Pressure effects on temperature measurement of polymer melt

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Abstract

Polymer melt temperature dependence on the pressure have been measured directly by a novel temperature sensor in a versatile test rig which was developed to measure melt temperature profiles in the injection moulding processing. The results show that the melt temperature increases linearly with the pressure applied to it. The larger the initial bulk melt temperature, the larger the temperature rise for a particle rise in pressure. The temperature rise resulting from compression is also related to the structure properties of the polymer.

Introduction

It is well known that the temperature of polymer melt plays an important role in the processing of thermoplastics. Therefore it is of significance to measure true melt temperature and control the variable in the processing. The melt temperature is a function of not only heat conduction processes occurring during processing, but also the shearing history under force and compression of the melt[1][2]. Shearing flow will result in the heat generation, which will results in an increase in the average melt temperature unless this is dissipated through the channel walls. Because polymers often encounter high pressures during processing (50–200 MPa in the case of injection moulding), the inclusion of pressures as a variable is important for studies on polymer behaviours. These pressures significantly affect the volume of the polymer, its thermal expansivity, its compressibility and the temperature region in which the transition behaviours occur[3]. Questions of the pressure dependence of melt temperature are of obvious importance to the control of processing operations. The instantaneous temperature rise resulting from the application of pressure can be expressed with the isoentropic function.

$$\left(\frac{\delta T}{\delta P}\right) \quad {}^{\circ}C/MPa$$

For most thermoplastics, this function has a value between 1 and 2 °C per 10 MPa[4]. The temperature rise which occurs on compression is reversible and as the material decompresses cooling by the same amount occurs[5]. The adiabatic compression temperature changes for some polymers at room temperature and in the pressure range 13.8–200 MPa were also found to be a function of pressure and temperature[6].

In the study of the temperature distribution and shear heating effects in polymer processing(7), it has been found that the pressure dependence of the melt temperature is significant in some cases. This paper will discuss the dependence of polymer melt temperature changes on melt pressure and initial bulk temperature as well as materials, which have been less reported in literature.

Experimental

The experimental apparatus is schematically shown in *Figure 1*. The apparatus is equipped with two novel temperature measurement sensors, which could be used to measure the melt temperatures at various radial positions in the flowing melt(7), and pressure transducers (Terwin Instruments Limited, GT76-10M), which were used to measure melt pressures at position near the temperature sensors. The apparatus attaches directly to the barrel end of an injection-moulding-machine (Negri-Bossi NB60), which has a DIMIGRAPHIC 90 microprocessor based control system for the digital control of all the operational machine parameters. The outlet from the apparatus was blocked during the test.
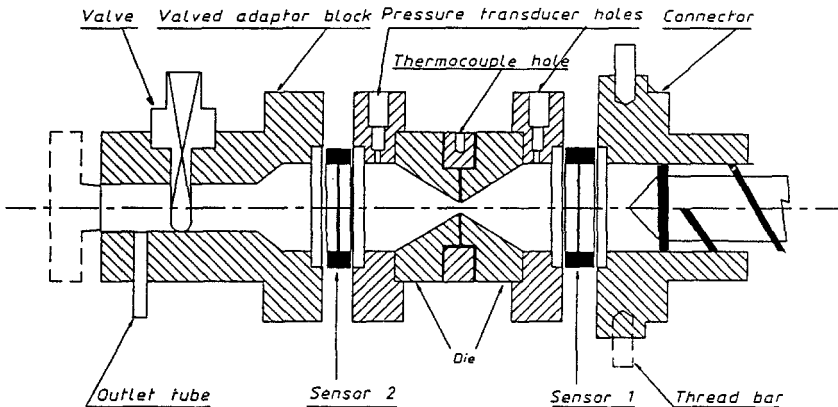

Figure 1   Experimental Apparatus

The moulding conditions, such as temperature settings, injection rate, injection pressure, screw revolution, shot size and back pressure, used are shown in *Table 1*. The screw position, machine hydraulic pressure, melt temperature and pressure were recorded simultaneously with time using a high-speed data acquisition unit (ADU) which was controlled via a personal computer.

