A study of the gate size effects on the process of optical data storage micro-scale replication

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Abstract

The present paper offers 3D CAD models of the gate system of an optical disc mould that are developed. The type of the gate system is known as a "Krauss Maffei" system, in which the central hole of the polymer substrate is formed by breaking off the circle gate from the polymer substrate. The gate depth and the gate position are defined as variable parameters and combined with different variants of the processing conditions in mould filling simulation. A range of improved variants of all the variable parameters is obtained with the help of iterative steps within the frame of the simulation code. A modified gate system is proposed in the process of research, which allows a gate with a lager depth parameter to be used. The modified system allows also alteration of the gate position with respect to the central hole. The best results are achieved, using the proposed modified gate system in the case, when a gate with a larger depth is used and the gate position is located symmetrically towards the central hole.

Keywords: optical data storage replication, 3D CAD model, simulation, nanostructures

1. Introduction

1.1. Optical data storage micro-scale replication and nanotechnology

Nanostructures can be replicated on large surfaces using injection molding of thermoplastic materials. Polymer injection molding is highly suitable for the mass fabrication of high precision micro- and nanostructures [1]. Optical discs have become increasingly used for information storage in recent years. The disc information structures are both in the micro/submicro range and in the nanometer range, and in the form of pits, are moulded into the disc during the injection moulding process. The key reason for the success of Compact Discs (CD) as storage media is the fact that injection molding makes it possible to transfer Gbytes of data points (surface pits) in a few seconds onto a cheap polymer carrier. This task has become even more important for the new formats (DVD and successors) with higher storage densities, where structure sizes of below 100nm have to be replicated [2, 3, 4].

1.2. Definition of the technical problem in optical data storage replication

The production of polymer substrates for optical discs requires high dimension accuracy, exact copying of the information structure and low birefringence. The experience gained up to now in the field of injection moulding of optical disc substrates has shown that the mould design and the gate parameters occupy a central place in the production process [5, 6, 7, 8, 9].

In the process of injection moulding of optical disc substrates, a hot polymer melt is injected in the thin cooled mould cavity under high speed and pressure with the help of a circle gate located in the cavity centre. This means that substrate indicators such as birefringence, residual tensions and copying of the information structure are highly dependent on the behavior of the melt flow, filling the mould cavity. It becomes clear that great internal tensions are available in the final product as a result of improper location, form and dimensions of the circle gate, which result at the end in high level of the main indicator for substrate quality - the birefringence. It follows from this, that the construction solution and the scheme of the circle gate location play a significant role in the quality of the final product. Finally, a "statement of the problem" for optical disc moulding starts with the fundamental difficulty of filling and packing a mould cavity of much greater length than depth, without incurring high levels of moulded-in stress and orientation. For instance, a 120 mm diameter erasable media disc, which is 50 times longer melt flow path than part thickness [10, 11, 12, 13].

In spite of the progress in this area, the approach applied up to now by different manufacturers in solving the problem of cavity filling and formation of the central hole substrate has not declined from the basic method - filling through a thin film circle gate located at the place where the central hole is to be formed. This requires the use of a complex and precise cropping punch or another system, removing the circle gate, in order to form the central hole. On the other hand, the necessity to shape the central hole by separating the circle gate from polymer substrate, calls for minimal depth of the circle gate enabling its easy removal. This approach influences badly the level of the product internal tensions and the orientation phenomena, accompanying the process of filling [14].

Computer simulation is occupying a significant role in the most of the recent papers, which consider the optical disc moulding, but they concern mainly the advantages of the program or the creation of nonlinear viscoelastic models without an analysis of the influence of the gate system geometry and parameters on the

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mould filling process. Probably, the reason of this is that the gate system is the key for useful optical disc moulding and its design represents Know-How of the companies, working in this area [15].

The purpose of the paper is to develop 3D CAD models of an optical disc mould and the gate system and to provide a primary research to study the effect of the gate size and the gate position towards central hole of the polymer substrate on the process of mould cavity filling. A range of correct gate parameters at appropriate processing parameters is to be obtained, so that easy mould cavity filling to be attained, using the 3D CAD models developed and computer simulation code.

Another purpose of the work is to give a possibility for future investigations of the gate size effects on the process of precise pits replication.

2. 3D CAD model of the gate system

The 3D modelling of an object is the first stage to be considered when computer simulation techniques are used. An author's flow chart of the stages, necessary to study the effect of the gate system design on the process of precise pits replication, using injection moulding is shown (see Fig. 1 and Fig. 2).

