

# AN ADDITIVE APPROACH TO CYCLE TIME REDUCTION IN ROTATIONAL MOLDING

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## Introduction

Rotational molding is a versatile process for the production of a wide variety of plastic parts,<sup>1</sup> but suffers from the disadvantage of long cycle times as compared to other plastic processing methods.<sup>2</sup> A Cycle Time Reduction Committee commissioned by ARM found that rotational molding cycle times can be decreased by up to 50% by adoption of three technologies:<sup>3</sup>

1. The use of internal air pressure to accelerate the sintering and densification process during heating;
2. The use of internal air cooling to speed up the solidification process during cooling; and
3. Monitoring of internal air temperature and pressure to enable improved process control.<sup>4</sup>

The rate of densification is also influenced by the molecular architecture of the polymer. Recently new grades of LLDPE manufactured using single-site catalyst technology have been introduced which exhibit faster densification vs. conventional Ziegler-Natta grades.<sup>5</sup>

Existing solutions to provide faster densification are not completely satisfactory. For example, molders are often reluctant to conduct rotational molding under pressure due to problems with flashing at parting lines as well as safety concerns. The new fast processing grades manufactured using single-site catalyst technology are not yet readily available globally. Thus there is a need for an alternative method to increase the rate of sintering and/or densification during the heating phase of the process to help enable shorter cycle times.

Processing stabilizers (typically combinations of primary and secondary antioxidants) are normally added to polyethylene to prevent oxidative degradation during exposure to heat and oxygen in the rotomolding process.<sup>6</sup> This paper reports the results of studies using special processing stabilizer systems which provide the ancillary benefit of accelerated sintering/densification during the rotomolding process.

## Results & Discussion

### Selection of Polymer Substrate and Formulations

The polymer used in this study was a high viscosity (low MFI) grade of LLDPE (hexene copolymer) recommended for tanks. Grades such as this one having a high viscosity and low MFI have been previously reported to be especially problematic in terms of densification and bubble removal in the rotomolding process.<sup>7</sup> Typical stabilization systems used in rotational molding LLDPE grades comprise a hindered amine light stabilizer to provide weatherability and a processing stabilizer (usually a combination of a hindered phenol and a phosphite) to protect the polymer from oxidation during the rotomolding process. Other components such as ultraviolet absorbers may also be included. Additives such as zinc stearate are usually incorporated to deactivate trace catalyst residues and provide a lubricating effect for improved mold release. The additive formulations used in this study are summarized in Table 1. The "Control" formulations are examples of standard stabilization systems that have been recommended for rotational molding grades by major additive suppliers. The

“New” formulations are combinations of a conventional hindered amine light stabilizer with new developmental processing stabilizer systems.

Table 1. Additive Formulations.

<b>Formulation</b>	<b>Composition</b>
Control 1	0.20% TINUVIN <sup>®</sup> 783 (hindered amine light stabilizer) 0.15% IRGANOX <sup>®</sup> B 215 (conventional process stabilizer) 0.05% zinc stearate
Control 2	0.20% CYASORB <sup>®</sup> UV 3346 (hindered amine light stabilizer) 0.075% CYANOX <sup>®</sup> AO 2777 (conventional process stabilizer) 0.05% zinc stearate
New 1	0.20% TINUVIN <sup>®</sup> 783 (hindered amine light stabilizer) 0.15% Proprietary Process Stabilizer 1 0.05% zinc stearate
New 2	0.20% TINUVIN <sup>®</sup> 783 (hindered amine light stabilizer) 0.20% Proprietary Process Stabilizer 2 0.05% zinc stearate

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#### **Additive Effects on Part Curing: Impact Strength, Density, & Color**

The morphological changes that take place during rotational molding have been extensively studied.<sup>1,7</sup> During the heating phase of the process the powdered polymer first undergoes sintering to give a three-dimensional structure containing numerous trapped air bubbles. The air bubbles represent imperfections in the part and serve to lower the impact strength and other mechanical properties. As heating continues the bubbles are gradually removed from the part by a process referred to as densification. During this process the density of the part increases and mechanical properties such as impact strength also increase. Bubble removal has been reported to be especially problematic in polymer grades having high molecular weight (low MFI, high viscosity), which has been attributed to slow diffusion of air.<sup>7</sup>

The evolution of impact properties with increasing peak internal air temperature (PIAT) is summarized in Figure 1. Formulations “New 1” and “New 2” are notable in that they reach optimal impact properties at a lower PIAT compared to the “Control 1” and “Control 2” formulations. All formulations tested provided good impact strength up to a PIAT of *ca.* 220°C. The new formulations are also notable in that they provide a broad processing window, *i.e.* they enable the production of parts having a high impact strength over a broader range of PIAT and heating times relative to the control formulations.

