ROTO-BLOW MOULDING, A ROTATIONAL MOULDING HYBRID

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Abstract

As the rotational moulding industry moves towards the new millennium, it continues to grow and develop at a phenomenal rate. Ever increasing customer demands and expectations are pushing the process to new limits. This has resulted in the once simple process developing many varied hybrids and a range of processing options. One such hybrid is to pressurise the internal atmosphere of the mould during the moulding cycle. Pressurising the mould complicates the traditionally simple process, but provides many unique opportunities to the moulder to enhance the quality of the moulded product.

Introduction

Pressurising the mould during the rotational moulding cycle has traditionally been difficult because of the relatively primitive machinery available to the industry. In recent years rotational moulding equipment has become somewhat more sophisticated, but technically still lags behind the other plastics processes. Recent developments now provide the rotational moulder with at least one gas line running through the arm of new machines, and in some cases two gas lines.

Initial use of the gas lines on many machines has been to purge the internal mould cavity with an inert gas, typically Nitrogen. This has helped to prevent oxidation of the inner surface of the moulded part, when longer cure cycles are required. The most common use for Nitrogen is when moulding Nylon 6[1]. Other uses for the gas line include powering transvectors to intensify the oven heat on a focused area of the mould. Operating the pneumatic valve located inside a drop boxes[2] when moulding a multi-layered part. Also, prevention of warpage[3] by pressurising the mould during the cooling cycle.

This paper describes other unique ways to use the gas line on the machine to enhance the aesthetic and mechanical qualities of the product. It has been found that pressurisation of the inner mould surface can remove bubbles and surface pores. This effectively creates a new process, a hybrid of the rotomoulding process, which could be described as "Roto-Blow" moulding.

Bubble Diffusion Theory

The presence of bubbles is an inherent characteristic of products manufactured by rotational moulding. Bubbles form due to the encapsulation of air pockets between powder particles as they melt and fuse together (see Figure 1). As the melting process continues, these bubbles remain stationary due to the high viscosity of the molten polymer. The bubbles then slowly diminish in size and may disappear, depending on the heating cycle time, the melt temperature and the viscosity characteristics of the polymer concerned. In general, bubbles can be more easily removed from lower viscosity (higher MFI) materials. These materials have weaker polymers structures, through which oxygen and nitrogen molecules can pass more freely. The effect of increasing the melt temperature aids the removal of bubbles in three ways:

a) degrades the polymer (also linked to time)
b) reduces the viscosity of the polymer
c) increases the pressure inside the bubble.

The combination of the polymer being subjected to a high temperature over a longer period of time to remove bubbles can have a devastating effect on the structure of the polymer. Although extending the oven cycle time does remove bubbles, it also increases the risk of oxidating the inner surface of the part. Another disadvantage to this method of removing bubbles, is the increase in cycle time experienced when higher peak internal air temperatures are used.

To understand the bubble formation and removal mechanism, it is necessary to understand the process of polymer sintering and densification. Solid particles, when in contact with one another at elevated temperatures, tend to decrease their total surface area by coalescence. This process, called "sintering", is usually accompanied by a decrease of the total volume of the powder mass, a process referred to as "densification". Frenkel[4] was the first person to consider the concept of viscous sintering, and derived an expression for the rate of coalescence of adjacent spheres under the action of surface tension. Since then Kuczynski and Zaplatynsk[5] and Lontz[6] have made contributions in predicting how bubbles form during the sintering and densification processes for a range of materials including glass, polymethylmethacrylate and polytetrafluoroethylene.

Crawford and Scott[7] described the melting and collapse of the powder as heat is applied from the base as two bulk movements. Firstly, the progression of the melt front through the powder mass to the free surface and the collapsing of powder particles into the melt. It is the latter that tends to trap air. They also stated that the trapped air will diffuse into the surrounding polymer mass and produced bubble measurements to support this. The initial bubble size has a significant effect on the rate at which it dissolves, as the surface area-to-volume ratio is inversely proportional to the diameter. Crawford and Scott derived a relationship which modelled the removal of gas bubbles from a polymer melt which took the following form:

$$\left(\frac{\phi}{\phi_o}\right)^2 = K_3 - K_2 t$$

where: ϕ is the diameter of the bubble
ϕ_o is the original diameter of the bubble
t is time and K_2 & K_3 are constants

Experimental Equipment & Materials

A Caccia RR 1400A shuttle type machine was used for all moulding tests during this work. This machine has an offset arm, capable of carrying moulds up to 175kg with a maximum diameter of 1400mm. The oven is heated by a gas generated flame, with burner capacity of 77,000Kcal/hr which allows a maximum operating temperature of 400C. A central pipeline through the arm of the machine provides a means to pressurise the mould. A pressure control panel was designed, manufactured and fitted to the machine and used to calibrate the pressure level prior to each experiment.

