THE IMPORTANCE OF MONITORING MOLD PRESSURE DURING ROTATIONAL MOLDING

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Abstract

During the rotational molding of plastic parts, the pressure inside the mold can become positive or negative depending on a variety of factors such as the size of the vent, the quality of the mold, the heating rate, etc. In commercial molding, the pressure is likely to vary in an arbitrary manner, depending on particular combinations of key variables. This leads to conflicting reports about the causes and cures of problems such as warpage, residual stress and shrinkage. This paper reviews the effects of pressure variations on the quality of rotomoulded parts and using experimental data, demonstrates the importance of monitoring the pressure inside the mold throughout the cycle. Methods of doing this are illustrated and the benefits in terms of reduced cycle times and improved part quality and consistency are demonstrated.

Introduction

The presence of internal and surface pin-holes in rotomolded parts has been recognized for many years[1-3]. It is desirable to remove these air pockets to get optimum part properties [4], and so there has been considerable research interest in how the bubbles form and, more importantly, how they can be removed. Rao and Throne[2] identified the importance of the nature of the particles. Ramazzotti[5] found that larger particles sizes, when used with a high viscosity material, cause poor surface quality.

Moisture content has also been identified as a cause of bubbles and pores in molded parts. The moisture can vaporize during molding and create bubbles and surface pitting of the part. The addition of carbon black pigmentation can also increase the rate at which moisture is picked up.

Kelly[6] showed that the trapped pockets of gas between the powder particles do not move during rotomolding. He proposed that at a high enough melt temperature, the air in the bubbles begins to dissolve into the polymer. Oxygen has about twice the solubility of nitrogen in polyethylene. At high temperatures, the oxygen is further depleted by direct oxidation reactions with polyethylene. The depletion of oxygen reduces the bubble diameter, which increases the pressure inside the bubble. This forces the nitrogen to dissolve in the polymer, thus the bubble diameter is further reduced and this chain of events repeats until the bubble disappears.

Crawford and Scott[7] carried out hot plate tests on powders, using video equipment to record and examine the processes of melting in detail. They showed that initial size of the bubble has a significant effect on the rate at which it dissolves, as the surface area-to-volume ratio is inversely proportional to the diameter.

Spence[1] carried out extensive experimental trials and showed that a large number of parameters affect the formation and/or removal of bubbles in rotomolded products. These included: (a) Powder - particle shape, size and distribution (b) Viscosity of melt - MFI (c) Additives - (e.g. pigments) (d) Mold surface (e) Temperature (f) Time (g) Gas inside the mold (h) Surface tension (i) Pressure inside the mold.

Extensive investigations of the sintering mechanism[8-11] and analysis of bubble dynamics[12] have added further insight into the phenomenon of pin-holes in rotomolded parts. What is now widely recognised, particularly through the work of Spence[1] and more recently from the results provided by Walls[13] and O'Neill[14], is that a slight positive pressure (2 lbf/in^2, 0.14 atmospheres or 13.8 kPa) inside the mold during the heating and cooling stages of the process has a major effect on cycle time and part quality.

This paper will look at ways in which rotomolders can utilise the advantages of mold pressurization. The primary recommendation from the work is that it is crucial to monitor the pressure inside the mold throughout the cycle in order to ensure that all pressure variations can be controlled.

Results

There is conclusive experimental evidence that by using internal pressure rotationally molded parts can be void-free, if the pressure is applied after all the plastic powder has formed against the mold wall.

Fig. 1 shows the difference in the Rotolog traces of moldings done with and without the application of pressure. It can be seen that there is a marked increase in the cooling rate, from about 11 to 18 ºC/min, because in this case the pressurized air used was at room temperature. Thus, the application of pressure affects not only the diffusion of the air bubbles, but also cools the inside of the part. It is important to note that when utilising internal pressure, it is possible to use a lower value of peak internal air temperature (PIAT). Normally a reduction of about 10% is possible, so that not only is a part with less bubbles achieved, but the cycle time is reduced (typically by about 20%) and the impact strength of the molded parts is improved (typically by about 25%). This latter effect is illustrated in Fig 2.

The above section gives a brief overview of the benefits of mold pressurization during heating. There is much more extensive evidence in the published literature to support this. During cooling the benefits are different but just as significant. They relate to the control that can be exercised over the point when the plastic part separates from the mold. Normally during a production run, the plastic part can release early or late in the cycle depending on a whole range of factors, some of which occur randomly. As the shrinkage of the part depends on the cooling rate, and the warpage depends on the temperature gradient across the part wall, these will both be affected by the length of time that the plastic remains in contact with the mold wall. Early release will cause the plastic to cool slowly and this will increase shrinkage. If close part tolerances are to be maintained, it is crucial that the point in time when the plastic releases from the mold is controlled and the application of internal pressure during cooling is an excellent way to achieve this.

