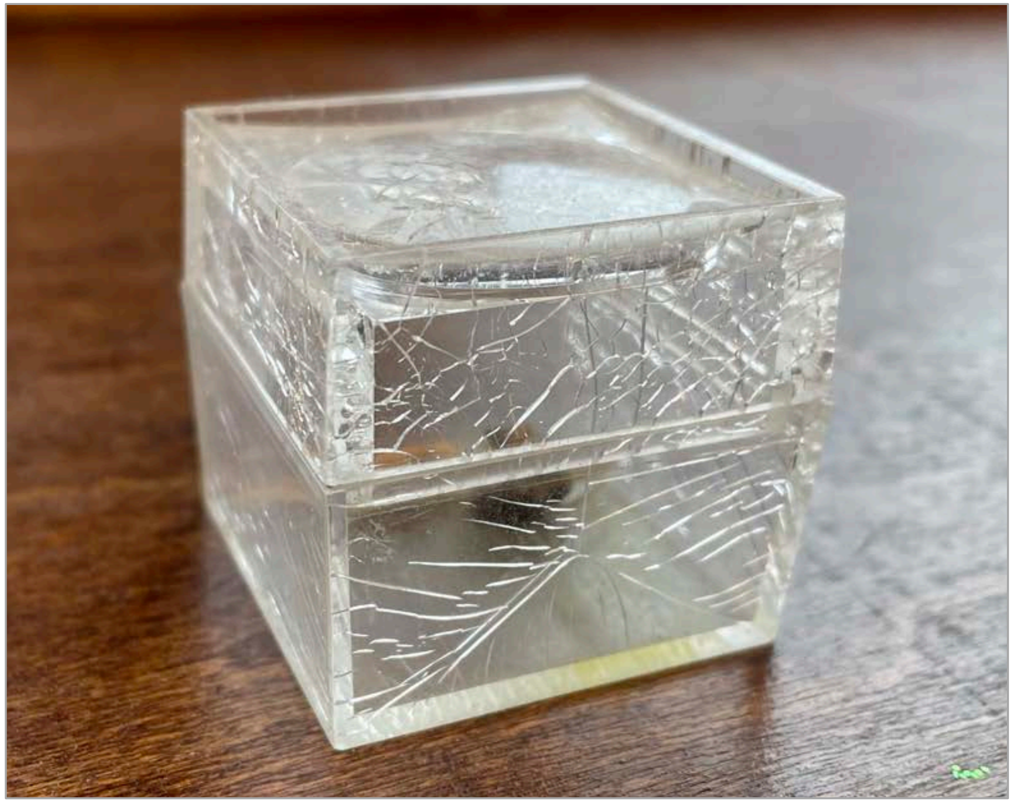
What Is Environmental Stress Cracking and How To Prevent It

Webinar Presented by Curbell Plastics

Agenda

- Creep / creep rupture
- ESC
  - Accelerated creep rupture
  - Approximately 25% of all plastic part failures
  - Not chemical degradation of the polymer
  - Plasticization process at the surface
  - Disentanglement of the polymer chains
  - Reduces the strength of the material
  - Brittle failures of normally ductile materials
- Testing plastics for ESC resistance
- Tips for preventing ESC



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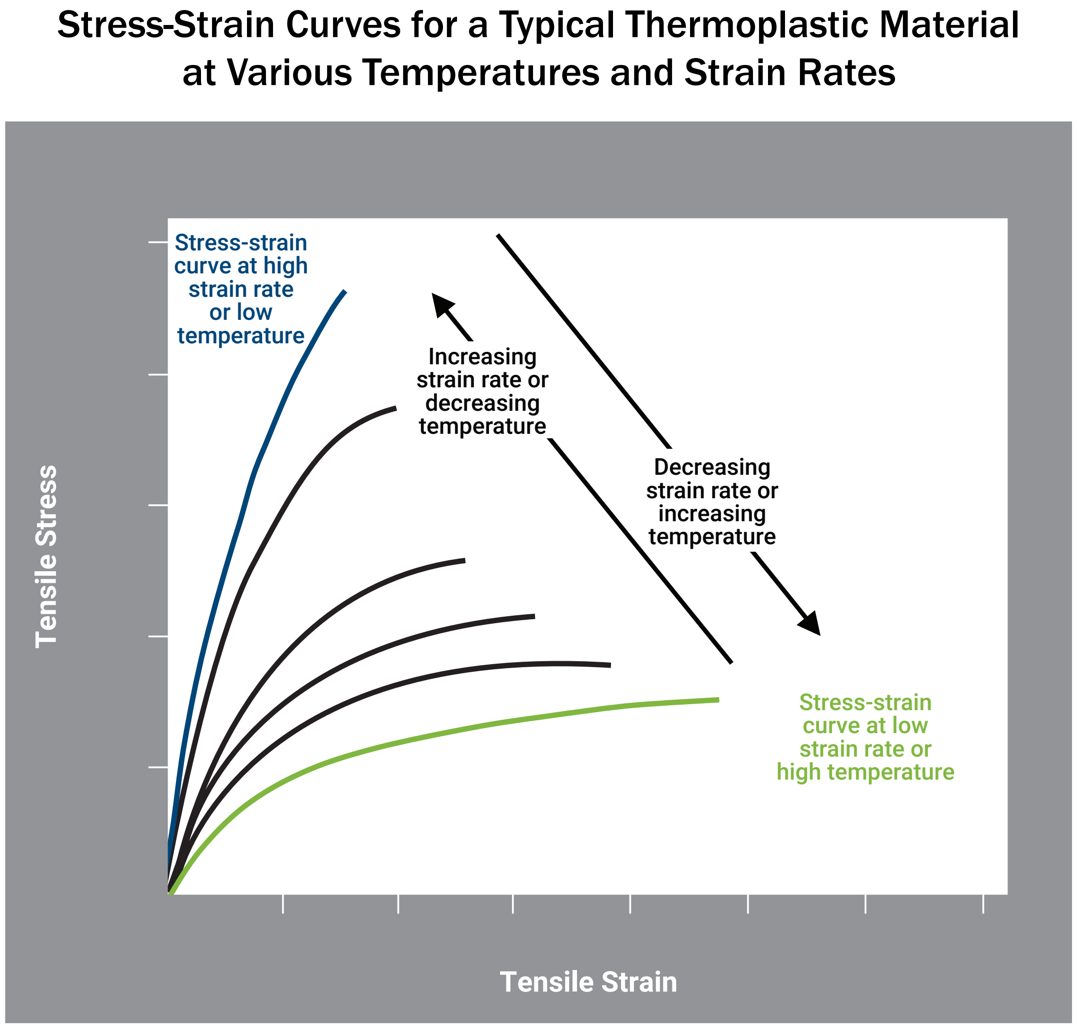
Creep