Changes in density over a range of PIAT are summarized in Figure 2. As expected, density increases with increasing PIAT until the nominal density of the polymer is attained. The “New 1” and “New 2” formulations reach the nominal density at a lower PIAT than the “Control 1” and “Control 2” formulations. Density and impact measurements give excellent agreement in assessment of optimal cure of rotomolded parts.

Rotomolded parts are subject to increasing discoloration as PIAT and heating times are increased. This effect is due to oxidation of the polymer substrate as well as the transformation of phenolic antioxidants (*i.e.* processing stabilizer components) into colored products.<sup>8</sup> Figures 3 and 4 show changes in part color (Yellowness Index) over a range of PIAT. As expected, discoloration is slightly more pronounced on the inside of parts at higher PIAT as a result of exposure to air. The “New 1” and “New 2” formulations provide the least discoloration during molding.

Figure 1. Impact Testing (-40°C) Results for Rotomolded Test Plaques.

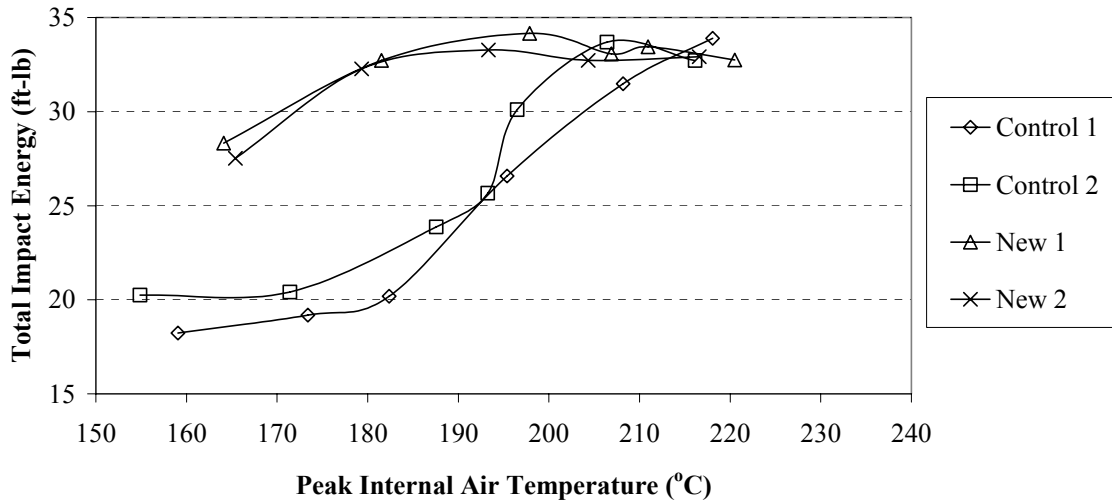


Figure 2. Changes in Part Density as a Function of Peak Internal Air Temperature.

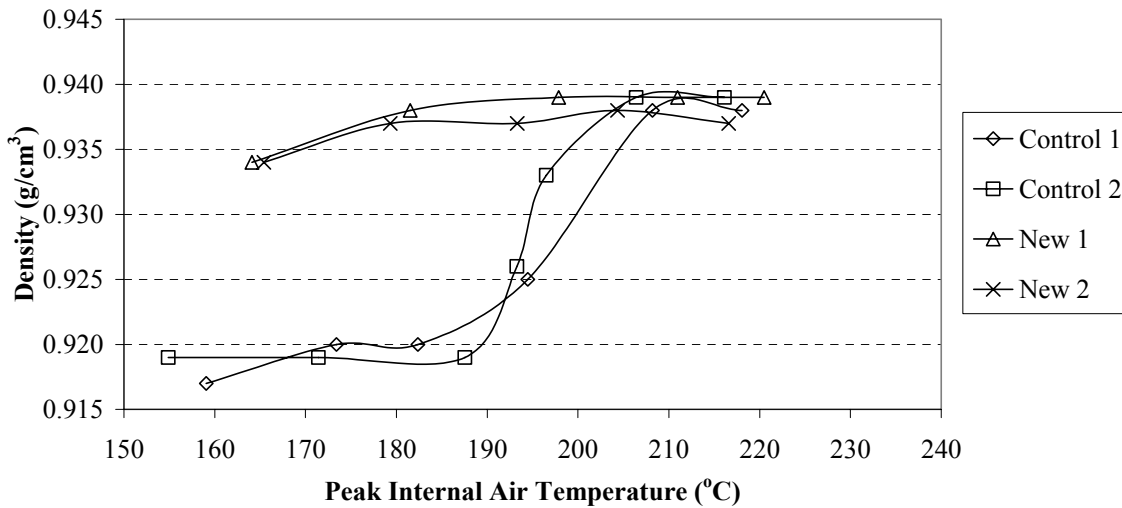


Figure 3. Changes in Part Color (Inner Surface) as a Function of Peak Internal Air Temperature.

