Defect-Free Microstructures

Forming of Textured Surfaces – an Application for Servoelectric Injection Moulding Machines

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The use of surfaces as functional elements, and not only the increasing degree of miniaturisation, is contributing to the growing importance of micromoulding. To produce trouble-free micro moulded parts, a precisely working injection moulding machine and a special process management are important factors.

In this regard, a distinction must be made between a micro moulded part weighing only a few milligrams and a moulded part with micro textured surface regions (microstructures). The latter is usually a moulded part of a size that is commonly encountered which exhibits textures or patterns having dimensions in the µm range [1]. The Microsystem 50 from Battenfeld has already been employed successfully in numerous applications to produce micro moulded parts.

The best-known examples of parts with micro textured surfaces are CDs and DVDs where textures with lateral dimensions of 0.4 µm and depths of 0.1 µm carry digital information. Many applications from the medical and diagnostic sectors are either already known or being planned. Development of the "lab on a

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chip" promises fast and efficient analysis. This mini-laboratory integrates all the steps of an analysis on a chip: sample extraction, mixing of liquids, the reaction and analysis. The production of ferrules (connectors for fibre optic cable) can be mentioned here as an example of the numerous applications in the communications sector.

Mould making Methods for Microstructures

Special mould making methods are necessary because of cavity texture dimensions in the micrometer range. Micro machining of brass or aluminium alloys with diamond tools is possible on suitable machine tools. Photo-imaging (called the LiGA technique in German from the words **Li**thographie, **G**alvanoformung, **A**bformung) is an expensive method that yields a high-quality surface. In this method, a resist (a film of PMMA) is applied to a metal substrate. This film is then exposed to x-ray radiation through a mask, with the result that the molecular chains in the irradiated regions become shortened. These are then subsequently removed with the aid of a solvent. The remaining pattern then undergoes electroplating so that a metal film replaces the previously removed polymer. The mould insert is obtained by dissolving away the remaining polymer. By utilising the photo-imaging method, patterns can be generated with minimal dimensions of less than 2 µm and a surface roughness of $R_a \leq 10$ nm. Other methods for generating micro textured cavities include etching or reactive ion etching in silicon, laser-assisted patterning as well as micro-EDM. Additional methods are listed in [2].

Variotherm Process Technique

While the aspect ratio (the ratio of maximum height to minimum lateral dimensions) is less than 1 in optical data carriers (CDs/DVDs), other applications required aspect ratios of 10 and higher. In order to produce high aspect ratios with sharp corners, a variotherm (hot/cold) process sequence is required (Fig. 1) During injection, the objective is to have in the textured regions of the mould a temperature at which the melt viscosity is low enough to accurately replicate the pattern. Fig. 2 shows sections of a micro textured surface that was filled incompletely as the result of too low a temperature during injection. It can be seen in the microscopic photograph that the pattern is not sharp-edged, but is rounded instead. As a result, the surface has lost its functionality.

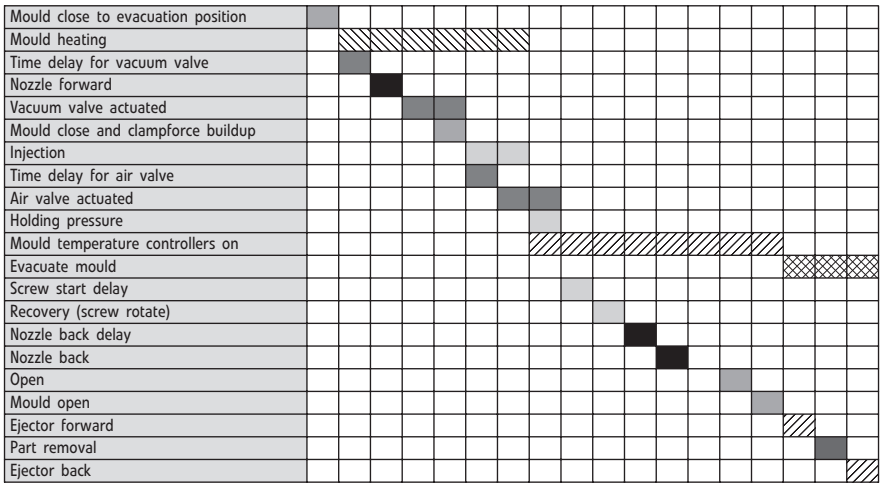

Fig. 6. Process sequence for replicating micro textured surfaces. The mould opens as soon as the set demoulding temperature is reached

Because of the generally longer cycle times with a variotherm process sequence, the residence time of the resin in the barrel is lengthened. This can lead to degradation of thermally sensitive materials, with a resultant decrease in physical properties and change in shrinkage of the degraded resin. Damage to the microstructure during ejection is a consequence of this material change (Fig. 3).

