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Faster temperature control systems for hot embossing and injection molding

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Abstract

Research work aims to develop a fast, production suitable hot embossing technology including appropriate tool systems for low-cost and production-integrated manufacturing of high-precision microfluidic structures in polymer films. The implementation is demonstrated by structuring of microfluidic films for disposable diagnostic devices used in home-care and point-of-care applications. The approach focuses on the development and thermal design of a tool system for fast hot embossing on basis of a fast non isothermal process. Close contour tempering of the active parts is the core of this approach. Based on an industrial specification the paper will describe tempering strategy, design and simulation of the tool concept. Heat flux and heat capacities together with the power loss in the system are used for calculating the tempering cycle. Based on that, the setup of an optimized tool system consisting of heating elements and a refrigerant system is presented. The new tool concept is thermally characterized by thermocouple and infrared measurements. Furthermore the system was tested in a commercial hot embossing equipment to demonstrate the improvements. It could be shown that a cycle time between one and two minutes is possible, in comparison to cycle times of fifteen minutes in conventional hot embossing systems. Although the test system was not optimized so far, in the embossing tests all items were replicated correctly and the microfluidic function was ensured. The results of the research work are applicable also for the optimization of injection molding tool systems.

Keywords: hot embossing, micro fluidics, tempering concept, tool systems, replication, injection moulding

1. Motivation

The technology of hot embossing enables microstructuring and surface functionalization of plastics, glass and metals in a relatively simple technological manner. Thus, in terms of technologically and economically, it is an interesting alternative to established structuring processes [1]. However, the use of hot embossing in mass production has so far been limited by low productivity at very high energy expenditure.

In particular, the tempering concept of tool systems for hot embossing of plastics considerably defines the cycle time, i.e. production cost, which significantly limits the use of this process. For a range of novel product developments there is no alternative manufacturing technology to hot embossing. Yet, the unit cost of embossed components is too high, which inhibits the application of this process for low-cost mass production [2].

2. Methodology

A specific tool system has to be realized for hot embossing of polymer films. This tool system shall provide tempering of two identical components for the upper and the lower die at operating temperatures of up to 250 °C, using minimized heat capacity due to heating and cooling elements close to the active component or to the structure, reaching cycle times of the temperature change of 50 K within one minute.

2.1. Tempering strategy

The development and evaluation of potentially suitable tempering concepts was conducted together with industrial partners DEW GmbH and WESKO GmbH. A variant with heating and cooling integrated into one plate has the advantage of better heat distribution, although the manufacturing cost is very high. In case of a change to a different application sensor, very high cost would occur, as the complete system has to be exchanged in serial production. Using separate plates for heating and cooling makes manufacturing more cost-efficient and more variable. In serial production only one plate would have to be exchanged.

When evaluating the various heating variants, a tubular heating system was selected. This was the only variant which could economically realize the conditions of the embossing process, requiring shortening of the heating and cooling times by as low a heat capacity as possible, and at the same time, with sufficient strength of the system. Furthermore this solution offers an advantage regarding the combination with a cooling system since its own heat capacity is low.

Four possible cooling variants were evaluated: water cooling, oil cooling, cryogenic cooling and cooling using a coolant in a closed cycle. The latter option was selected since it ensures high cooling capacity and fulfils the objective in the best manner.

The definition of the technological parameters and the establishment of a universal process cycle formed the basis for the conceptional design of the complete system. Main focus lay on the development and realization of the tool system and its integration into the complete system.

2.2. Thermal simulation

In order to assist thermal dimensioning of the tool system, the heat transfer processes were investigated and calculated by approximation. The resulting mathematical description of the heat transfer processes enables the simulation of the expected behavior of the system, i.e. it supports decision-making for calculating the capacities of the heating and cooling elements. Software for spreadsheet calculation was used to generate heating and cooling curves using an iterative numerical approach.

The diagram in figure 1 shows an example of a heating curve and a cooling curve for the dimensioned tool system. Under ideal conditions, a cycle time of below one minute should be possible.

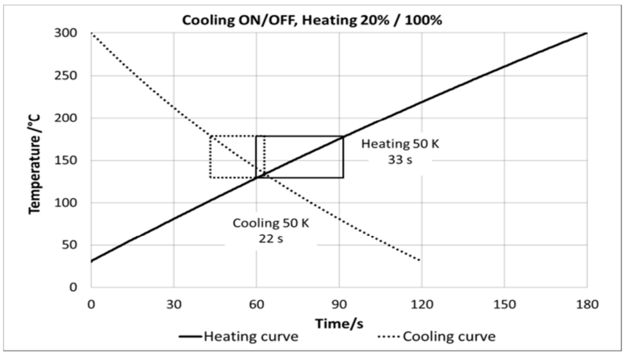

Figure 1. Tempering curves of thermal simulation.

