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Simulating Cold Mould Defects, In the Process of Low-Pressure Polymer Moulding with Chemical Foaming Agent, Using Magma

Stanislav Gatsev[a]*, Stoil Todorov[b]

[a]*Magister, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski", Sofia 1574, Bulgaria*

[b]*Professor Doctor of Engineering, Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski", Sofia 1574, Bulgaria*

[a]*Email: s.gatsev@gmail.com*

[b]*Email: smt@ims.bas.bg*

Abstract

In the article, we described potential defects, which are result of low mould temperature in the process of low-pressure polymer moulding. We identified the parameters, which will affect this process in Magma Soft. We executed a series of simulations in order to verify that changes in these parameters result in reliable simulation results. We identified the result characteristics, which indicate that there will be defects on the produced part surface. We validate the simulation results with real experiments.

Keywords: Simulation; Mould temperature; Polymer; Chemical foaming agent; Magma.

1. Introduction

In the article "Simulating defects, which were result of incorrect dosage of chemical foaming agent in the process of low-pressure polymer moulding" [1] we showed how Magma Soft can be modified in order to support simulation of polymer moulding process. The defects which were simulated were result of incorrect dosage of the chemical foaming agent in the process. The results are close to the reality that clearly proved Magma Soft reliability to simulate processes of polymer moulding with chemical blowing agent.

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* Corresponding author.

Low-pressure polymer moulding with chemical foaming agent is one of the best ways to produce light and in the same time amazingly strong and durable plastic parts [2,3]. With this method the plastic parts come out with a thick wall, which consists of equally porous structure (air bubbles) in the core and solid external skin on the sides [8]. Products of this method are widely used in the heavy machinery production and automotive industries. One of the biggest challenges ahead of this method relate to the quality of the surface of the produced parts. The parameter, which can greatly influence the finish of the part's surface is the temperature of the mould [4]. In the research published in the article "The Impact of Mould Temperature and Blowing Agent Content on Structure and Properties of Injection Moulded Parts", Elzbieta Bociaga and Pawel Palutkiewicz* Czestochowa University of Technology, Department of Polymer Processing, Poland (2013), showed the influence, which the changes in the mould temperature can cause to the gloss of the surface. These observations are also described in another article by the same authors [5]. Above that it is clear that mould temperature can also influence significantly the number and size of pores in moulded parts. Another characteristic, which may change due the mould temperature is the shrinkage of the part [6]. Study about this behaviour shows what can happen if the mould temperature is not well calibrated and how it can be done in practice. In this study, the authors use simulation software [7] which were already reviewed in another article.

Having in mind the great influence, which mould temperature has on the process of low-pressure polymer moulding with chemical foaming, it seems clearly that a module in Magma Soft, which can simulate the results of incorrect mould surface temperature can optimize the process a lot. This module can also help improve the overall quality of the produced plastic parts.

2. Methods and Materials

As we already have module, which simulates defects, result of incorrect dosage of the chemical foaming agent, we can use it in order to simulate a correct process, regarding this parameter. We will then extend the existing module by identifying how changes in mould temperature will affect the final quality of the produced plastic part. We will analyse the simulation results and identify if any changes in other process parameters can help better identify potential issues. By introducing such research, we will enhance Magma's, already identified, capability to analyse and predict errors in the design and process of low-pressure polymer moulding with chemical foaming agent.

We will reuse the same polymer material, which was used for the simulations of incorrect dosage of chemical foaming agent. We will redefine all its parameters and identify the exact function of the density. By this we will isolate defects, which are result only from the incorrect tempering of the production mould. At last we will validate all the results by executing moulding experiments on multiple plastic parts in order to confirm that the results are reliable.

The characteristics of the material HDPE (High-density polyethylene), which we already have in the database are taken from its datasheet [9] and are shown in Table 1 and Table 2. Note that we have taken in account the specifics of the mathematical module of Magma Soft and set values for 1° C and 2000° C, even though such values make no sense in the context of polymer moulding process.

