Analysis of Shrink Voids in Extrusion

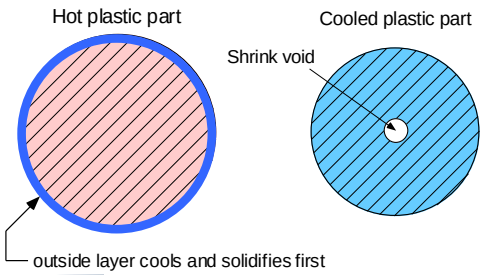
Chris Rauwendaal
Rauwendaal Extrusion Engineering, Inc.
Auburn, California
www.rauwendaal.com

Extrusion 2017

Shrink Voids

- Result from non-uniform cooling
- Outside layers cool and solidify first - become hard and rigid
- As inside layers cool they shrink toward outer wall away from center
- Results in a shrink void in the center

Mechanism of Shrink Voids



Shrink Voids Occur in

- Strand pelletized plastics
- Thick-walled products (rod, pipe)
- Semi-crystalline more susceptible than amorphous polymers
- Rapid cooling
- High melt temperatures
- Water trough close to die exit

Eliminating Shrink Voids

- Avoid thick walls
- Cool more slowly
- Use staged cooling rather than one long cooling section
- Reduce melt temperature
- Avoid highly crystalline plastics

chillWARE® by SMS plus

- Simulates cooling by FEA/FDM
- Material data base
- 2D/3D temperature field
- Residual stress analysis
- Optimization of cooling process
- Optimization US wall thickness

chillWARE® Modules

- Pipe (2D)
- Cable (2D)
- Coex pipe (2D)
- Rod (2D)
- Sheet (3D)
- Profile (3D)

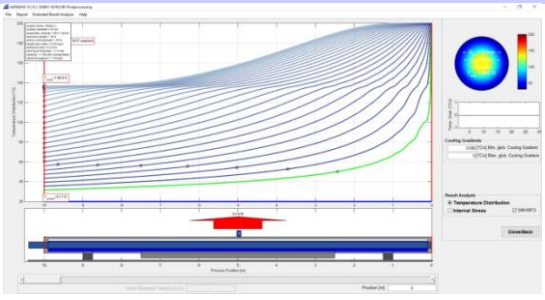
Extrusion 2017

HDPE Simulation

- 6-mm diameter solid rod
- Mass flow rate 43 kg/hr
- Line speed 26.7 m/min
- Material HDPE
- Single water bath 10m long
- Water maintained at 20ºC

Extrusion 2017

Temperatures for HDPE



6-mm HDPE rod extruded at 43 kg/hr with 10 meter long cooling bath

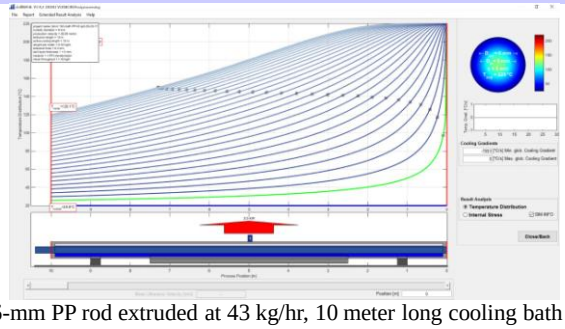
Extrusion 2017

PP Simulation

- 6-mm diameter solid rod
- Mass flow rate 43 kg/hr
- Line speed 26.7 m/min
- Material PP
- Single water bath 10m long
- Water maintained at 20ºC