3. Tool system design and validation methodology

The heating capacity of 2 kW was divided into 8 individual elements with 250 W per element. At a heated length of 160 mm, the resulting surface load is 7.65 W/cm². During operations the temperature rises to a maximum of 350°C in case of good heat dissipation. Different heating zones (edge/center) can be set up and controlled. Thus, various heat losses can be compensated and a more regular heat distribution can be achieved over the entire area.

The cooling plate was designed in such a way that several separate circuits exist for the vaporization of the coolant. The coolant is guided into the plate by supply bores of Ø 2 mm. The liquid coolant reaches the vaporization bore of Ø 3 mm via a connecting bore of Ø 0.5 mm. The coolant expands in the vaporization bore and absorbs the heat of the plate. The exhaust bore of Ø 4 mm diverts the expanded coolant into another plate where it is sucked off into the cooling device. The open ends of the bores are closed by plugs and soldered gas-tight (see figure 2).

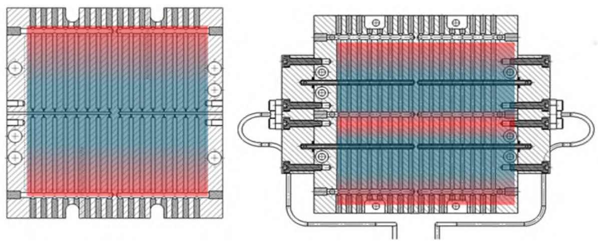

Figure 2 Two different designs for contour- and cooling plate

Thermal characterization of the complete tool system took place outside of the testing plant. An infrared camera (Cedip Infrared Systems) was positioned above the tool system and extensive tests were recorded dealing with heating and cooling processes as well as complete temperature cycles. The testing plan was set up in 7 series of measurements which were based on one another, allowing for complete thermal characterization of the system. Within the series of measurements numerous individual tests were carried out whose complete report would exceed the framework of this contribution.

4. Results

The first version of the tool system heated up fast and homogeneously. When the cooling is turned on, the area of coolant entry is mainly cooled as well as the center of the embossing zone. However, the peripheral areas of the embossing zone are not significantly cooled. It was demonstrated that a cycle time of below one minute is possible. The temperature distribution in the embossing zone has to be improved.

Based on these results, an optimized cooling system was designed and tested (figure 2, right). Due to adapting the structure of the cooling system, more homogeneous temperature distribution of ± 5 K could be reached in an adjusted zone of (100 x 55) mm². Thus a cycle time of 160 seconds was reached, which meets the requirements (figure 3). Further potential for optimization opens up by adapting the capacity into individual heating zones, by re-designing the coolant entries into the area of the heating elements and by optimized, coordinated control of heating and cooling.

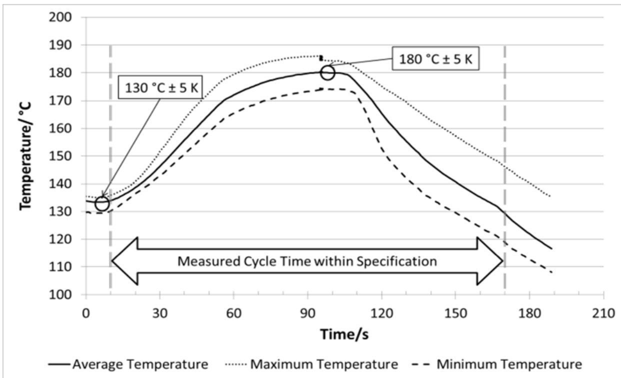

Figure 3 Temperature curves for embossing area of (100 x 55) mm²

An application-oriented test was performed by modifying an existing hot embossing system HEX03. The developed tool system was installed on one side. The results of the optimized test set up allowed for the conclusion that a heating-cooling cycle from 130 °C to 180 °C and back is possible within two minutes total. In order to demonstrate a microfluidic function of the embossed films, the components were laminated onto sensor substrates and then processed. Using a colored model fluid, filling tests were conducted with the microfluidic sensors. It was shown that the investigated sensors were filled correctly and that they did not differ from sensors manufactured by the standard embossing process.

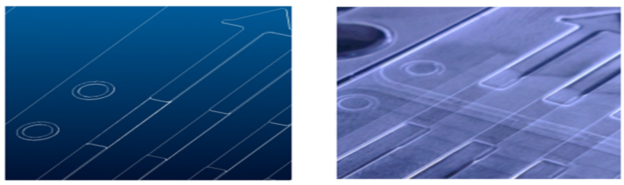

Figure 4 Design (left) and hot embossed film (right) of test structures.

5. Summary

As a conclusion the project proved that a hot embossing process is possible and practical for structuring thermoplastic polymer films in a cycle time of one to two minutes, when using an appropriate manufacturing system. Variants of retrofitting existing hot embossing systems are also possible.

In industrial implementations the structured mold should be pressed with the heating cartridges and the cooling plate should be arranged underneath. Thus, the system can be designed even cheaper and thus more economical.

References

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