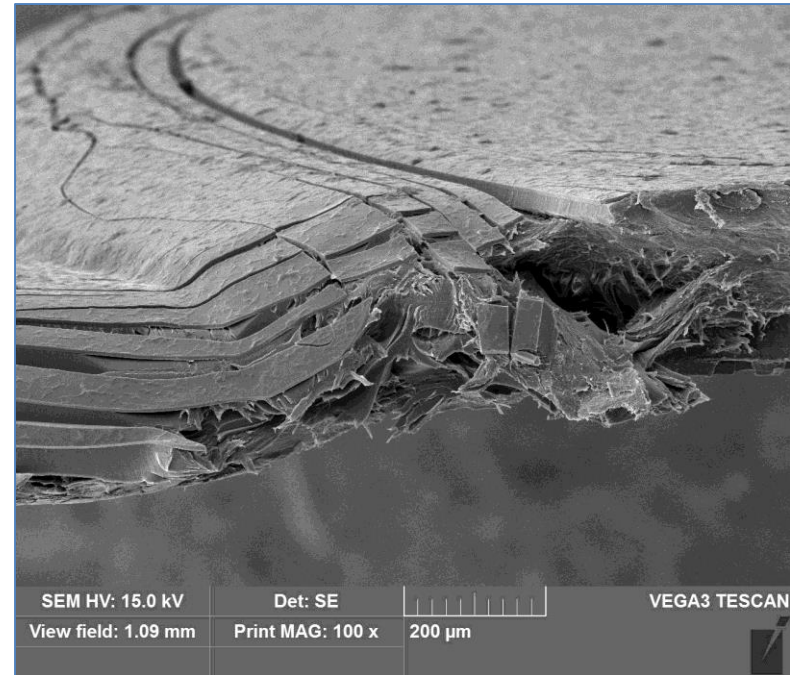


# Plastic Design - Failure Analysis and Prevention



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# Collapse of a 3-Story Aquarium



- Acrylic aquarium in Scotland failed ~3 years after being installed.
- Two vertical seams opened releasing all water and fish
- Catastrophic failure with over 200 large sections of acrylic
- Scanned each piece to digitally put back together
- Mapped every fracture surface to locate fracture origins - seams

# Prevent Failure

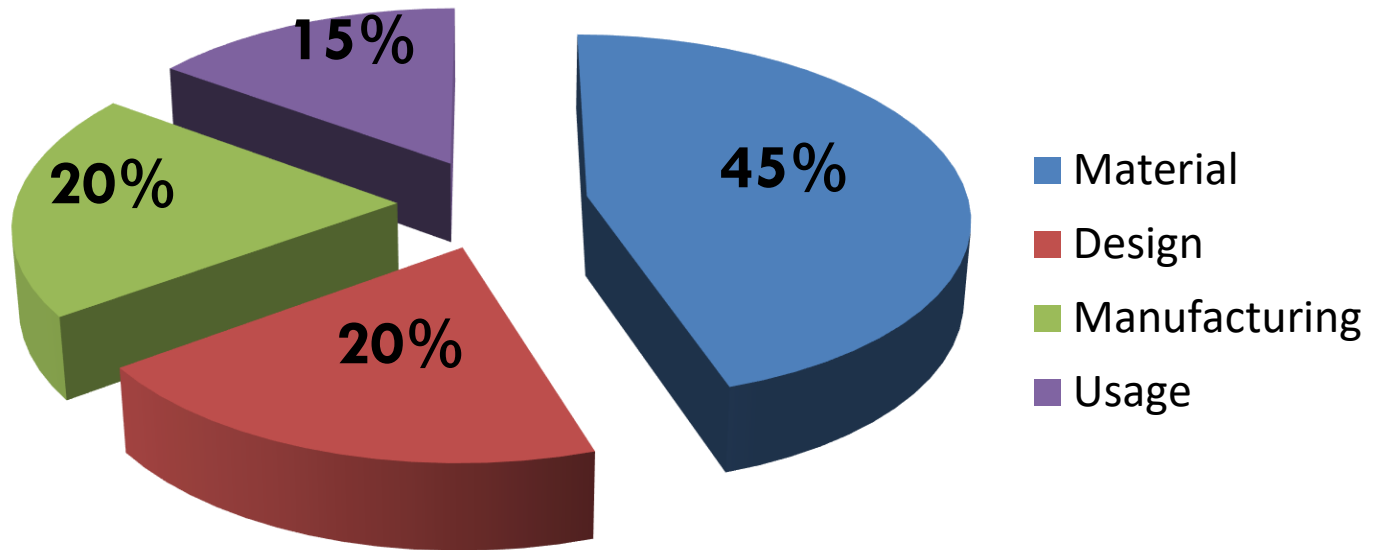
- Best way to prevent failure is to understand failure.
- Understand how and why failure occurred.
- Material behavior.
- Processing/manufacturing of part.
- Plastic part design.
- How part will handle stress over time.
- The environment the part will be exposed to and its affect on plastic.



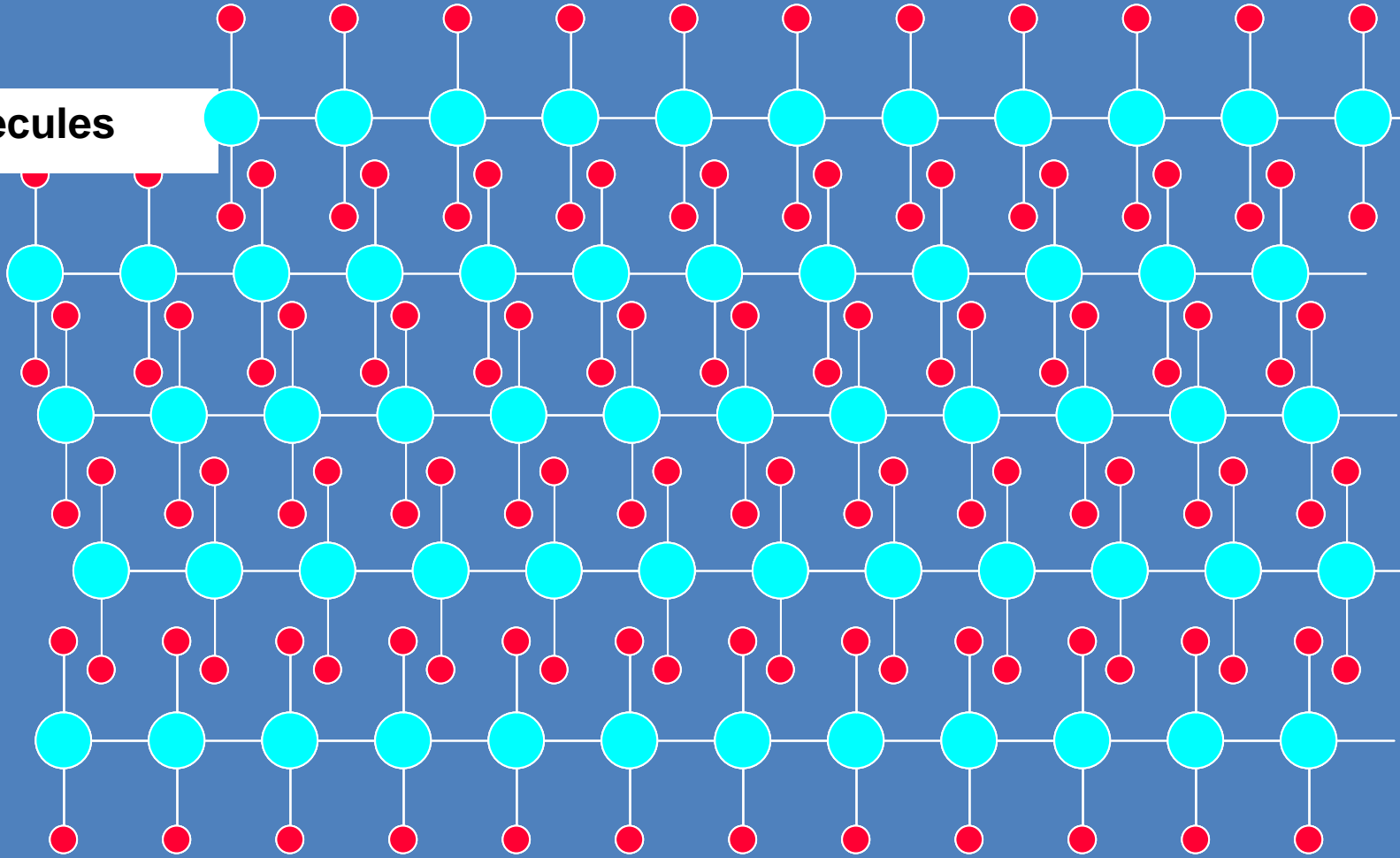
Properties of Nylon 6 change dramatically when exposed to moisture.

