Applied Mathematical Modelling 40 (2016) 7001–7011

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

The influence of flow and thermal properties on injection pressure and cooling time prediction

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A R T I C L E I N F O

Article history:
Received 20 May 2015
Revised 20 January 2016
Accepted 3 March 2016
Available online 10 March 2016

Keywords:
Viscosity
Heat capacity
Thermal conductivity
Injection pressure
Cooling time
Injection moulding simulation

A B S T R A C T

Thermoplastic materials properties play an important role in mould filling and cooling analysis of injection moulding. Among the many, the melt's viscosity, heat capacity and thermal conductivity may be the critical ones. An experimental and computational case study to determine the injection moulding window of a rectangular ABS plate is presented. When apparent viscosity of the material was adopted for cavity filling simulations, it was found that the computed injection pressure was overestimated in contrast to experimental data. Shear stress and rate corrections applied to apparent viscosity as well as the no-flow temperature (NFT) set to T_g (glass-transition temperature) helped to achieve more accurate pressure estimation. The heat capacity and thermal conductivity were both measured separately in solid and molten states and it was found that the best estimation for pressure and cooling time was achieved when molten state heat capacity was adopted for computation. The effect of thermal conductivity was negligible on pressure prediction, although the most accurate prediction for cooling time was attained when both molten state heat capacity and thermal conductivity were utilised.

Therefore, the quality of material data input was found to be a critical factor in achieving reliable flow properties. Accurate data available for mould and process design purposes may help to generate less production waste and save costs, making a step towards sustainable manufacturing.

1. Introduction

Injection moulding has been a common processing technique to produce plastic components. The cycle starts with the injection or filling phase, during which the injection screw moves forward carrying molten material to be injected into the mould cavity. When the cavity is nearly filled, the packing phase commences by forcing further molten material into the cavity to compensate for the shrinkage of the part. When the packing is finished and no pressure is further maintained, the cooling phase starts. Although heat loss from the melt may occur from the onset of the cycle, during this phase the remaining (largest amount of) heat from the material is removed until it is sufficiently solid to be ejected from the mould [1]. To explore the injection moulding feasibility of thermoplastic components, a processing window can be determined. In one approach, the injection pressure as a function of melt temperature and injection time may be recorded [2]. This injection pressure, utilised as a reference parameter, can be important for mould and process design purposes. In order

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http://dx.doi.org/10.1016/j.apm.2016.03.002

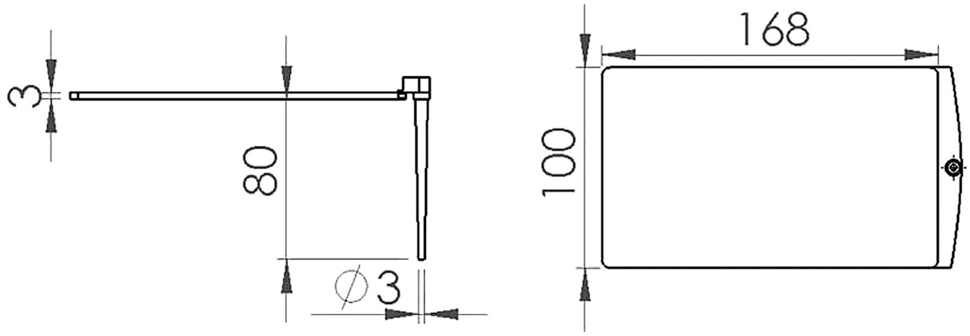

Fig. 1. Major dimensions of the rectangular part.

to simulate the flow of the melt and determine the processing window, material properties are needed [1]. Among the many, viscosity, heat capacity and thermal conductivity may be the critical ones, which will ultimately influence the reliability of injection pressure and cooling time prediction.

The literature available regarding injection moulding and simulations is rich and it is beyond the interest of this paper to give a thorough insight into most of the work that has been undertaken. The purpose is to present to the reader a few examples regarding filling, packing and warpage analyses which were based on utilising computer simulation packages, such as Autodesk Moldflow (later on Moldflow).

In one study [3], the cavity fill balancing was emphasized as being an important criterion during filling analyses to improve the quality of the moulded parts. If an unbalanced flow pattern existed, that would lead to packing difficulties. Another work [4] pointed out that the appropriate selection of gate position would help to reduce the filling time and balance the moulded parts' temperature distribution. Others [5] studied a numerically obtained flow pattern of polypropylene at different injection velocities and compared the results with experimental data. It was found in some cases that the numerical analysis was not able to capture short-shot and jetting phenomena. Another paper [6] reported that filling difficulties could arise when moulding thin-walled components, as the frozen layer of the part would more rapidly develop with reduced thickness. To control the formation of the frozen layer, the appropriate selection of injection time and melt temperature would be necessary. Regarding packing analysis [7], it was reported that increased packing pressure would reduce the shrinkage of HDPE cups. Specific to a warpage problem [8], it was shown that sustaining a longer cooling time and reduced melt temperature helped to improve the warpage of a box-like component.

Clearly, the correct interpretation of numerical results that were published in the aforementioned literature would not have been possible without the utilisation of accurate material properties. Regardless of whether additional packing and/or warpage analyses are performed (which require more complex material properties, such as pressure-volume-temperature data, coefficient of thermal expansion, mechanical properties, etc.) the very first task is to fill the mould cavity.

However, little information has been found that deals with the effect of the quantity and quality of material data input into injection moulding simulation packages.

For instance, it may happen that only apparent viscosity is available for a flow analysis. While other material properties, such as the heat capacity and thermal conductivity are not always readily available within that temperature range at which the plastic material is processed. This may be due to lack of data or having measurement difficulties at elevated temperatures. In this case, the designer may rely on literature or thermal properties available only in the solid state of the thermoplastic material. If inaccurate viscosity data or inappropriate magnitude of thermal properties is used for melt flow simulations, the computed injection pressure and cooling time might be incorrectly estimated which could be misleading for subsequent mould design analyses. In order to improve the efficiency of the design process it is therefore critical to utilise as accurate viscosity data as possible, and suitable values of specific heat capacity and thermal conductivity at various temperature ranges within the computational model.

An earlier work [2] pointed out the importance of corrections that can be applied to apparent viscosity. To extend this, in this paper not only the effects of the viscosity, but the NFT and the aforementioned two thermal properties of an amorphous ABS thermoplastic material with respect to a cavity filling analysis are considered. The details of experimental and numerical analysis are presented below.

2. Aim and methodology

The study was conducted to determine the mould processing window of a 3 mm thick rectangular plate with major dimensions [mm] depicted in Fig. 1. It is important to note that the justification for selecting such a simple design was to eliminate the effect of geometrical complexity, thus concentrating solely on the effect of material properties.

The experimental work utilised a Haitian HTF120X moulding machine and a generic grade of ABS thermoplastic. The processing window, i.e. the injection pressure limits were determined through the utilisation of a systematic factorial design consisting of three melt temperatures (220-, 240-, 260 °C) and three injection times (1-, 2-, 3 s). This was accomplished by