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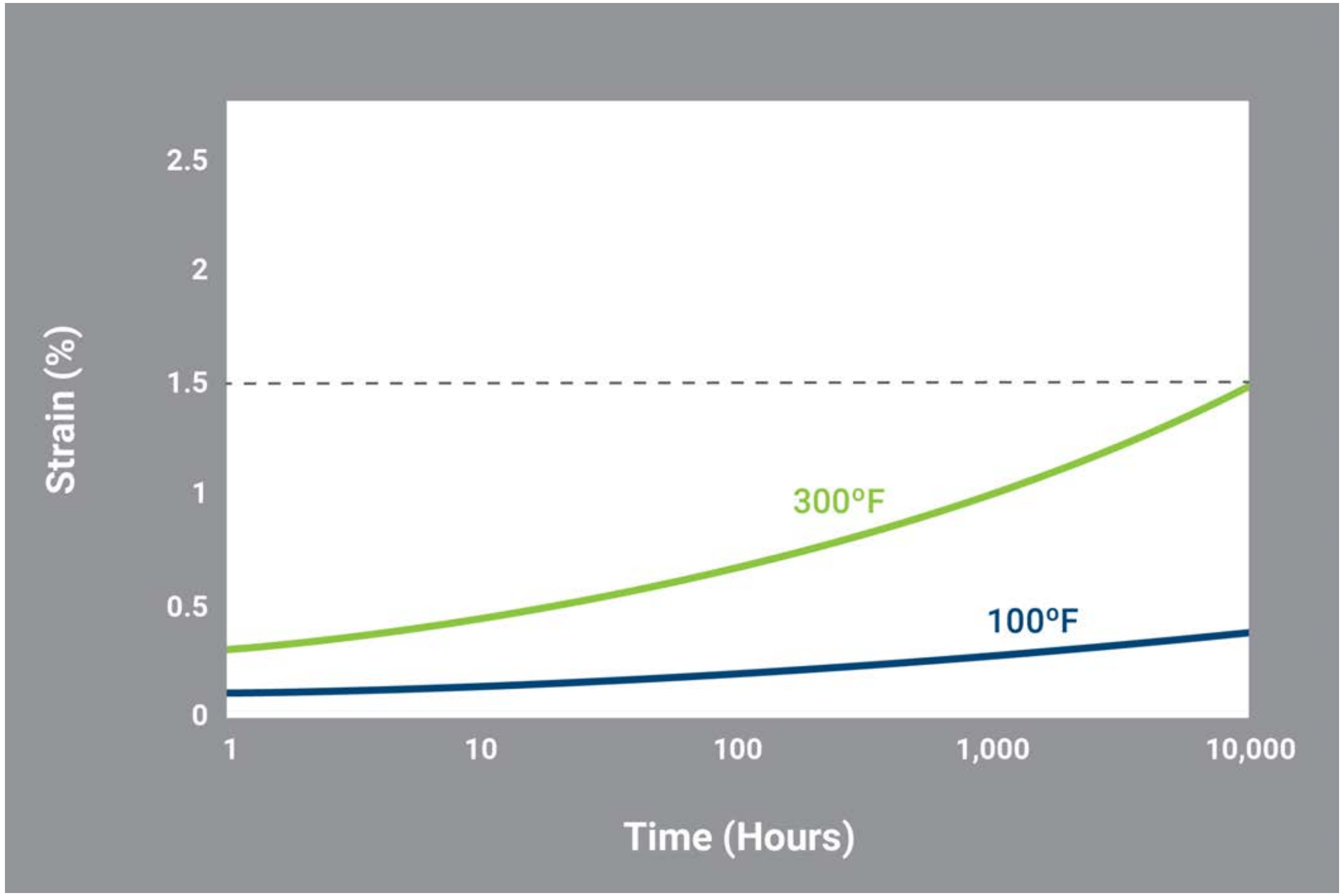
Creep

Creep strain increases with:

- Increasing temperature
- Increasing stress

Thermoplastic Creep Behavior:
1,000 psi Load at Various Operating Temperatures



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Creep Rupture

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Creep Rupture

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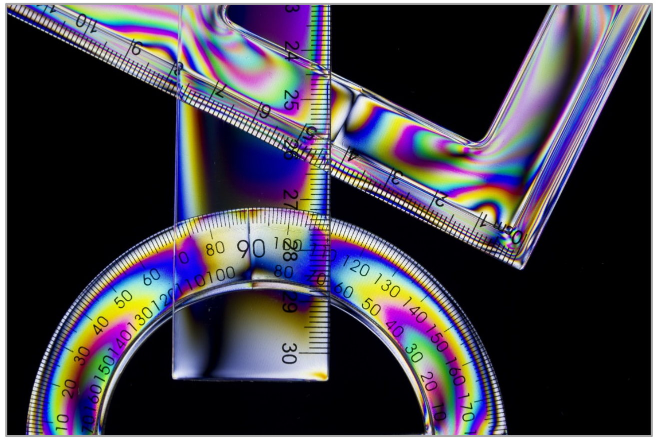
Environmental Stress Cracking



Environment + **Stresses** = **Cracking**

Environment

Cleaners
Adhesives
Lubricants
Chemicals

+

Stresses

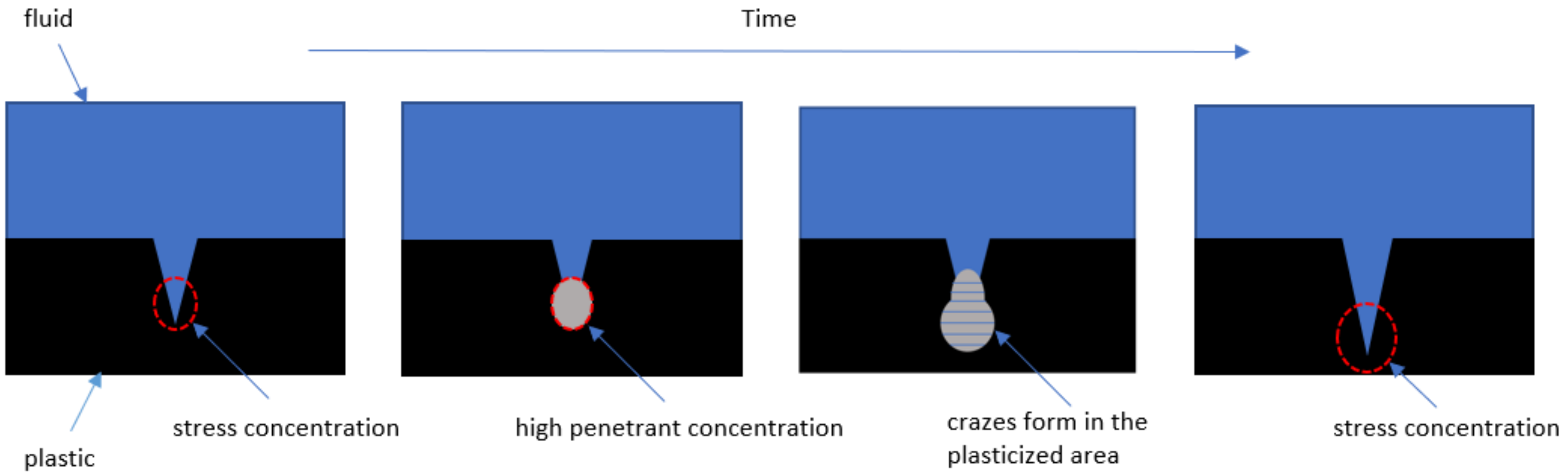
Molded-in
Machined-in
Fasteners
Externally applied

=

Cracking

Failure mode

ESC Via Fluid Absorption at a Surface Notch



A localized stress field exists at surface flaw tips

Penetrants preferentially absorb at the stress concentration and locally plasticize the polymer network

Crazes initiate and propagate in the plasticized stress field

Crazes coalesce and initiate cracking. A new stress field is created at the crack tip and the process continues.