In this study, commercial grade polymers used were Low Density Polyethylene (LDPE, Exxon Escorene Chemical Ltd-- LD605BA), High Density Polyethylene (HDPE, LACQRENE--2006SN60), Polypropylene (PP, MOPLEN--1M24EAC1) and Polystyrene (PS, LACQRENE--1540).

Before each set of temperature measurements, the polymer melts were held in the test rig for thirty minutes, this allowing the temperature of the melt to stabilise. The screw was then

Table 1   Injection Moulding Conditions

Conditions	Settings
Temperature (°C)	
--Nozzle Section	200
--Metering Zone	200
--Compressing Zone	190
--Feeding Zone	180
Shot Size (mm)	75
Injection Rate (cm^3/s)	40
Screw Rotation Speed (rpm)	150
Back Pressure (MPa)	0.1

moved forward to compress the melt to a preset pressure. Simultaneously melt temperatures and pressure were recorded. In this work reported here, the data were taken from sensor 2 where the melt temperature was less affected by the barrel temperature than that from sensor 1 when the melt was compressed due to the outlet tube being blocked.

Results and discussion
      Figure 2 illustrates the temperature changes with pressure
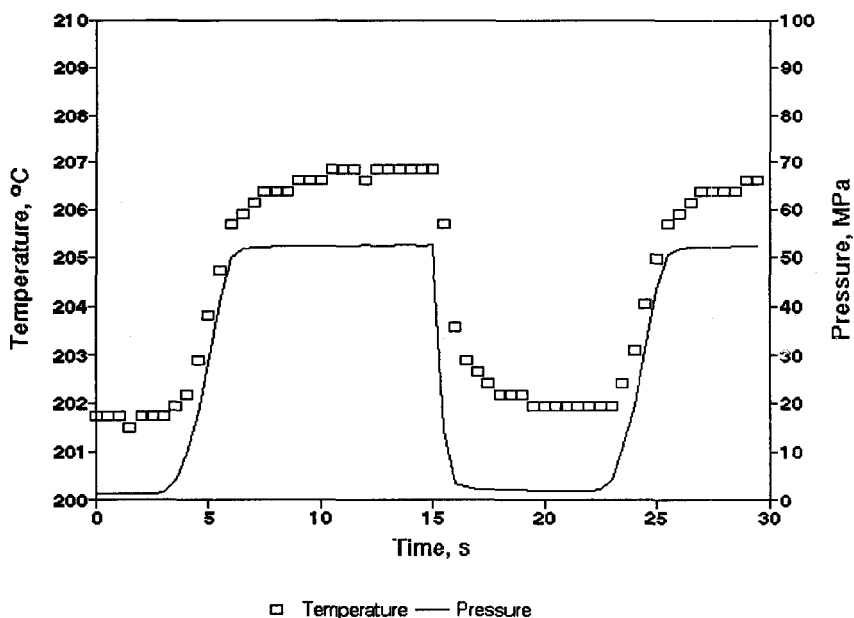

□ Temperature ── Pressure

Figure 2   The change in the temperature of a LDPE melt
            observed with cycle change in pressure

of the LDPE melt tested in the apparatus. When the melt in the
test rig was compressed temperature increased simultaneously and
when the pressure was released the melt temperature dropped
simultaneously down to the original level, the changes in melt
temperature clearly being linear to the application and removal
of the pressure. This experimental result shows that there is
reversible compression heating occurring when pressure acts on
the polymer melt. This is, from the view of thermodynamics,
because the molecules become less movable under pressure and the
kinetic energy is transferred to inner thermal energy resulting
in temperature increase.

