Investigations in Injection Moulding of Micro Structures and Microstructured Surfaces

W. Michaeli, F. Klaiber

Institute of Plastics Processing, RWTH Aachen University, Aachen, Germany

Abstract

Telecommunication, information and medical industries have a high growth potential. A key technology for those industries is the replication of micro-structures. Precise micro-structured parts with functional surfaces can be produced economically by injection moulding. The whole process chain (thermal mould condition, moulding, demoulding, measurement and analysis) must be analysed carefully to ensure the highest precision and reliability. To enable the precise production of the above mentioned structures fundamental studies were conducted at the IKV. The studies considered on the one side several polymers (PMMA, PC, POM ) and on the other side various test structures. In addition an external inductive heating unit was analyzed and implemented into the process to heat the cavity surface efficiently. Using this technique new mould concepts could be developed with a dynamic inductive heating system to increase the moulding accuracy and reduce the formation of orientations in the moulded part drastically. The final step of the process chain comprises the measurement and analysis of the micro-structured moulded parts. To analyse the microscopic deviation between mould cavity and the surface of the moulded part, a special software-prototype was developed. This software calculates the so called “differential surfaces” to show the influence of shrinkage and warpage on the microstructures and the macroscopic part geometry.

Keywords: Injection Moulding, microstructures, dynamic heating

1. Introduction

The market for micro systems increased over the past years constantly. The growth rate is predicted with 10% per year [1]. This is a good example for the fact that micro-system technology has the potential to become one of the greatest technology trends of this century. The boom of the micro systems started with the microelectronics and is now moving towards functional surfaces with common applications. For example, the illumination of displays can be improved if micro-structured light guiding elements made from plastics are used. Furthermore, micro-fluidic structures and microtiter plates with structures in size of a few µm give the advantage to save time and money in medical analysis because different processes can be parallelised. The microplate has become a standard tool in analytical research and clinical diagnostic testing laboratories.

Micro-structured surfaces are a current research topic. Lots of tiny elevations and depressions in the micrometer range can result in an astonishing effect. In addition the illumination of displays can be improved with the help of micro-structured light guiding elements. Also a great product potential lies within the area of bionics. Three most well known effects in the field of micro-structuring surfaces are the Lotus effect, the riblets of a shark skin and the moth-eye effect.

The Lotus effect is an example for self-cleaning surfaces of any kind. The self-cleaning effect is realized through rough surfaces. The effect itself is based on a regular microstructure and a simultaneous hydrophobicity of the material itself [2]. A shark skin (riblets) structure reduces the drag by creation of vortices and with that the flow resistance in turbulent flow [3]. The moth-eye effect was already published in 1967 but only now with an advanced production technology it can be reproduced. The structure is smaller than the wave length of light and therefore it cannot be seen directly. A gradual transition from the refraction index of air and the substrate is caused by the structures, which lead to a reflection reduction [4].

To accurately replicate the above mentioned structures a variothermal process cycle is needed [5]. It can be realized with two conventional liquid temperature control units that alternately pump warmer or colder liquid through the mould. Another approach is to heat the mould surface with an internal or external inductive heating system. Tests with an external inductive heating system were conducted at the IKV. Using this heating technique the replication accuracy of microstructures was investigated. Finally software was developed at the IKV to analyse the 3-dimensional measurement data of the moulded parts. This software is an efficient tool to quantitatively grade the replicated surfaces.

2. Injection Moulding of Micro-structured Surfaces

The most important processing parameters for micro-structured parts are mould temperature and holding pressure. A high mould surface temperature is a prerequisite in order to achieve good moulding quality of the micro structures, but this leads to an extended cycle time. In order to achieve good surface quality of the micro-structured parts mould temperatures close to the melting temperatures are needed.

In conventional injection moulding the mould temperature is limited to a maximum value where the parts can just be demoulded without deformations. Also the mould temperature is directly related to the cycle time, meaning that it takes longer to cool the part down to the ejection temperature. The variothermal process cycle is a trade-off between these limitations. A variothermal process can be realized through internal (oil, water) and external heating systems, such as radiation or induction. Because of the mass of a mould and its resulting inertia is it advantageous to choose a heating system which heats only the necessary area, the mould cavity and mould surface. Figure 1 shows a process cycle using an external dynamic heating system. The inductor is attached to a Wittmann W 721 robot. This
A robot ensures exact reproducible positioning of the inductor 5 mm in front of the cavity. An inductive heating unit generates the heat directly in the surface of the metal cavity. A current carrying conductor, which is located in the inductor in front of the cavity, produces an alternating high frequency magnetic field. This alternating magnetic field induces currents that cause the cavity to heat up depending on the electrical resistance of the metal [6, 7].

Due to the fact that the heat is only generated around the cavity surface only a minimum amount of heat is generated in the mould in comparison to internal heating, e.g. by oil. Inductive heating therefore also has shorter cooling times (Fig. 2).

To study the behaviour and the effects of the inductive heating system on the replication of micro structures, a test series was done where the processing parameters were changed systematically. The robot-inductor system was designed in a way that the power of the inductor unit could be set by the robot control unit between 0 KW and the maximum of 10 KW. This enables the user to program the inductor position and the inductor power with the robot control unit.

