WHAT HAPPENS DURING COOLING?

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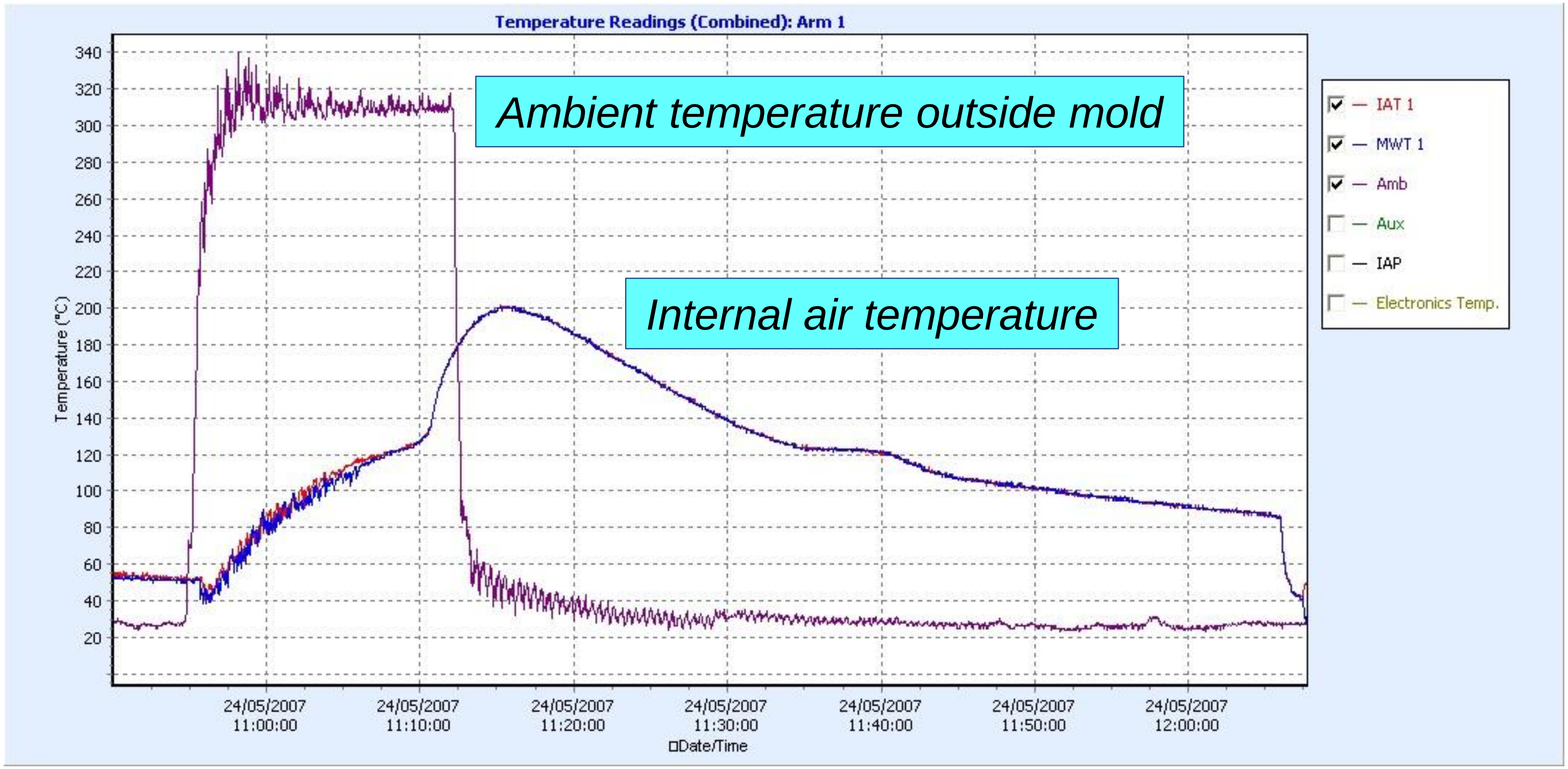
PRESENTATION OVERVIEW

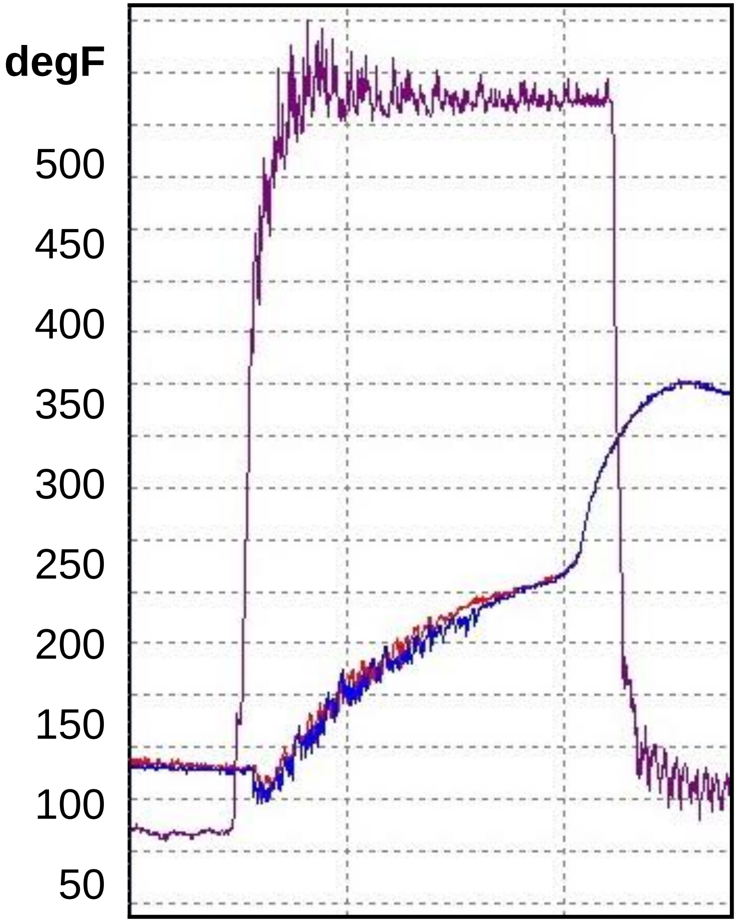
- ***Anatomy of the cooling cycle***
- ***Cooling polyethylene & similar polymers***
- ***Conclusions & discussion***