# 85% of Plastic Part Failures Relate Back to the Engineer

## Cause “Why” of Plastic Failure



**Molecules**



# Analogy: Plastic and Spaghetti



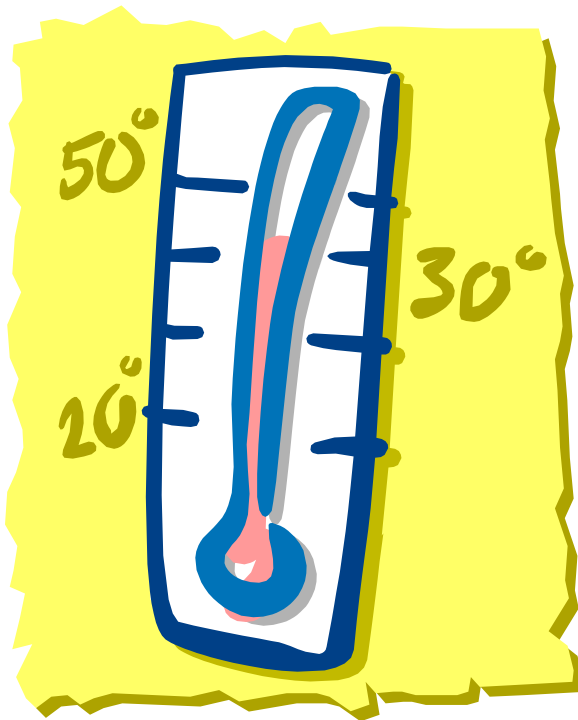
Sticky – Hard to Pull Noodles Apart

Elastic



Stress

# Plastics Are Not Like Metals



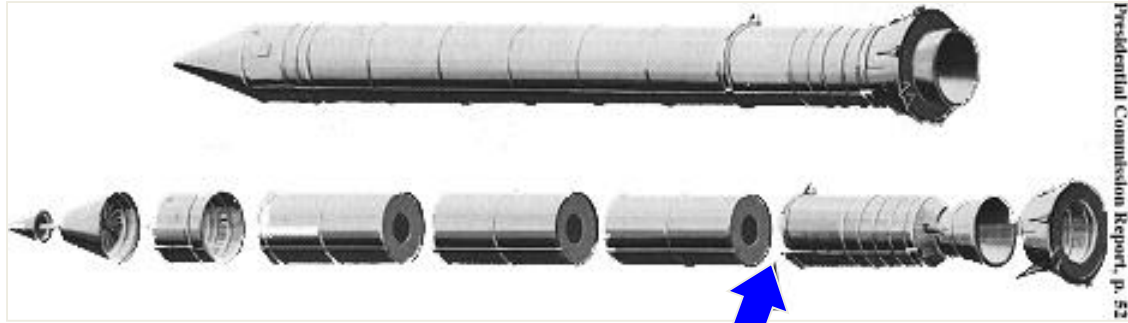
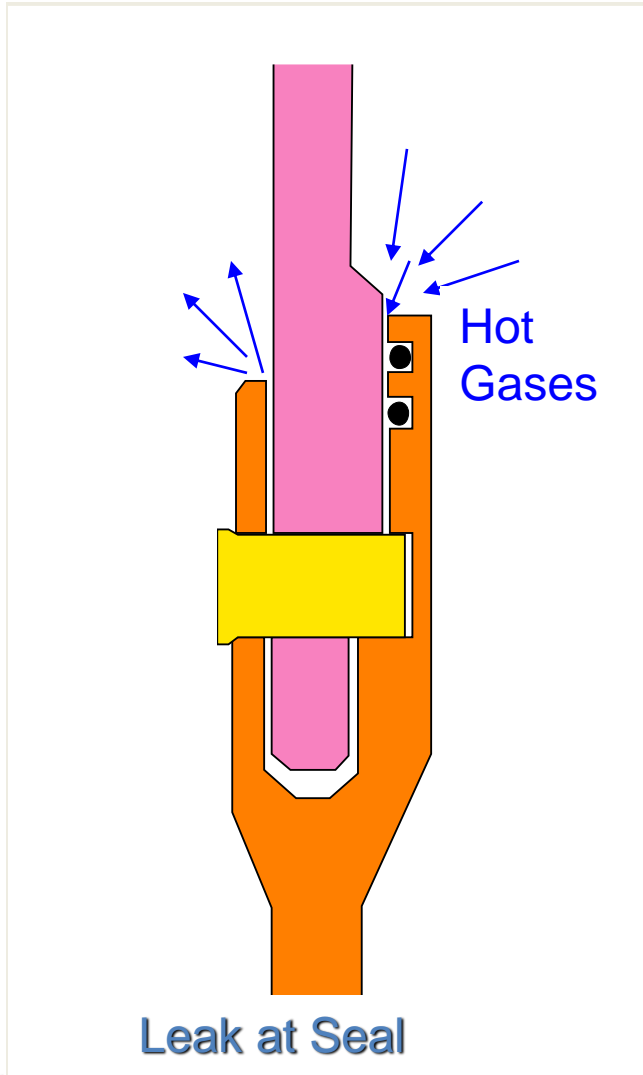
Temperature



Time



# Space Shuttle



Failed Response of Plastic at Cold Temperature



# Plastics Are Not Like Metals



## Response of Plastic at Cold Temperature

# Plastic Parts Over Time

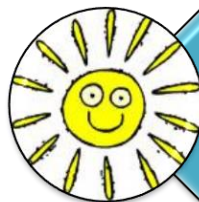
A plastic part can fail after a period of time when in the presence of some applied force, chemical or environmental condition.



