Rotational Molding Process Control

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Abstract

Process control for the rotational molding industry has been continually evolving in recent years. Initially, impact strength, and bubble content in the wall of the molded parts, were used to gauge the level of cure and also to control the process. More recently, the development of the Rotolog process control device has provided a more scientific means to ensuring good process control.

This paper highlights some recent work that expands upon the methods previously mentioned, applying new methodology to measure and control the process. The effects of various processing conditions are considered, in particular, with respect to the cooling cycle, and how they relate to process variation. The results outlined provide new processing knowledge that can be used to further develop the control of the rotational molding process.

Introduction

Rotational molding has continued to develop and grow during the last several decades. Initially, rotationally molded products were mainly hollow shapes of simple design. In recent years, the products being produced by the process have become more sophisticated, allowing new markets to be penetrated. Much of this growth has been due to the creativity of designers and molders who have become familiar with the process. Unfortunately, the technological development of the process has not matched the market growth it has enjoyed. In particular, the control of the manufacturing processes necessary to produce parts of consistent high quality has been slow to evolve.

Traditional Process Control Indicators

For most rotationally molded materials, molders have historically relied on basic tests and indicators to gauge the quality of the molded part[1]. These indicators have typically been one of the following:

- Impact strength
- Bubble content
- Internal surface appearance/color
- External surface appearance

While other mechanical tests do exist, dart impact is by far the most widely used and least expensive test to perform. A good quality part will typically yield ductile impact behavior or acceptable impact strength – depending on the material type, density & melt index. Bubble content is probably the next most common process control indicator. High bubble content across the wall thickness of the parts suggests low cure, while little or no bubble content suggests high cure. Typically, molders like to have some bubbles in the wall to know that over-cure has not taken place. For natural parts and most colors, the inner surface of the part can provide more process control information. A lumpy surface texture suggests low cure, while a discoloration suggests over-cure – due to oxidation. The external surface of the part may experience poor fill or surface porosity, suggesting incorrect resin selection, low cure or excessive moisture content. The relationships between these traditional process control indicators are summarized in Figure 1.

While in their own way, the process control indicators listed can provide an effective means to gauge the quality of the molded part. All have the shortcoming of being post-molded tools. Most other plastic processes utilize real-time process indicators that guarantee the quality of the part as it is being produced.

Recent Process Control Indicators

In the early 1990's a new technology known as "Rotolog" emerged as a more scientifically precise way to determine the amount of cure experienced by the part during the molding cycle[2]. The Rotolog consists of an insulated electronic system, (used to take temperature measurements) and a radio frequency transmitter. The Rotolog rides on the arm of the machine, through the oven and cooling cycles, taking temperature measurements from inside the mold and transmitting them in real time to a receiver, linked to a PC. A typical output for a rotational molding cycle using the Rotolog can bee seen in Figure 2. From the Rotolog trace, the following critical points have been identified:

- Point A – The plastic begins to melt and adhere to the wall of the mold.
- Point B – All of the plastic has melted.
- Point C – The peak internal air temp. of the cycle.
- Point D – The point at which the plastic solidifies.

When considering process control, point "C" on the Rotolog trace has the greatest importance, as it reflects the highest temperature experienced by the internal surface of the part. In general, the peak internal air temperature (PIAT) has often been directly correlated to the amount of cure experienced by the part[3 & 4]. This claim has been substantiated by impact testing parts that have been molded to a range of peak internal air temperatures – see Figure 3. Typically, an optimum range of cure can be identified for each material with upper and lower cure boundary limits. This paper investigates alternative methods to using Rotolog data to provide more precise process control.

In recent years, infrared thermometry (IRT) has been pursued as method to provide process control for rotational molding[5]. The system includes an infrared thermometer in the oven and cooling chamber, which can be directly linked to the machine control panel. The thermometers gather temperature information in real time, which is then processed to provide a temperature profile for the external surfaces of the rotating molds. This data can then be used to control the index of the molds to and from the oven and cooler, as well as controlling some of the cooling process parameters.