The mould design concept is based on a well-known type of an optical disc mould, in which the central hole of the polymer substrate is formed by breaking off the circle gate from the polymer substrate, using a moving bush in the opposite direction of the sprue bush. The general disadvantage of this construction is the necessity to use a minimal depth of the circle gate for its easier removal, which contradicts to the support of the optimal conditions of the process of mould cavity filling. Another disadvantage is the impossibility to change the gate position towards the central hole. The reason for this is the necessity to

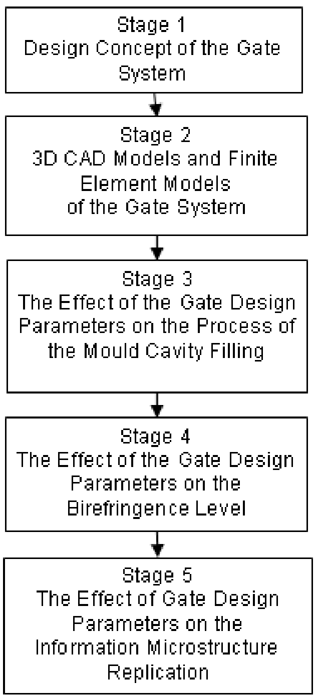

Fig. 1. The basic stages of the entire scheme of the Investigations.

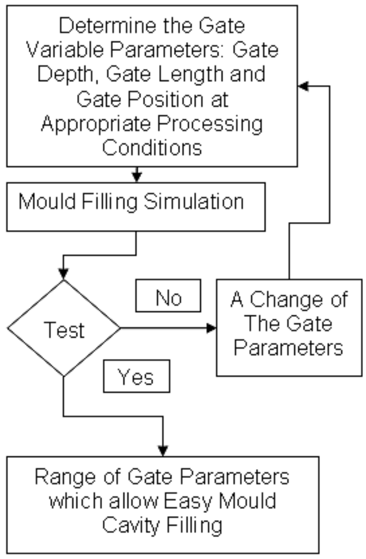

Fig.2. The stage 3 (see Fig. 1).

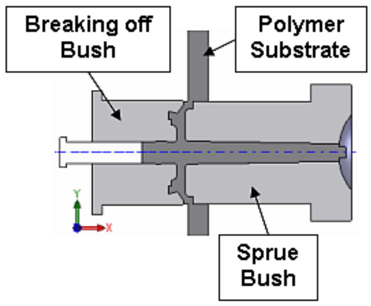

Fig. 3. The "Krauss Maffei" type of the gate system.

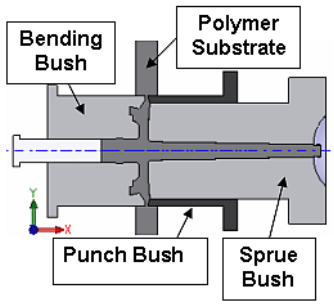

Fig. 4. The modified gate system.

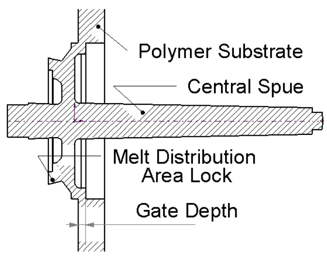

Fig. 5. 3D CAD model of the "Krauss Maffei" type of the gate system.

locate the gate in the edge, located in the opposite direction towards the sprue bush, which is detailed described of the authors of this concept [14].

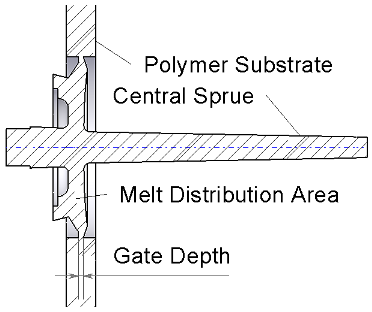

Fig. 6. 3D CAD model of the modified gate system.

In the process of our work, on the bases of a previous author's punch system design, a modified gate system design is realized. The central hole is formed by moving "a bending bush" and a punch bush in a direction, opposite to the sprue bush. As a result of the motion of the bending bush, the central gate is bent and at this moment the punch bush splits the gate from the polymer substrate. This allows the formation of the central hole of the polymer substrate in the case when a gate with a greater depth is used and gives a possibility to change the gate position towards the central hole (see Fig. 4).