Table 1: General Characteristics

Solidus temperature	180° C
Liquidus temperature	240° C
Initial temperature of the molten material	280° C
Specific energy	171.54 kJ/kg

Table 2: Temperature dependent characteristics

Thermal Conductivity	1° C	0.21110 W/mK
	2000 ° C	0.21110 W/mK
Specific Heat Capacity	1° C	2859 J/kgK
	2000 ° C	2859 J/kgK
Viscosity	1° C	1183.00 m^2/s
	180° C	1183.00 m^2/s
	200° C	968.9710 m^2/s
	220° C	809.3290 m^2/s
	240° C	687.4990 m^2/s
	2000 ° C	687.4990 m^2/s

The only parameter of the material, which is still not defined, is the density, as this is the one which defines the amount of chemical blowing agent in the moulded material. In order to specify it we executed a series of simulations. On Figure 1 and Figure 2 is shown the structure of the part. The mould is constructed by two plates. The part itself has unique form, with numerous differences in the thickness. Its thickest zones go up to 15mm. There are multiple transfers from thin zones, which may cause issue for material flow and feeding at the solidification state. All these characteristics are very demanding in terms of mould design. Above this the quality of the final product is very important as it not only has to be light and hard but should also have nice looking and even outer skin.

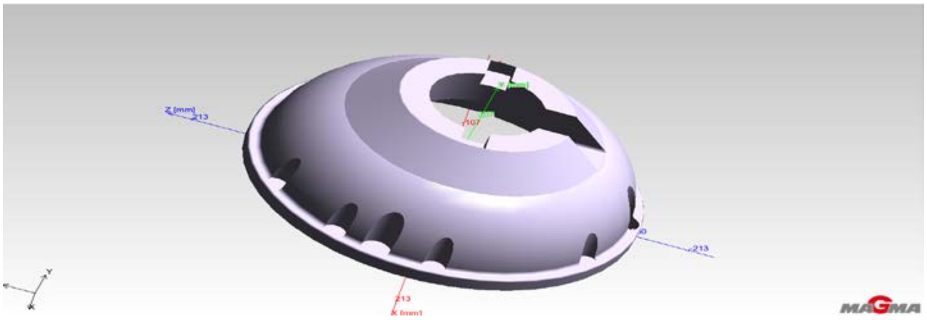

Figure 1: Part

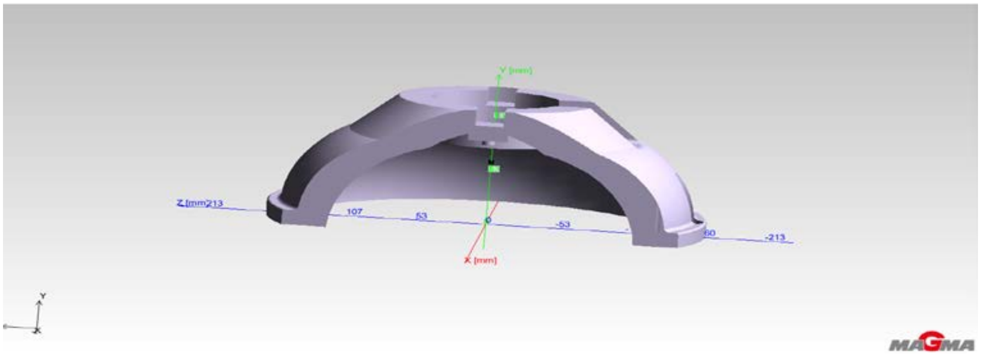

Figure 2: Part Intersected

By executing the simulations, we defined that the density parameter should have the following function, Table 3. These parameters satisfy the need of blowing process in the moulding.

Table 3: Density Definition

Density	1° C	310.00 kg/m^3
	180° C	310.00 kg/m^3
	210° C	300.00 kg/m^3
	240° C	300.00 kg/m^3
	270° C	500.00 kg/m^3
	280° C	743.81 kg/m^3
	2000 ° C	743.81 kg/m^3

In order to setup the mould temperature we went deeper in Magma’s parametrization capabilities. After series of simulations we identified two parameters, which may give us the needed results. These are the Mould Initial Temperature and the Thermal Conductivity between the mould and the part. Changing these characteristics mainly changed two main aspects of the results, which we received by our simulations. The first was the Cooling Rate, as by increasing the Heat Transfer between the mould and the moulded polymer and decreasing the Mould Initial Temperature we observed increased Cooling Rate. This effect was expected and led us to the other characteristic in which we observed a change. Magma Soft has Microporosity characteristics in its results set. In terms of metal casting Microporosity is taken in consideration as Microshrinkage. High Microporosity can result in dramatic deterioration of mechanical and fatigue properties. [10] Results on this parameter and the results from the Cooling Rate showed us a regularity that as faster is the Cooling Rate the more and with higher impact are the zones with Microporosity on the external skin of the produced part. This regularity is shown in the two experiments, described below.