Source: Jansen, 2006

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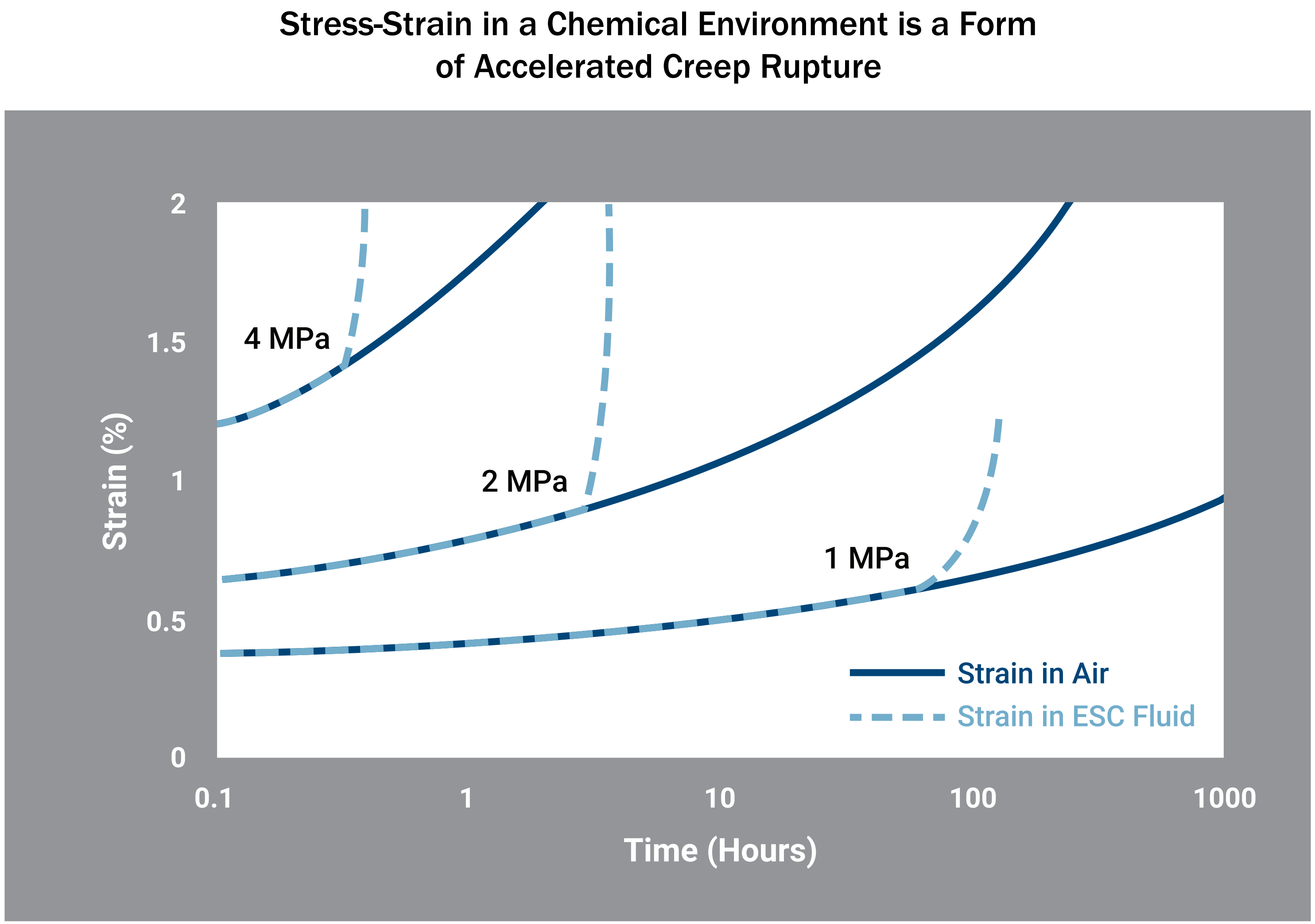
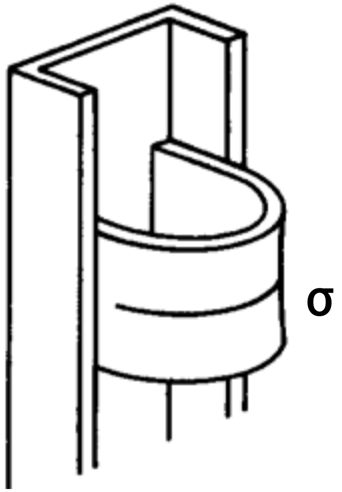
Stress Cracking in Air vs. Chemical Environment

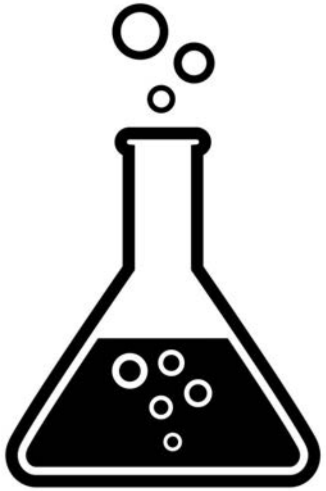


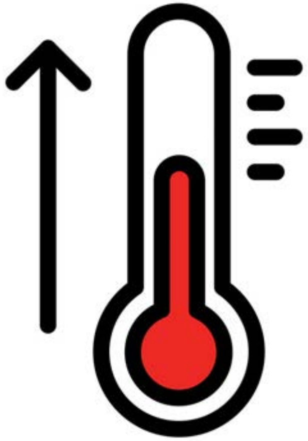
Source: McKeen, L.W., *1 - Introduction to Creep, Polymers, Plastics and Elastomers*, in *The Effect of Creep and Other Time Related Factors on Plastics and Elastomers (Third Edition)*, L.W. McKeen, Editor. 2015, William Andrew Publishing: Boston. p. 1-41.

Factors that Accelerate ESC

- Increasing stress /strain on part
- Stress concentrations, surface imperfections
- Increasing temperature
- Contact with chemicals
  - Chemical concentration
  - Exposure time
- Vibration, fatigue







Source: Image (left, Bell Telephone Apparatus): Brown, R.P. (1980). "Testing plastics for resistance to environmental stress cracking." Polymer Testing, Volume 1, Issue 4, Pages 267-282, https://doi.org/10.1016/0142-9418(80)90010-0.