ANATOMY OF THE COOLING CYCLE

TYPICAL TEMPERATURE TRACE



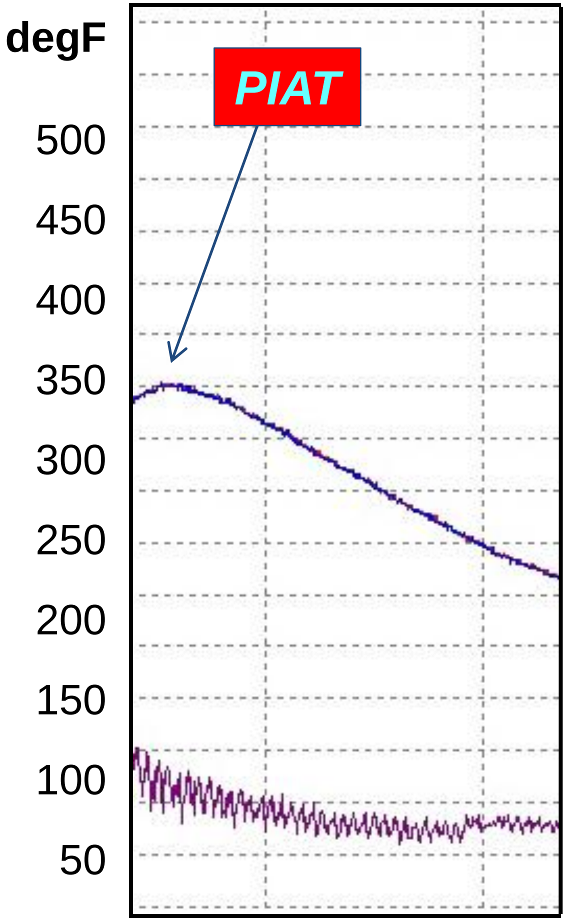
COOLING – STAGE 1



Ambient temperature drops rapidly as mold exits the oven.

*Internal air temperature continues to rise, even **after** mold is withdrawn from oven. Typically, overshoot is 30 – 40 °F (depends on wall thickness). For polyethylene, a Peak Internal Air Temperature (PIAT) of 370–430 °F is recommended, in order to ensure correct cure of material.*

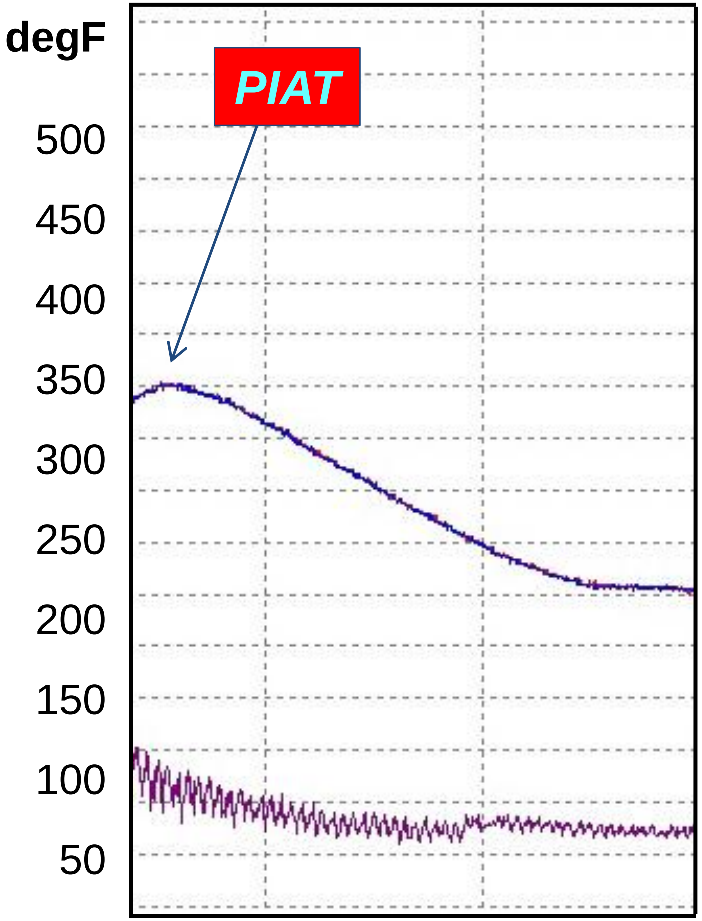
COOLING – STAGE 2



Internal air temperature drops from its peak value as the mold cools. Cooling rate at this stage is relatively fast, because the material is still in contact with mold and conductive heat transfer is possible.

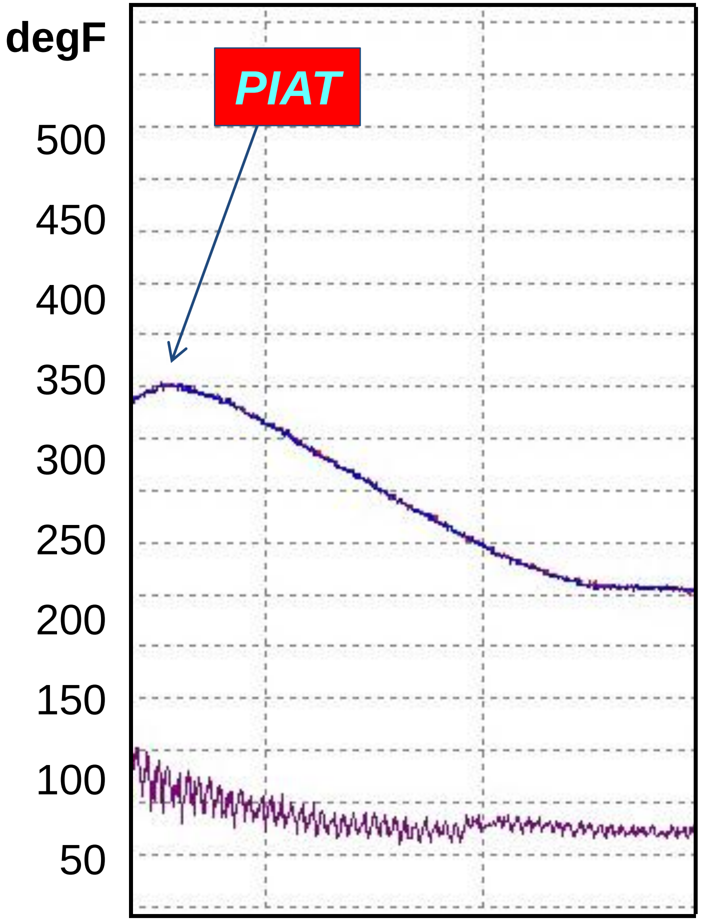
Ambient settles down at near to ambient factory temperature.