New Process Control Concept

The proposed new control concept utilizes some of the process control methods previously mentioned, but analyzes the data provided in a different way. The new process control concept uses the area under the Rotolog curve, above the melting temperature of the plastic (120°C for polyethylene), as a process control indicator. Figure 4 defines the "degree of cure" (DoC), with units of degree-minutes. It is suggested that this measurement provides a more accurate means to gauge cure than any of the more recent technology methods mentioned, as it can compensate for variations in molding cycle conditions. It is believed that this method takes into account the "time" aspect of processing as well as "temperature", providing a time-temperature control parameter.

The Influence of the Heating Cycle on the New Process Control Concept

Changes to the oven cycle demonstrate the benefits of measuring DoC. For example, Figure 5 illustrates internal air temperature measurements of the same part molded at three different oven temperatures on a Ferry 220 machine, using a cast aluminum mold (approximately 560 x 445 x 267 mm). For these parts, the peak internal air temperature was approximately 210°C for the 370 °C and 315 °C oven settings and 202°C for the 260°C oven setting. Typically, in this PIAT range, a higher peak internal air temperature would produce higher mean failure energy impact values. Figure 6 illustrates that at relatively similar PIATs, the impact energy can be significantly different depending on the processing parameters. In fact, this trend indicates that the impact strength decreases with increasing PIAT, which is opposite of what is expected.

The DoC was also measured (illustrated in Figure 6) for the three molding trials. This trend indicates the results as would be expected for this type of molding scenario; i.e. higher degree of cure correlates to higher impact energy.

The same correlation holds true for the traditional measurement of cure at various wall thickness. Richard Treacy [7] demonstrated this by molding a series of parts in a cube shaped mold at Queen's University Belfast, using an oven temperature of 350°C with an air-only cooling cycle. Several materials were molded with the same range of peak internal air temperatures and ARM impact resistance was measured on each molding. Figures 7 & 8 illustrate bubble content, DoC and impact strength, plotted against PIAT, for a 3.2mm wall thickness of part. The results indicate that the correlation is similar to what we would expect when using PIAT as a process control indicator, in that higher degree of cure result in better impact resistance. However, Figure 7 confirms that an upper cure limit exists, where impact strength drops off, due to oxidation of the inner surface of the part. Treacy also repeated these experiments with thicker-walled parts (see Figure 9 as an example) and found that similar relationships existed. However, the degree of cure value increased significantly, therefore making it difficult to use generic DoC numbers when trying to use this method as a process control indicator for parts of variable wall thickness.

The Influence of the Cooling Cycle on the New Process Control Concept

This work also demonstrated that the cooling cycle can have a significant influence on the amount of cure experienced by the part. By keeping the oven cycle constant and varying the cooling parameters, a range of DoCs can be created. This was investigated varying the following cooling parameters:

- Ambient temperature
- Velocity of the cooling air
- Amount of water used
- Water particle size
- Air delay

These parameters were varied to produce a number of parts with uniform wall thickness, and PIAT of 211 +/- 3°C. The Rotolog traces for these cycles can be seen in Figure 10.

Impact testing, bubble analysis, and DoC measurements were taken for each molding and the results illustrated in Figures 11 and 12. From Figure 11, the results confirm a strong relationship with increasing Degree of Cure, resulting in the reduction of bubble content in the wall of the part. It should be noted that PIAT of the parts molded remained constant during this set of experiences. The reduction in bubble content, in turn yielded increased impact strength as shown in Figure 12. Figure 12 also suggests that a relationship exists between DoC and impact strength. Increasing the DoC, increases impact strength – until a point at which the material oxidizes.

Another potential reason for the change in impact values may be due to differences in the crystalline structure of the polymer, due to different cooling rates[8]. However, the cooling conditions used for these experiments utilized small amounts of water (less than 2.5 minutes), suggesting that the difference in crystalline structure would be minimal. The over-riding factor would appear to be the reduction in bubble content due to increasing Degree of Cure, yielding high impact strength.