During the rotational moulding trials a cast aluminium (260mm sides x 10mm thick) mould was used for all experiments. The mould was split along its centre line, and sealed using an `O' ring. Typically a 1 kg shot size was used to produce a 3mm thick part. The majority of the experimental work was carried out using standard rotational moulding grades of polyethylene, details of these polymers are listed in Table 1.

Results & Discussion

Pressurised Rotational Moulding of Polyethylene

Initial rotational moulding trials confirmed that moderate pressure (0.5 bar) could successfully remove bubbles and pores, if applied after the polymer had melted. Mould pressurisation provided a simple mechanical means by which bubbles and pores could be removed from the product. Figures 2 and 3 illustrate how pressurising the internal atmosphere of the mould can remove surface porosity from the part. Therefore it was decided to investigate in greater detail some of the effects of rotational moulding with pressure.

Effectiveness of Pressure at different Temperatures

During a series of moulding trials, 1 kg of NCPE 8017 was rotationally moulded using a sealed aluminium mould. The oven temperature was set at 300C and the mould was removed from the oven at various internal air temperatures. While being removed from the oven, a 0.5 bar pressure was applied through the arm of the machine for a set period of time. From these trials an approximate indication of the bubble density was determined from the moulded parts. From the data represented in Figure 4, it can be seen that the effectiveness of pressure to remove bubbles increases with increasing melt temperature. This can be related to the polymer viscosity which decreases as the melt temperature increases.

Low temperature (-20C) impact tests were carried out on samples from each moulding. The data from these tests, which is illustrated in Figure 5, confirmed that mechanical properties increased when bubbles and pores were removed from the part. With no pressure applied, the bubble count is 100%, which corresponds to the least energy that is required to break the sample. Bubbles weaken the polymer structure by providing crack initiation zones. When bubbles are removed, the impact strength typically rises by about 15-20%, and on some occasions by as much as 25%.

Effect of Pressure Level on Mechanical Properties

The effect of the applied pressure level on the mechanical properties of the product was investigated using NCPE 8017. During this series of tests, the polymer was heated to 190C and then removed from the oven. As it was being removed from the oven, pressure levels ranging from 0-3 bar were applied for 10 minutes and then relieved. Impact tests (at -20C) again highlighted the advantage of using pressure to remove bubbles (see Table 2). From the impact tests, the three applied pressure levels all removed bubbles and pores completely, and hence increased the parts impact strength. However, there was no noticeable increase in impact strength experienced for each increasing pressure level. Tensile tests, unlike impact tests, were affected by the applied pressure level (see Table 3). As the applied pressure level increased, the tensile strength and tensile modulus both increased. It is suggested that the tensile properties improved because increasing the pressure level consolidates the polymer structure and improves its resistance to the externally applied forces.

Effect of Pressure on Part Shrinkage

The effect of pressure on part shrinkage was studied in conjunction with NCPE 8113. During a series of trials, different pressure levels were applied to the mould during the cooling cycle and relieved when the part reached 80C, when it was demoulded. Part shrinkage was measured by monitoring a 200 mm square grid, which had been moulded into the part. The grid was first measured with the part still hot (50C). Shrinkage was then recorded after 1, 5 and 30 days (see Table 4), with each mould being stored in a temperature controlled environment at 20C. From the shrinkage data, it can be seen that mould pressurisation reduces shrinkage by as much as 1%. Pressurisation of the mould, restrains the contractional forces inside the polymer structure as it cools and solidifies. The data indicates that the majority of shrinkage occurs during the first 24 hours after moulding.

Effect of Pressure on Material Density

During these tests using NCPE 8113 and Du Pont 8107, each material was first rotationally moulded without pressure, and then moulded with pressure to remove bubbles and pores. Sections from each moulding were then accurately machined to set dimensions and weighed. From the dimensions and mass of each section the density was calculated (see Table 5). The density calculations confirmed that the air inside the bubbles and pores is forced out of the polymer when pressure is applied. This is apparent from the data, because of the rise in material density when bubbles were removed.