COOLING – STAGE 3



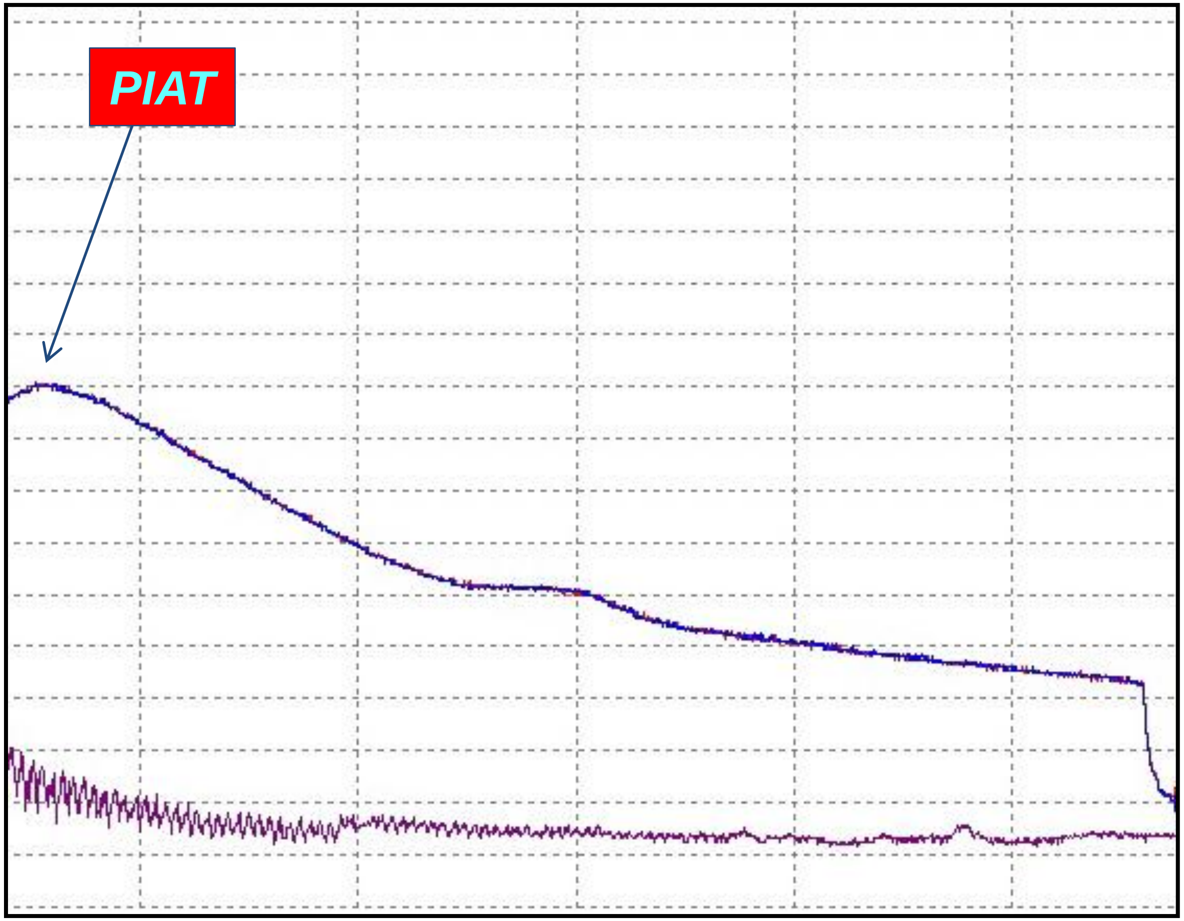
Internal air temperature starts to flatten as latent heat of crystallization is released.
In the case of semi-crystalline polymers like polyethylene, crystallization is accompanied by ***shrinkage*** *and the material starts to separate from mold wall.*

