscopical slides to observe in transmitted light. Thermo Shandon Finesse ME+ microtome was used with a solid steel knife. The results of microscopical investigation are presented in Fig. 10-14. Due to the high glass fiber content (30%) cutting the parts on the microtome was difficult. The results can be threaten as just estimative because of difficult cutting conditions which could cause the bubble deformation.

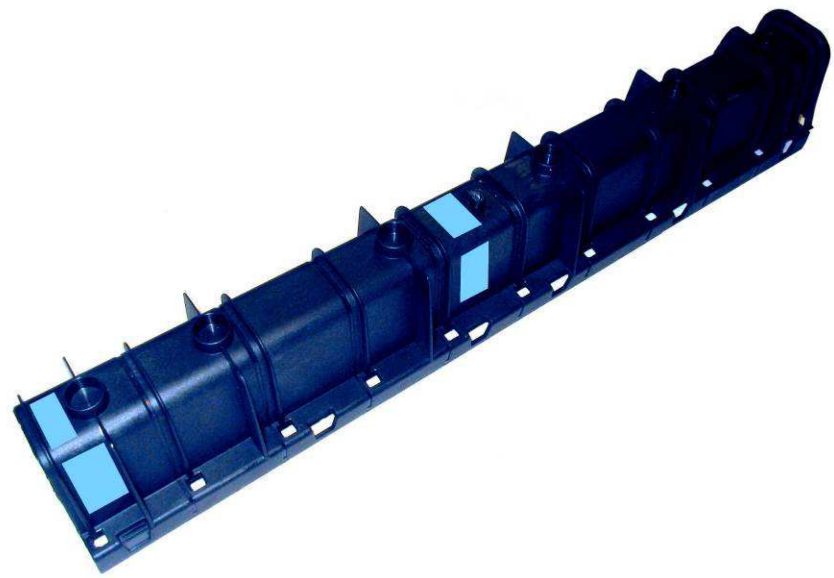

Fig. 10. A photograph of the investigated part with the marked samples cut for microtoming and structure investigation

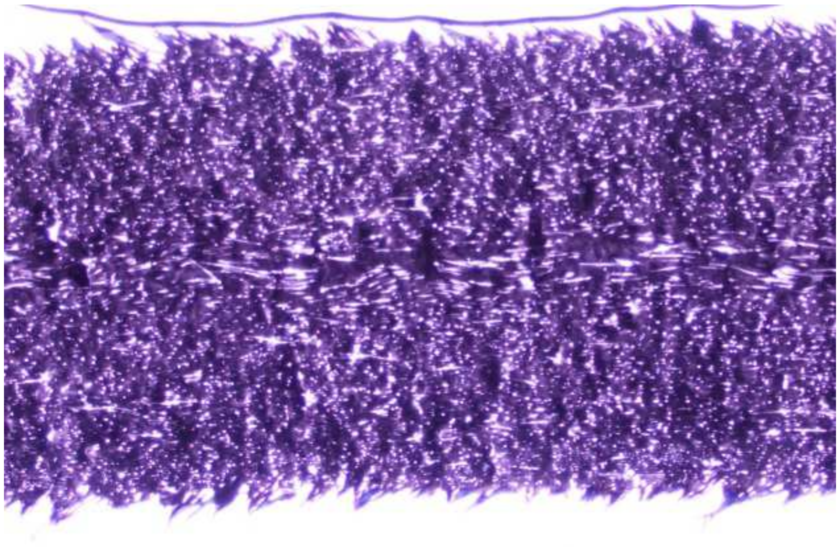

Fig. 11. The microscopical view of the conventionally injection moulded part - observation in the transmitted light, x 20

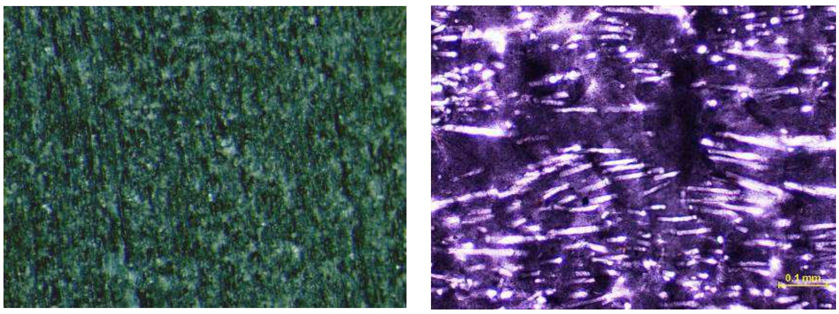

Fig. 12. The microscopical images of the cross-sections in the part manufactured by conventional injection moulding. Left - the microtomed surface observed in reflected light, right - microtomed slice observed in transmitted light