After injection, the mould is cooled to a temperature that permits defect-free ejection of the moulded part. To achieve this, a combination of electric heating with oil- or water-based mould temperature control is often encountered in addition to a purely oil-based variotherm process. Defect-free replication of microstructures (Fig. 4) is possible only if, prior to injection, the mould is first heated to the requisite temperature for the particular resin employed and the moulded part is then subsequently cooled to a suitable demoulding temperature.

Machine Technology

It is known that, compared to an hydraulic machine, a fully electric injection moulding machine (Fig. 5) provides noticeably better precision and reproducibility during injection in addition to higher acceleration and deceleration. To injection mould parts with micro textured surfaces, a reproducible process is essential.

Every impurity in the vicinity of the surface structure results unavoidably in rejects, so that production must take place under clean room conditions. Their proven suitability for clean room conditions is also an advantage for electric machines. Moreover, the electromechanical drive concept provides the potential for a definite energy savings versus the hydraulic machine, especially with long cycle times.

Tailor-made Solution

To control the replication of micro textured surfaces, the engineers at Battenfeld have integrated into the injection moulding machine a specific module called Vario-Mold. This module contains the controls for heating the mould with up to 26 heating circuits as well as the subsequent cooling to the demoulding temperature with the aid of temperature control units. If the cooling channels in the mould are evacuated prior to heating, it is possible to use water instead of oil as the temperature control fluid. The higher thermal conductivity of water results in more efficient cooling, with a resultant shorter cooling time. In addition, evacuating the cooling channels in the mould prior to heating has the advantage that the cooling fluid need not be heated along with the mould. The Vario-Mold module also provides for evacuation of the mould and injection of air during the cycle. The process sequence is shown in Fig. 6.

Additional special program sequences are possible with the aid of a user-programmable control. To prevent thermal degradation of the resin in the barrel as the result of long residence times, purging after an adjustable period of time is possible without interrupting the actual cycle. As an alternative, a special screw geometry that reduces residence time is available.

If the microstructure is located on the stationary side, defect-free demoulding of the parts requires that the mould be opened very slowly. In the servoelectric

injection moulding machine from Battenfeld, mould opening and closing are accomplished by a toggle that is driven by a planetory roller screw. To assure exact movement of the moving platen, the motion of the crosshead (to which the planetary roller screw spindle is attached) is employed as the control variable for the first few tenths of a millimetre of the opening stroke. This prevents a sudden opening of the mould even in the µm range. Sensitive mould protection during closing prevents damage to the micro texture/micro structure of the cavity surface in the event that a part sticks in the mould.

By placing a laminar flow box on top of the machine, production can take place under clean room conditions. The part removal device can be combined with a quality control system. To monitor quality, process-specific parameters are available in the form of a quality table as are external systems that are integrated into the machine controls, e.g. optical systems for image processing and weighing of parts with high-precision scales.

Conclusion

Exact replication of micro textured surfaces requires very high precision from an injection moulding machine. A special program in the machine control is necessary for the specific process sequence. The Vario-Mold module satisfies these requirements reliably.

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Fig. 1. Comparison between stationary and variothermprocess ($T_{M:}$ Melt temperature of the resin; $T_{E:}$ Demoulding temperature); Werkzeugtemperatur = Mould temperature; Stationär = Stationary; Variotherm = Variotherm

Fig. 2. Example of an incompletely formed structure

Fig. 3. Example of a microstructure damaged during demoulding as the result of exceeding the maximum residence time when using a non-optimised injection unit

Fig. 4. Example of a sharp-edged micro structure produced via the "Vario-Mold" process

Fig. 5. Fully electric injection moulding machine with the "Vario-Mold" module