COOLING – STAGE 4



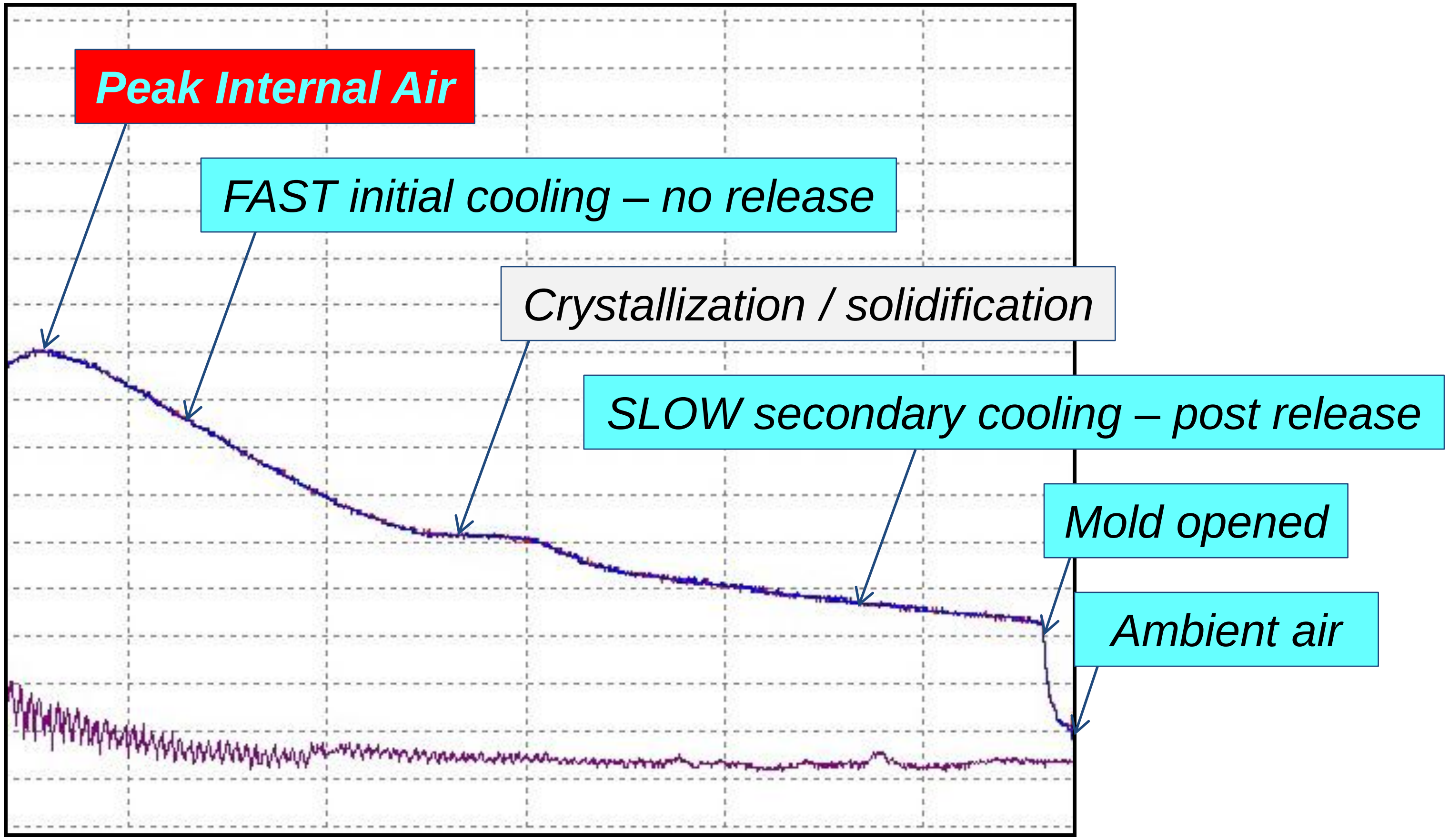
Internal air temperature drop slows significantly after release (ie separation) of material from mold wall, because the resultant small air gap reduces heat transfer rate.

DE-MOLDING



Internal air temperature drops almost to factory ambient as soon as mold is opened.

COOLING – SUMMARY



COOLING TARGETS (PE)

- *Overshoot after oven exit: 30 – 40 °F (depends on wall thickness)*
- ***Peak IAT: 370–430 °F***
- *Crystallization plateau, IAT: 260 °F*
- ***Release point, IAT: 200 – 260 °F***
- *Demolding point, IAT: 190 °F and below*

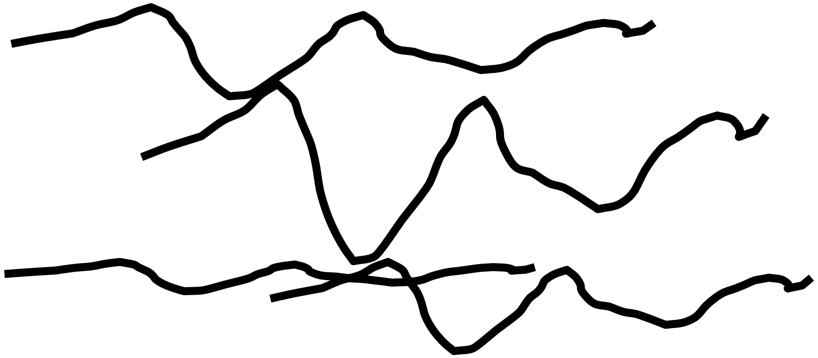
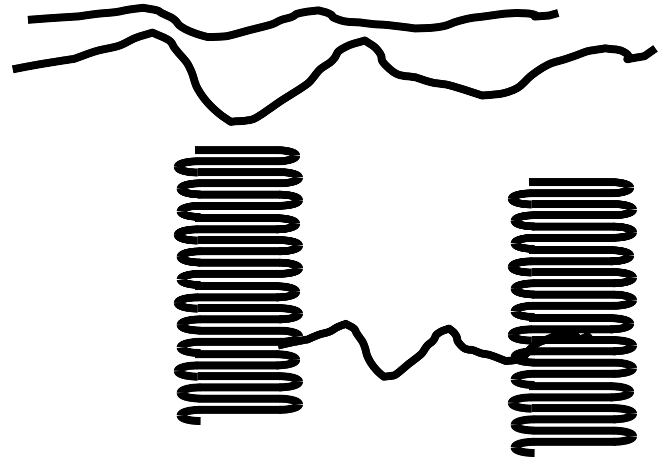
COOLING POLYETHYLENE & OTHER POLYMERS

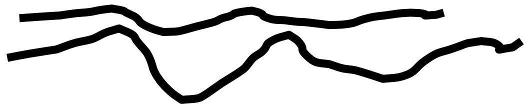
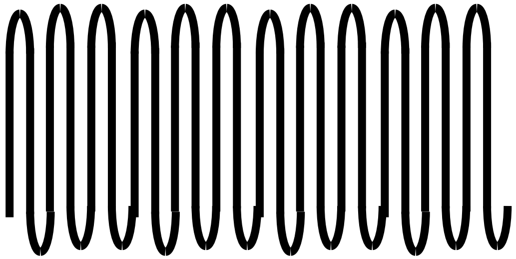
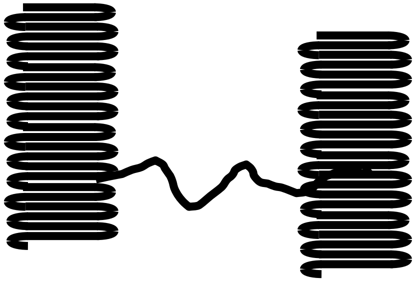
POLYMER COOLING BASICS

- *PE is a semi-crystalline polymer*
- *So are PP, PA & POM*
- *Semi-crystalline polymers shrink*
- *PC & PVC are amorphous polymers*
- *Amorphous polymers don’t shrink*