Practical Approach to Mold Pressurization

From the preceding sections it is apparent that it is highly desirable to apply pressure to the inside of a rotational mold during the cycle – or at the very least be able to monitor the internal pressure. So how is this achieved with a rotating mold? This is where it is difficult to generalise because there are so many different types of rotational molding machines. On a Rock & Roll or a Rocking Oven machine it is relatively easy to measure the mold temperature, the temperature of the air inside the mold and the pressure throughout the cycle. This can be done by having a hollow central support shaft and feeding an air-line and/or thermocouples through its hollow core. The air-line can be connected to the mold vent tube so that the venting action can be maintained. A pressure sensing device connected to the air line will enable the pressure to be monitored throughout the cycle. As the pressures are usually relatively small, a convenient way to monitor the pressure is using a water manometer. In a biaxial machine a bit more engineering ingenuity is needed but the same effect can be achieved.

Most rotomolders are reluctant to pressurize a mold – and they are right to be cautious for health and safety reasons. The advantage of monitoring the pressure inside the mold is that a lot of very useful information is obtained. By monitoring the pressure it often becomes apparent that the desired levels of pressure occur naturally during a rotomolding cycle. The problem is that the pressure variations usually occur at the wrong time. However, monitoring the pressure provides reassurance that the mold can contain the necessary pressure – it is then a matter of controlling the pressure variations to achieve the desired effects.

Temperature and Pressure Measurements

It has been shown that if the vent is closed throughout the cycle, then the pressure variation should follow the temperature variation, since

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$
$$P_2 = P_1\left(\frac{T_2}{T_1}\right) \qquad (1.1)$$

From this equation it is apparent that in an ideal rotational molding cycle, if the mold is completely sealed, the mold pressure trace should follow the familiar shape of the internal air temperature trace.

In practice, if the vent is closed, blocked or not operating effectively, the pressure trace is as shown in Fig 3. In the early part of the cycle, no matter what state the vent is in, it is common for the air to escape at the parting line of the mold. In Fig 3 it is seen that there is no pressure build-up for the first 5 minutes. Then the plastic starts to melt and seals over the parting line so that the pressure builds up according to equation (1.1). The shape of the pressure trace follows the predicted shape, but note what happens after about 17 minutes in this case. At point V the internal pressure goes below atmospheric pressure because the air expelled through the parting line cannot get back into the molded part. This is a common problem in rotational molding, but it should not happen. If the vent was operating efficiently then the measured pressure trace should be a horizontal line at atmospheric pressure. Note that for the vent to operate efficiently, during cooling it has to be large enough to allow re-entry of the air that was expelled through the vent and through the mold parting line.

If we consider Fig 4, some other interesting things can be seen. Initially the pressure trace is similar to Fig 3 in that there is no pressure build-up due to air escaping at the vent and/or the mold parting line. Then the pressure increases as the parting line (and vent?) get sealed with the molten plastic. However, at Point L there is a sudden loss of pressure – caused by a blow-hole being formed at the parting line. This then seals and the pressure builds up once more. From the point of view of quality control, this type of pressure trace would indicate that there is a potentially serious weakness hidden in the wall of the molded part.

Another interesting thing on this pressure trace is that at Point M the pressure stops decreasing and starts to tend back towards atmospheric pressure. This occurs because the plastic part has separated from the mold wall (perhaps been pulled off by the negative internal pressure?). In this particular part, one mold surface was shielded and no plastic formed on it. Thus, once the plastic peeled away from the mold, there was an access route from the inside of the mold to the parting line and this provided venting once more.

In Fig 5 we see an example of a catastrophic blow-hole forming in the part. The measured pressure trace was building up as before but this time, at point P, a blow-hole formed in the part. It was too large to get re-sealed by the powder/melt and so it provided a continuous venting access from the inside of the plastic part to the mold parting line. Hence, the internal pressure dropped off to atmospheric and stayed there for the remainder of the cycle.

Observations

The temperature and pressure traces in Figs 3 – 5 come from measured data on a rotational molding machine. They are only a small sample of the valuable information that can be obtained by monitoring the conditions inside the molded part throughout the cycle. The important message is that even if it is not desirable to pressurize the mold, it would be very wise to record the internal pressure – it will provide a valuable insight as to what is going on.

It seems certain that in the future, molds and molding machines will be designed to facilitate the recording of mold temperature, internal air temperature and mold internal pressure simultaneously. There are major benefits to be gained by doing this in terms of faster cycles, better mechanical properties and more consistent quality. The industry must address the need for this technology very urgently.