Three series of experiments with different materials were examined: PMMA (Plexiglas 7N, Röhm, Darmstadt, Germany), PC (Makrolon 2805, Bayer AG, Leverkusen, Germany) and POM (52021 Hostaform, Ticona AG, Frankfurt, Germany). Scanning electron microscopy was used to evaluate the moulding quality of the micro structures. The results of the trials where PMMA was used are presented exemplarily. Fig. 3 shows the influence of the additional heating time on the moulding quality of micro structured surfaces. Shown in Fig 3. are four sided pyramids with a base side length of 15 µm. As injection moulding settings a melt temperature of 240°C a cavity temperature of 70°C, an inductor power of 10 KW and a holding pressure of 800 bar were chosen. The quality of the micro structures without additional heating is unsatisfactory. It is clearly visible that the dynamic heating system leads to an improvement with respect to reproduction accuracy. A stepwise extension of the heating time led to better performance. At 20 seconds heating time no further improvement in moulding quality was achieved in this case. When the

---

**Internal Heating System:**
- the whole mass of the mould must be heated ➔ long cycle times
- no additional movements needed

**External Heating System:**
- local heating of the cavity surface
- additional movements necessary
- very fast heating

---

![Figure 1: Concept of inductive heating from the parting plane of the mould](image1)

![Figure 2: Simulated temperature of the cavity surface](image2)
A cavity is heated for 15s; a temperature of 250°C is achieved in the center of the cavity. Including the additional heating system leads to higher cycle times because of the increased cooling time. Depending on the heating time the whole cycle time can be up to 55 seconds longer than without an additional heating system. The results in Fig. 3 show that the use of inductive heating leads to a significant improvement of the moulding accuracy. One can conclude that the cavity surface temperature has an immense impact on the replication accuracy. An innovative variothermal process can be realised by the usage of an inductive heating system.

In addition, one has to differentiate between various kinds of micro structures. Figure 3 shows microstructures with small aspect ratios. An interesting attempt would be the use of a variothermal inductive heating system in combination with high-aspect micro structures, e.g. LiGA structures. At the IKV a LiGA generated cavity with thousands of honey comb structures with a width across flats of 40 µm and an aspect ratio of 2,5 was replicated by injection moulding [8, 9]. Results without dynamic heating and a mould temperature of 120 °C were not satisfactory. The polymer melt (POM) is freezing instantly so that the honey comb structures are not filled completely. Good results were achieved with the dynamic heating system, where the cavity is heated to the melting temperature of the polymer which is approximately 210 °C for POM. This is a quite good example for the need of a variothermal moulding process control.

3. Measurement of the Moulding Accuracy

The resulting moulding accuracy of micro-structured parts during the injection moulding process is influenced by the macroscopic part geometry and especially by the microscopic structure geometry. This includes the dimension and geometry of the microstructures as well as the aspect ratio, which is defined as the ratio between structure depth and lateral structure dimension.

Microscopic measurement methods can be used to get a picture of the quality of demoulded parts. A more precise determination of the microscopic structures and a comparison between moulded part and mould cavity can only be realised with an adequate measuring program and a compatible evaluation program. In order to be able to compare 3-dimensional surfaces a special software tool – AIX-Comp – was developed at IKV [10].

With the above mentioned software one can characterise the moulding quality by calculating differential surfaces from the 3-dimensional measurement data (Fig.4). Part A of Fig.4 shows the 3-dimensional surface of the concave mould insert. Part B of Fig.4 shows the 3-dimensional surface of the replicated convex part. The differential surfaces are computed by geometric subtraction of the measured cavity surface data from the moulded part surface data (one data set has to be inverted). The resulting geometric structure (Part C of Fig.4) represents the deviation of the part from the cavity. This deviation of the surfaces is in the micrometer range (different scales are used). This information can be used to give an iterative feedback to preliminary process steps e.g. mould design and construction. With that the material and geometry specific shrinkage and warpage can be corrected by reworking the cavity. The principle of this method is to carefully examine each step in the process chain and find out how it can be optimised for the
injection moulding of micro-structured parts. It is important to identify the most influencing factors on the moulding accuracy and to show interactive effects on the part quality.

4. Outlook

This research work shows that the process parameters have a significant influence on the processing results. The use of an inductive heating system for the moulding of micro structures and LiGA-generated cavities shows very promising results. With this device a heat generation of 15 K/seconds and temperatures of up to 350 °C can be realised to accurately replicate micro structures with a few micrometers only. The comparison of the 3-dimensional surfaces of cavity and moulded part is a helpful method to correct the cavities to counteract shrinkage and warpage.

Acknowledgement

The investigations set out in this report received financial support from the Federal Ministry of Economics and Labour (BMWA) by the AiF (No.: 12703 N and 11697 N) and the German Research Foundation (DFG) as part of SFB/TR 4 “Process Chains for the Replication of Complex Optical Elements”, to whom we extend our thanks.

References

10. Gärtner, R., Analysis of the process chain for the production of micro-structured parts by injection moulding. Dissertation, RWTH Aachen University, 2005