COOLING POLYETHYLENE

- *PE is a semi-crystalline polymer*
- *Solid PE contains areas that are crystalline & areas that are amorphous*
- *Crystalline areas are responsible for shrinkage*
- *Variable (uncontrolled) shrinkage creates warpage*
- *Shrinkage (& warpage) are affected by the rate of cooling & the release point*

Melt State of PE	Totally Amorphous	
Solid State of PE	Partially Amorphous Partially Crystalline Tie Molecules	

		Increases
Amorphous Phase		Flexibility Transparency Ductility Long-term properties
Crystalline Phase		Stiffness Opacity Brittleness Shrinkage
Tie Molecules		Ductility Resistance to fatigue Long-term properties ESCR

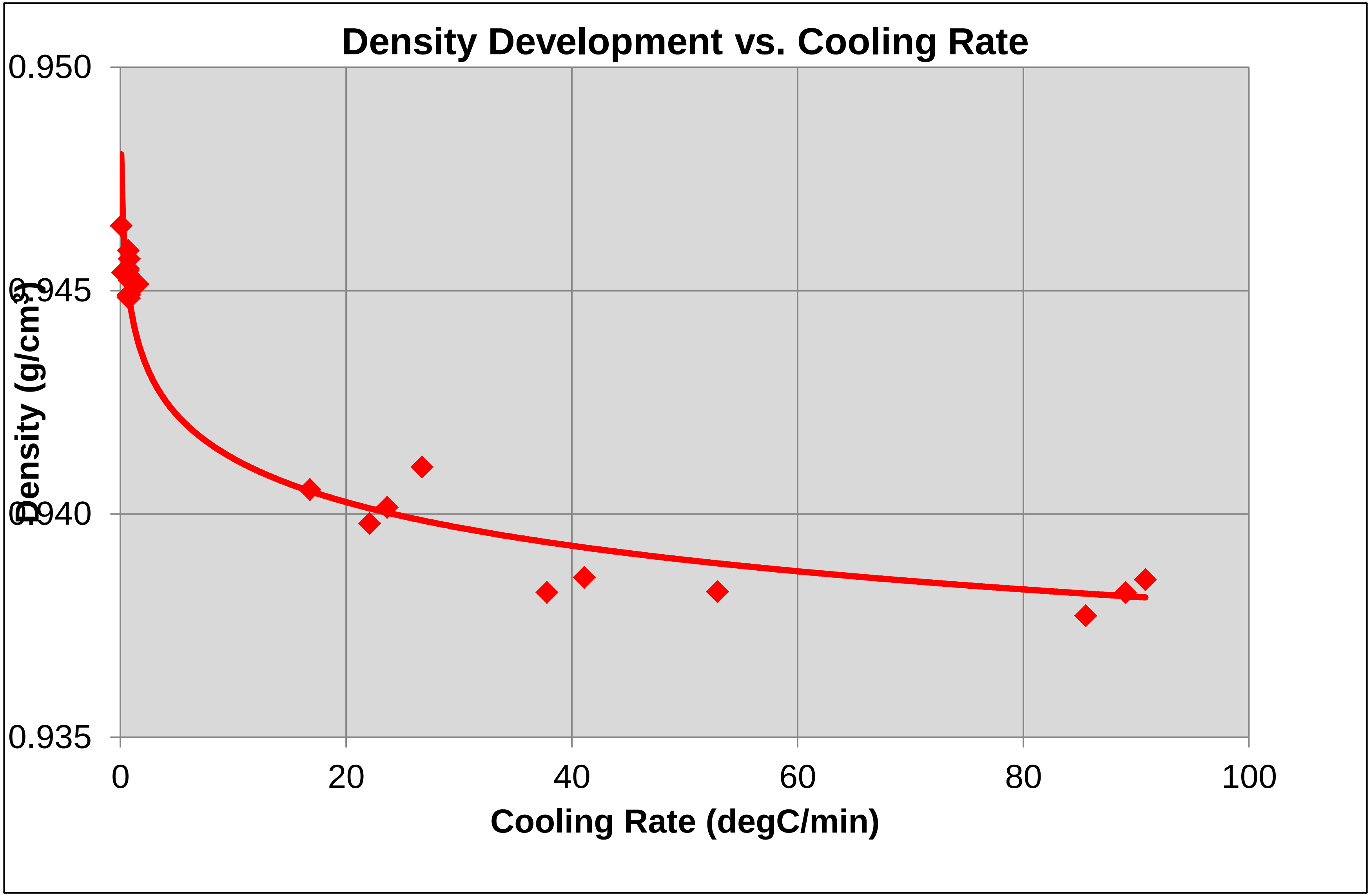
COOLING RATE/RELEASE POINT

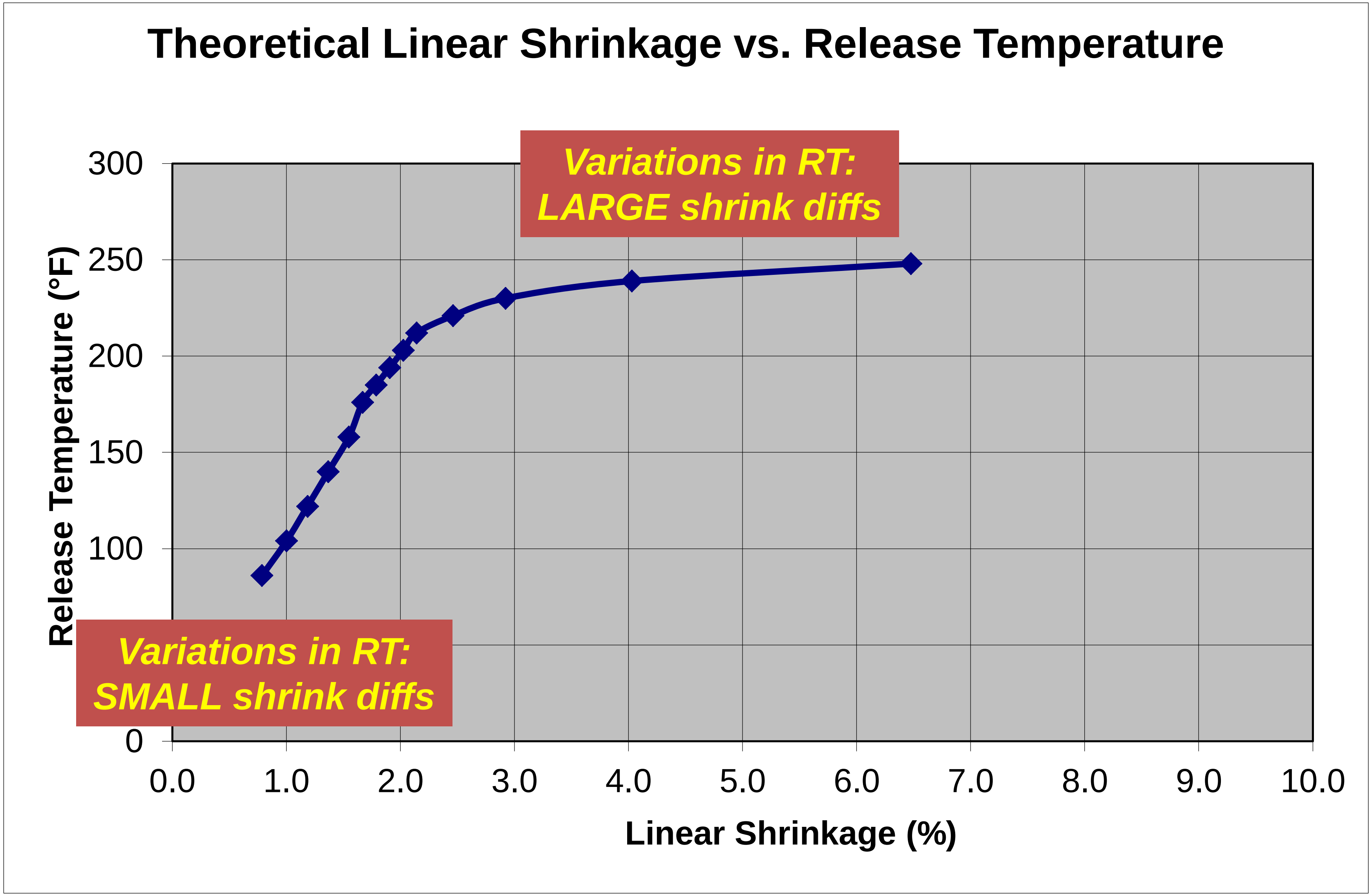
- ***Shrinkage (& warpage) are affected by the rate of cooling & the release point***
- ***Cooling rate for rotomolding is SLOW, compared to other molding processes***
- ***Limits on our current ability to control cooling rate***
- ***Release point depends on many factors & cannot be controlled directly***