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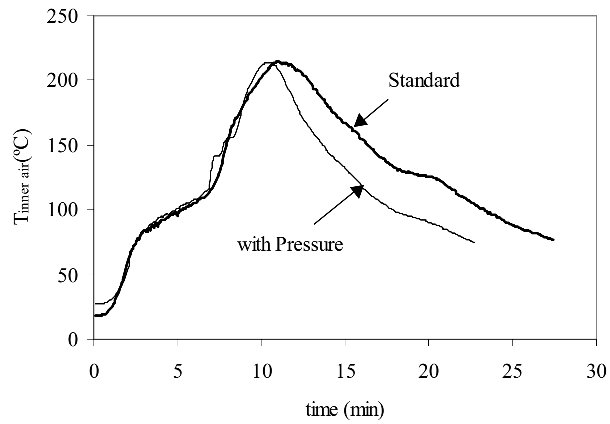

Fig. 1 - Rotolog traces of PE moldings with and without pressure.

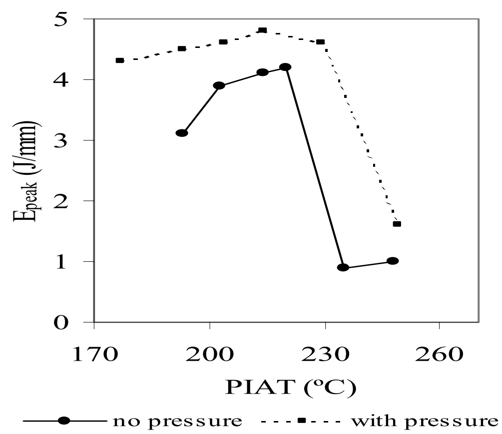

Fig 2 Effect of internal pressure on impact strength of PE rotomoldings

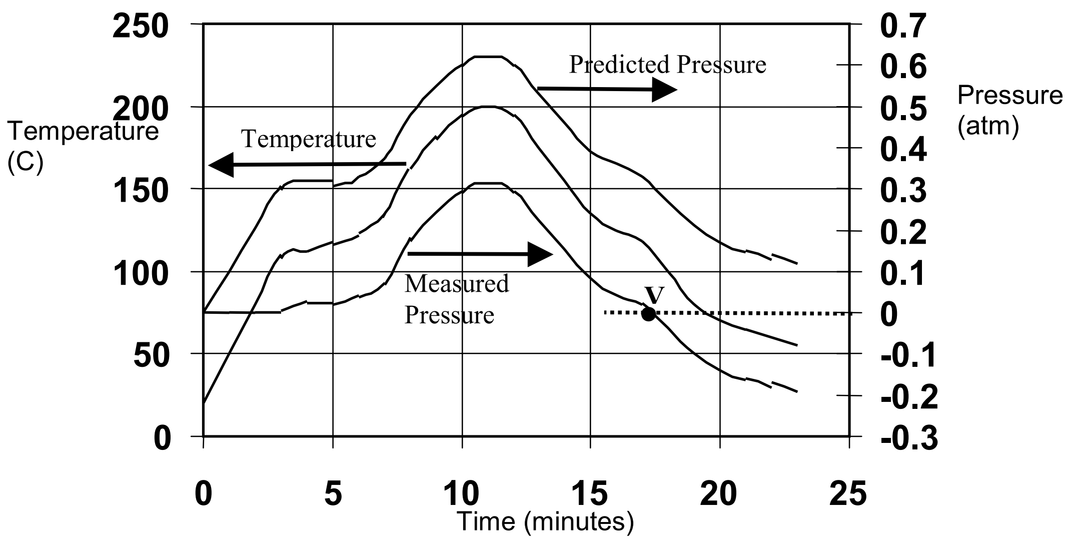

Fig 3 Measured internal air temperature with measured and predicted mold pressure