Force – Assembly (CREEP)

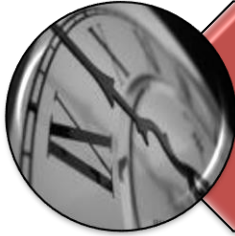


Chemical – Cleaning Agents

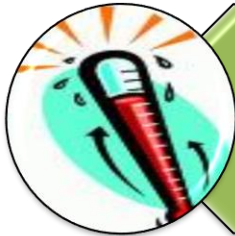


Environmental – Sun Light

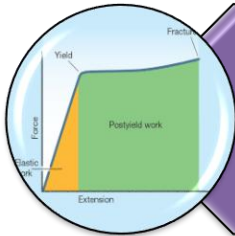
# Creep



Time Related Failure

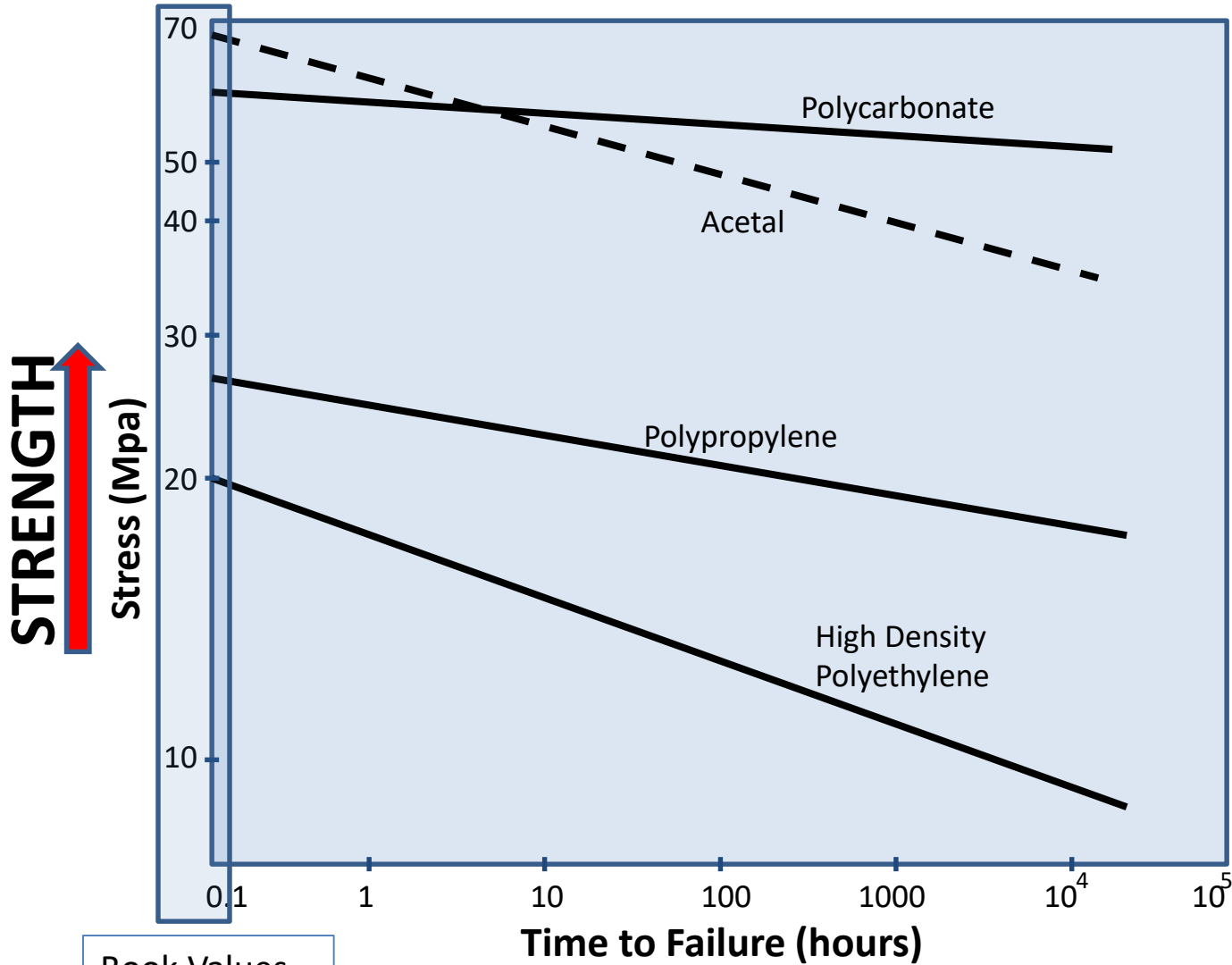


Highly Dependent on Stress Level,  
Temperature, and Molecular Weight



By Definition – Occurs at a Stress Level  
that is Below the Material's Yield Point