3. Results and Discussions

In the first experiment we set the Initial Temperature of the mould to 160° C and defined the Heat Transfer between the mould and the moulded polymer as on Table 4.

Table 4: Heat Transfer Coefficient on Heated Mould

Heat Transfer Coefficient	1° C	200 W/m^2K
	180° C	200 W/m^2K
	210° C	300 W/m^2K
	240° C	400 W/m^2K
	280° C	400 W/m^2K
	2000 ° C	400 W/m^2K

By configuring the process in such manner, we wanted to simulate an already heated mould.

Results were that we had more controlled Cooling Rate of maximum 132.5° C/s and relatively small amount of differences in the Microporosity level on the external skin of the produced part as it is visible on Figure 3 (Cooling Rate) and Figure 4 (Microporosity)

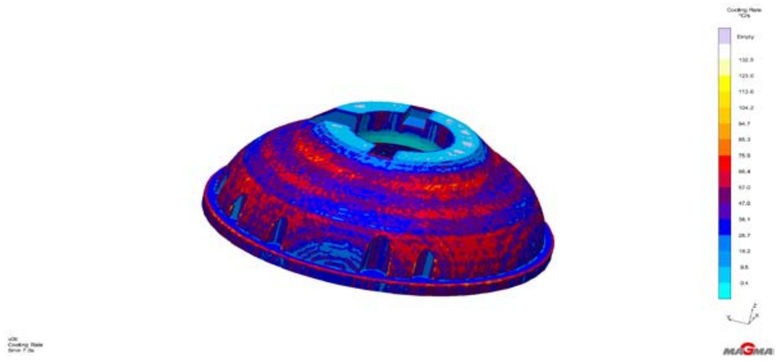

Figure 3: Cooling Rate Result on Heated Mould

Figure 4: Microporosity Result on Heated Mould

The next experiment simulates a cold mould. We set the Initial Mould Temperature to 20° C and defined the Heat Transfer between the mould and the moulded polymer as on Table 5.

Table 5: Heat Transfer Coefficient on Cold Mould

Heat Transfer Coefficient	1° C	200 W/m^2K
	180° C	200 W/m^2K
	210° C	500 W/m^2K
	240° C	1000 W/m^2K
	280° C	1000 W/m^2K
	2000 ° C	1000 W/m^2K

We observed results with a lot higher Cooling Rate of maximum 209.9° C/s and with a visible increase zones with of Micro-porosity differences on the external skin of the produced part. These results can be seen on Figure 5 and Figure 6.

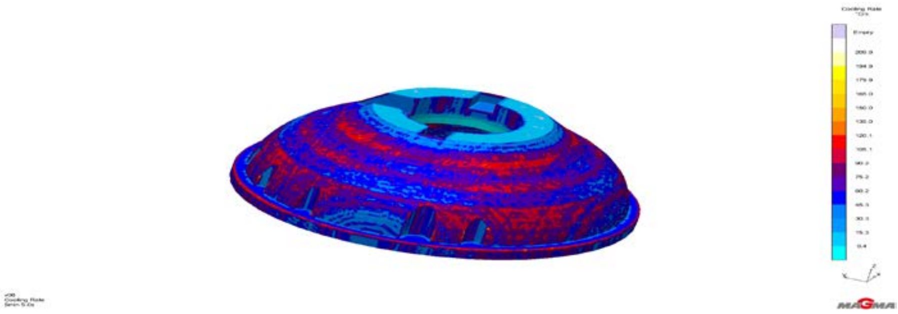

Figure 5: Cooling Rate Result on Cold Mould

Figure 6: Microporosity Result on Cold Mould

The final step was to execute real experiments with the mould, which was used for the simulations. The goal was to observe the actual defects, which are result of the low initial temperature of the mould surface. As final step we compared and validated these results against the ones from the already done simulations. In Figure 7 we have a result from the moulding of the part, which we simulated with very good outer skin finish as the mould was already heated at around 160° C

Figure 7: Heated Mould Result

On Figure 8 we see the result of a cold mould.

Figure 8: Cold Mould Result

4. Conclusion

Magma Soft is capable of simulation defects result of cold mould temperature, by defining redefining the Initial Temperature of the mould and the Heat Transfer between the mould and the moulded polymer. These simulations can be used as part of the calibration process, as it can simulate the defects and give clues to the production line designers for the temperature which needs to be preserved on the mould surface in order to execute the moulding process with the best possible quality.

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