Conclusions

From this work, the following conclusions are suggested:

1. Monitoring the peak internal air temperature using the Rotolog device can provide a reasonable accurate means to judge the cure of the part – provided there are no significant changes in the heating and cooling parameters.
2. Monitoring the degree of cure has the potential to provide a high level process control indicator, that correlates to traditional methods to gauge cure, such as bubble content in the wall of the part and impact strength.
3. The Rotolog peak internal air temperature measurement provides a reasonably generic value that can be used as a process control indicator for a wide range of part wall thickness. This is not the case when considering the degree of cure, as the DoC value will increase, with increasing part wall thickness. While this is not necessarily a limitation, it could make analysis of the data more complicated.

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Key Words and Phrases

Rotational Molding, Process Control, Rotolog, Degree of Cure

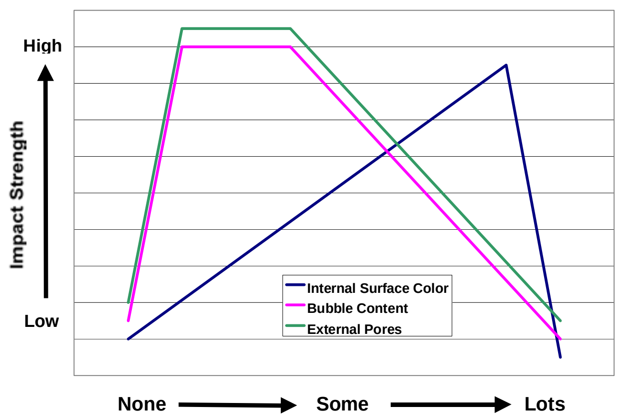

Figure 1 Traditional Process Control Relationships

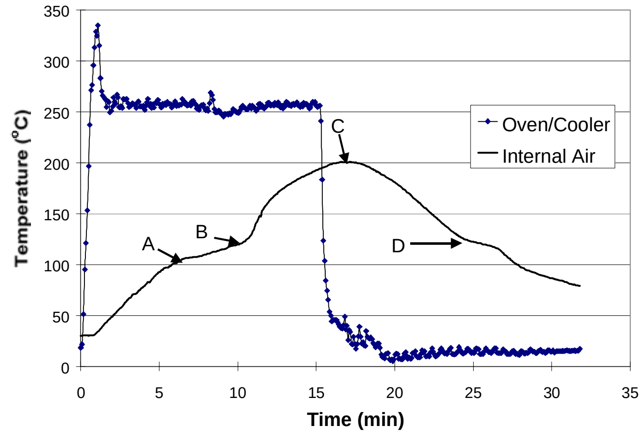

Figure 2 Typical Rotolog Trace

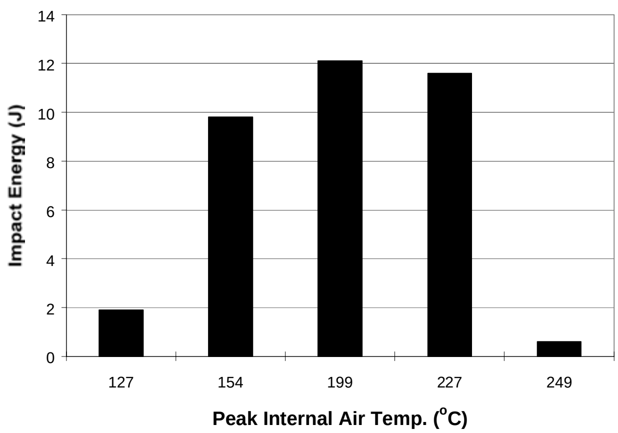

Figure 3 Mean Failure Energy (ARM Impact Test)