# Failure Over Time (Creep Rupture)



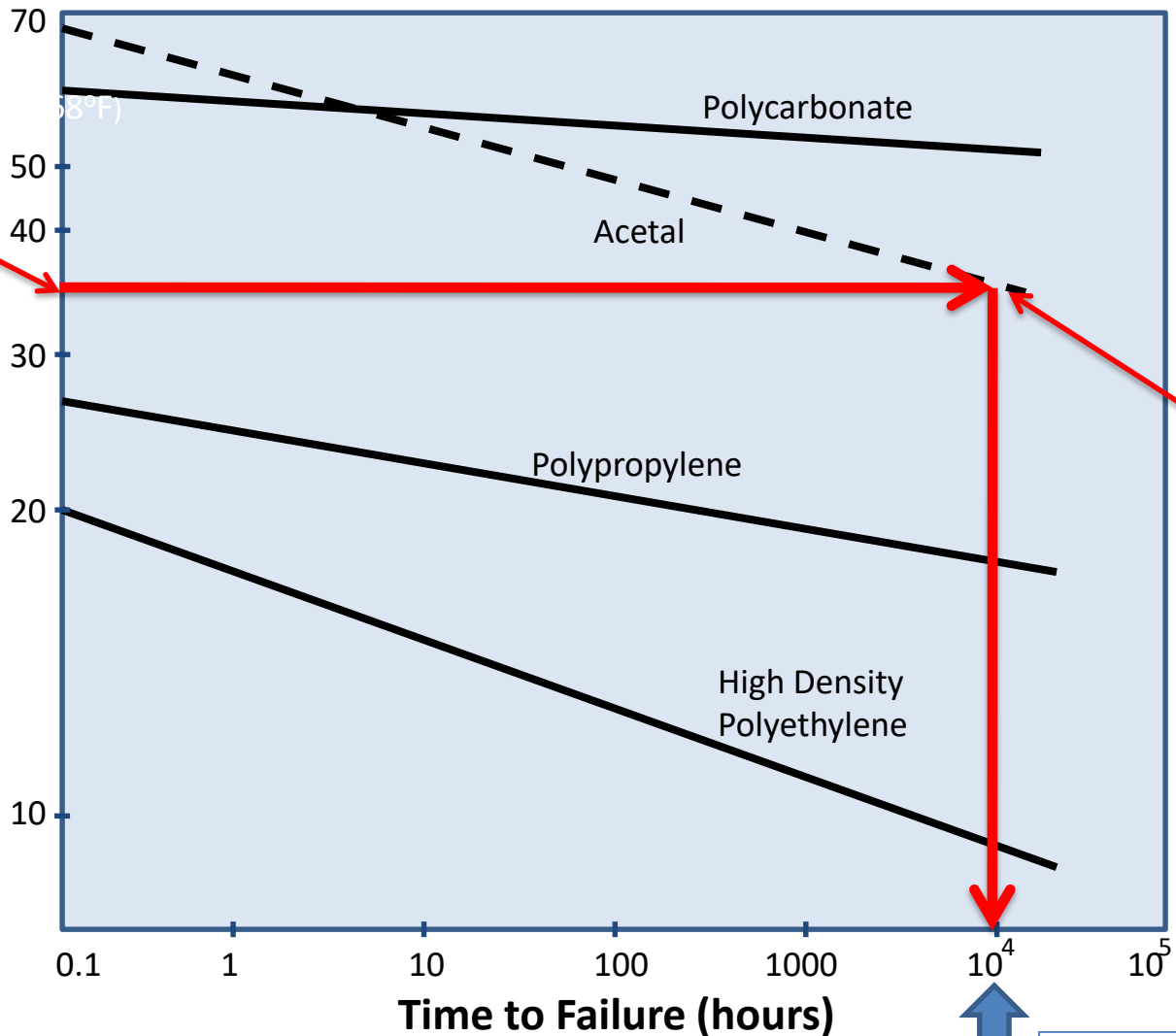
Book Values  
ASTM D 638



# Failure Over Time (Creep Rupture)



**STRENGTH**

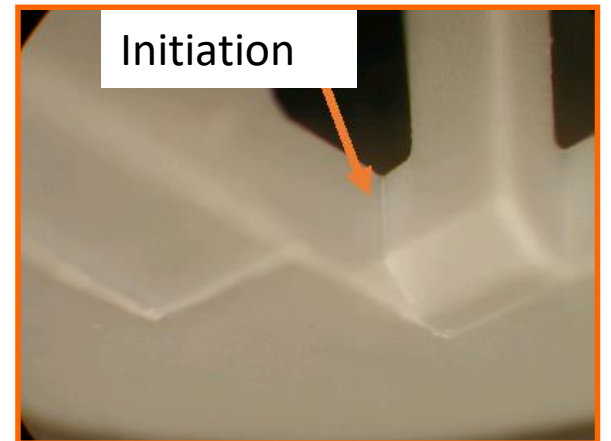


1 Year



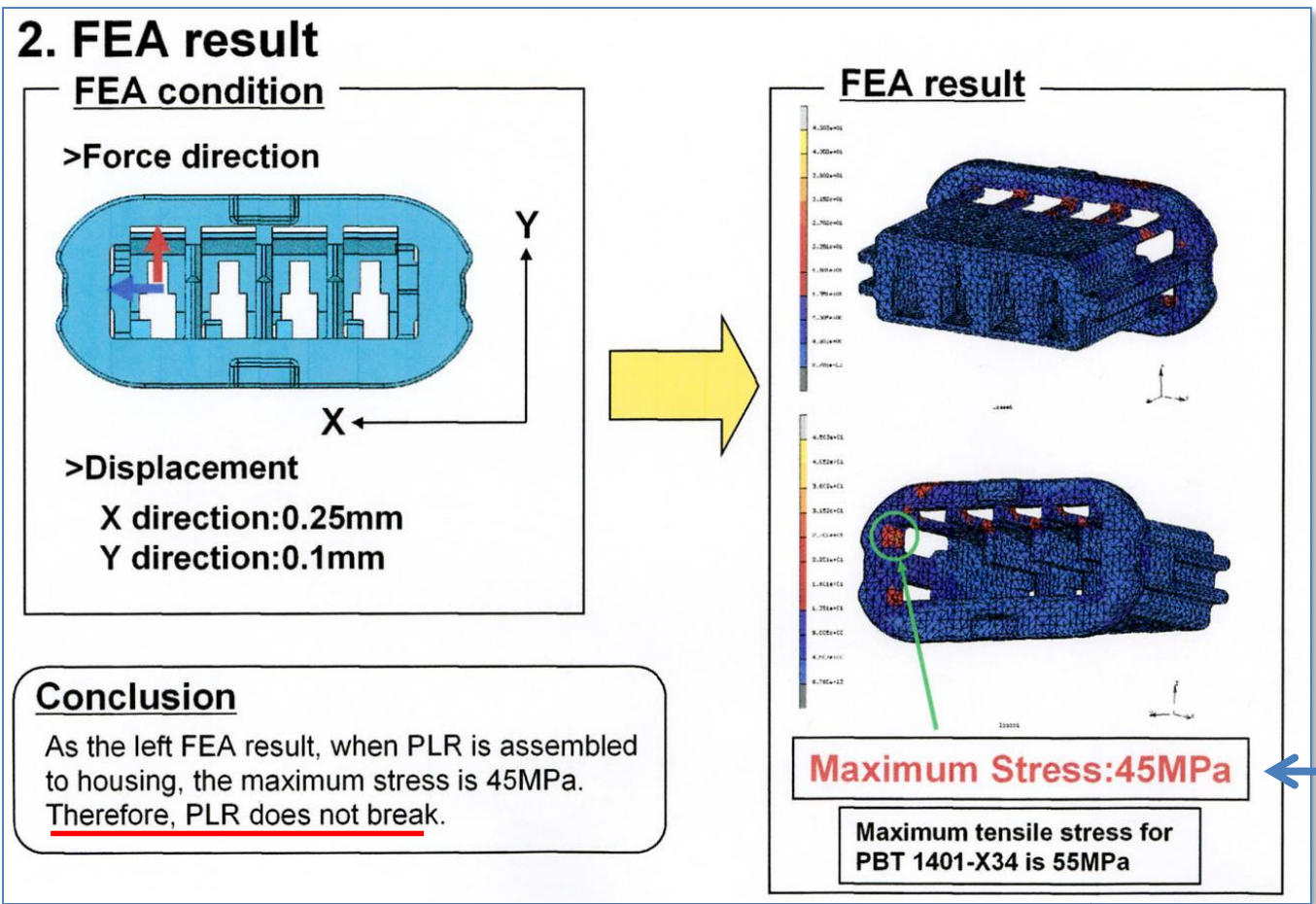
# Creep Rupture of a Plastic Electrical Connector

- Injection-Molded electrical connector
- Manufactured from unfilled poly(butylene terephthalate) PBT resin
- Snaps onto housing during service
- Part experienced consistent cracking several weeks after assembly