Conclusions

1. Mould pressurisation successfully removes bubbles from the polymer melt by creating a pressure difference between the inside and outside of the bubble. By first allowing the polymer to melt in the normal fashion, and then introducing a small positive pressure inside the mould, bubbles are removed.

2. Mould pressurisation allows greater transfer of definition from the surface of the mould to the surface of the part. This could be advantageous when using polished moulds, textured moulds, moulded-in threads or a mould with sharp corners.

3. By removing weaknesses in the moulding due to bubbles and pores, the use of pressure has been shown to increase the mechanical strength of the moulded product. Impact strength can increase as much as 25% and tensile strength typically by 5%.

4. Pressurisation can also reduce the moulding cycle times. By consolidating the melt and removing bubbles at reasonably low temperatures (130-150C), stronger parts can be formed.

5. Mould pressurisation has been shown to reduce the amount by which the part shrinks, by as much as 1%. This could provide an opportunity to reduce the tolerances required for rotationally moulded products.

6. Mould pressurisation can be extremely dangerous if care is not taken. Suitable safety devices (such as pressure relief valves) and safety procedures must be in place before considering mould pressurisation.

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Key Words and Phrases

Rotational Moulding, Pressurisation, Bubbles.

Disclaimer

The effects of pressure described in this paper are known to be safe when used correctly. However, it is the responsibility of the moulder to check that moulds are sufficiently strong to withstand the pressure applied. Great care should be taken to ensure that excessive forces are not generated within the mould, and that adequate safety devices and procedures are in place.

Product Code	Supplier	Polyethylene Type	MFI (g/10 mins)	Density (kg/m^3)	Colour
NCPE 8017	Neste	Medium Density	3.2	934	Natural
NCPE 8113	Neste	Medium Density	3.2	934	Sky Blue
NCPE 8605	Neste	Medium Density	8.0	935	Black
8107	Du Pont	Low Density	5.0	924	Black

Table 1 Materials used during Rotational Moulding Trials

Applied Pressure	Thickness (mm)	Force (kN)	Energy (J)	Energy/mm (J/mm)	Mode of Deformation
0	2.83	1.74	8.16	2.88	Ductile
1 bar for 10 mins	2.76	1.86	9.70	3.51	Ductile
2 bar for 10 mins	2.75	1.81	9.24	3.36	Ductile
3 bar for 10 mins	2.70	1.76	9.42	3.49	Ductile

Table 2 Impact Data (-20C) for Increasing Pressure Levels

Applied Pressure	Tensile Strength (MN/m^2)	2% Secant Modulus (GN/m^2)	Elongation at Break (%)
0	17.53	0.323	200-500
1 bar for 20 mins	18.05	0.327	1000+
2 bar for 20 mins	18.17	0.333	1000+
3 bar for 20 mins	18.76	0.347	1000+

Table 3 Tensile Data for Increasing Pressure Levels

Material Thickness (mm)	Pressure	Shrinkage %			
		50°C	1 day	5 days	30 days
3	0	2.55	3.16	3.18	3.18
3	1 bar/20 mins	1.55	2.09	2.13	2.14
3	2 bar/30 mins	1.40	2.09	2.10	2.11

Table 4 Effect of Pressure on Shrinkage

Material	MFI	Manufacturer's Density Value (kg/m^3)	Density with Bubbles (kg/m^3)	Density without Bubbles (kg/m^3)
NCPE 8113	3.2	934	917	933
Du Pont 8107	5.0	925	918	923