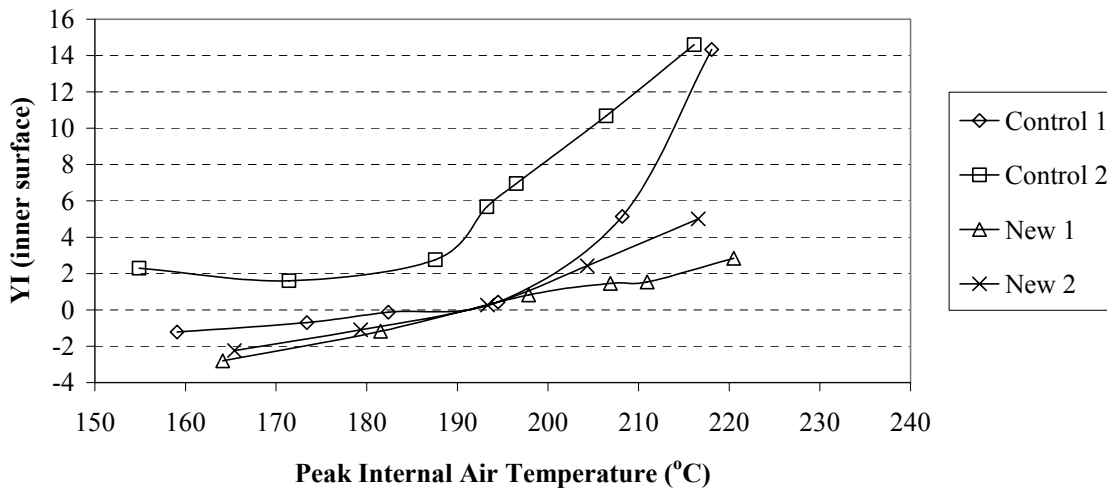
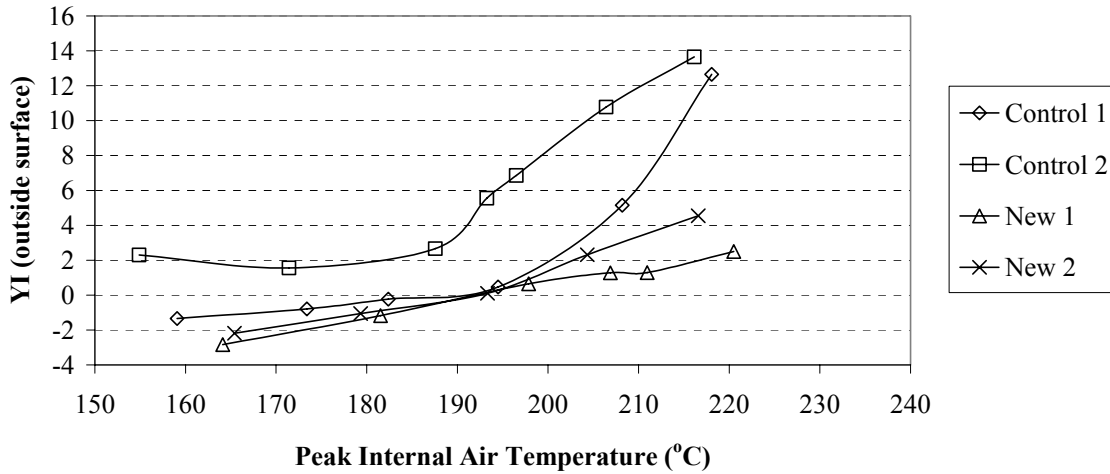


Figure 4. Changes in Part Color (Outside Surface) as a Function of Peak Internal Air Temperature.



Properties of parts molded to optimum cure are summarized in Table 2. The “New 1” and “New 2” formulations achieve optimum cure at lower PIAT and shorter heating times than the controls. Color of the part at optimum cure is improved for the new formulations due in part to the shorter heating times and also the reduced discoloration characteristics of the new processing stabilization systems.

Table 2. Summary of Additive Effects on Part Curing.