# Creep Rupture of a Plastic Electrical Connector

FEA Analysis of Manufacturer Confirming Part will NOT Break

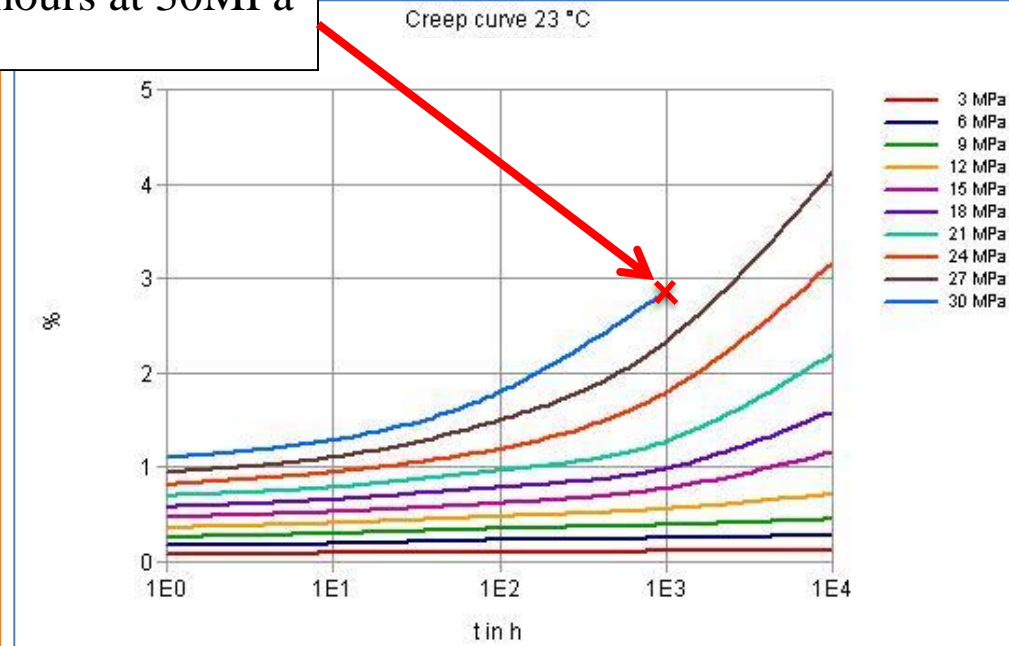




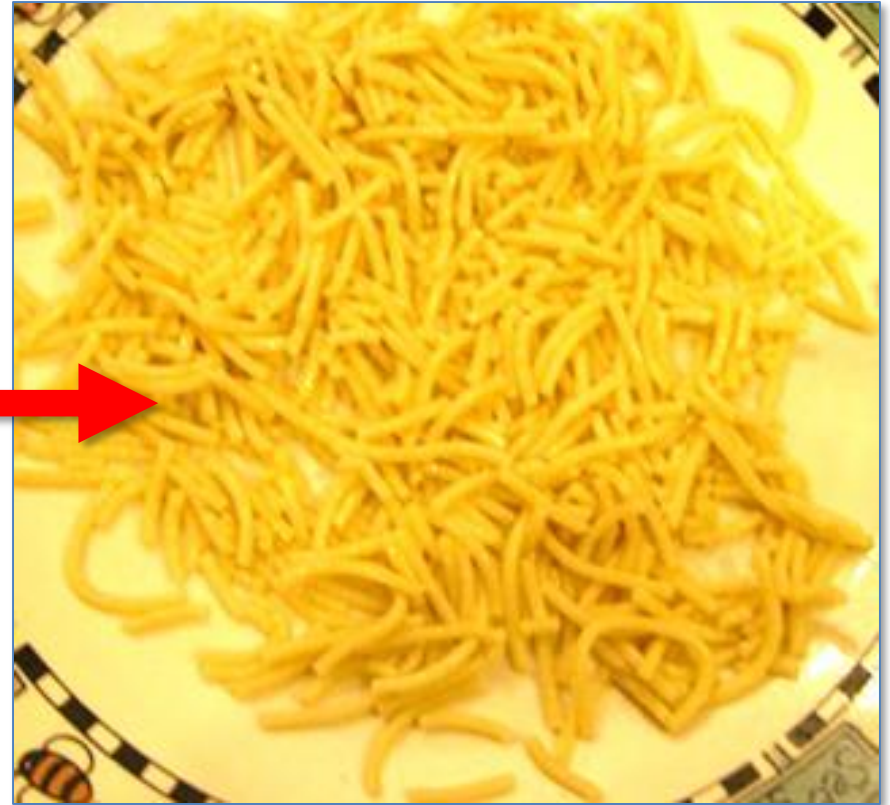
# Creep Rupture of Plastic

Using Data Available on the Web Predicts Failure

Part Predicted to Break  
at ~1000 hours at 30MPa



- Material testing predicted failure would occur at 1,000 hours after assembly



## Chemical Attack – Cutting the Spaghetti

Hard to Pull Noodles Apart



Easy to Separate

# Plastic Degradation

(Reduction in Molecular Weight)



High Molecular Weight  
MW~40,000  
(Milk Container)

- Ductile
- High Impact Resistance
- Does Not Break Easily



Low Molecular Weight  
MW ~ 500  
(Candle)

- Brittle
- Low Impact Resistance
- Breaks Easily

# Case Study: Processing Failure – Failure of a Horse Stirrup

- Polyethylene Core - Made of Recycled Tyvec
- Failure Occurred at Staple Used to Hold Leather Covering to Plastic Core
- Resulted in Massive Injuries to the Rider