Table 5 Effect of Pressure on Material Density

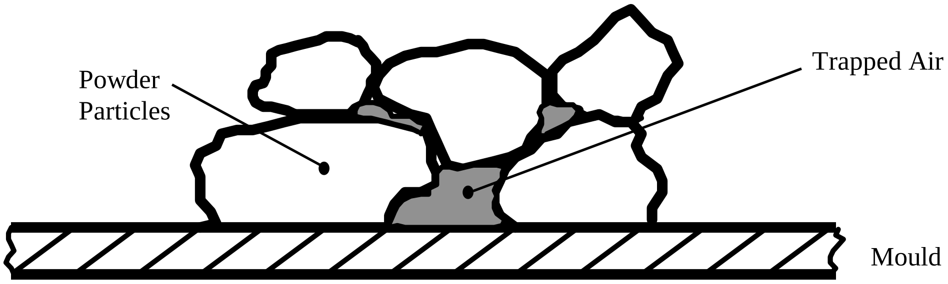

Figure 1 Model for Sintering Concept

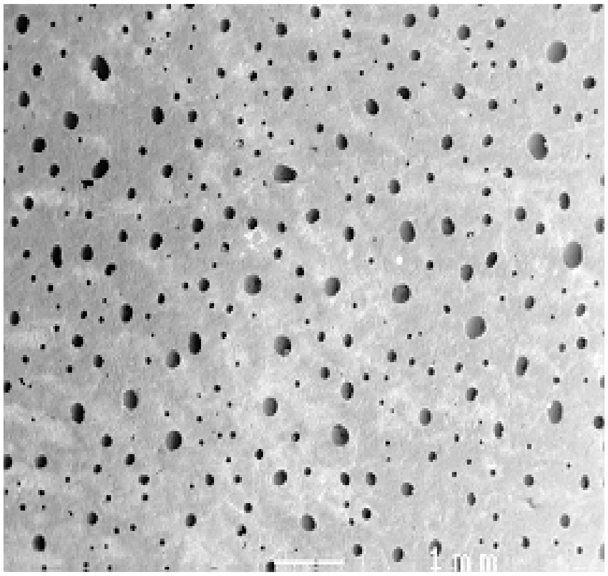

Figure 2 Typical Surface Porosity

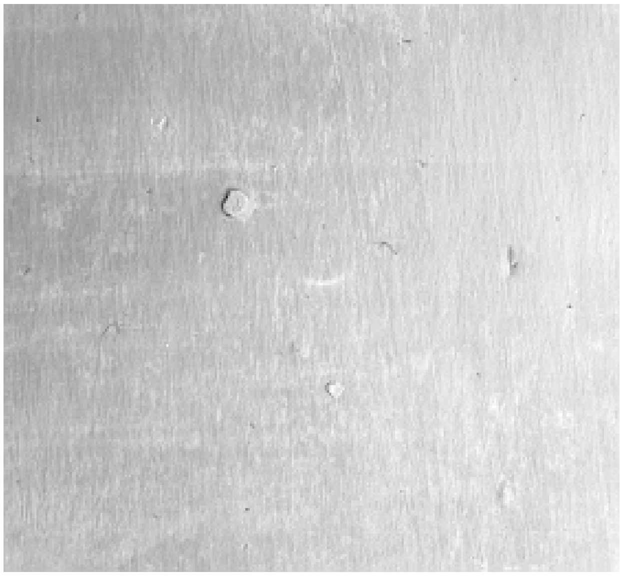

Figure 3 Effect of Pressure on Surface Porosity

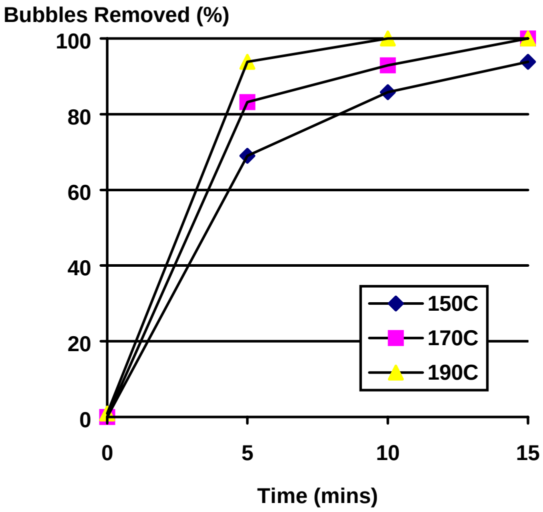

Figure 4 Bubble Density for Various Temps.

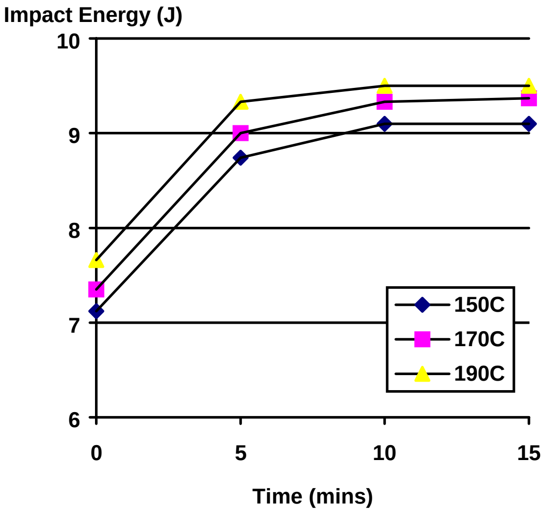

Figure 5 Impact Strength for Various Temps.