The radial temperature rise on compression are compared to
the temperature rises resulting from shear heating during
injection moulding (under the moulding conditions in table 1) in
Figure 3. The temperature increase by compression along the
radius were uniform while the temperature changes by shear flow
were not due to the shear rate different along the radial
direction. Since the thermal conductivity of polymer melt is low,
the compressing of melt by high pressure and speed can be
considered as adiabatic processing, this resulting in uniform
adiabatic temperature change. Therefore, it is clear that the
temperature rises measured in this work (blocked the outlet of
the apparatus) were caused by compression heating rather than
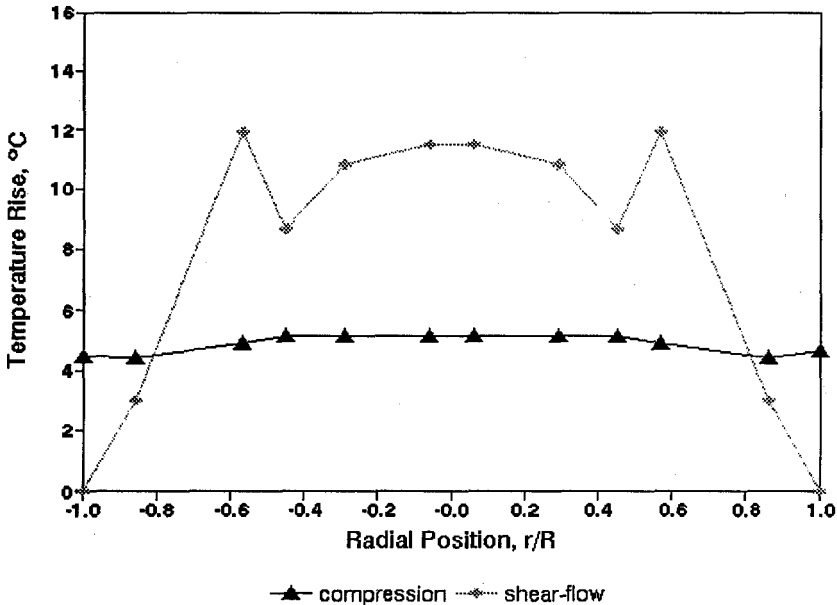shear heating (the apparatus outlet was opening).

Figure 3 Radial temperature profiles for LDPE melt
as result of compression (40 MPa pressure) and
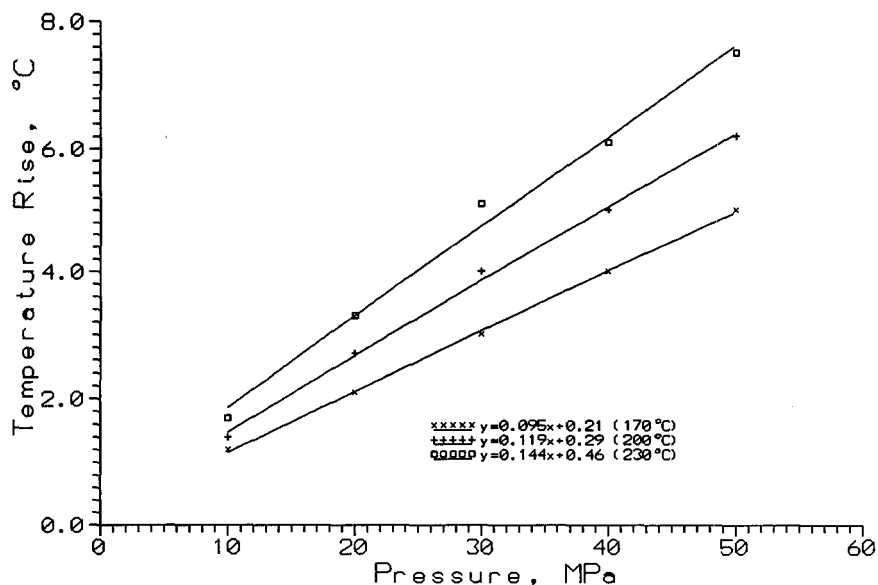shear heating (Injection conditions see Table 1)