# Horse Stirrup: Leather Covered HDPE Core

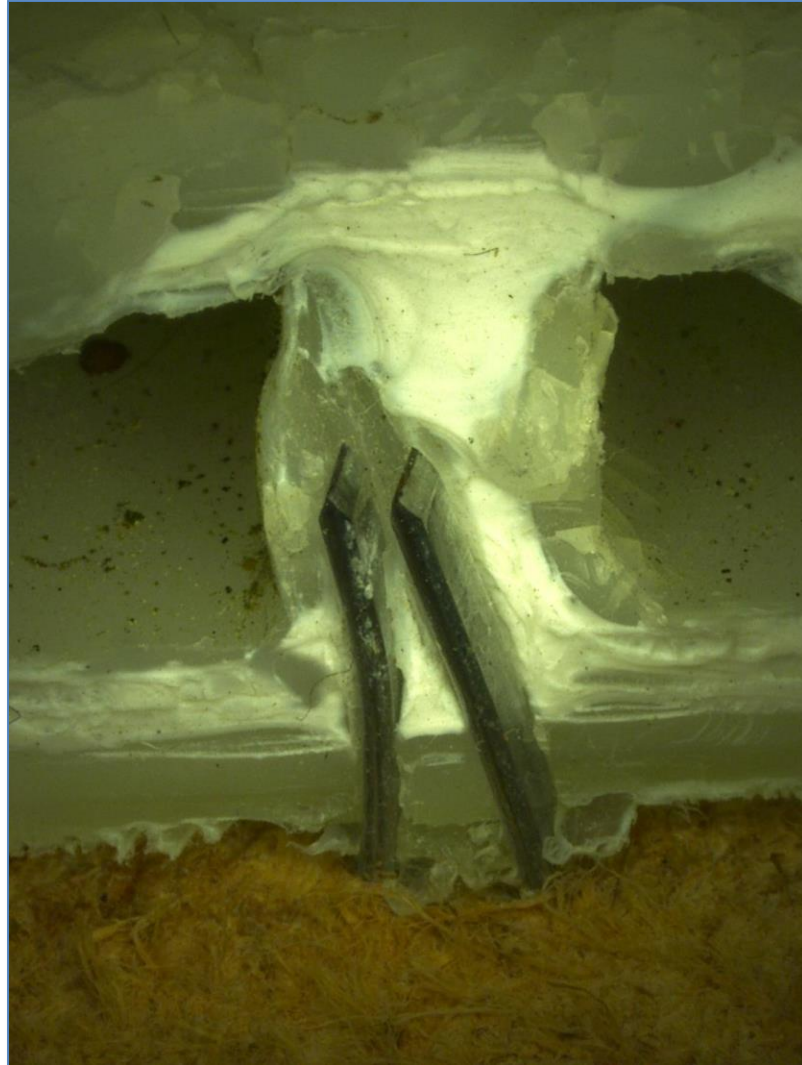


# Case Study: Design Failure – Electrical Assembly





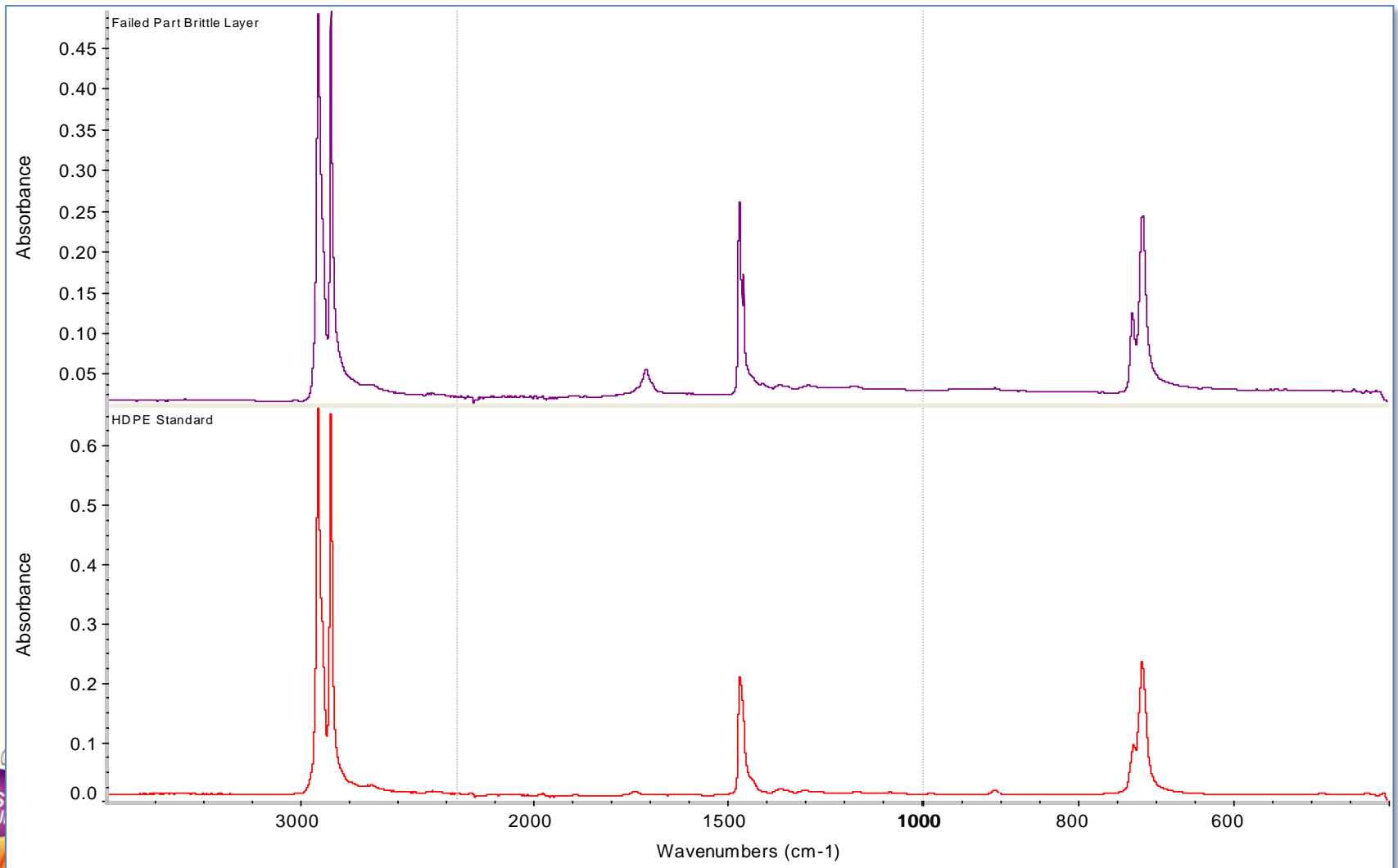
# Horse Stirrup: Leather Covered HDPE Core



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# Identify Plastic with FTIR



# Determine Material Quality with Gel Permeation Chromatography

Sample	Run #	Mw	Average Mw
Failed Stirrup	1	60739	60660
	2	60580	
Exemplar Stirrup	1	228511	229790
	2	231068	
Virgin Tyvec Pellets	1	219797	232470
	2	245143	



Large Difference in Molecular Weight

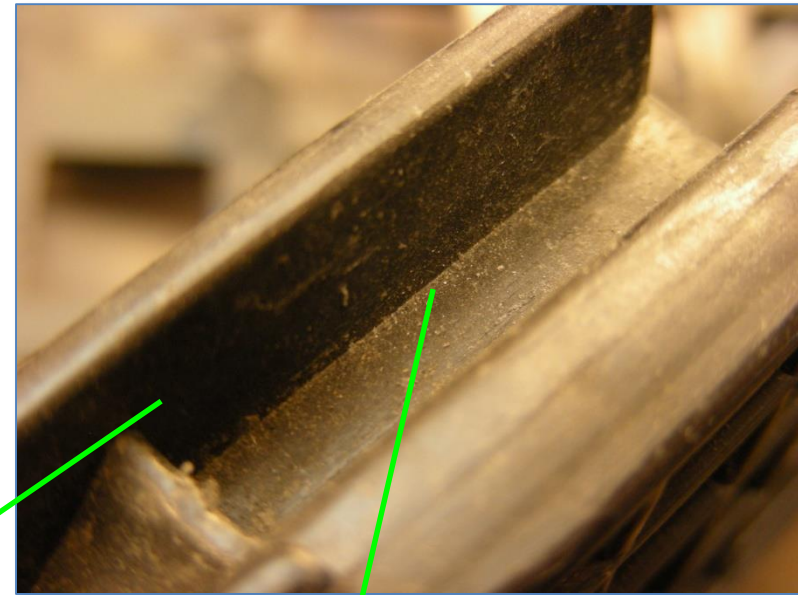
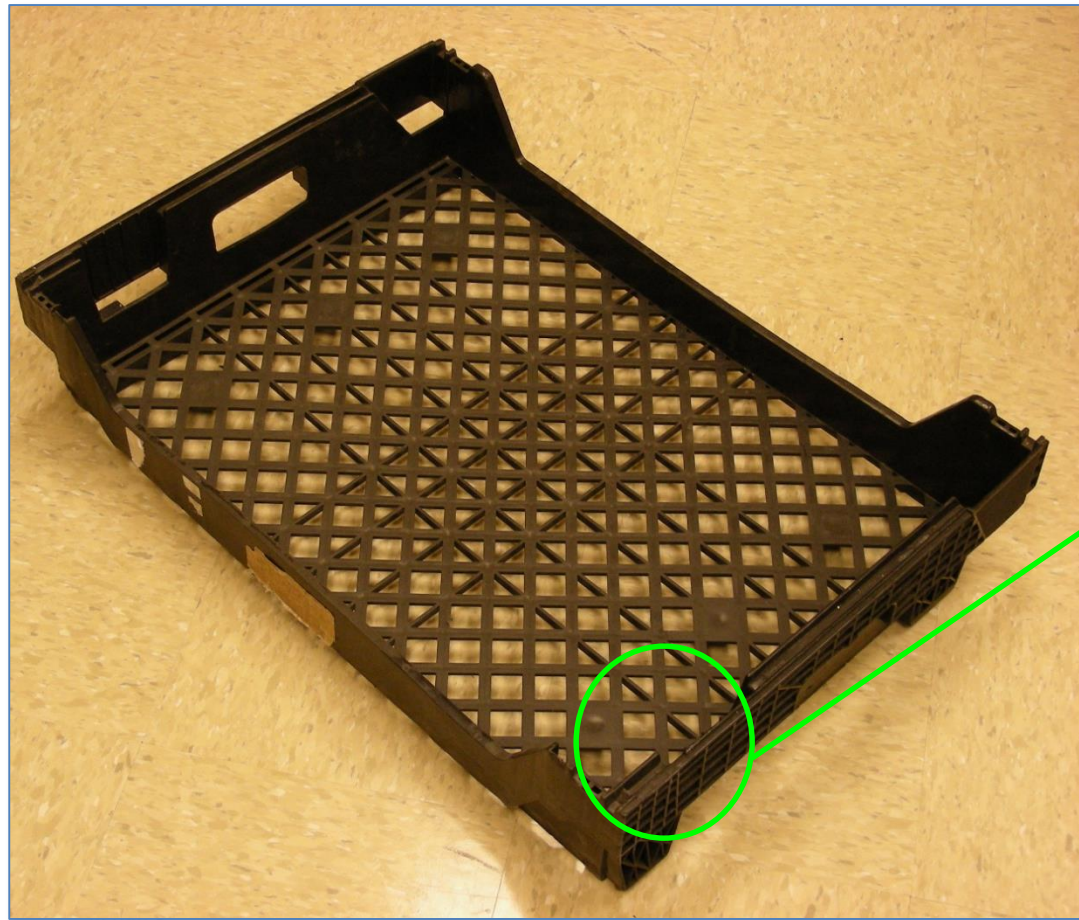
# Design



# Design

- Design rules for metals do not always work for plastics.
- Sharp geometric transitions need to be avoided.
- Need to think about stresses: molded-in, assembly, in the field.
- Time and temperature.