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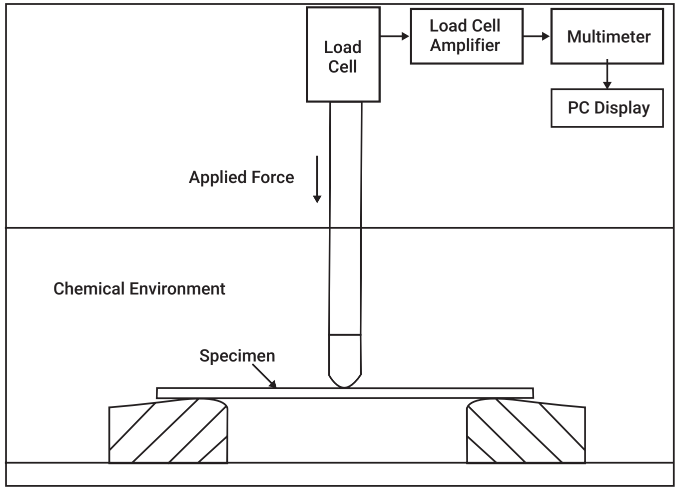
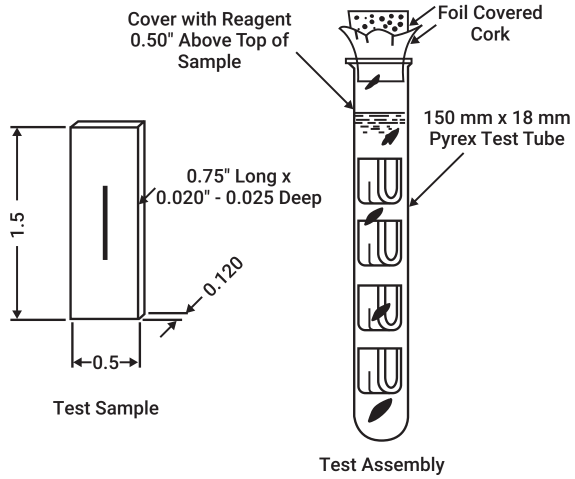
ESC Testing

- The onset of crazing can take a long time to occur under low stress conditions
- Test specimens are strained, sometimes notched, and then contacted by an ESC agent
- Examples of test methods
    - ASTM D1693
    - ASTM D2561
    - ASTM F1248
    - ASTM D543
    - ISO 4599
    - ISO 4600
    - ISO 6252
    - ISO 22088

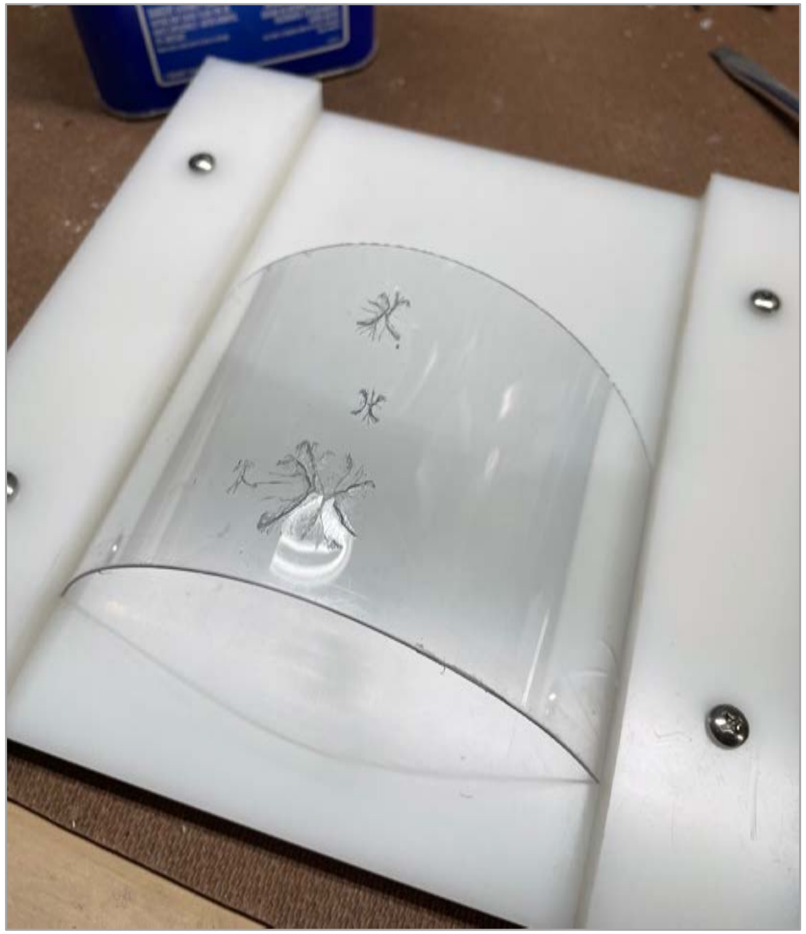




Sources:
Image (top): Al-Saidi, L., Mortensen, K., and Almdal, K. (2003)
Image (bottom): DeCoste, J. B., F. S. Malm and V. T. Wallder (1951).

ESC Testing – Limitations

- Polymers undergo time-dependent stress-relaxation throughout test
  - Stress will decay over time which lengthens test times
- The level of stress at a specified strain depends on modulus
  - Can't directly compare different plastics using the same test
- Difficult to exactly reproduce notches
- Results are sometimes visually determined (onset of cracking)



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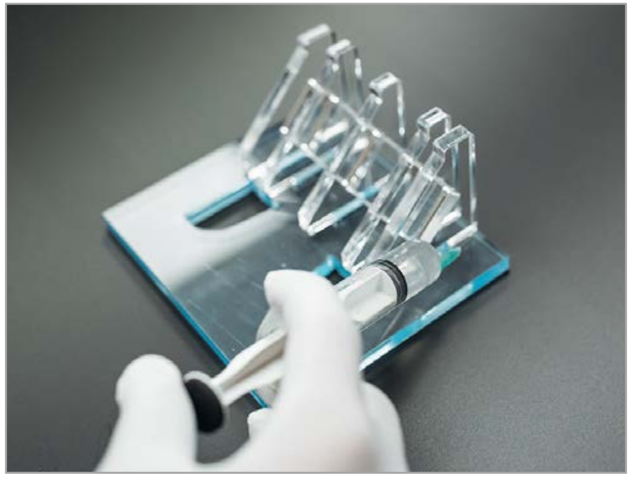
Reducing the Likelihood of ESC

Unexpected ESC Agents

- The culprit is usually ***unexpected*** chemical contact
- ESC liquids, residues, or vapors
- Adhesives, sealants, lubricants, cleaning agents, anti-rust agents, plasticizers, and oils can be ESC agents for certain plastics



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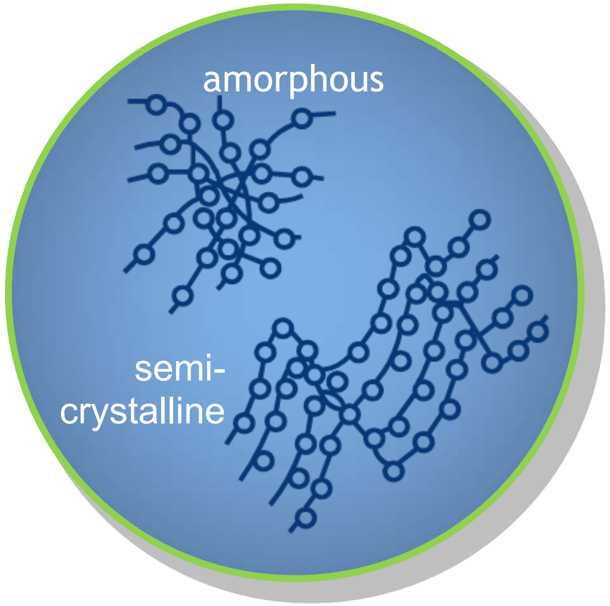
Preventing ESC – Material Selection

- Semicrystalline plastics generally have superior ESC resistance compared with amorphous plastics

Amorphous

- Ultem®
- Polycarbonate
- Acrylic
- ABS
- Polystyrene



Semi-Crystalline

- PEEK
- PTFE
- Delrin®
- Nylon
- Polyethylene

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Preventing ESC – Polyethylene

