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Flow visualization and simulation of the filling process during injection molding

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ABSTRACT

To directly compare experimental moldings from an injection molding machine with simulations, a special mold has been produced with a glass window. The injection plane is perpendicular to the opening and closing planes, in order for the 55 mm thick glass window to be easily visible from the side. A high speed camera recording 500 frames per second was employed, and the mold had three thermocouples and two pressure sensors installed. The molded part is a 2 mm thick plate with a 0.5 mm thin section, which creates a characteristic V-shaped flow pattern. Two different materials were employed, namely ABS and a high viscosity PC. Simulations were performed using the actual machine data as input, including the injection screw acceleration. Furthermore, the nozzle and barrel geometries were included as a hot runner to capture the effect of compressibility of the material in front of the screw. These two had significant effects on the filling times and injection pressure calculated by the simulations. Other effects investigated included transient thermal management of the mold, pressure dependent viscosity and wall slip, but their effect were not remarkably large in this work. The obtained simulation results showed deviations within 10–30 ms (relative deviation in the order of 5–10%) for the ABS and slightly more for the high viscosity PC in the range of 100–500 ms (relative deviation in the order of 20–30%) on timings between different sections during filling.

Introduction

Direct flow visualization with the use of a high speed camera is a known methodology to analyze the flow behavior in injection molding and other processes. In several studies experiments have been conducted with different kinds of camera setups in the molding tools. Yang et al. [1] have employed flow visualization using a quartz glass window in a micro injection molding tool to investigate the flow of micro parts with high injection speed, using high speed camera able to capture videos with 1000 frames per second. The mold contained a reflection mirror to allow space for the placement of camera and thermocouples. The main purpose of the investigation was the micro injection molding process characterization. Other studies which also use a reflective mirror type mold construction are: Nian and Yang [2] use previously mentioned mold however this time combining transparent and colored material to get further information of the flow. Han and Yokoi [3] use a high speed camera capable of recording at 13,500 frames per second and a microscope, to investigate the filling of micro grooves on a glass prism insert. Hasegawa and Yokoi [4] use a glass insert with branching runners in order to investigate the influences of inertia forces on melt filling behavior at high injection speed. Layser and Coulter [5] investigate hesitation and emphasizes the use of the packing phase due to the use of a window made of fused quartz glass, which was able to withstand a packing pressure of up to 50 MPa. Spares et al. [6] have modified a thermal imaging camera to increase the frames per seconds, to investigate the thermal field during injection of micro molding. Whiteside et al. [7] have also investigated micro molding with a high speed camera and sapphire glass insert in order to study different effects in micro injection molding. Yokoi and Yoshida [8] use a high speed camera with a mold with a build in microscope in order to investigate micro cavities and the effect of injection speed. All the mentioned work so far, uses a reflective mirror and no simulation comparison.

Other researches in the field of flow visualization in injection molding have been performed using a different mold design that, instead of using a reflective mirror, included a transparent insert directly applied to the mold cavity which is oriented parallel to the injection direction, so the flow can be directly filmed from the side of the injection molding machine. Yanev et al. [9,10] applied a

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sapphire insert to this type of mold design. The researchers have also performed a simulation comparison to verify the filling performance of the software. It was stated that the simulation is capable of giving good overall agreement with the obtained flow patterns, but significant difference was found during the beginning of the filling phase. Furthermore, Dvorak et al. [11] also used a direct observation of the flow with a high speed camera without making use of a reflective mirror, for the characterization of ceramic injection molding.

The main focus of this work will be on making an experimental setup similar to [9,10] i.e. using a turned insert for direct visualization of the flow in the cavity, which is oriented parallel to the injection screw of the molding machine. However in the present work a more comprehensive study of the influencing parameters on the simulation results is carried out. Using pressure sensors and thermocouples in combination with a high speed camera, the goals are to capture and characterize the filling of the mold cavity, as well as to analyze and compare the flow pattern with simulation on a time basis. Deviations between experiments and simulation predictions will be studied. Different features in the software will be utilized to minimize the observed deviations in order to obtain the correct timings of the filling pattern. The use of a high speed camera with a glass mold will provide a direct comparison of the filling, with an increased accuracy with respect to more conventional validation techniques such as the short shots method.

