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Abstract of the thesis

Design of a rapid heating/cooling system: control the properties of micro-injection molded parts

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Abstract

Microinjection molding (μIM) is one of the most efficient processes for wide scale production of thermoplastic polymer microparts. In order to produce high-quality microinjection-molded components, a crucial aspect to be fully understood and optimized is the filling of the cavity by the polymer. The standard injection molding process with constant mold temperature control suffers from problems caused by the large temperature difference between the mold and the incoming polymer. The mold temperature appears to be a key parameter for the fabrication of microparts of a more large range of materials. Even though variotherm technology has existed for decades and includes many kinds of heating methods, it is still not a proven one for use with μIM. Therefore, in the literature, the polymer melt flow phenomenon in a cavity for μIM with rapid variations of temperature is still not well discussed.

In this thesis, a special surface-conditioning concept that fulfils rapid temperature evolutions during the μIM is designed and adopted to extend the freezing time and affect the morphology of semicrystalline polymers. The dynamic temperature concept is based on a multilayer cavity with thin heating elements, thermocouples and insulation layers: it permits to increase the temperature of an amount of 100°C in a few seconds and obtain a cooling time of about 10 s. The system is used for the μIM of a poly-lactid acid (PLA) and an isotactic polypropylene (iPP).

The PLA is a biodegradable polymer with a low crystallization rate. Calorimetric analysis on pellets of PLA permitted to study the crystallization behavior in quiescent conditions and set a temperature for the annealing steps during the process. In this manner, the system for the temperature control was adopted to influence the final crystallinity of the PLA, by applying isothermal steps. Furthermore, the system was used to apply different thermal histories in different zones of the sample after the solidification in the microcavity and generate a crystalline phase and an amorphous one in the same part. Morphology modifications were analyzed by means of optical observations, calorimetric analysis, X-ray and IR spectra. To study the effect of the morphology on the biodegradation rate, experiments of hydrolysis were also carried out revealing that the parts exhibit different degradation kinetics and different mechanical behavior.

The potentiality of the system for the rapid temperature control was verified for a thin cavity with a geometry characterized by two entrances. The iPP was considered as material for the tests and the effect of the application of different temperature of the cavity on the weld line formation was studied. The effect of the temperature on the weld line formation is remarkable: increasing the value of the cavity temperature the weld line appear less evident and tends to disappear at 130°C. Morphological investigations represented a key factor to determine the effect of the different thermal histories on the final mechanical properties.

By means of Moldflow simulations, a mold for industrial scale was studied. In this case, to minimize the thermal dispersion, a moving system for the cavity seat was created. The study demonstrates that during the heating step, the use of the system allows the reduction of the thermal dispersion and the achievement of a temperature increase of the order of one hundred degrees at the cavity surfaces. Furthermore, the high thermal conductivity of the cavity permits to obtain a fast cooling when the mold is closed.