Figure 4 Effect of initial temperature of LDPE melt
on the temperature rise observed on compression

Figure 4 shows the effects of the bulk melt temperatures on
the temperature rise observed on compression with the LDPE melt.
It can be seen that the temperature rise coming from the
compression increases with the bulk melt temperature under the
same pressure. From this figure, it can be also seen that the
melt temperature rises about 1-2 °C per 10 MPa pressure increase,
and the rate of temperature change increases with increasing the
bulk melt temperature of tested polymer. This may be because that
melt has higher motion activity energy (more flexibility) at high
temperature than that at low temperature. When compression at
same pressure, the high temperature melt has more motion activity
energy being transferred to inner thermal energy, which results
in larger temperature rise.

The temperature rises observed are also a function of the
polymer tested, as shown in *Figure 5*. The rise with HDPE is the
largest, while that with PS is the smallest one. This may be
related to the melt density and the structure. The nature of the
material and the relative degree of flexibility of the polymer
chain had an effect on the adiabatic temperature changes. The
greater the polymer chain flexibility, the larger were the
thermal effects(6). Among the four materials tested, PS molecules
was the most rigid one due to the benzol structure while HDPE
molecules has simple regular ethylene unit which results in the
flexible chain.

The following question may rise: Is the temperature sensor
sensitive to pressure? If the sensor is sensitive to pressure,
the temperature rise should be the same for different initial
bulk melt temperature or polymers at same pressure applied. From
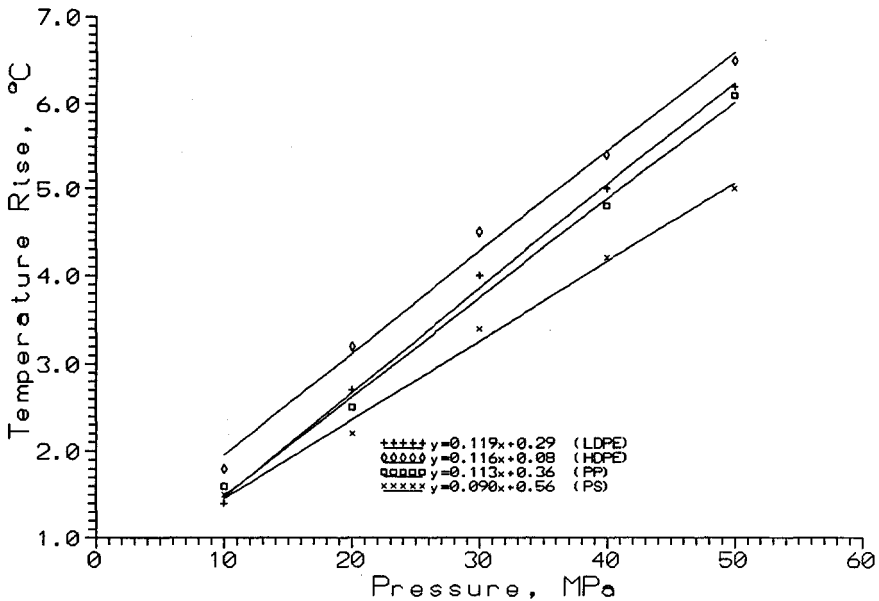both figure 4 and figure 5, the test results show this is untrue.

Figure 5 Effect of pressure on the melt temperature
of different polymer melts at 200°C

Therefore, it can be believe that the temperature rise mentioned
above comes from compression rather than the temperature sensors
sensitivity to pressure.

Conclusion
It can be concluded that the application of pressure results
in an increase in the melt temperature. The larger the initial
bulk melt temperature, the larger the temperature rise for a
particular rise in pressure. The temperature rise resulting from
compression is also related to the structure properties of the
polymer.

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