Experimental

Glass mold

In order to compare simulations directly with the filling of the cavity, a special glass mold was manufactured. The injection plane is almost perpendicular to the opening and closing plane, in order for the glass window to be easily visible from the side. The reason for not being turned 90°, but instead 82 °C, was due to the opening and closing of the mold, to prevent a too close and tight fit and possible breakage of the glass, either in opening and closing of the mold or during the packing phase by applying the holding force. This mold design makes it particularly effortless to install any kind of recording device to the mold. The glass window is made of a 55 mm thick Borosilicate glass (width and height 60 mm × 140 mm), and it is capable of withstanding at least 130 MPa in machine pressure during injection, and 50 MPa during packing. It was tested to go up to 220 MPa which did not break the glass, even though this pressure level was not used during the experiments. Due to the (almost) perpendicular injection plane, and a fairly large air vent thickness (0.02 mm), moldings could result in some flash during some of the experiments. The experimental setting including the two mold halves, the glass window and the placement of the high speed camera, as well as a schematic overview of the mold can be seen in Fig. 1.

Equipment and materials

The employed high speed camera is an X-PRI produced by AOS Technologies AG (Fislisbach, Switzerland) and it is capable of recording 1280 × 1024 pixels images at 500 frames per second. The camera was easily installed inside the safety door of the injection molding machine, and attached to the track of the sliding door. Some additional lighting was also installed to improve the brightness of the recorded videos.

The mold is equipped with a total of five sensors. Three of the sensors are thermocouples, which are used to time when the melt is at the specific location. Furthermore, two pressure sensors are installed, one in the runner and one in the cavity just after the gate location. The two pressure sensors are used to determine when the polymer melt passes them, and to directly compare with the simulated pressure, in conjunction with the high speed recording system. Fig. 2 shows the location of the different sensors. In addition to the installed sensors, the machine data is also collected to be used as input for the simulation setup, in order to simulate the actual conditions in which the experiments are conducted.

The injection machine used is an Engel Victory 60 with a 35 mm diameter screw. Two different polymer materials were employed for the experiments, the first being a natural colored acrylonitrile butadiene styrene (ABS) grade with a melt flow index (MFI) of 7 g/10 min and the second a gray colored high viscosity polycarbonate (PC MVR 6) grade with a MFI of 34.3 g/10 min. Viscosity and pvT of both polymers were characterized in order to have accurate input for the simulations also in terms of material properties.

Test part

The geometry used in the experiments can be seen in Fig. 2. It consists of an 18 mm wide and 45 mm long rectangle with a thickness of 2 mm. It has a thin section in the middle of 0.5 mm, which produces a flow which will slow down over the middle section, as the frozen layer starts to develop. This creates a characteristic V-shaped frozen front over the thin section, as the sides flow faster due to being thicker, hence not solidifying through the thickness and allowing melt to pass.

Setup

The injection flow rate was specified in order for the filling (i.e. injection) time to be close to 1 s. This target was achieved by adjusting the injection ram speed, which was close to constant at

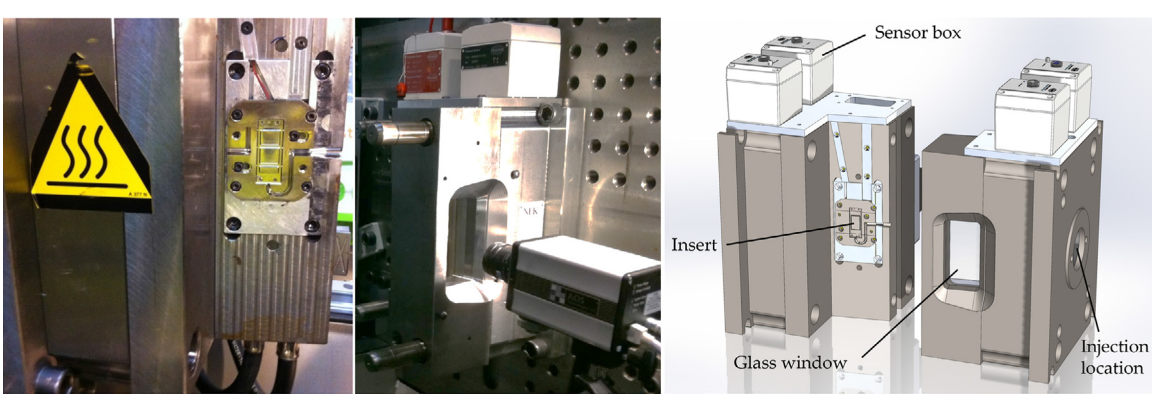

Fig. 1. Two mold halves of the glass mold and schematic overview.

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