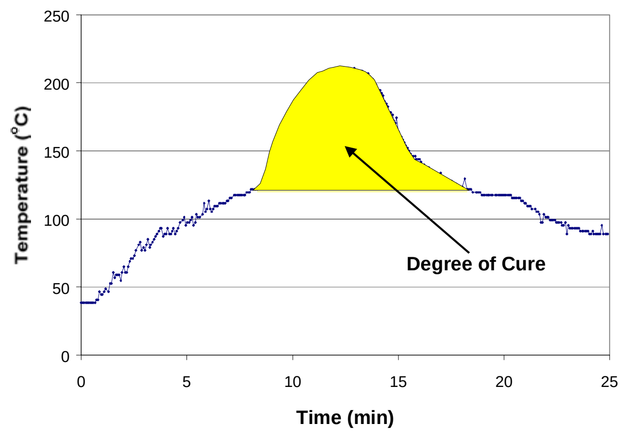

Figure 4 Definition of Degree of Cure

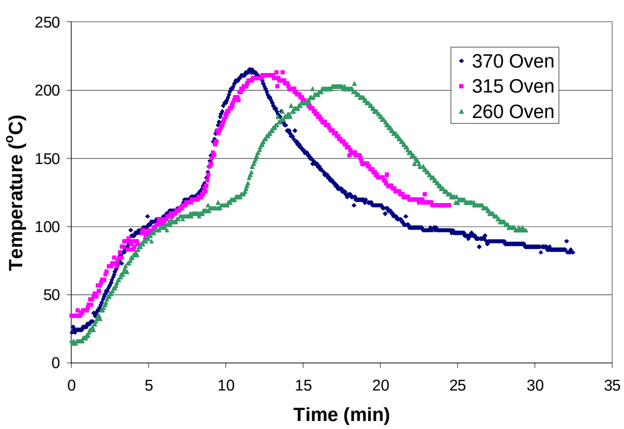

Figure 5 Rotolog Trace at Three Oven Temperatures

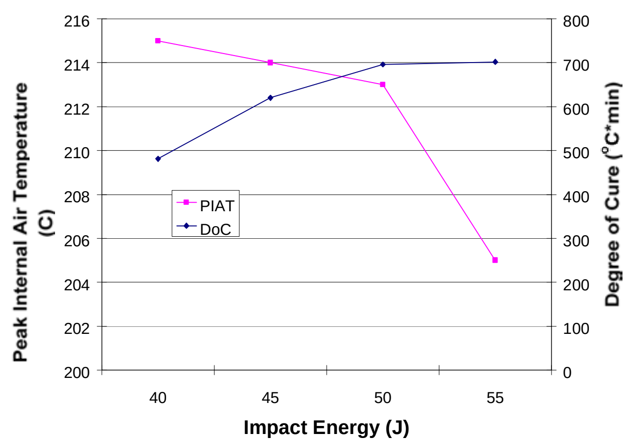

Figure 6 PIAT and DoC vs. Impact

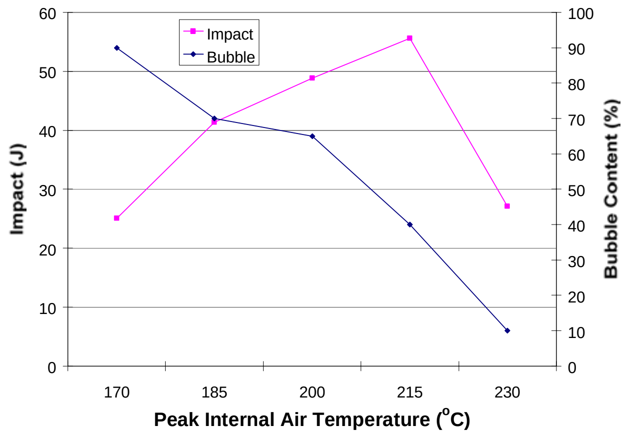

Figure 7 Treacy Impact and Bubble Content for 3.2 mm Wall

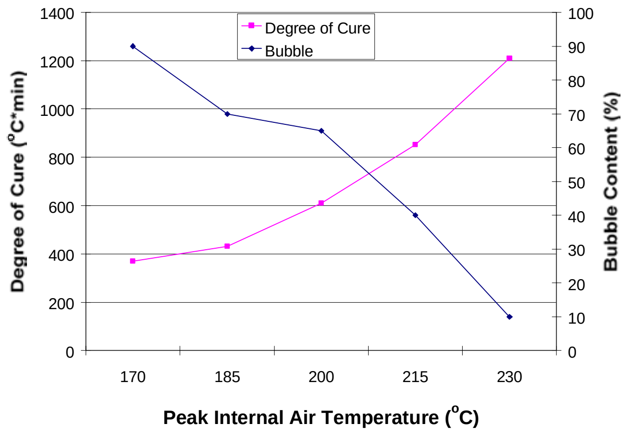