Extrusion 2017

Temperatures for PP



6-mm PP rod extruded at 43 kg/hr, 10 meter long cooling bath

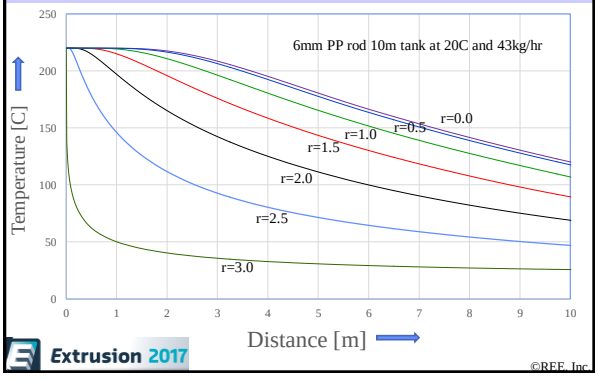
Extrusion 2017

HDPE versus PP

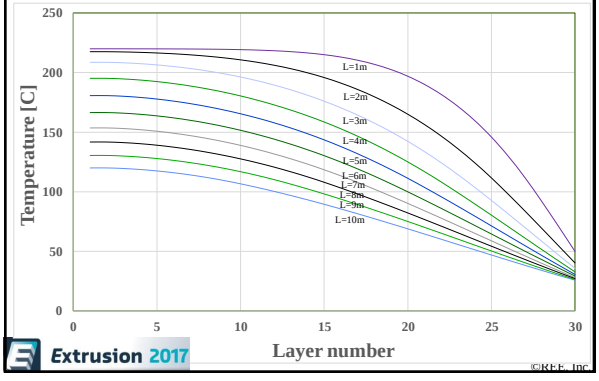
- PP cools more rapidly than HDPE
- Reason: enthalpy change in HDPE is greater than in PP
- With T_{mp} = 170°C the PP rod has solidified after 6 meters

Extrusion 2017

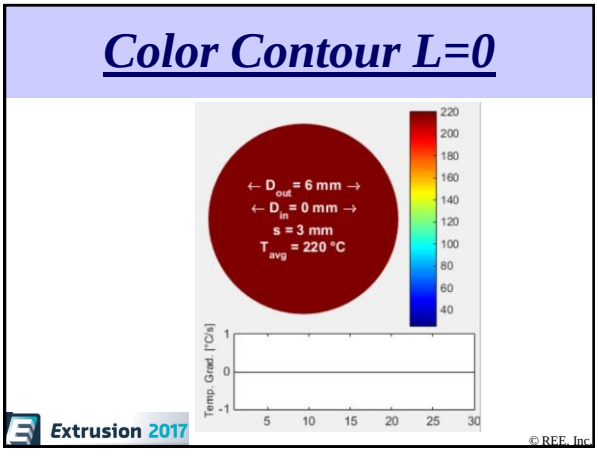
Data Exported to Excel



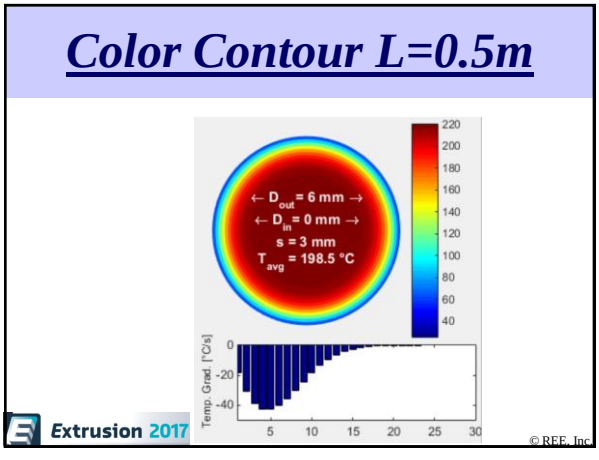
Radial Profiles



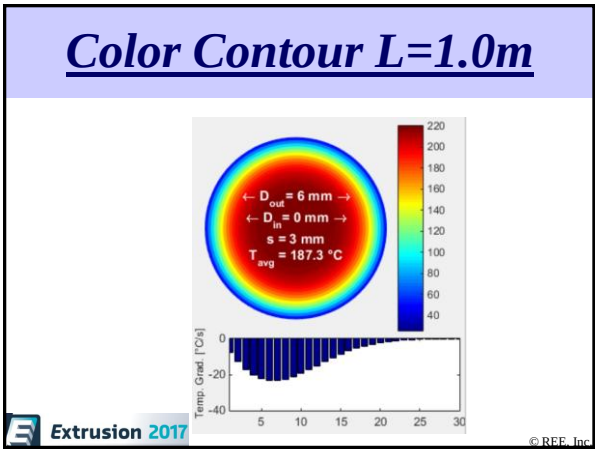
Color Contour L=0



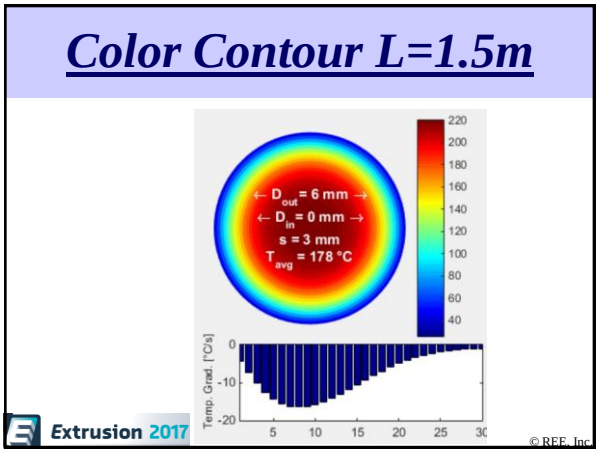
Color Contour L=0.5m



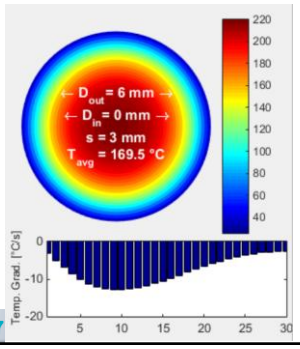
Color Contour L=1.0m



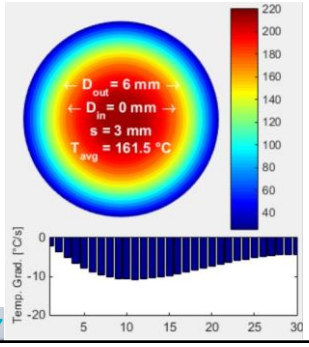
Color Contour L=1.5m



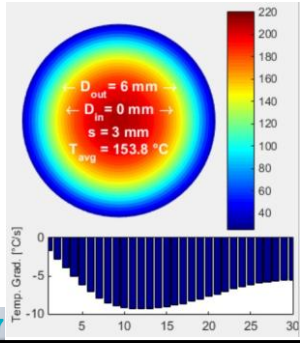
Color Contour L=2.0m



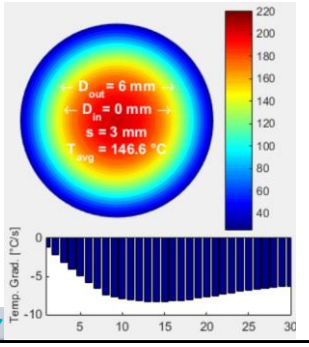
Color Contour L=2.5m



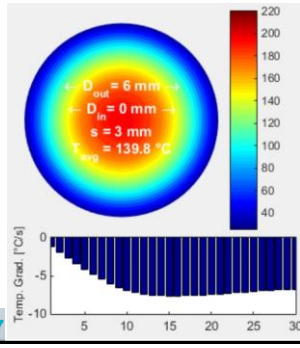
Color Contour L=3.0m



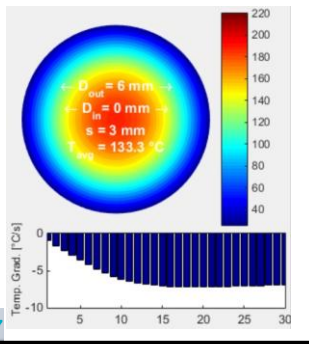
Color Contour L=3.5m



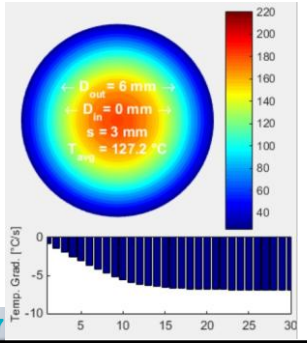
Color Contour L=4.0m



Color Contour L=4.5m

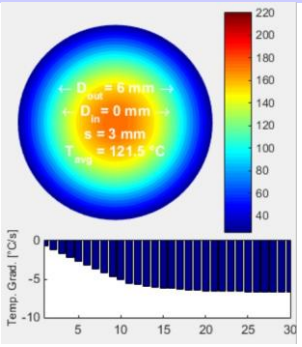


Color Contour L=5.0m



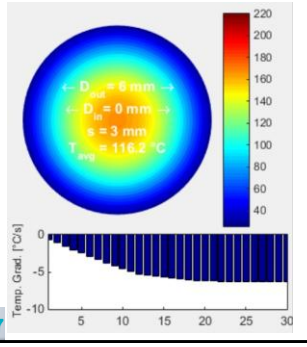
Extrusion 2017 © REE, Inc.

Color Contour L=5.5m



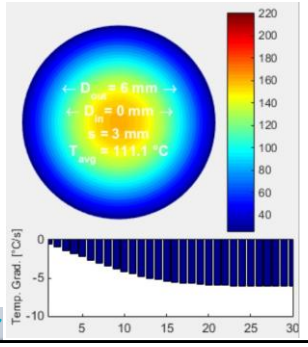
Extrusion 2017 © REE, Inc.

Color Contour L=6.0m



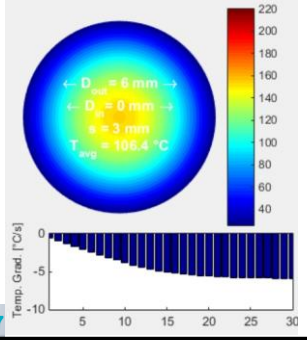
Extrusion 2017 © REE, Inc.

Color Contour L=6.5m



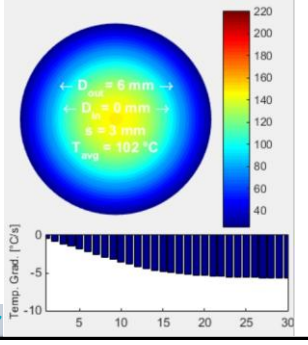
Extrusion 2017 © REE, Inc.

Color Contour L=7.0m



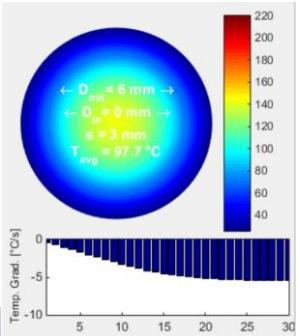
Extrusion 2017 © REE, Inc.

Color Contour L=7.5m



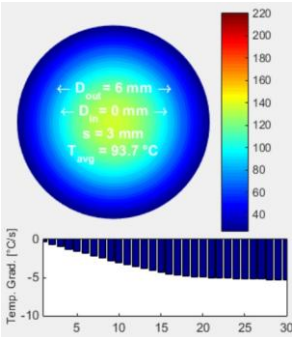
Extrusion 2017 © REE, Inc.

Color Contour L=8.0m



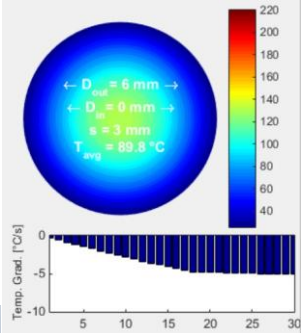
Extrusion 2017 © REE, Inc.

Color Contour L=8.5m



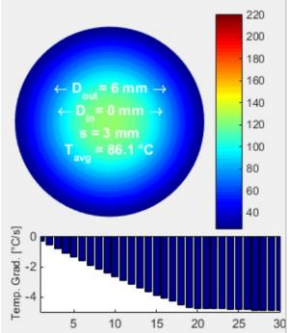
Extrusion 2017 © REE, Inc.

Color Contour L=9.0m



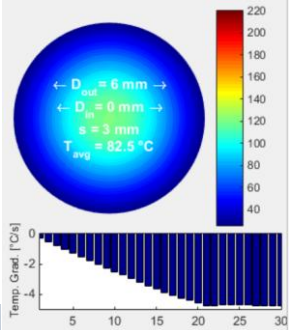
Extrusion 2017 © REE, Inc.

Color Contour L=9.5m



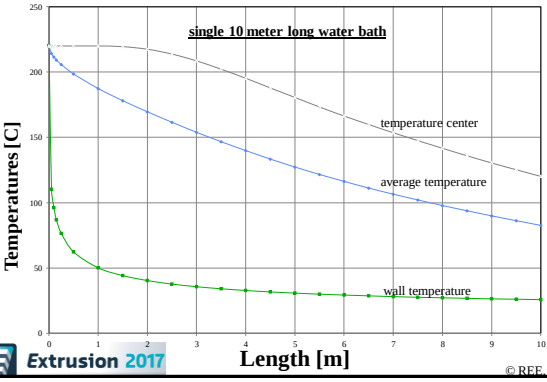
Extrusion 2017 © REE, Inc.

Color Contour L=10.0m



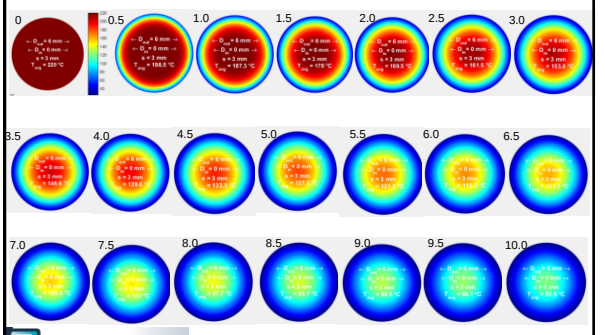
Extrusion 2017 © REE, Inc.

Temperature vs Length



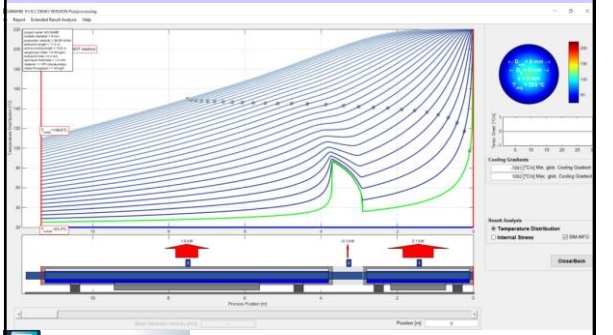
Extrusion 2017 © REE, Inc.

Color Contours 10m Water



Extrusion 2017 ©REE, Inc.

PP 2.9-0.8-7.7 Water Bath



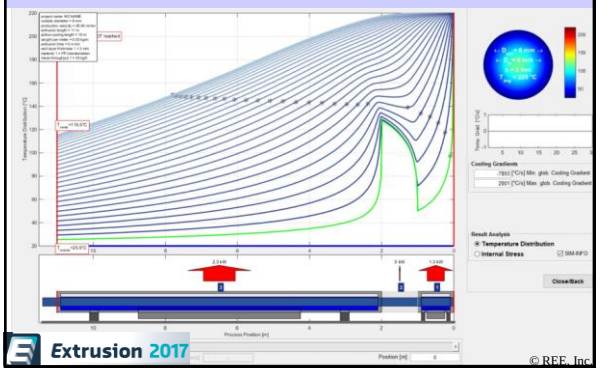
Extrusion 2017 ©REE, Inc.

Temperatures in Air Space

- T_{wall} increases from ~36°C to ~90°C
- Air space acts as annealing section
- Solidified wall ~1.3 mm end 1st bath
- Shrink voids form before end 1st bath
- 1st bath is too long to avoid voids – reduced to 1 meter length

Extrusion 2017 ©REE, Inc.

PP 1-1-9 Water Bath 20C



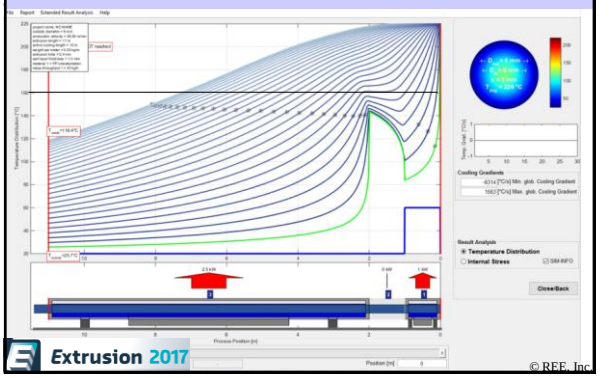
Extrusion 2017 ©REE, Inc.

Annealing Section

- T_{wall} rises from ~50°C to ~130°C
- Solidified wall ~0.6 mm end 1st bath
- Shrink voids form but less severe
- Next water temperature in 1st bath increased to 60°C

Extrusion 2017 ©REE, Inc.

PP 1-1-9 60/20 water bath



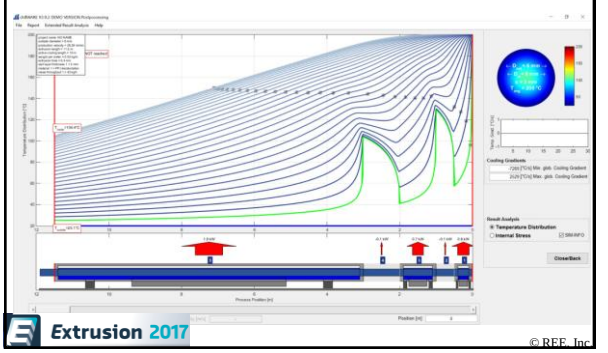
Extrusion 2017 ©REE, Inc.

Annealing Section

- T_{wall} rises from ~85°C to ~140°C
- Solidified wall ~0.5 mm end 1st bath
- Shrink voids almost gone
- It appears that the solidified wall cannot exceed 0.5 mm to avoid voids

Extrusion 2017 ©REE, Inc.

0.5-0.5-1.0-1.0-8.5 cooling



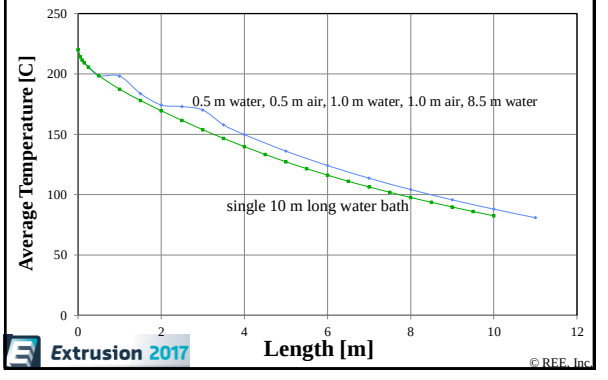
Extrusion 2017 ©REE, Inc.

Two Annealing Sections

- T_{wall} rises from ~60°C to ~130°C in first annealing section
- Shrink voids are gone
- It appears that solidified wall thickness cannot exceed 0.5 mm

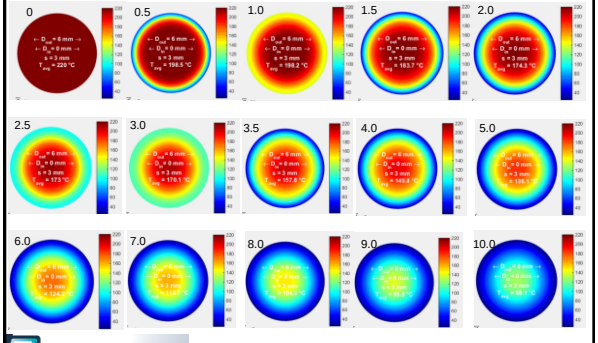
Extrusion 2017 ©REE, Inc.

Temperature vs. Length



Extrusion 2017 ©REE, Inc.

Color Contours All



Extrusion 2017 ©REE, Inc.

Conclusions

- Computer simulation is a powerful tool to analyze extrudate cooling
- Allows optimization of cooling line and elimination of shrink voids
- We can move from **art** to **science** and practice **smart extrusion**

Extrusion 2017 ©REE, Inc.

Thank you!

- For attending and listening
- Any questions?
- Later questions:
  - *chris@rauwendaal.com*

Extrusion 2017