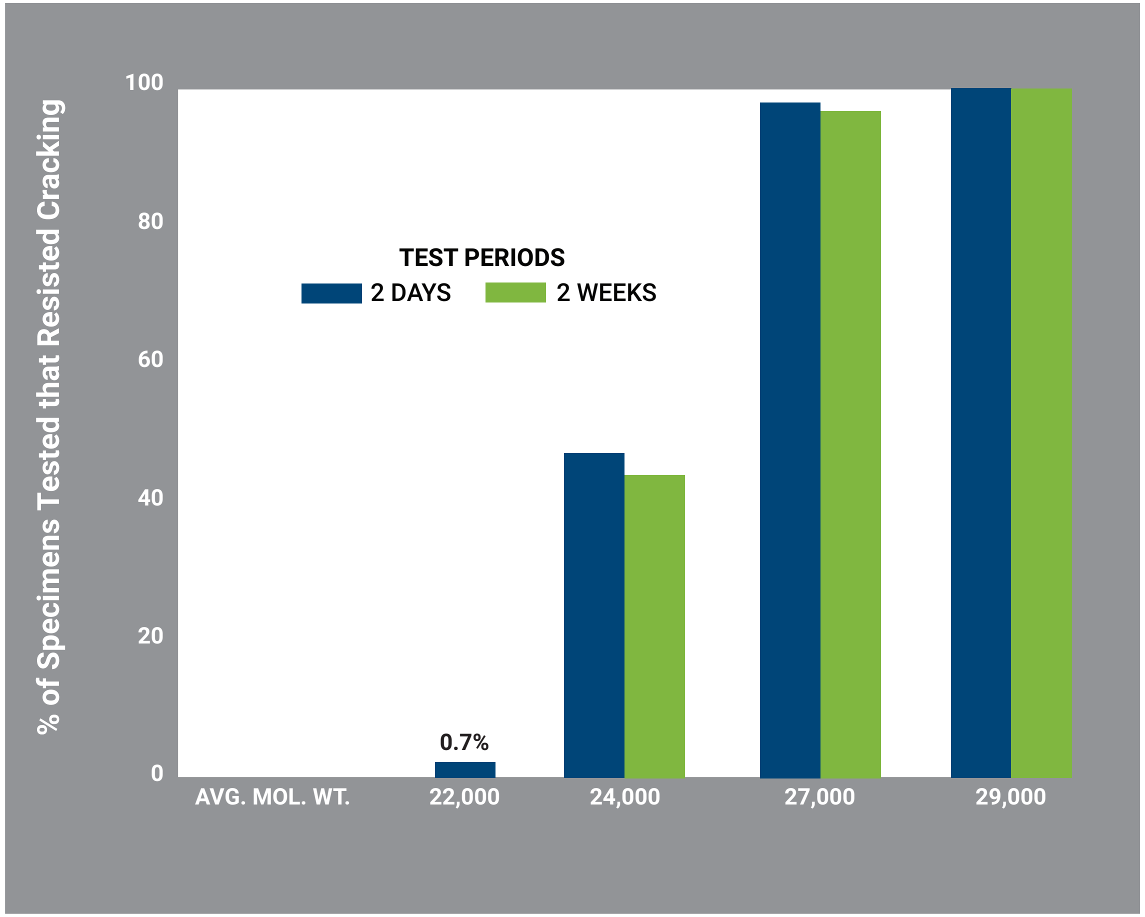
- High molecular weight polyethylenes have improved ESC resistance compared with lower molecular weight PE. Be careful when using regrind.
- Low density polyethylene (LDPE) has improved ESCR compared to HDPE
- HDPE has the poorest ESCR of the polyethylenes and is considered to be sensitive to ESC

HDPE → **LDPE** → **UHMW-PE**

ESC Resistance

Preventing ESC – Polyethylene

ESC Resistance for Polyethylene Materials with Various Molecular Weights - Exposed to Igepal at 50°C for 2 Weeks



Source: DeCoste (1951)

Preventing ESC – KYDEX® THERMOPLASTICS

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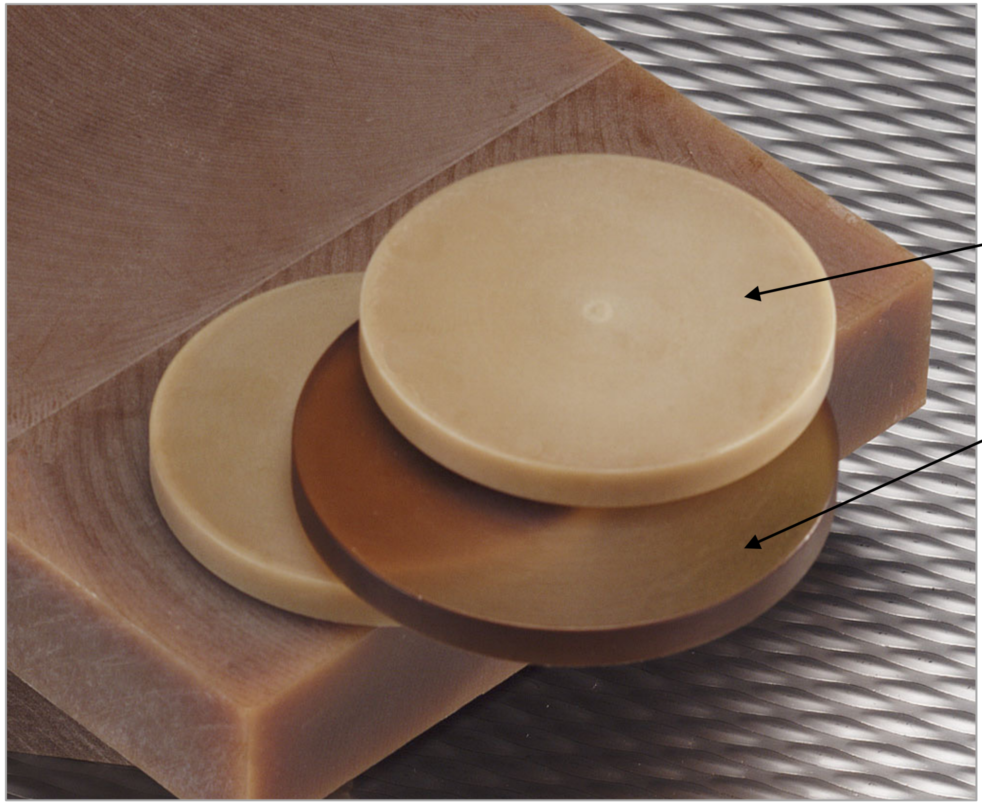
Preventing ESC – Glass Reinforced Grades



Preventing ESC – Plastic Part Assembly Tips

- Clean all fasteners so that they are free from oil

Preventing ESC – Plastic Part Assembly Tips

- Avoid elastomer washers that may outgas ESC agents
- Consider soft thermoplastic washers that don't have migrating plasticizers in their formulations

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Preventing ESC – Plastic Part Assembly Tips

- Avoid liquid thread lockers unless that have found to be compatible with a particular plastic material

