Experimental analysis of ultrasonic heating of polypropylene during ultrasonic moulding process

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Abstract

The present study shows the results obtained in the experimental measurement of polypropylene heating when applying high power mechanical ultrasonic. The objective is to understand the behaviour of the polypropylene pellets during the ultrasonic moulding process (USM). For this study, a simplified geometry has been considered (a solid cylinder), and the evolution of the temperature has been recorded with a high velocity infrared camera. The results show that the heating ratio in the polymer is non-linear and highly inhomogeneous. For the analysis of each step, the cylinder has been divided into three different regions depending on the distance from the sonotrode, and the temperature evolution shows four different steps, according to the heating mechanisms involved. Both ultrasonic amplitude and applied pressure affect the temperature evolution of the whole polymer while the change in the applied force modifies the temperature distribution in the polymer and the heating mechanisms present.

Ultrasonic Moulding Process

Ultrasonic Moulding (USM) is a new moulding process powered by ultrasonic mechanical excitation and specifically designed for the production of mini and micro plastic parts [1,2]. This process plasticizes the polymer pushing it to a vibrating ultrasonic sonotrode. The polymer is then transferred to the mould while it is being melt. The different elements and steps involved in the process are sketched in Figure 1.

The commercial machine used for the USM process is the Sonorus 1G, manufactured by Ultrasion. The main components included in the machine are displayed in Figure 2.

Some advantages over conventional microinjection moulding are:

- Short time of residence at high temperatures
- Lower temperature needed to inject material
- Lower injection pressure
- Energy savings
- Material savings

On the contrary, some drawbacks still to be addressed are:

- Possible presence of bubbles due to cavitation
- Extremely fast heating and difficult to control
- Little knowledge in the effect of the parameters.

Results

Temperature evolution

The average and maximum temperatures have been identified for each area and for the whole cylinder during all the cycle.

Analysis of results

The average heating rate changes with the amplitude but not with the force, and the heating is more important in the upper region. On the other hand, the dispersion in the results is very high, specially at high amplitudes. That can be due little differences in the initial cylinder position

Special case: Low force

When a force of 5kN is applied to the cylinder, there is no STEP 2 in the heating rate evolution. In this case, the force applied is too low to couple the polypropylene cylinder with the sonotrode. This causes a hammering effect that heats the upper region of the cylinder very fast. This is magnified for high amplitude (experimental runs from 51 to 60).

Cycle 43 average temperature and averaged heating rate in different regions

Cycle 51 average temperature and averaged heating rate in different regions

Conclusions

The results obtained show that the heating of a polypropylene cylinder due to an ultrasonic mechanical excitation is highly inhomogeneous and presents different heating steps during the time. In this study, the different heating mechanisms in each step have been identified and the influence of the main process parameters have been evaluated. From the analysis of the results it can be concluded that both ultrasonic amplitude and applied pressure affect the temperature evolution of the whole polymer although the change in the applied force also modifies the temperature distribution in the polymer and the heating mechanisms present. More experimental measurements will be done in the future to validate the results with other types of polymers.

References


For each experiment, the temperature has been obtained and exported using FLIR Thermacam Researcher® software.

The camera temperature range has been chosen to be from -40°C to 160°C, since the heating of the polymer in solid state was the main objective of the experiment.

The evolution of the temperature change in the three considered regions shows four steps: in STEP 1, the sonotrode gets in contact with the polypropylene specimen, impacting it. As result, the temperature rise increases abruptly defining an initial peak value. When the sonotrode is in complete contact with the specimen (STEP 2), , the upper region is heated due to the viscoelastic effect, while the lower part of the cylinder is heated due to the friction with the mold. In this second step of the process, the heating rate keeps constant, until some region of the polymer reaches the softening temperature of the material (around 90°C). At this point, the material is not able to follow the sonotrode vibration and its upper region heats very quick due to a hammering effect (STEP 3). The heating rate defines a second peak, much higher and abrupt than the previous one. Finally, the polymer starts its deformation and its temperature increases until it melts (STEP 4). The material is now much softer and gets coupled again with the sonotrode. Viscoelastic heating is the predominant heating mechanism during this fourth and last step.