The 3D CAD models are built on the bases of an integrated 3D CAD model of the gate system and the polymer substrate, considered as one object. The gate system consists of a central sprue, a melt distribution area and a circle gate (see Fig. 5 and Fig. 6).

3. Mould filling simulation and results

All the experiments are carried out in the case when the polymer substrate outer diameter is equal to 120.20 mm and the polymer substrate thickness is 1.30 mm. The gate depth and the position of the gate towards the central hole thickness are chosen as variable parameters (see Fig. 5 and Fig. 6).

A mould filling simulation program MoldflowXpress (integrated with SolidWorks) is used in the primary investigation to study the effect of the gate size and the gate position towards the central hole on the mould cavity filling process. The program can predict whether the injection moulding will be successful. The algorithm is based on the gate geometry, the plastic injection location, the type of plastic material and the processing conditions (melt and mould temperatures and injection time).

A polycarbonate plastic material Makrolon (PC) of the BAYER AG supplier is used. A PC Intel Pentium processor (2.7 GHz) with 1200 MB DDRAM is used.

A number of simulations of the two types of the gate system at values of the gate depth equal to 0.20 - 0.40 mm at intervals of 0.10 mm and at different positions of the gate towards the central hole thickness are provided. The parameters selected in three variants of the processing conditions (melt and mould temperatures) are combined: (a) Tmelt=280^0C; Tmould=80^0C (b) Tmelt=300^0C; Tmould=100^0C (c) Tmelt=320^0C; Tmould=120^0C). In many cases the results show that the mould cavity filling process is not sufficiently good at the parameters above given.

Experiment 1: "Krauss Maffei"-type of the gate system: A) Processing conditions: a) Tmelt=280^0C; Tmould=80^0C; b) Tmelt=300^0C; c) Tmelt=320^0C; Tmould=120^0C; B) Gate depth=0.20–0.40 mm at intervals of 0.10 mm.

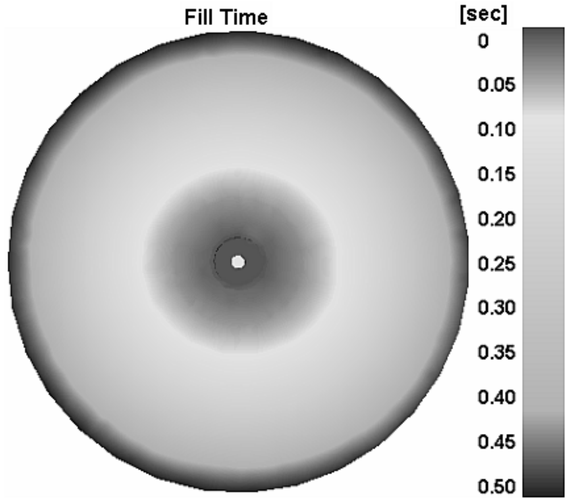

Fig. 7. Mould filling simulation with "Krauss Maffei" gate system type: gate depth=0.40 mm; Tmelt=320^0C; Tmould=120^0C.

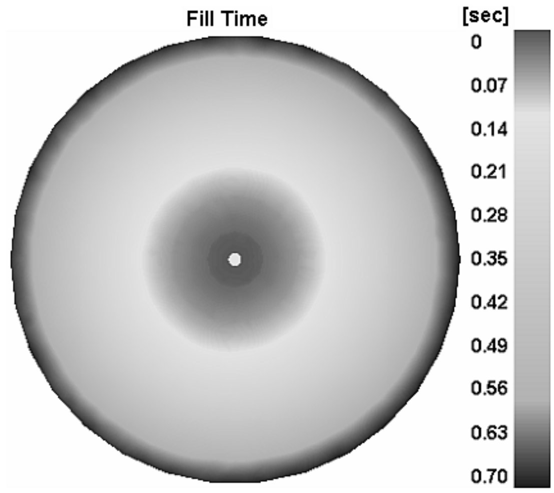

Fig. 8. Mould filling simulation with modified gate system: gate depth=0.30 mm; Tmelt=300^0C; Tmould=100^0C.