FAST Cooling	**Relatively LOW Crystallinity** **Relatively LOW Density** **LESS Shrinkage - !!!**
SLOW Cooling	**Relatively HIGH Crystallinity** **Relatively HIGH Density** **MORE Shrinkage - !!!**
VARIATIONS in Cooling	**VARIABLE Effects** **Variations BETWEEN Mouldings** **Variations WITHIN the SAME Moulding**

COOLING AFFECTS DENSITY

DATA SHEET Cooling (eg ASTM D4703, Proc. C) 15 °C/min (27°F/min)	**0.939 g/cm^3**
FAST Cooling (eg water quench) 100 °C/min (180°F/min)	**0.936 g/cm^3**
SLOW Cooling (eg leave overnight) <1 °C or °F / min	**0.945 g/cm^3**


Density Development vs. Cooling Rate
0.950
0.945
0.940
0.935
Density (g/cm³)
0
20
40
60
80
100
Cooling Rate (degC/min)


Theoretical Linear Shrinkage vs. Release Temperature
Variations in RT: LARGE shrink diffs
Variations in RT: SMALL shrink diffs
Release Temperature (°F)
300
250
200
150
100
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Linear Shrinkage (%)

CONCLUSIONS & DISCUSSION POINTS

CAN I CONTROL COOLING?

SCARY VERSION…

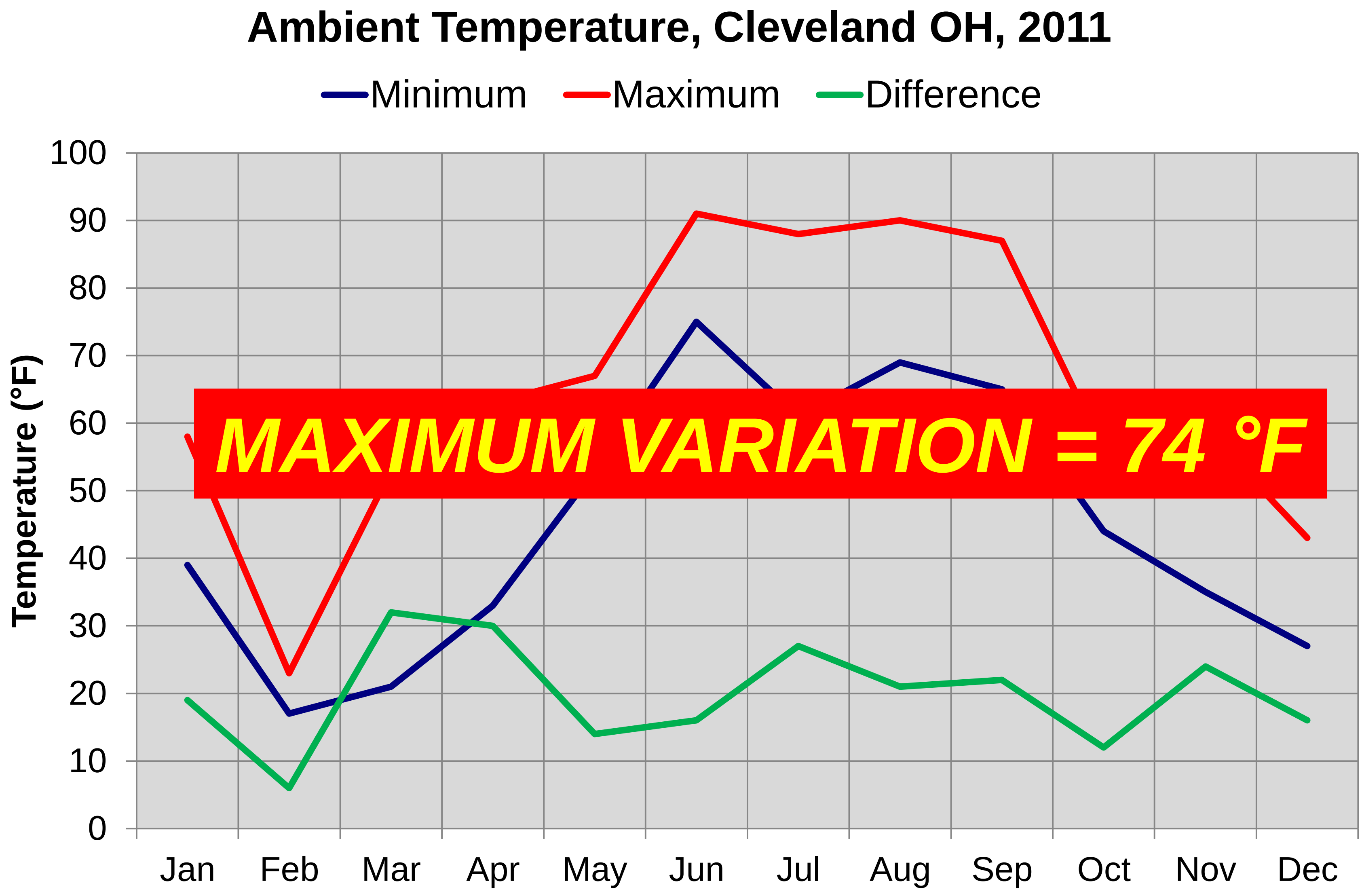
Not Completely!

