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Ultrasonically-assisted polymer molding: an evaluation

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Abstract

Energy reduction in extrusion and injection molding processes can be achieved by the introduction of ultrasonic energy. Polymer flow can be enhanced on application of ultrasonic vibration, which can reduce the thermal and pressure input requirements to produce the same molding; higher productivity may also be achieved. In this paper, a design of an ultrasound–assisted injection mold machine is explored. An extrusion-die design was augmented with a commercial 1.5 kW ultrasonic transducer and sonotrode designed to resonate close to 20 kHz with up to 100 μm vibration amplitude. The design was evaluated with modal and thermal analysis using finite-element analysis software. The use of numerical techniques, including computational fluid dynamics, fluid-structure interaction and coupled Lagrangian-Eulerian method, to predict the effect of ultrasound on polymer flow was considered. A sonotrode design utilizing ceramic to enhance thermal isolation was also explored.

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Keywords: ultrasound; polymer; melt; processing; finite element; thermal isolation

1. Introduction

Polymer processing is an important and diverse field in the manufacturing industry. By applying vibration to a polymer flow, for example as reviewed in Ibar (1998), its effective flow rate may be enhanced. It is generally believed that the observed improvements are due to one, or a combination, of three possible modes: (1) high shear rate imposed by the vibrating surface that reduces the viscosity of the polymer melt; (2) shearing of polymer chains

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at the molecular level that reduces the effective molecular weight; and (3) rapid oscillation of the polymer molecules that induces localized heating.

In this paper some critical aspects of the application of ultrasound (US) to polymer processing are considered. First, the design of a commercial transducer and sonotrode were evaluated for the potential application of ultrasonically-assisted injection molding. The design concept is based on a patented technique (WO 2004/024415 A1). Essentially, the polymer passes through a die, where it is exposed to an ultrasonic energy field before continuing to the mold. An interstitial die, located between the extruder and the injection mold die, was designed. The US application targets increased cost, improving effectiveness due to reduction in thermal and/or pressure requirements. The application of fluid-dynamics techniques to establish US interaction with the polymer melt was then explored. Next, a method of enhancing the thermal isolation of US equipment for polymer melt processing is presented. The goal was to ensure the US device did not suffer from exposure to high temperatures, typical of molding machines.

Nomenclature

BC	boundary condition
CFD	computational fluid dynamics
dt	time increment
f	frequency
FEM	finite-element modeling
FSI	fluid-structure interaction
US	ultrasound

2. Method

2.1. Simulation methods

2.1.1. Finite-element modeling: solid mechanics

To study and optimize an ultrasonically-assisted polymer molding process, finite-element modeling (FEM) was performed in a commercially software (Abaqus, version 6.14). Material properties were as specified in Table 1. All models were full 3D representations, without symmetry, using the C3D8R hex elements or C3D8RT element type for thermal analysis. Dimensions of the commercial sonotrode and interstitial die were provided by our partners. A schematic diagram of the in-house designed thermally isolated die is shown in Figure 1. Modal analysis used the linear perturbation frequency step, with bounds of 15 kHz and 25 kHz.

The effect of pressure loading on the sonotrode's tip in the interstitial die as a result of exposure to the fluid flow was evaluated by applying a pressure load to the appropriate region of the tip.

Thermal analysis was transient until steady-state, with thermal input via heaters as per the design specification. The atmosphere was considered to be 297 K. For the interstitial die, the shared boundaries with an extruder and a mold were 473 K and 323 K, respectively; the heater set point was 473 K. For the in-house designed thermally isolated transducer the set point was 423 K.