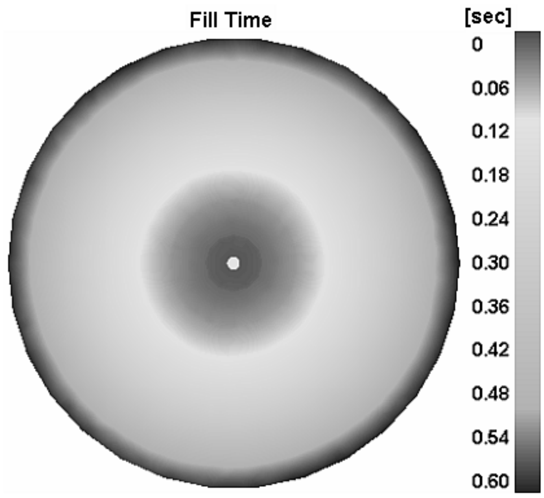

Fig. 9. Mould filling simulation with modified gate system: gate depth=0.30 mm; Tmelt=320^0C; Tmould=120^0C.

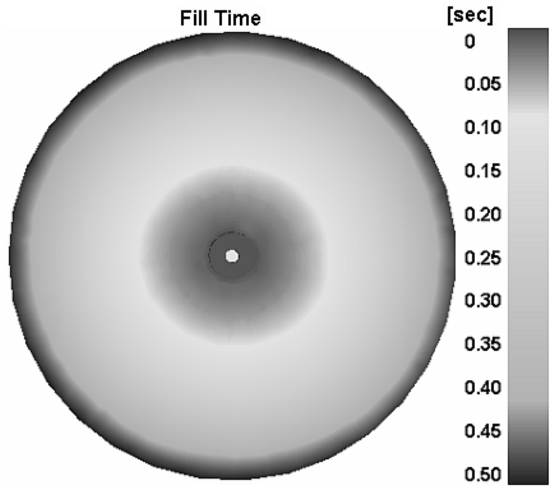

Fig. 10. Mould filling simulation: Modified gate system: gate depth=0.40 mm; Tmelt=320^0C, Tmould=120^0C.

The results of the experiment with the "Krauss Maffei" type of the gate system show that it is difficult to fill the mould cavity when the gate size is equal to d=0.20 – 0.28 mm and d=0.32 – 0.36 mm. Good results are obtained when d=0.29 – 0.31 mm and d=0.37 – 0.40 mm, but only in the case, when Tmelt=320^0C and Tmould=120^0C. Some good results of investigation are shown (see Fig. 7).

Experiment 2: Modified Gate System: A) Processing conditions: a) Tmelt=280^0C; Tmould=80^0C; b) Tmelt=300^0C, Tmould=100^0C; c) Tmelt=320^0C; Tmould=120^0C; B) Gate depth=0.20 – 0.40 mm at intervals of 0.10 mm.

The results of the experiment with the modified gate system show that it is possible to fill the mould cavity at all gate depths chosen, except in the case, when the gate depth is equal to 0.20 - 0.30 mm and Tmelt=280^0C and Tmould=80^0C. Some good results of the experiments with the modified gate system are shown (see Fig. 8, Fig. 9 and Fig. 10).

The best results with the modified gate system in respect to an easy mould cavity filling are obtained, when the gate depth is equal to 0.31 -0.40 mm at all of the processing parameters.

4. Conclusions

3D CAD models of an optical disc mould and the gate system are developed, in which the central hole of the optical disc is formed by breaking off the circle gate from the polymer substrate. The simulation program MoldflowXpress (integrated with SolidWorks) is used for initial investigation to study the effect of the gate size and the gate location towards the central hole thickness on the mould cavity filling process.

Two ranges of correct gate sizes are determined, in which an easy mould cavity filling is attained. The results of the experiments with this type of the gate system show that it is difficult to fill the mould cavity, except in the case, when greater values of the mould and melt temperatures are used.

A modified gate system is obtained in the working process. The modified system allows the change of the gate position towards the central hole and the use of a gate with a greater depth.

The results of the experiments with the modified gate system show that it is possible to fill the mould cavity at all variable parameters chosen, including also some cases, when the values of the gate depth and the melt and mould temperatures are minimal.

The correct gate dimensions for the two gate systems at appropriate processing parameters are obtained in the process of computer simulation. The best results are achieved, using the modified gate system at a greater depth of the central gate and when the gate is symmetrically located towards the central hole.

The approach presented and the 3D CAD models of the gate system can be used as a ground for future development of the mould filling simulation, oriented towards more precise determination of the resulting injection pressure, the residual stresses distribution and the temperature distribution.

Acknowledgements

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