REALLY SCARY VERSION…

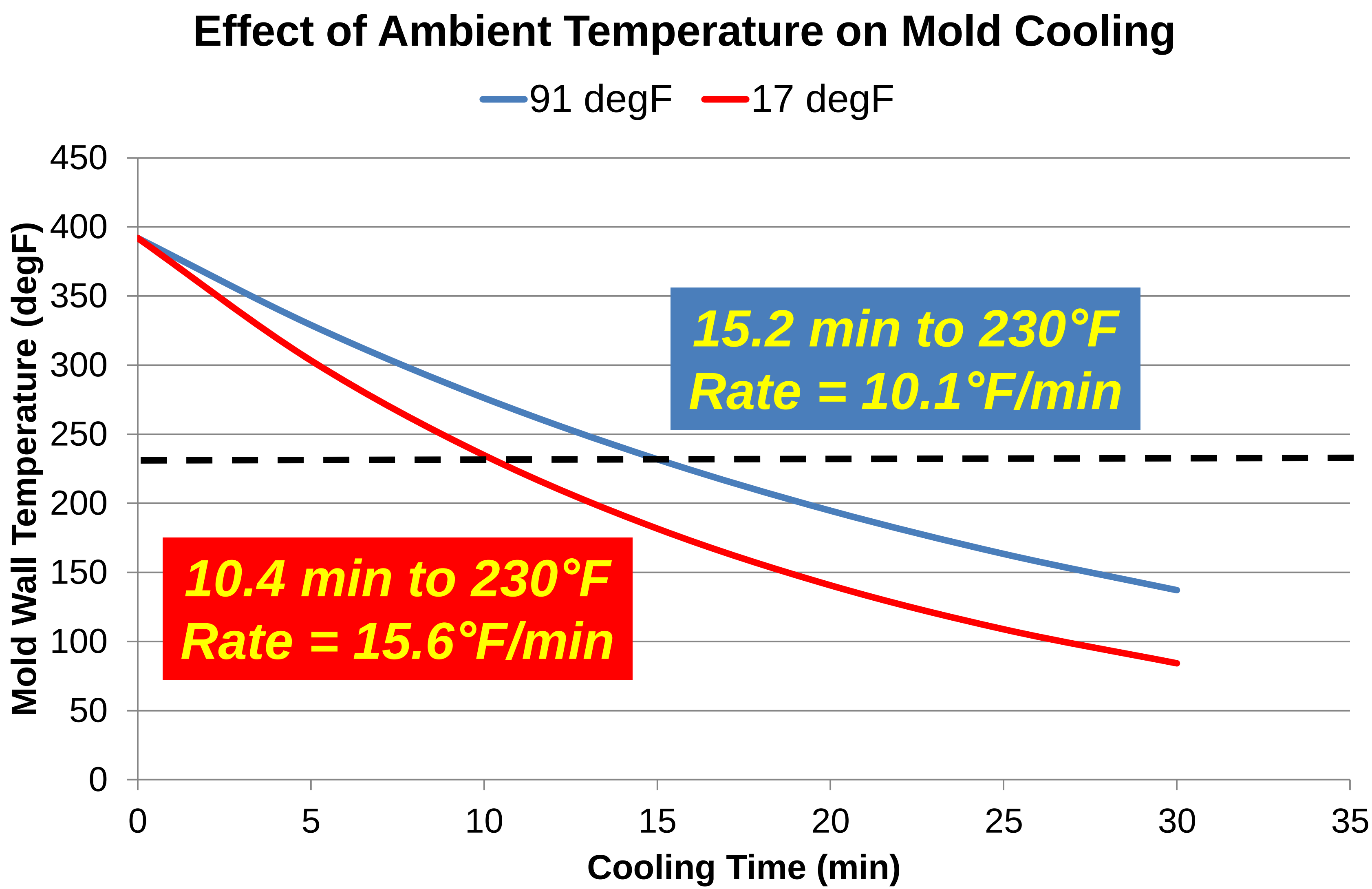
Maybe not at all!

SO WHAT'S STOPPING ME?