Preventing ESC

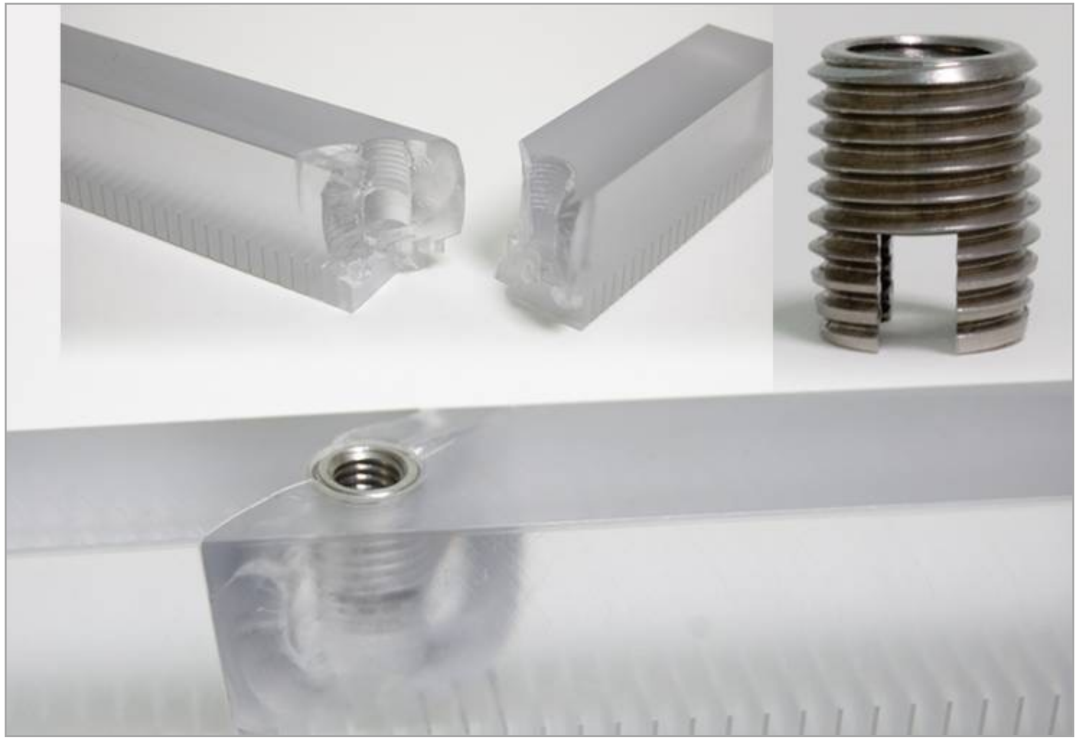
- Avoid aggressive cleaners and disinfectants

Preventing ESC

- Control torque on fasteners during assembly

Preventing ESC

- Be careful when selecting threaded inserts or self-tapping screws
- Be cautions of sharp internal threads

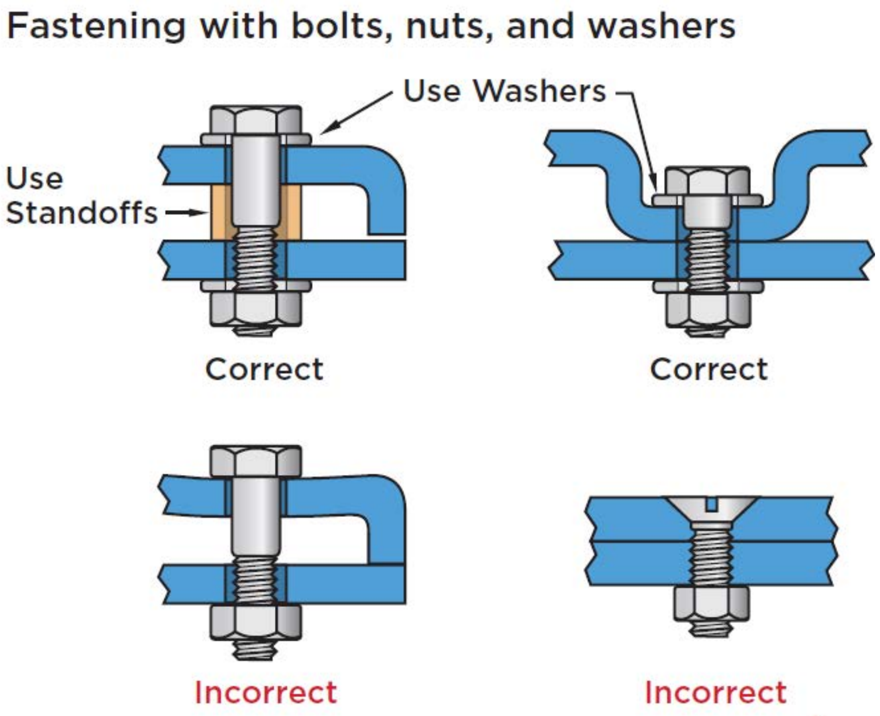


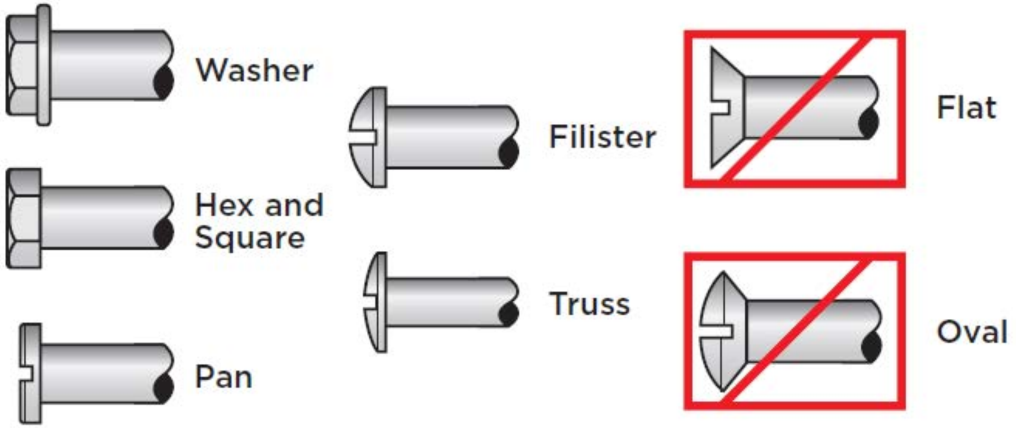
Preventing ESC

- Avoid flat head screws

Preventing ESC – Minimize Stress Concentrations

- Use round head or pan head screws with flat washers on both sides
- Flat head screws or rivets can create a significant hoop stress