Figure 8 Treacy DoC and Bubble Content for 3.2 mm Wall

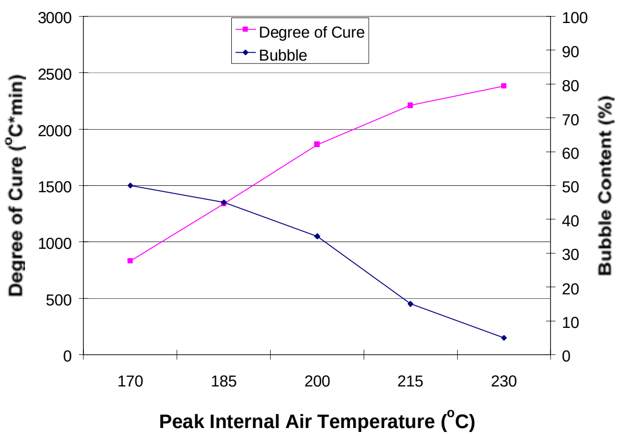

Figure 9 Treacy DoC & Bubble Content for 9.5mm Wall

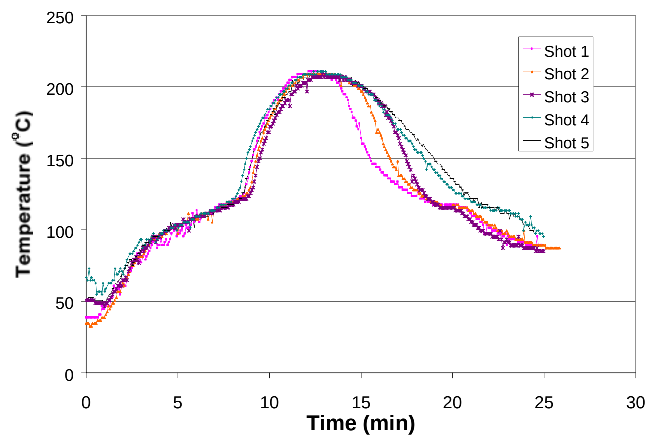

Figure 10 Rotolog Trace of Various Cooling Cycles

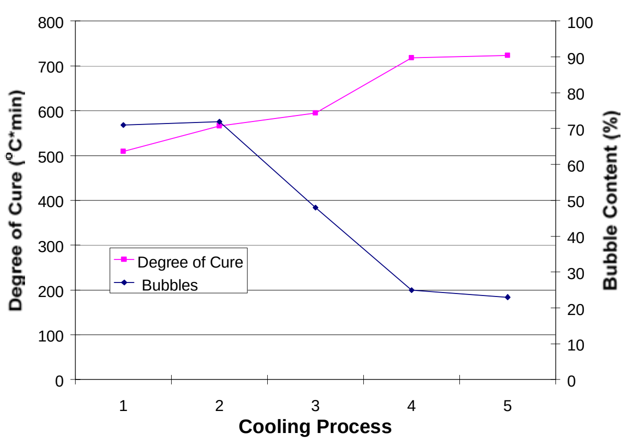

Figure 11 Effect of Cooling on DoC and Bubble Content

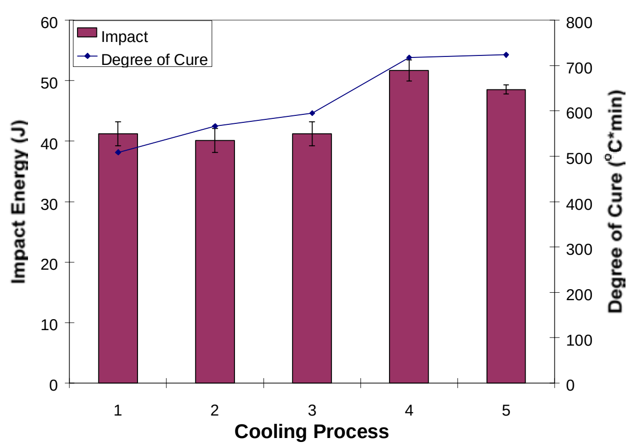

Figure 12 Effect of Cooling on Impact and Degree of Cure