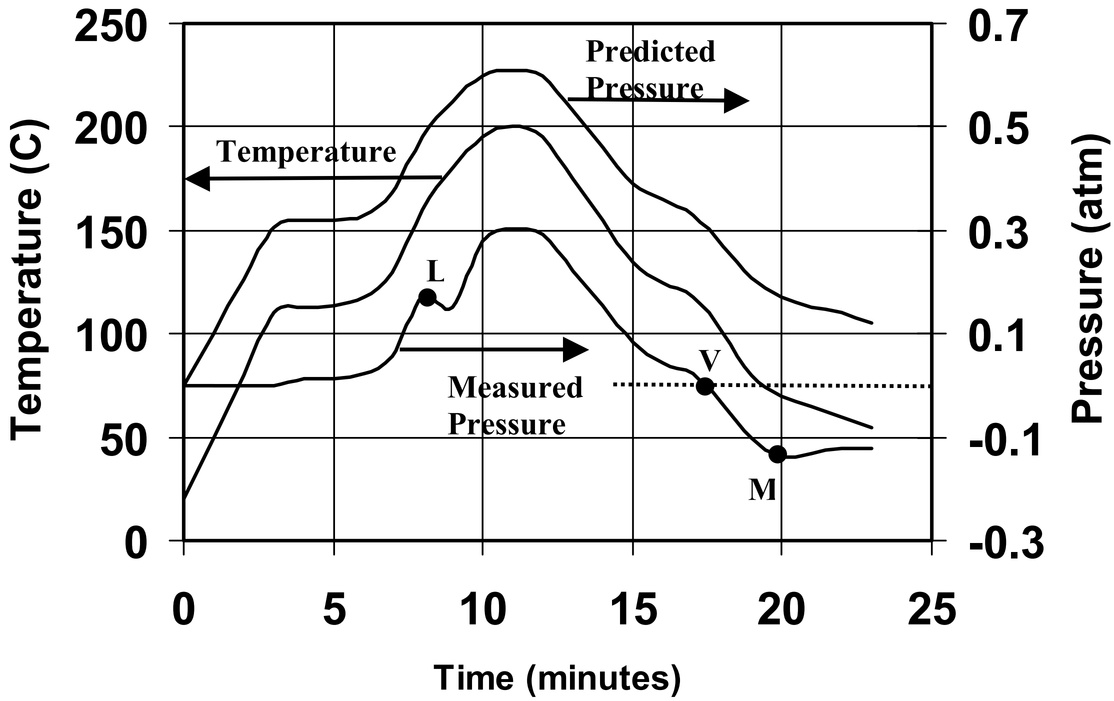

Fig 4 Measured internal air temperature with measured and predicted mold pressure

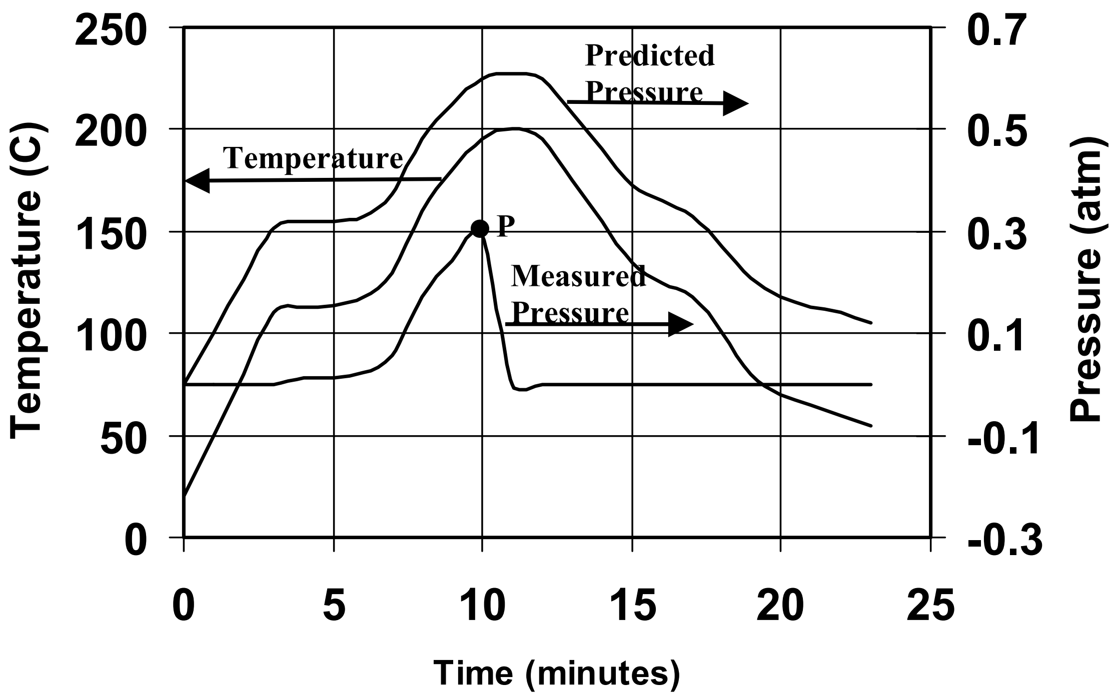

Fig 5 Measured internal air temperature with measured mold pressure when blow hole is formed.