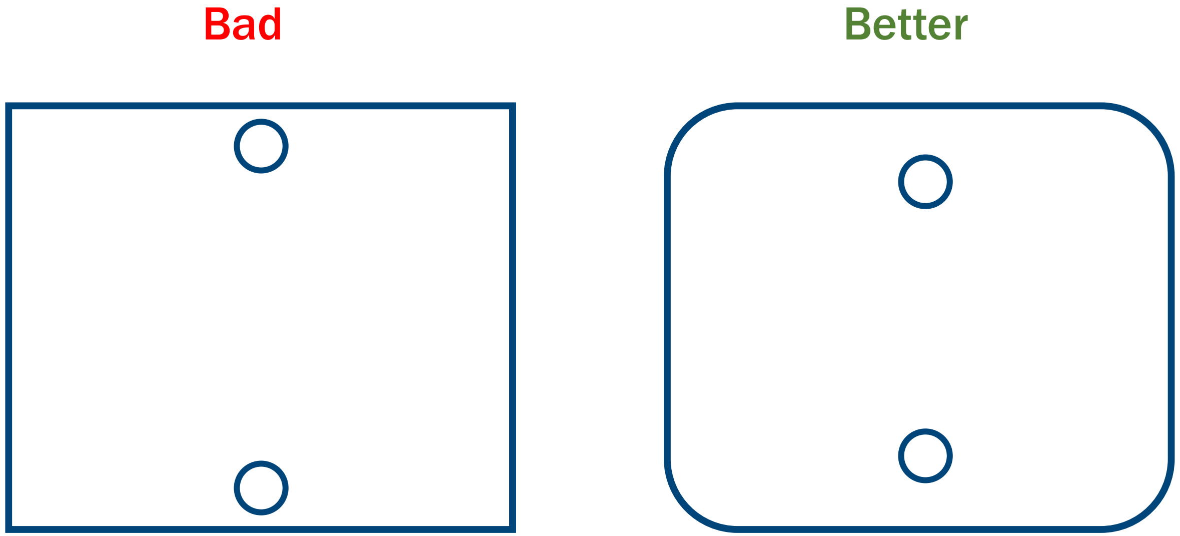




Source: Plaskolite, LLC. (2019). TUFFAK® polycarbonate sheet fabrication guide and technical manual.

Preventing ESC – Minimize Stress Concentrations

- Position fasteners as far as possible from the edges of the part



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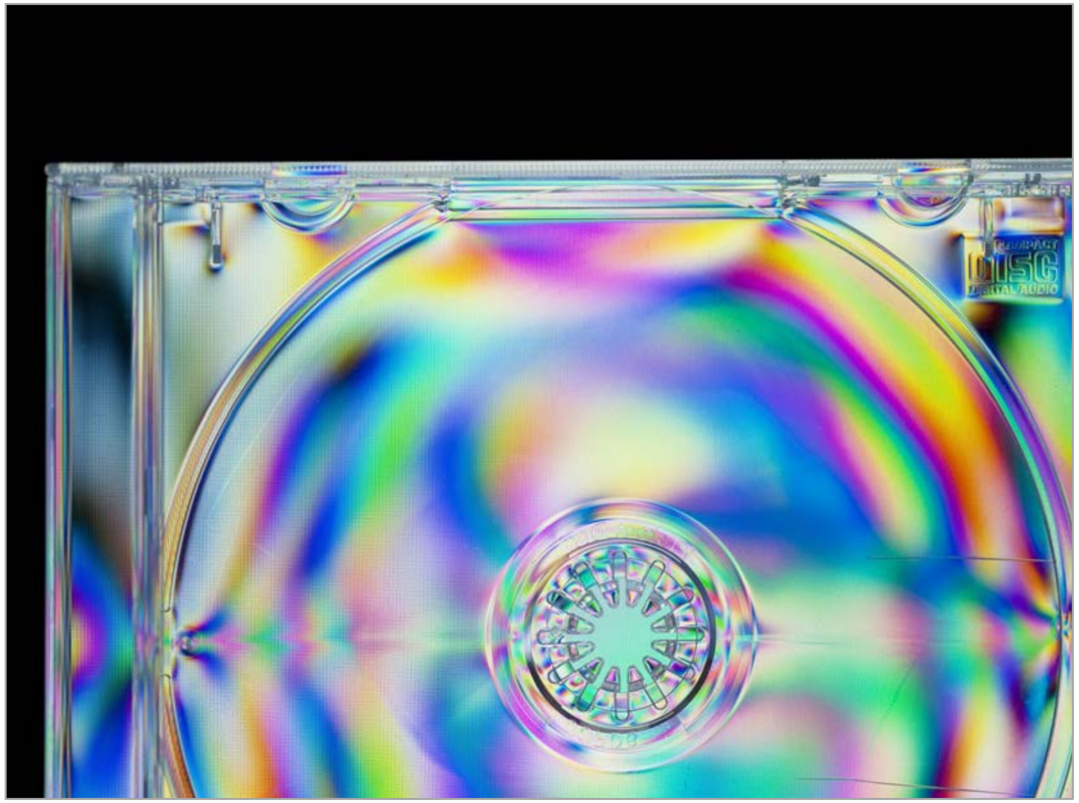
Preventing ESC – Optimize Molding processes

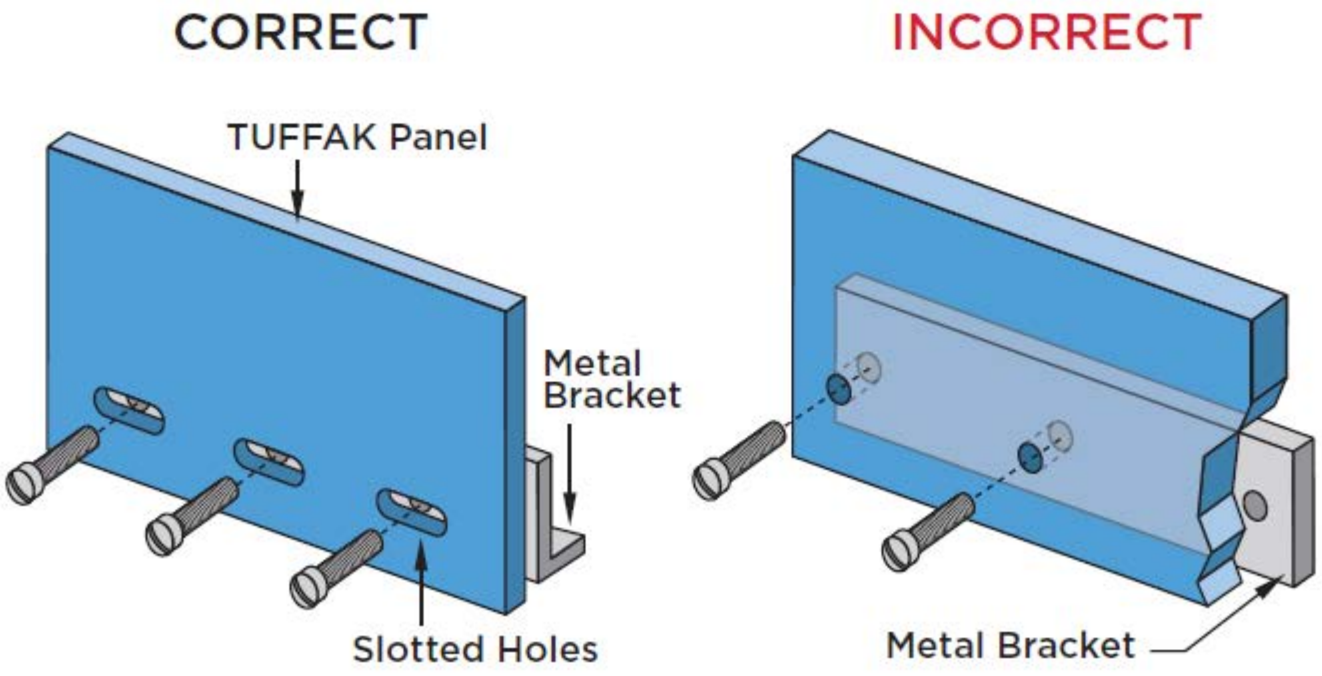
- Minimize molded in stress
  - Pressure and temperature settings during molding
  - Mold geometry
  - Melt viscosity
  - Part geometry
- Minimize molecular weight degradation during molding
- Avoid using regrind



Source: Van Goudswaard, 2019

Preventing ESC – Account for CTE

- Oversize through holes to allow for thermal expansion (CTE) mismatch between the plastic part and the mating material



Source: Plaskolite, LLC. (2019). TUFFAK® polycarbonate sheet fabrication guide and technical manual.

