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Subproject B4

Title
Analysis of the thermal coupling of melt, microstructure and mould for precise prediction of shrinkage and warpage in the injection moulding process

Project management/-processing
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Task definition
Current models for describing shrinkage and warpage in thermoplastic injection moulding do not take sufficient account of thermal interactions between melt, microstructure and mould. An exact description of the underlying processes requires a deeper understanding and therefore a precise measurement of the melt temperature during the running process. For the injection moulding process, a tool concept is to be developed that allows the temperature distribution in the plastic melt to be measured. Further thermal material data are additionally measured in laboratory tests under injection moulding relevant boundary conditions depending on the microstructure. For this purpose, among other things, the further development of an apparatus for pressure-dependent measurement of the heat transfer coefficient is being carried out. In the second phase of the Collaborative Research Centre, this sub-project focuses on the description of suitable process-related material models, which can be validated with the developed measuring methods of the first phase as well as supplemented with precise process-dependent material parameters. In a first step, this requires the extension of the measurement methods used to determine spatially resolved temperatures and the heat transfer coefficient. Special focus is placed on the consideration of the high cooling rates occurring in the injection moulding process, which massively influence the solidification process and thus the microstructure. Physically motivated correlations are derived from the knowledge gained and implemented in the microstructure calculation developed at the IKV. For a more precise description of the heat transfer from the plastic into the mould, the heat of crystallisation released during solidification is also taken into account.
A precise prediction of the microstructure enables the calculation of local, inhomogeneous thermal and thermoelastic material properties in the multi-scale approach developed in subproject B7. In the second

phase, methods are to be derived to transfer these properties to entire components in order to enable a precise prediction and a deep understanding of the distortion.

Procedure

To measure the temperature distribution, an ultrasonic tomography concept was proposed and implemented in an injection mold. It could be shown that with the help of the proposed setup the temperature can be calculated at 200 points in the radially symmetrical measuring range using algebraic reconstruction techniques (approx. 3.5mm²). The work in the past year focused mainly on the evaluation of the ultrasonic signals, which is difficult due to the high signal-to-noise ratio. In addition to signal filtering by band-pass filters, experiments were also carried out on an electric injection moulding machine to minimise the noise effects. Furthermore, echo measurements showed that sufficient signal intensity can be transferred from the transducer to the melt.
To determine the pressure-dependent heat transfer coefficient, a plate-shaped mold insert was developed with which the temperature gradient in the melt can be determined over a part thickness of 2 mm with the aid of six thermocouples inside the melt and three thermocouples in the mold wall. In addition, three further thermocouples in the mold allow the determination of the thermal gradient into the mold. In this way the calculation of the heat transfer coefficient is possible. In particular, design measures have been taken to ensure that the thermocouples, which are only 0.1 mm thick, can be inserted suitably into the cavity without being destroyed by the process conditions and without affecting the measurement result. The mold insert and the associated peripherals are currently being put into operation.
To describe the pvT behavior at high cooling rates, flash DSC measurements are performed, which enable thermal material analysis at high cooling rates (4000 K/s). The Flash-DSC is currently in procurement. With the help of the data, the currently common Tait approach for the calculation of the pvT behavior is to be extended in the future and described in dependence of the concrete solid-liquid portion, since this relationship describes the phase transition more precisely than the temperature range in which the phase transformation takes place.

Results

The ultrasonic tomographic measurements on an electrically operated injection moulding machine show a significantly lower noise level compared to measurements on a hydraulically operated injection moulding machine. Nevertheless, the signal cannot be detected properly. The measuring system detects sound frequencies that cannot be detected by the ultrasonic transducer itself. This effect could be confirmed by sound measurements in water and thus indicates a disturbance within the measuring system (e.g. insulation). For this reason band-pass filters are used to filter the signal in the expected frequency range of approx. 2 MHz. Here, all measurements show a clearly readable signal, which develops as expected during the injection moulding process (injection process, holding pressure phase, etc.). However, the point in time at which the signal develops is significantly behind the expected transit time and is probably due to the superimposition of different ultrasonic waves in the measuring range (e.g. due to scattering). In the expected transit time range, potential signals differ only slightly from noise, which has already been averaged over several measurements for reduction. However, it could be shown that the ultrasound is coupled into the melt in a suitable manner. For this purpose, reflection measurements were carried out on a transducer with an empty cavity and a cavity filled with melt. The different mould/air and mould/melt transitions cause the ultrasonic reflection behavior to be differently pronounced, which means that a significant signal drop is to be expected in the reflection measurement in the presence of the melt. This effect could be confirmed.

Summary and Conclusion

Precise modelling of the heat compensation processes is crucial for the precise prediction of shrinkage and warpage. For this purpose, process-related input data, such as the temperature distribution of the melt and the heat transfer coefficient, are absolutely necessary. In principle, the ultrasonic tomography developed in subproject B4 allows the temperature distribution of the melt to be determined. It could be shown that a sufficient number of signals can be recorded to calculate the temperature distribution at different points in time during solidification. Signal evaluation is currently problematic due to the high signal-to-noise ratio despite intensive filtering and prevents an exact reconstruction of the temperature profile. Experiments to measure the heat transfer coefficient and material analysis are currently still pending. The common Tait model to describe the pvT behaviour of plastics is currently being conceptually extended and shall be validated by Flash-DSC measurements.

Publication

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