Heating and Melting of Thermoplastics using Energetic Ultrasound

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Abstract

The plasticising and dispensing of small amounts of plastic for the production of micro parts using conventional plasticising procedures is still a challenge. An alternative to the techniques used so far is the plasticising with energetic ultrasound. In this method, the physical properties of thermoplastic polymers – the conversion of mechanical vibration stresses into heat due to internal damping and external friction – is used. Thereby only the smallest amount of material is melted which is required for one production cycle. This makes it ideal for expensive, thermally sensitive materials such as absorbable resins which are used in medical technology.

1 Introduction

In the strongly growing market of micro systems polymer micro parts, not least because of their broad range of technical properties, are becoming more and more important. They are mainly used in medical devices, electronic components and mechatronic systems. In addition to the increasing degree of miniaturisation the complexity of the components is rising as well. Today polymer micro parts show very low weights between 0.05 mg and a few grams [1].

Economic production of these micro components made of thermoplastic material is currently being realised by micro-injection moulding. This process is characterised by the material- and process-oriented preparation of the required minimum amounts of plastic, while a consistently high component quality is achieved through very precise process control.

To avoid material degradation due to thermal overload, the dwell time of the provided amount of melt must be kept to a minimum [2]. In this context the plasticising with

energetic ultrasound represents an alternative method to the commonly used piston or screw plasticising of conventional injection moulding machines.

2 Basic principles of plasticising with energetic ultrasound

The plasticising with energetic ultrasound is based on the effect that polymers heat up under cyclic deformations due to inner (damping) and outer friction losses (surface friction). The conversion of mechanical energy into heat takes place in the plasticising chamber, which is a cut out of an anvil of a conventional ultrasonic welding press. During the process the ultrasound sonotrode fulfils the functions of both transferring the mechanical oscillation under compression to the polymer and, if desired, further conveying the melted material. The principle of plasticising with ultrasound is shown in figure 1.

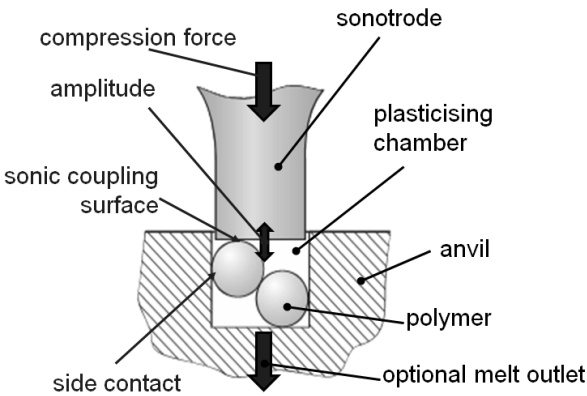

Figure 1: Scheme of the ultrasonic plasticising set-up

The plasticising process can be divided into three steps. After the polymer material is dosed into the plasticising chamber the sonotrode is lowered on the material and starts to oscillate after a predefined trigger force is reached. The cyclic deformation of the material through the sonotrode's vibration results in the fusion of the material. The successively generated melt is transferred out of the plasticising chamber by the sonotrode. At the end of the cycle the sonotrode can be utilised providing a holding pressure if the forming cavity is directly attached to the plasticising chamber.

3 Analysis of the heating mechanism

For a basic understanding of the heating process, the two overlapping heating mechanisms are analysed separately. The heating by friction on the contact surface of the individual granules is determined by experiments under different tilt angles. The volumetric heating of the polymer is measured by using flat disk geometries to minimise the influence of the friction. The melting process can be documented using infrared thermometers and a thermal imaging camera. In parallel, material data (e. g. storage and loss modulus) for the ultrasonic frequency of 20 kHz are determined for a numerical approximation of the volumetrical heating using dynamic mechanical analysis (DMA). Both, the numerical approximation and the measured temperature of the volumetric heating during the plasticising of polypropylene for two different amplitudes (29.4 µm and 39.2 µm) is shown in figure 2.