# Sharp Corner In Bread Basket



Sharp corner resulted failure of stacking rail and personal injury

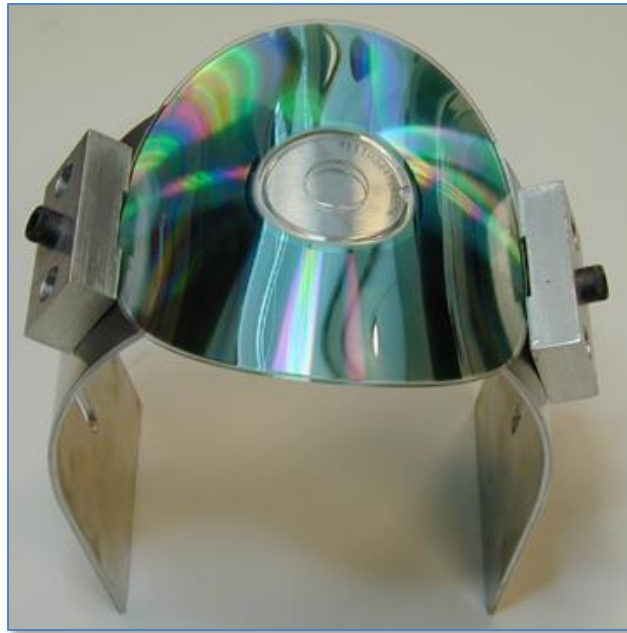


## Environmental Stress Cracking (ESC)

Add Spaghetti Sauce

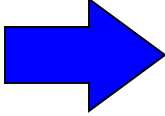
Noodle are Lubricated – Easy to Pull Apart

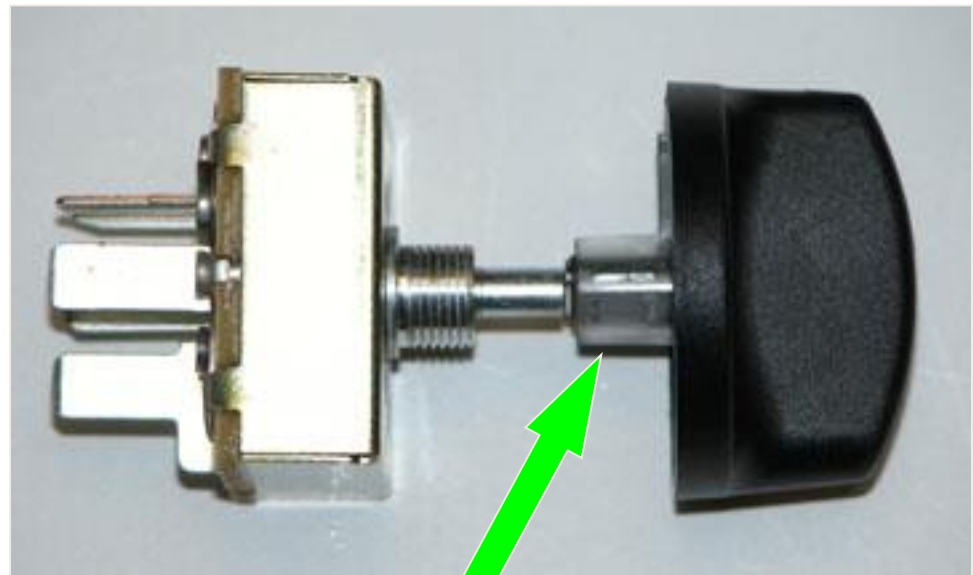
# ESC of Polycarbonate



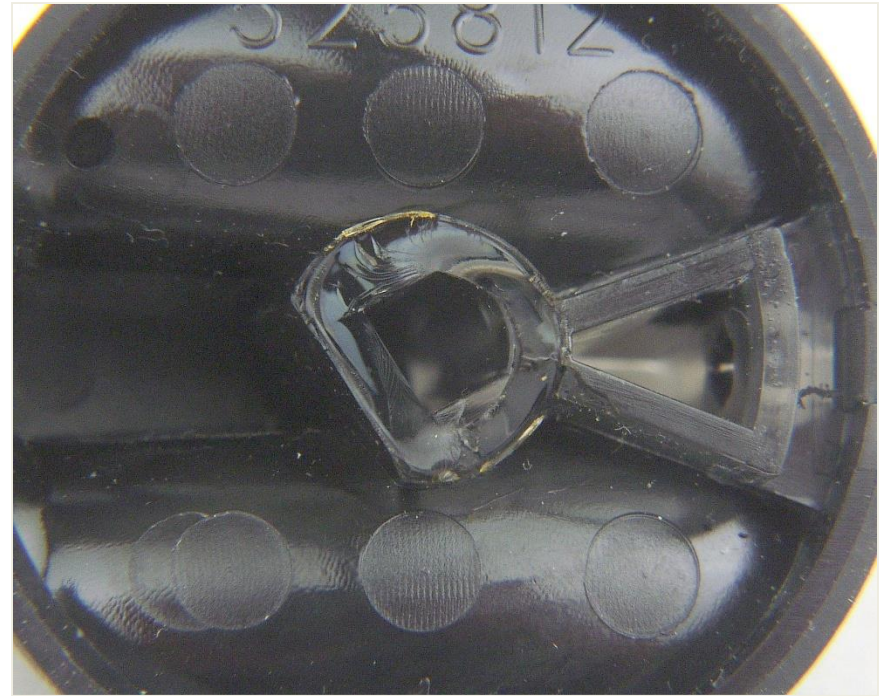
Environmental Stress Concentration (ESC)