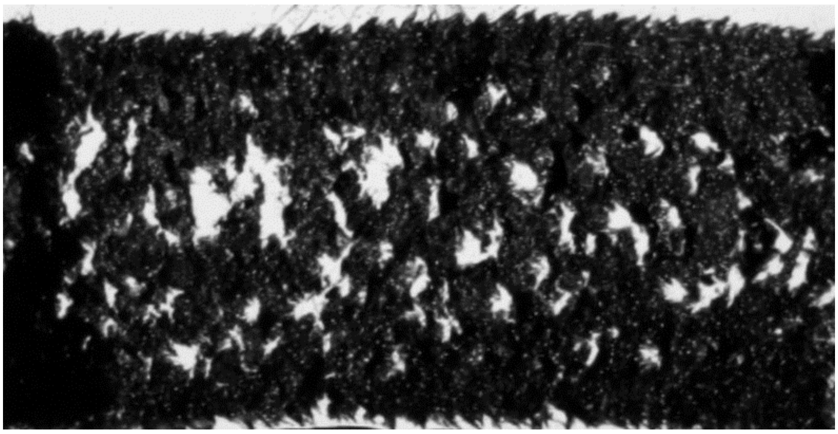

Fig. 13. Microscopical image of MuCell part - transmitted light

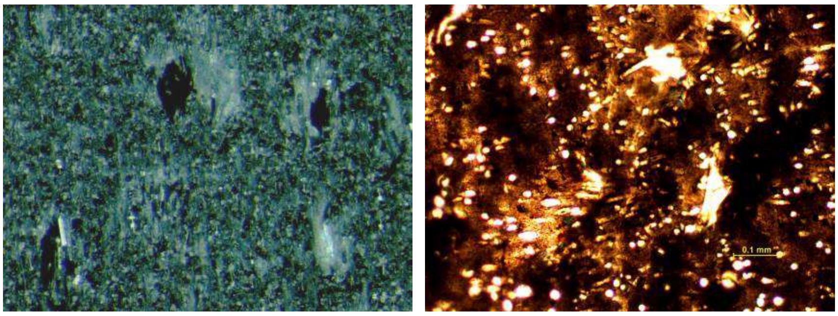

Fig. 14. The microscopical images of the cross-sections in the part manufactured by MuCell injection moulding. Left - the microtomed surface observed in reflected light, right - microtomed slice observed in transmitted light

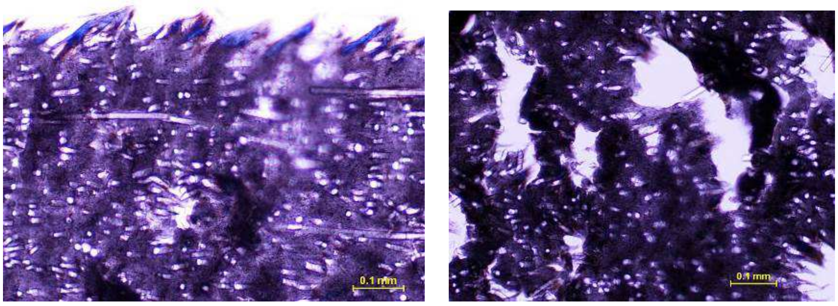

Fig. 15. Structure of MuCell part. Left - area at part skin, right - in the middle of the part thickness.

6. Summary and conclusions

MuCell process is one of the most interesting methods of injection moulding with many positive effects possible to achieve which have the influence of the injection moulding process and manufactured parts' properties. Some of these positive effects are:

- part mass reduction (material density)
- residual stress reduction in the part
- elimination of sink marks
- burn effect reduction
- improvement of dimension tolerance
- increase of the flow way by the drop in material viscosity
- reduction of the required machine (mould) clamping force
- shorter cycle time
- new possibilities in plastic parts' design

The following conclusions can be withdrawn from the investigation made:

- microcell (bubble) growth is not homogeneous across the part. It depends on the processing conditions but also on the way of plastic flow in the mould cavity. Significant differences in bubble size in different areas of the part were found out. The difference in bubble size across the part wall thickness was also observed. In the sprue region the biggest bubble diameters were registered in the middle of wall thickness but at the flow end region the biggest values were found in high shear (and temperature) region - between the mould wall and the middle of wall thickness.

- as a consequence of the above conclusion is that the mechanical strength in the places with big concentration of big diameter bubbles will be smaller than in the areas, with low bubble concentration or with no bubbles (for example on the part surface)

- MuCell application causes local weakenieng of the injection moulded parts but many properties are improved. Flexibility, resistance to vibrations, damping, sink marks reduction are the examples of quality improvement.

- the MuCell parts can have inhomogeneous properties but possible to forecast. It means that it is possible to manufacture the parts with the desired properties, depending on the application. Unfortunately, it is not possible to increase the material strength by microfoaming

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