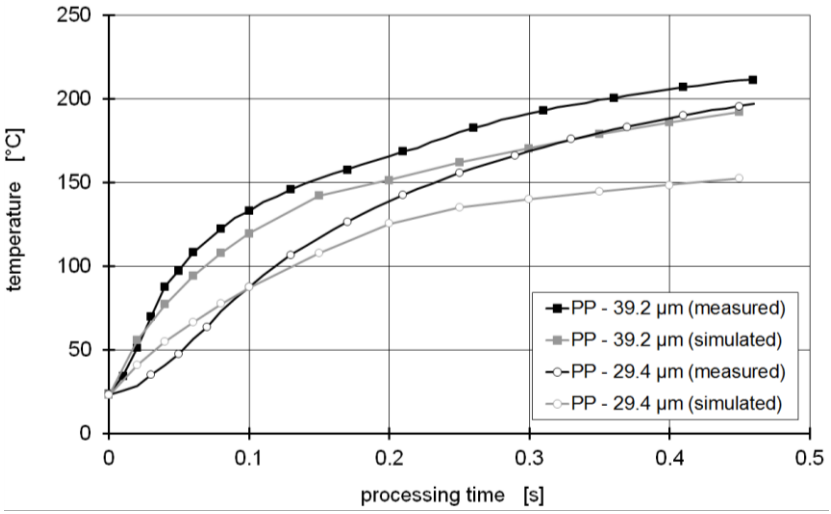

Figure 2: Development of the temperature of the volumetric heating during the plasticising of polypropylene (material: Sabic PP 505, Sabic Corporation, Riad)

The measurements show that a rapid heating of the material is possible. Depending on material and amplitude the heating rate reaches up to 600 K/s. Furthermore the volumetric heating can be fairly good approximated by the numerical simulation. The differences between simulation and experiment are due to unavoidable friction losses (e.g. contact on the side wall).

4 Manufacturing of micro parts using ultrasound and direct injection

For the production of micro parts using ultrasonic plasticising a cavity, which is connected through a gate system, adjoins the plasticising chamber. In this process the sonotrode serves as an injection plunger which carries the melted plastic into the cavity as well. A sectional view of the system is shown in Figure 3.

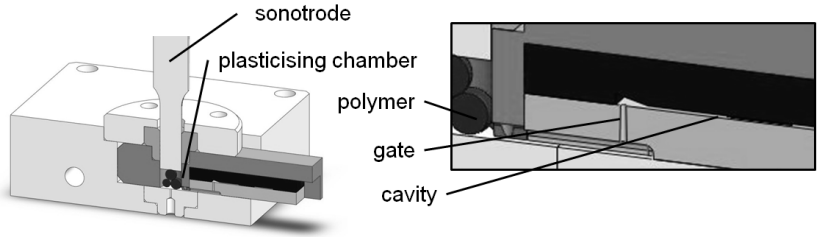

Figure 3: Sectional view of the plasticising with ultrasound and direct injection

Using this approach micro-tensile bars (Campus tensile bar, scale 1:16) can be produced and tested for their mechanical and morphological properties. The analysis of the parts show that they only reach one third of the quality of injection moulded tensile bars of the same size. This is attributable to air pockets (Figure 4) or unmelted material, which result from the low controllability of the filling during the process. In addition to that the simple system design allows uncontrolled early runoff of unmelted material.

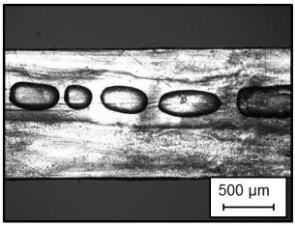

Figure 4: Section of micro tensile bar with airpockets

5 Conclusion and perspective

The investigations have shown that ultrasound can be used in principle to plasticise plastics gently and in small amounts. For further investigations the ultrasonic plasticising is coupled with a conventional injection plunger allowing direct control of the injection rate and pressure and therefore improving the quality of the produced parts.

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