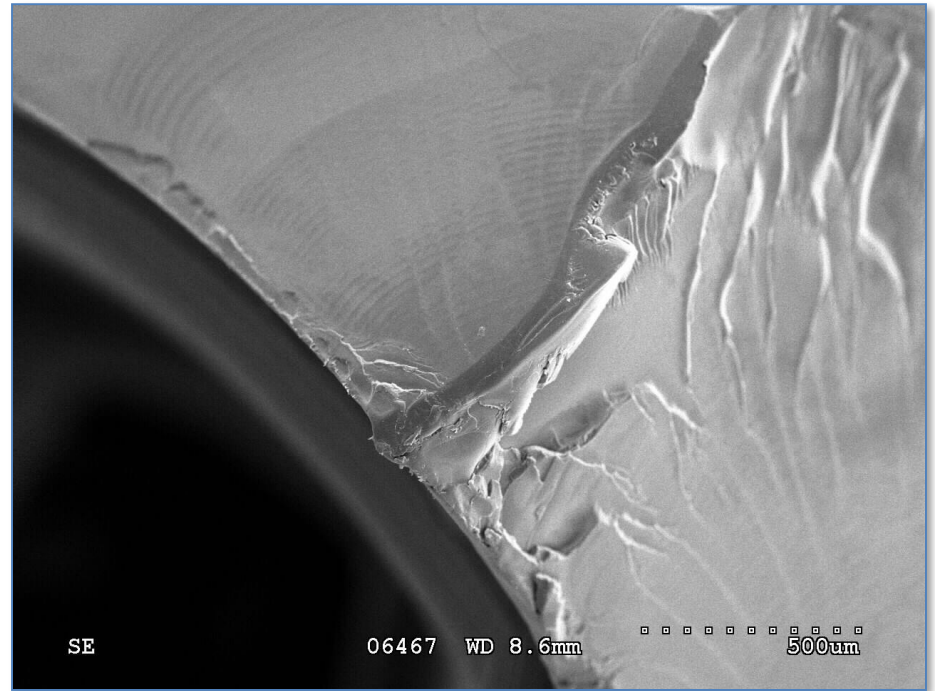
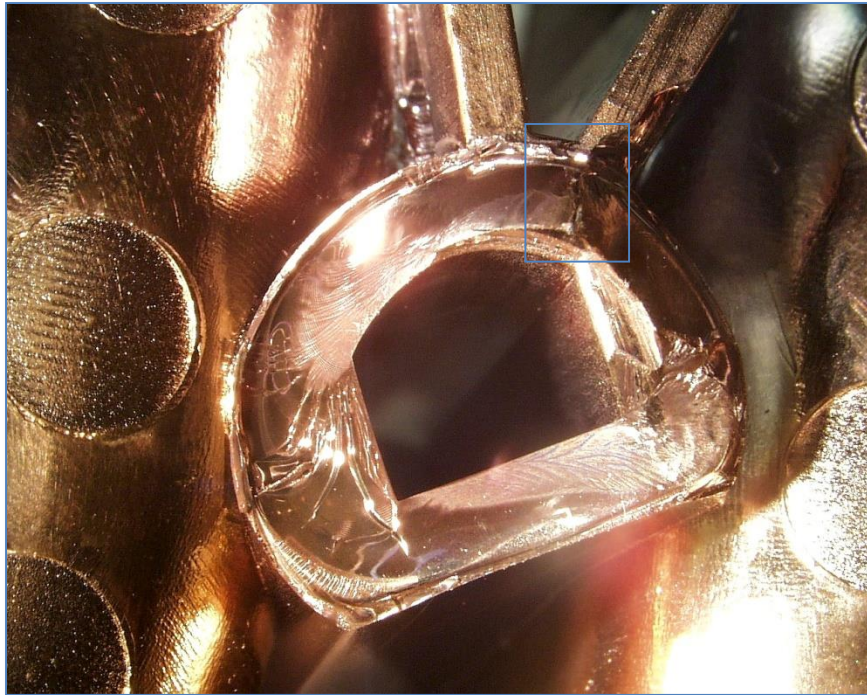
Ductile  Brittle



# Polycarbonate Knob



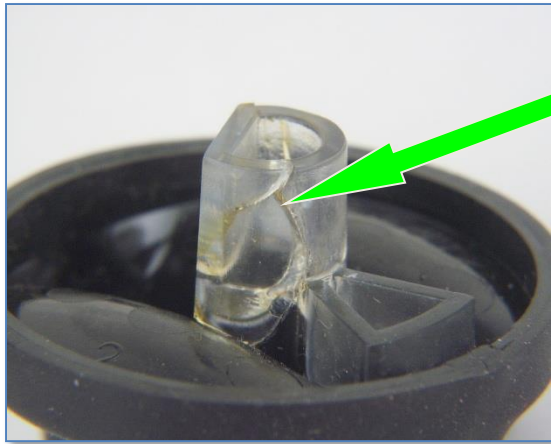
# Forensic Analysis



## Scanning Electron Microscopy

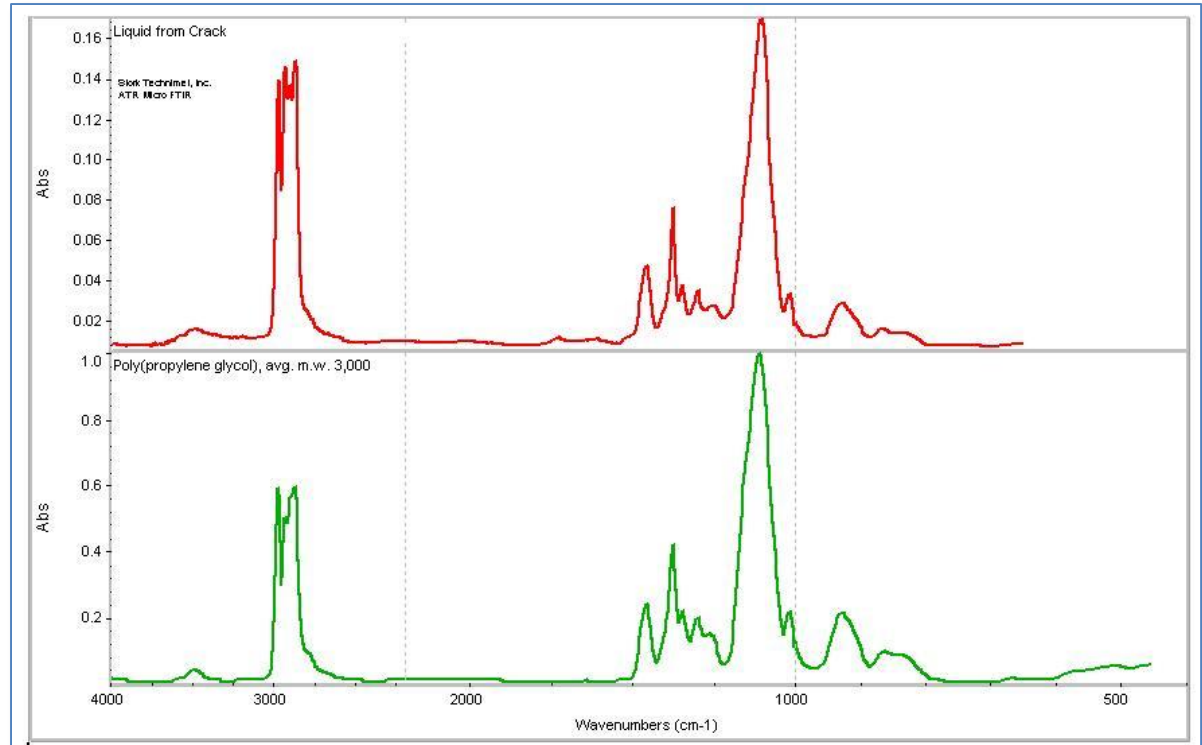


# Forensic Analysis



Infrared Spectrum (IR)  
on Oil Residue

Liquid at  
Crack



Polypropylene  
Glycol

# Scented Stick



# The Madison Group

- Formed in 1993
- 12 Engineers + Admin Staff
  - Ph.D., M.S., B.S.
  - Mechanical, Chemical, Material Science, Chemists
- Design, Manufacturing, Material Selection, Failure and Prevention



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# Questions?

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