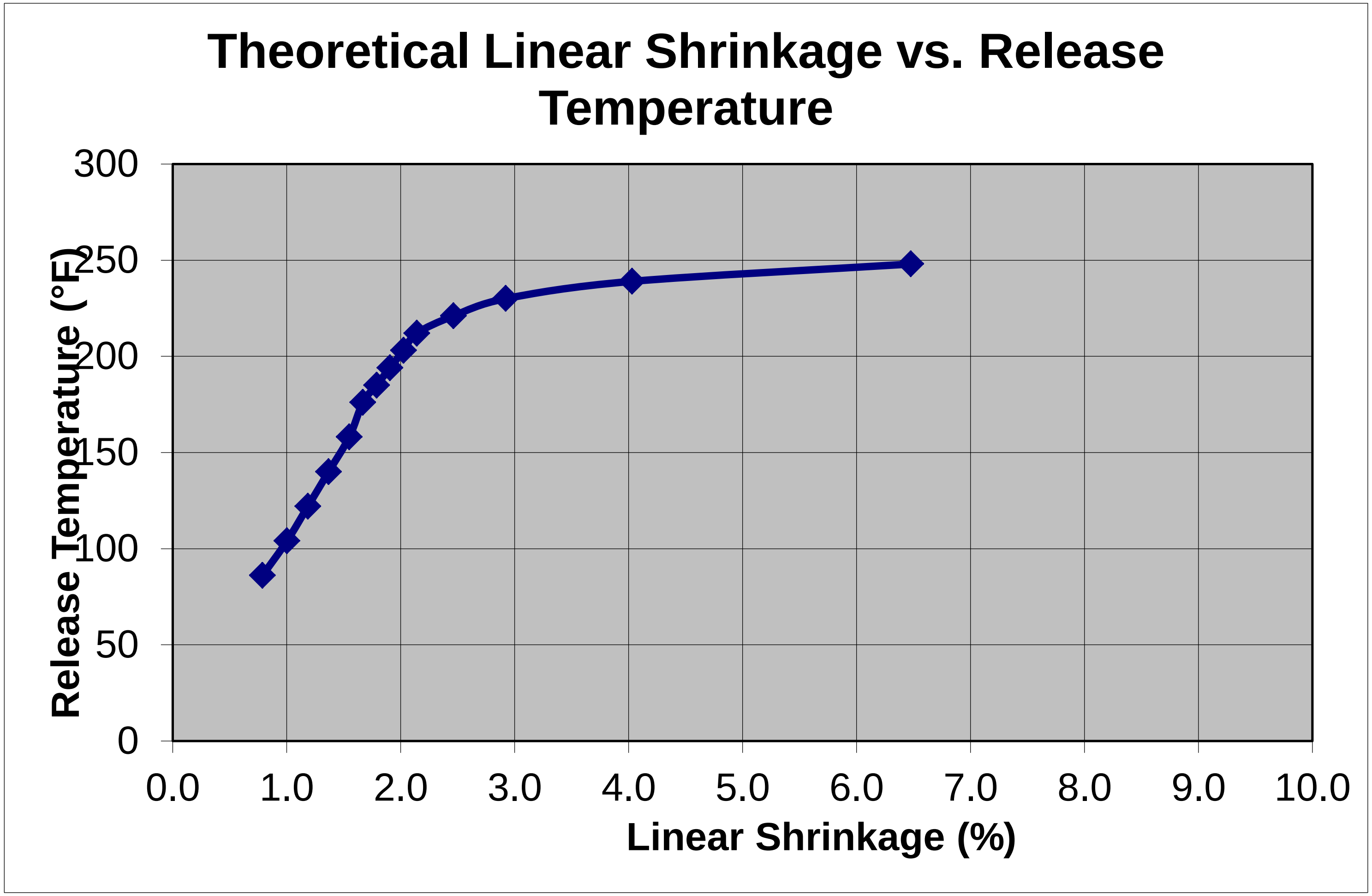
- *A basic lack of process control*
- *Variable ambient conditions*
- *Variable release point*



Ambient Temperature, Cleveland OH, 2011
Minimum
Maximum
Difference
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MAXIMUM VARIATION = 74 °F

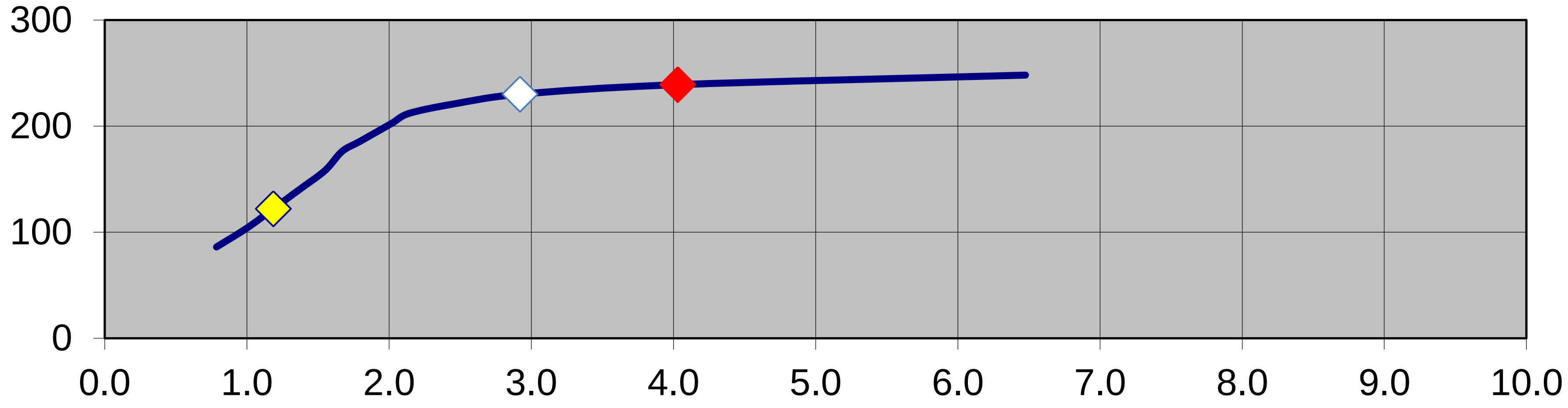

Effect of Ambient Temperature on Mold Cooling
91 degF
17 degF
Mold Wall Temperature (degF)
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
Cooling Time (min)
15.2 min to 230°F
Rate = 10.1°F/min
10.4 min to 230°F
Rate = 15.6°F/min

RELEASE POINT SCENARIOS



RELEASE POINT SCENARIOS

COOLING SCENARIO	Release Temp. (°F)	Predicted Shrinkage (%)
NORMAL COOLING	230	2.9
WATER TOO SOON	240	4.0
STICK-UP	120	1.2



BEST COOLING STRATEGY

Apply more gentle cooling

in a more controlled fashion

to the entire cycle

by cooling the air first

not the mold…