Formulation	PIAT at Optimum Cure (°C)	Heating Time to Optimum Cure (min)	Total Cycle Time* (min)	Total Impact Energy (ft-lb)	Density (g/cm <sup>3</sup> )	YI (inside)
Control	208	14	38	31.5	0.938	5.2
Control 2	206	14.5	39	33.7	0.939	14.6
New	181	13	35	32.7	0.938	-1.2
New 2	179	12	35	32.3	0.937	-1.1

\* End of cycle defined as when PIAT drops below 100°C.

### Implications for Cycle Time Reduction

The results demonstrate that the heating times required to attain optimal part cure can be reduced through selection of the proper stabilization formulations such as “New 1” and “New 2”. Reduction of heating times provides the direct benefits of lower energy costs and reduced discoloration during molding. Translating shorter heating times into reduced overall cycle times and improved molding productivity will be dependent on a number of factors, including the type of molding machine, part thickness, part geometry, and the use of other types of cycle time reduction technology such as internal air-cooling of the part.

When clamshell or single-carriage shuttle machines are used for molding the heating and cooling steps are conducted sequentially. In this case some cycle time reduction can be realized by reduction of the heating times. In the present laboratory study conducted using a clamshell machine the overall cycle time could be reduced from 38-39 minutes to 35 minutes using either of the new formulations. Further reduction of cycle time should be achievable using internal air-cooling to shorten the cooling time.<sup>3</sup>

In the operation of dual-carriage shuttle designs (1 heating and 2 cooling stations), cycle time reduction should be possible if the heating step is the rate-limiting step in the overall process. This would also be the case for fixed- and independent-arm turret machines. For parts where longer cooling times are required, the use of two cooling stations may render the heating step rate limiting

and enable cycle time reduction. Alternatively, internal air-cooling could be employed to shorten the cooling time and enable shorter molding cycles.

## Conclusions

New processing stabilization systems have been developed which accelerate the polymer densification process during rotational molding and enable parts to be molded at lower peak internal air temperatures and shorter heating times. As a result, the new systems can provide reduced discoloration during molding, lower energy costs, and the potential for cycle time reduction. The use of the new systems presents an excellent alternative to other approaches to acceleration of the densification process such as molding under pressure. The new systems also give a broad processing window, enabling the production of parts having high impact strength over a broader range of PIAT or heating times vs. conventional systems.

Additional work is planned to study the mechanism by which the new stabilization systems accelerate the densification process and to better define the benefits that can be achieved through their use in rotational molding.

## Experimental

### Polymer Substrate

A standard rotomolding grade of Ziegler-Natta, hexene-LLDPE was used having a density of 0.938 g/cm<sup>3</sup> and a nominal MFI of 3 dg/min. The formulations were prepared from minimally stabilized “barefoot” resin and additives by single-screw extrusion compounding. The extruded pellets were ground to a powder using a Reduction Engineering Model 50 pulverizer with a gap size of 0.330 mm at a temperature of 60-70°C. Typical powder properties are given in Table 1.

Table 3. Typical Powder Properties.

Property		Typical Values
Bulk density (g/cm <sup>3</sup> )		0.33
Flow rate (sec/100 g)		28.2
Particle size distribution	< 150 μm	23.5%
	150-212 μm	26.8%
	212-300 μm	29.4%
	300-425 μm	16.3%
	425-500 μm	1.9%
	500-600 μm	1.9%
	> 600 μm	0.2%

### Rotomolding

Cubes (12 inch sides, 4 mm thick) were molded using an aluminum mold in a Ferry FSP M20 clamshell machine at an oven temperature of 525°F (274°C). The heating times were varied in order to mold parts over a range of peak internal air temperatures. The cooling cycle involved air-cooling with two intervals of water spray. Rotation speed was 6 rpm on the primary axis and 1.5 rpm on the secondary axis. The mold was pretreated with a semi-permanent mold release (Mono-Coat 1001W from ChemTrend). Internal air temperature was measured during molding using a Type J thermocouple probe with data acquisition every 10 seconds using an OM-CP series data logger and software (Omega Engineering).

### **Impact Testing**

Rotomolded plaques were conditioned at  $-40^{\circ}\text{C}$  for a minimum of 48 hours and impacted according to ASTM D-3763 using a Dynatup impact tester (10 replicates). The outside surface of the part was subjected to impact.

### **Density Measurements**

Density was measured at room temperature using an air compression pycnometer.

### **Color Measurements**

Yellowness index measured according to ASTM 1925-77 using a DCI SF600 spectrophotometer.

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