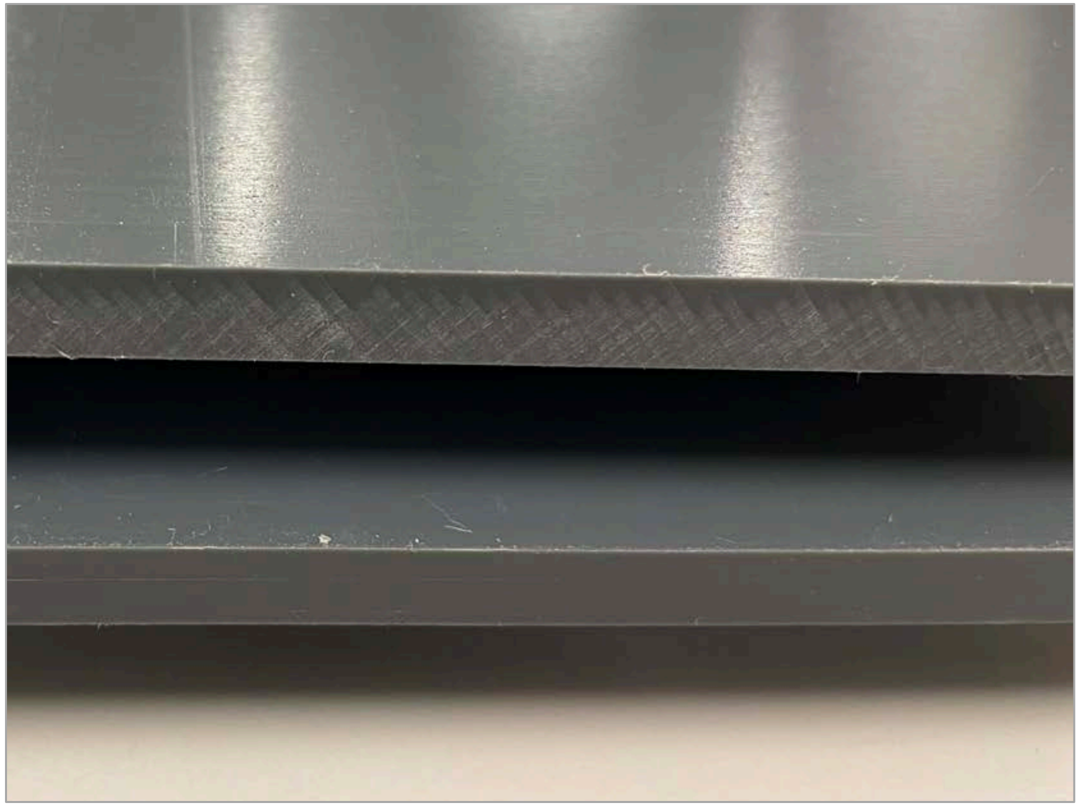
Preventing ESC – Sharp Internal Corners

- Avoid sharp, 90 degree internal corners that can result in stress concentrations
- Add generous radii when possible

Preventing ESC – Edge Quality

- Make sure that all machined edges are smooth and not chipped or melted

- Bit geometry, sharpness, feed rate, and RPMs will all contribute to edge quality



Poor

Better

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Preventing ESC – Flame Polished Edges of Acrylic

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Chemical Exposure / Stress Concentrations

Glass / Polycarbonate Laminates

- Layers of glass, polycarbonate, and polyurethane laminated in an autoclave
- Different CTEs during cooling create stress
- Control heating and cooling to minimize stress
- Avoid sealing or cleaning with potential ESC agents

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Chemical Resistance Charts

- Qualitative rating or a maximum suggested operating temperature for chemicals in contact with plastics
- Rating based on weight-gain, dimensional changes, and possibly ESC observations
- Of limited utility for predicting ESC

Chemical Substance	Concentration[a]	HOMO-POLYMER Max[b, d] Temp		COPOLYMER Maximum[b, d] Temperature 2850		COPOLYMER Maximum[b, d] Temperature 2800	
		°F	°C	°F	°C	°F	°C
Acetaldehyde		NR	NR	NR	NR	NR	NR
Acetamide		75	25	NR	NR	NR	NR
Acetic Acid	10% in water	230	110	220	105	200	95
Acetic Acid	50% in water	200	95	200	95	200	95
Acetic Acid	80% in water	150	65	125	50	125	50
Acetic Anhydride		NR	NR	NR	NR	NR	NR
Acetone	10% in water	125	50	100	40	100	40
Acetone	11-25 % in water	75	25	75	25	NR	NR
Acetonitrile		125	50	100	125	NR	NR

Source: *Polyvinyldiene fluoride chemical resistance chart*. Kynar® by Arkema, 2021.

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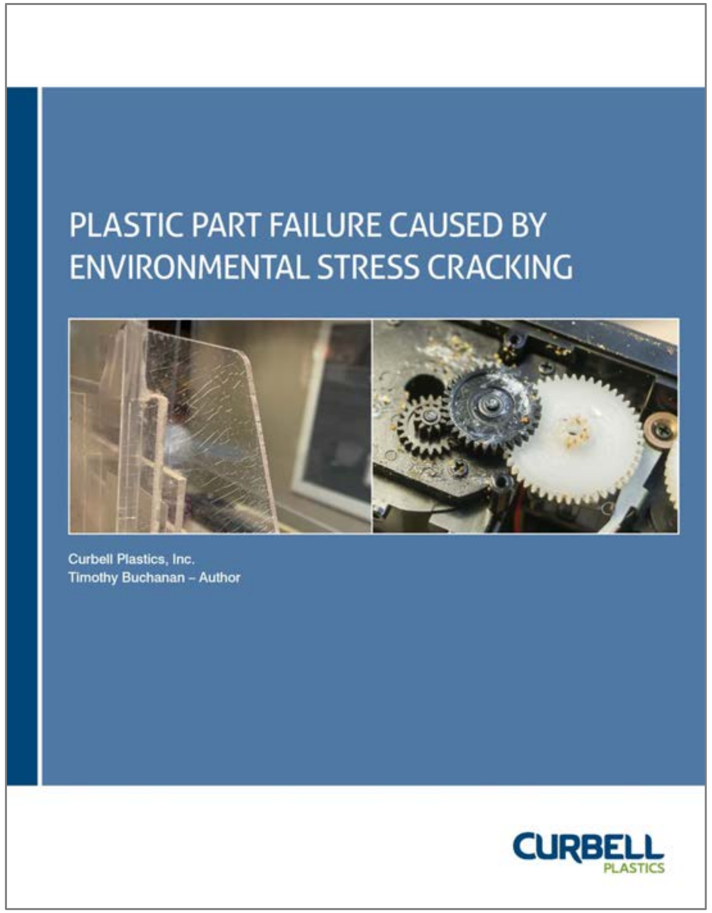
NEW White Paper

For additional information about selecting and assembling plastics where ESC may be of concern read our white paper:

Plastic Part Failure Caused by Environmental Stress Cracking



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Thank you for your time today! Questions?

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