# Evaluation of Coolant Induced Environmental Stress Cracking In Poly(ethylene terephthalate)-Glycol


PURDUE MATERIALS ENGINEERING

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Environmental Stress Cracking (ESC) is a decades-old problem in the polymer industry that causes failure of polymers. Buehler has experienced ESC in its Poly(ethylene terephthalate)-Glycol (PETG) safety windows for its abrasive cutting machines due to its interaction with coolant. Accelerated ESC propagation testing was utilized to determine the compounds most responsible for ESC and in what concentrations said compounds initiate ESC. Alternative coolants and chemical compounds that reduce the ESC growth rate were identified and suggested to Buehler.



This work is sponsored by: Buehler, Lake Bluff, IL.


## Environmental Stress Cracking

- Environmental Stress Cracking (ESC) is the premature crazing, cracking, and embrittlement of plastics due to a combination of associated stress/strain in the presence of secondary chemical agents like adhesives, coolants, etc.
- ESC is responsible for the failure of ~25% of polymer products

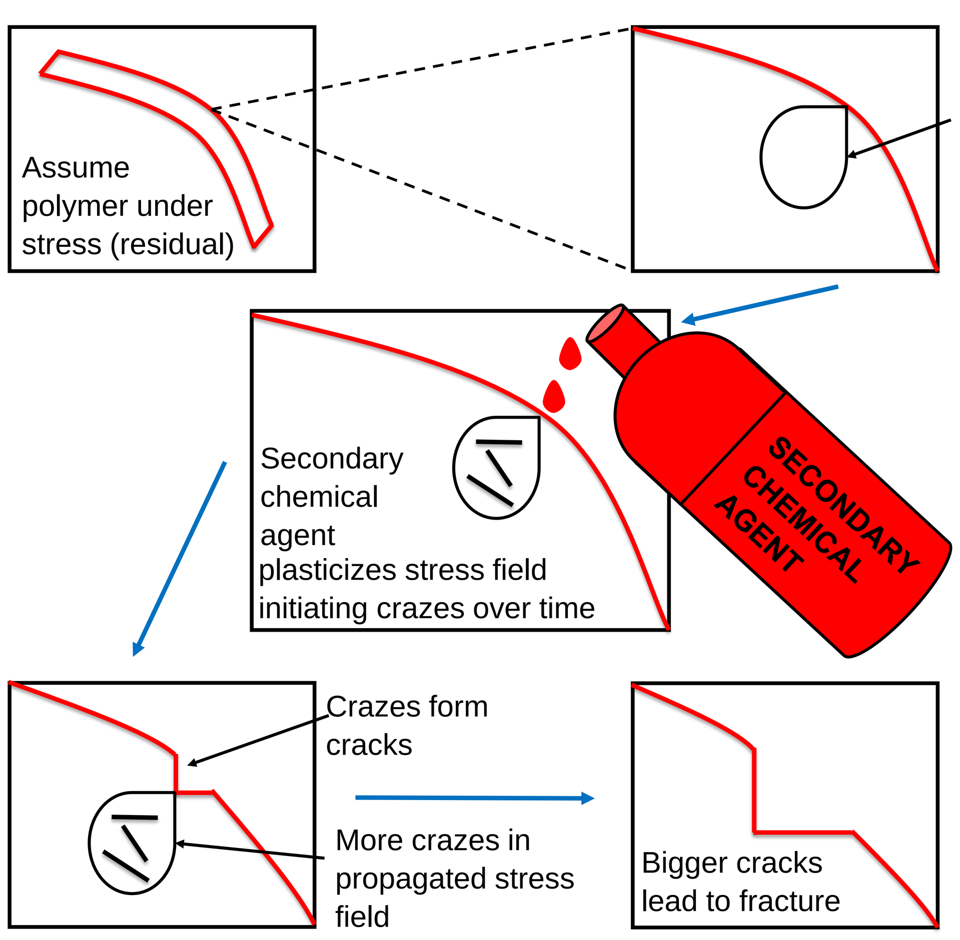


*Figure 1: Mechanism of failure through Environmental Stress Cracking.*

## Experimental Procedure

- Buehler reports ESC appears after about 6-months of heavy usage on PETG.
- An accelerated testing regiment was developed to simulate rapid ESC growth and propagation.
  - Total testing time reduced to 1-hour.
- ESC Growth Experimentation
  - Three samples of 5/64 inch thick PETG inserted into tensile jigs (fig. 2) and strain of 0.5.
  - Samples then submerged in coolant solution
  - A sample was withdrawn from coolant at 15-30- and 60-minutes for analysis.
  - Experiment was designed to give clear indication of ESC propagation through the polymer.

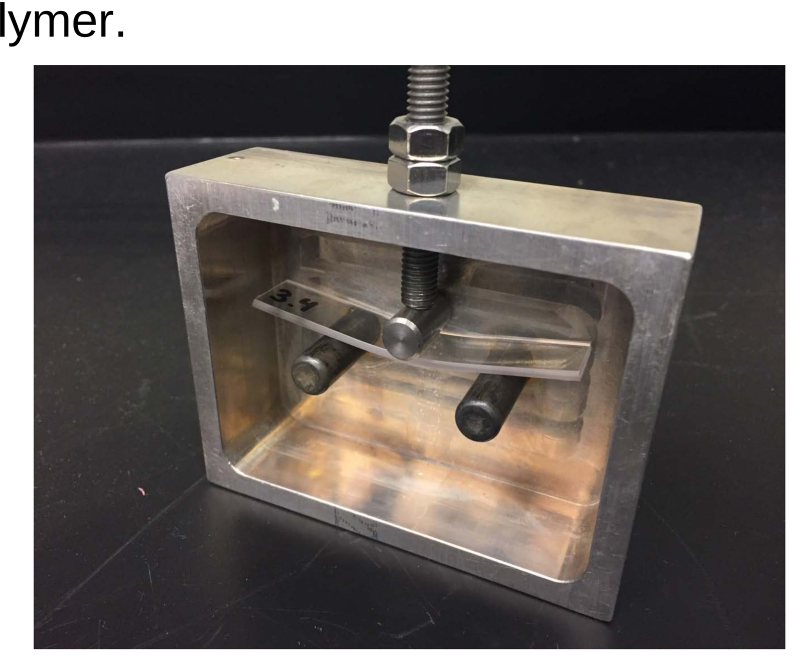

*Figure 2: Jig with sample under stress ready to be submerged in coolant.*

- Buehler's Cool 3 coolant has 4 components in it:
  - Component 1 – Water
  - Component 2 – Methyldiethanolamine
  - Component 3 – Butoxydiglycol
  - Component 4 – