



Effect of Molding Process on Shrinkage of LSR Components

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Agenda

- Shrinkage of LIM materials
 - Why is it critical to molding project?
 - What factors impact the shrinkage?
 - Case Study of Molded Pump Tubing
 - Key molding process parameters
 - Design of Experiments
 - Data analysis
 - Conclusion
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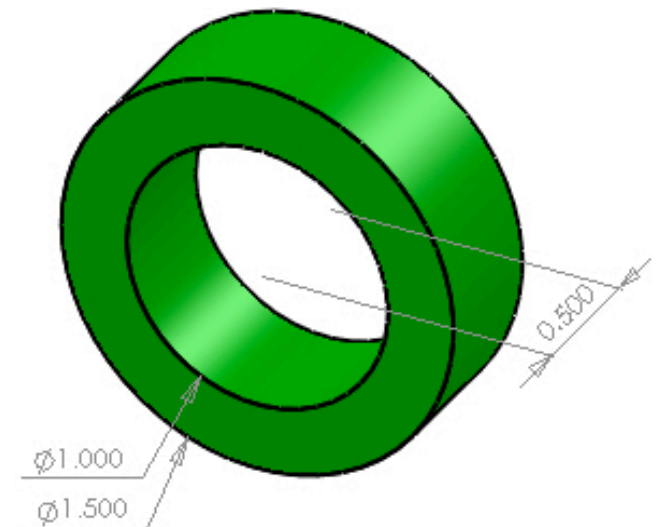
Liquid Silicone Rubber (LSR)

- Typical shrinkage 1.5% to 4.0%

Why is getting the shrinkage factor correct before tool design important?

| | ID | LSL | USL |
|------------------------------|-------|-------|-------|
| Target | 1.000 | 0.990 | 1.010 |
| Mold Dim. With 2.5% Shrink | 1.025 | | |
| Actual Dim. With 1.5% Shrink | 1.010 | | |
| Actual Dim. With 2.0% Shrink | 1.005 | | |
| Actual Dim. With 3.0% Shrink | 0.994 | | |
| Actual Dim. With 3.5% Shrink | 0.989 | | |

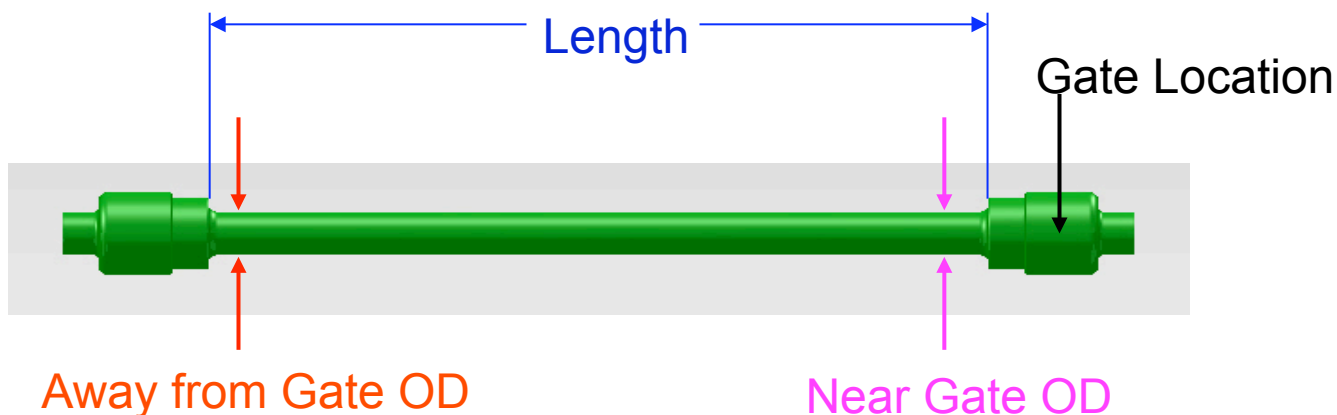
Process
Capability?



What impacts the shrinkage?

- Material
 - Supplier's composition, durometer
- Part Design
 - Part geometry, gate restriction
- Mold Design
 - Gate location, # of gates, gate design
- Molding Process
 - Molding parameters (Mold Temp., Cure Time, Injection Profile, Hold Profile)
- Post Molding Process
 - Post Baked versus No Post Baked
 - Sterilization (At elevated temperature or under stress)

Design of Experiment



Critical Parameters:

1. Mold Temperature
2. Injection Profile (Velocity Controlled Process)
3. Hold Profile (Hold Time and Hold Pressure)
4. Cure Time

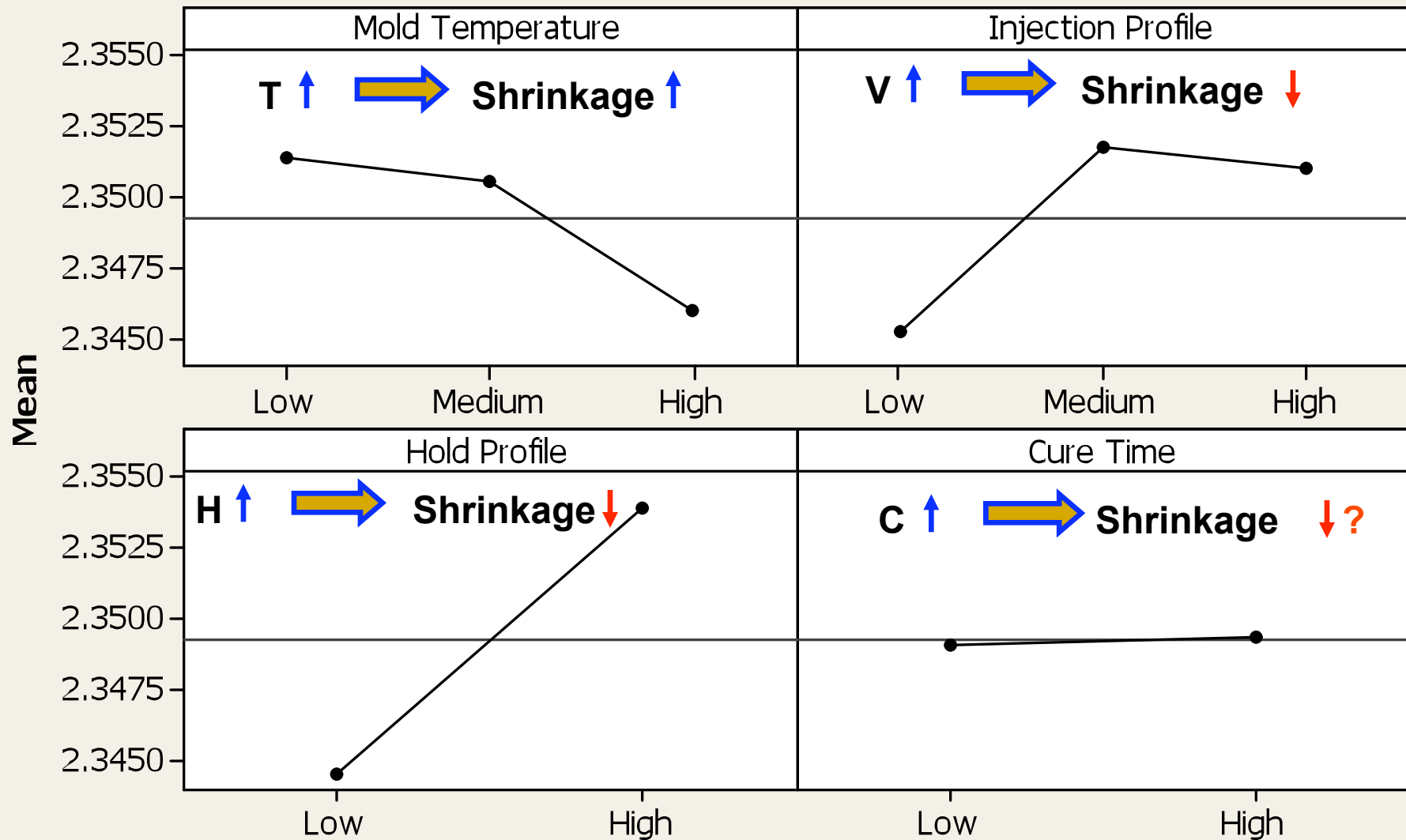
How do you establish the process?

- **Mold Temperature (260°F to 420°F)**
 - Cycle time, Flash, Knit lines, Gate stress mark
- **Velocity Profile (0.5 to 3 sec.)**
 - Flash, Consistency, Gate Stress Mark, Flow Lines
- **Hold Profile (0.2 to 3 sec.)**
 - Avoid screw bounce back, Consistency (cushion), Backrinding, Flash, Gate stress mark
- **Cure Time**
 - Sufficient to cure the molded part, sprue tip, cycle time

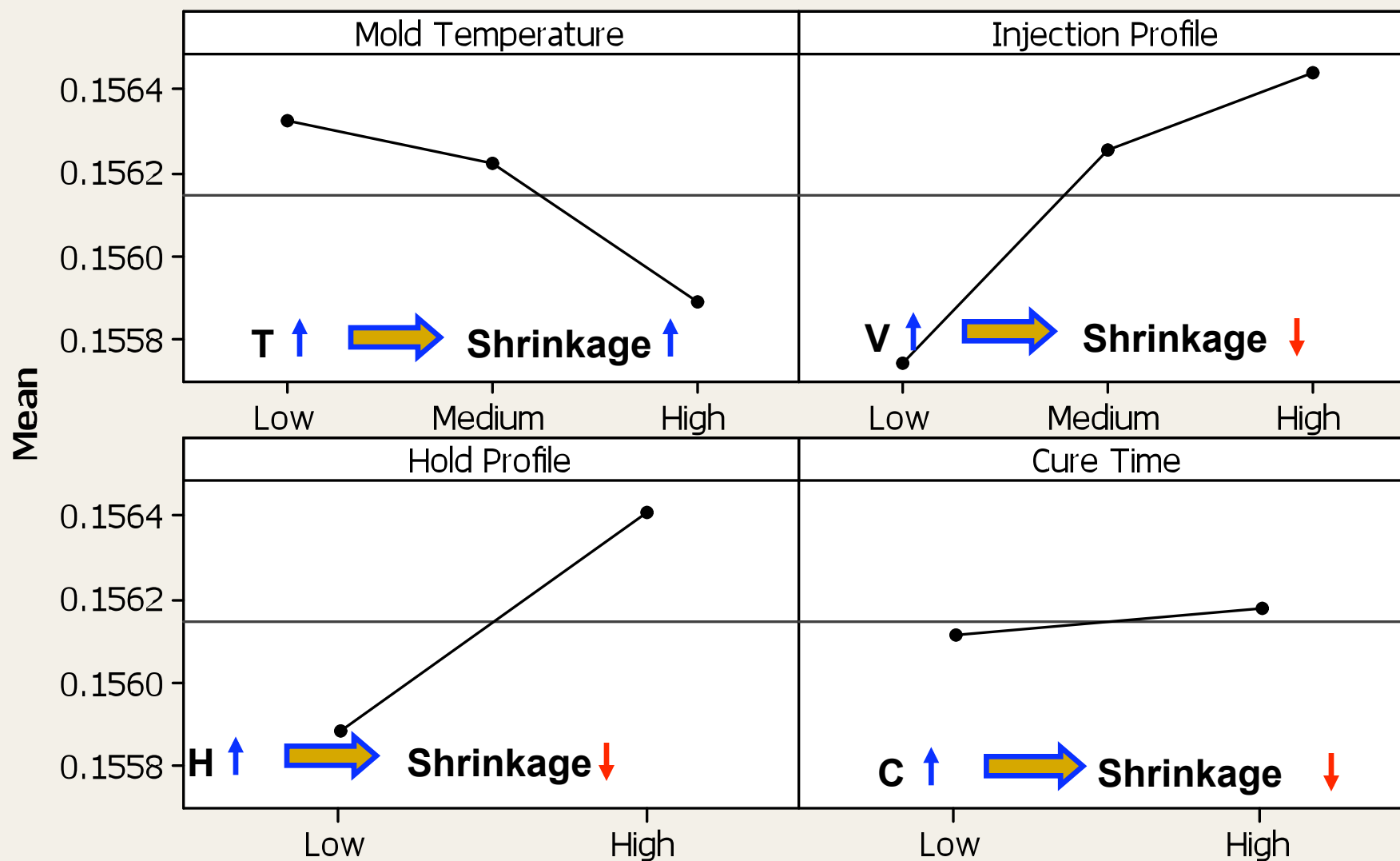
DOE General Factorial Design

- 4 Factors
 - 3 Levels for Mold Temp and Injection Profile
 - 2 Levels for Hold Profile and Cure Time
- 36 Combinations or trials for DOE
 - Each trial included 10 samples
 - Average of 10 parts were used for the study

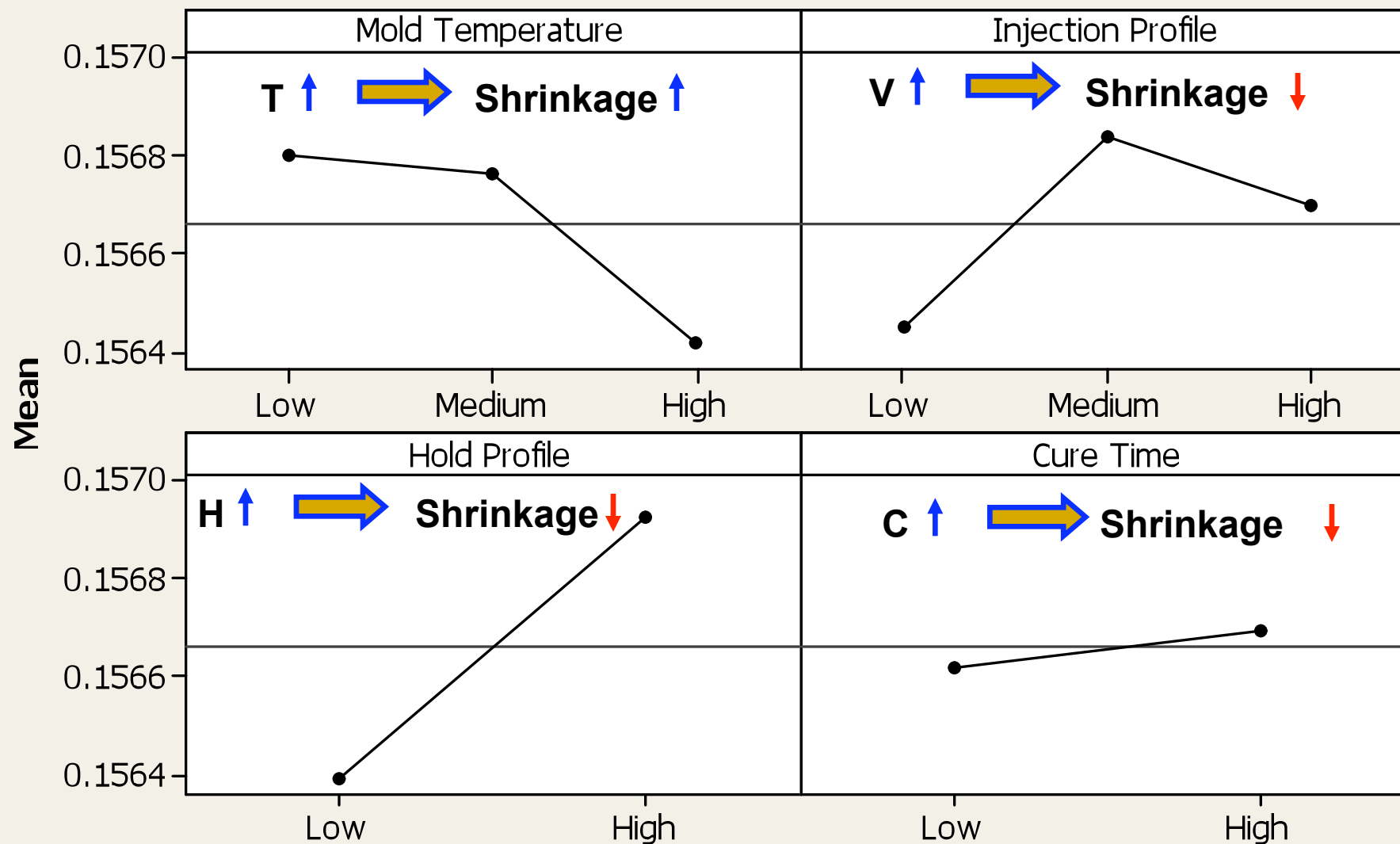
Process Effects on "Length"



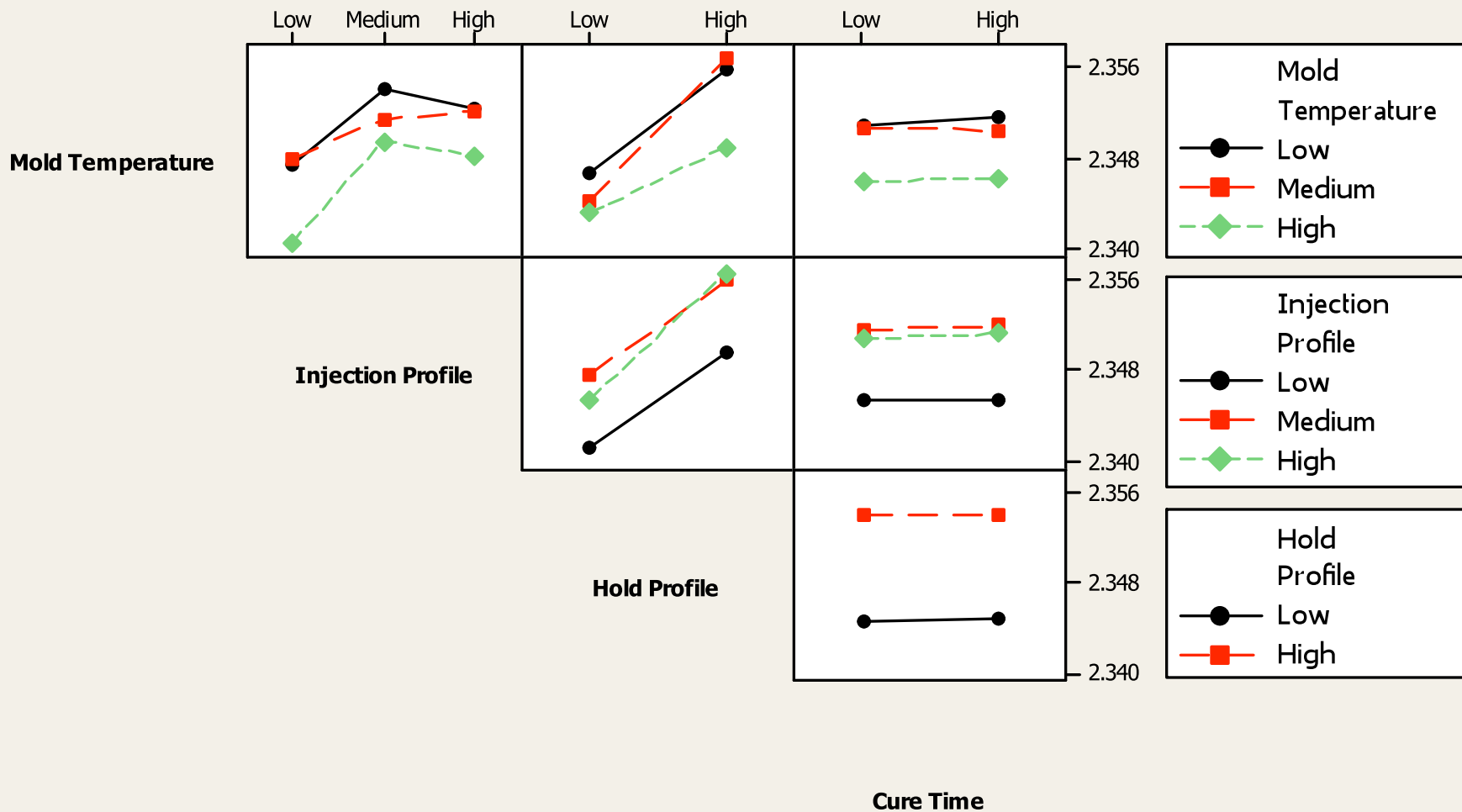
Process Effects on "OD AWAY FROM GATE"



Process Effects on "OD Near Gate"



Interaction Plot for "Length"



Summary of Results

■ In order of Statistically Significant

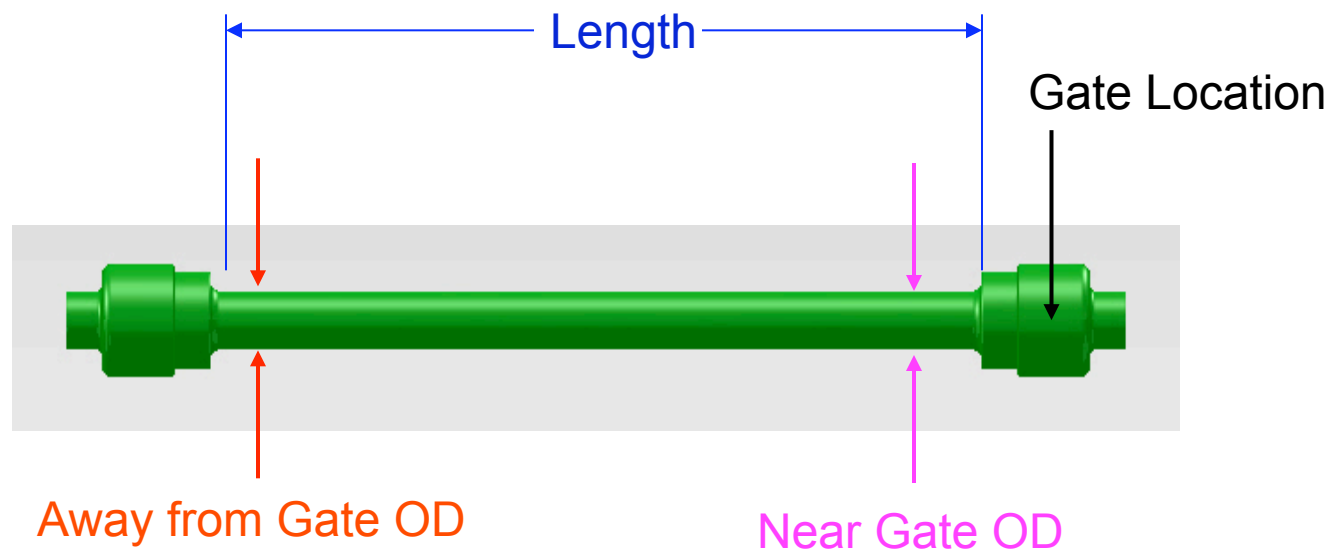
- Hold Profile ↑ → ↓ Shrinkage
- Mold Temp. ↑ → ↑ Shrinkage
- Velocity Profile ↑ → ↓ Shrinkage
- Cure Time* ↑ → ↓ Shrinkage

*Statistically Insignificant

Actual Shrinkage Range

(Shrink used on tool 2.0% Diametric and 2.5% for Length)

Length: 2.3% to 3.2%
Nominal (-0.017", +0.005")



OD Away from Gate: 1.8% to 2.9%
Nominal (-0.0014", +0.0003")

OD Near Gate: 1.6% to 2.5%
Nominal (-0.0008", +0.0006")

Post Baking Effect on Shrinkage

When should you post bake?

- ❑ Food Grade Application
- ❑ High temperature and low temperature application
- ❑ Sealing application over 100°F (Including sterilization processes)

What happens when you post bake?

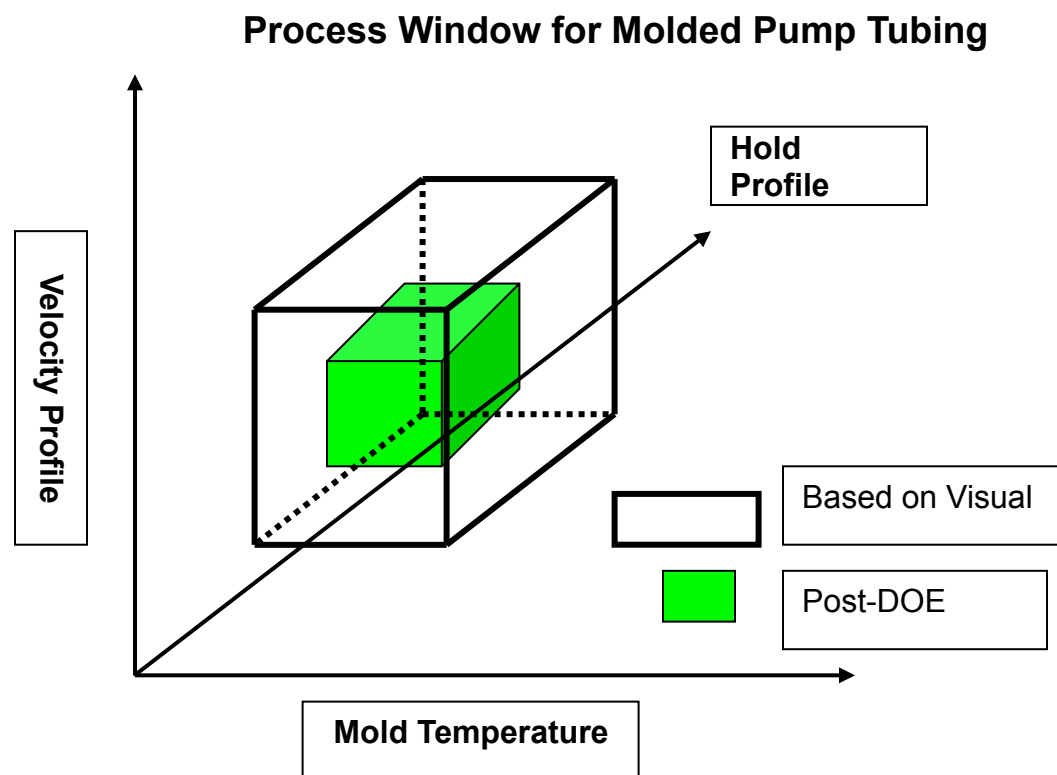
- ❑ Post baking removes low molecular weight cyclics and volatiles
- ❑ Enhances compression set and advances to complete cross-linkage
- ❑ Further shrinks the parts by additional 0.4% to 0.8%

Post Baking Condition?

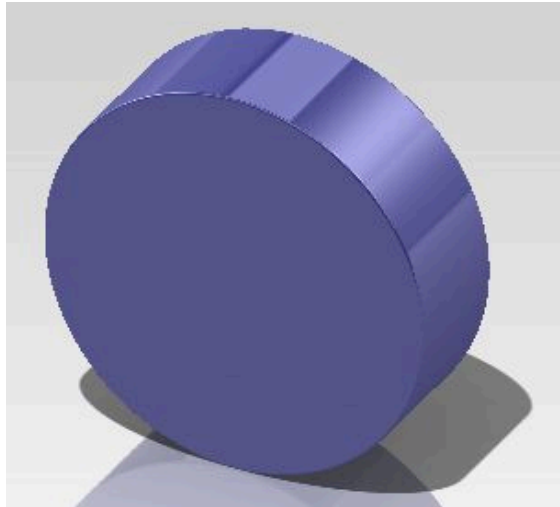
- ❑ Supplier recommended conditions are 4 hours at 400°F

Process Capability Study (IQ/OQ/PQ)

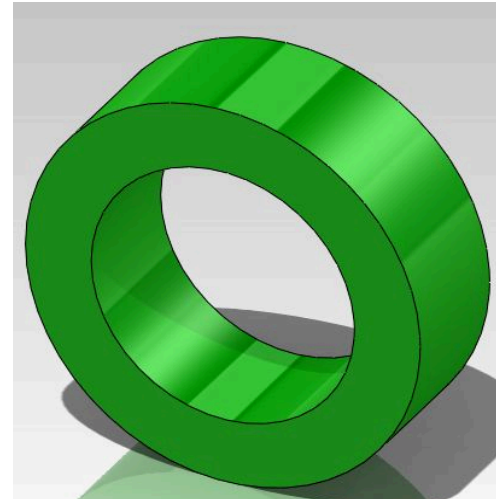
- Narrow down your process window to meet the process capability using DOE data
- Make the tooling change if necessary
- Run OQ at the high and low conditions of the critical parameters and confirm the results from DOE



Other Example



Shrinkage: 1.5% to 2.7%



Shrinkage: 2.2% to 3.6%

Recap

- Design review and product requirements
 - Critical parameters, functional tests and capability requirements (IQ/OQ/PQ)
 - Identify and set proper tolerances (RMA standard)
 - Identify choice of material grade
 - Build fixtures as necessary; consider Gage R&R study
- Understand the impact of
 - gate location, # of gates
 - part design (long flow length versus short, cored part versus solid, thin versus thick)
 - Process conditions, post baking versus as molded
 - Machine operator impact on the consistency of the cycle
- Make steel-safe choice on critical dimensions
- Perform formal DOE to establish solid process window

Questions?
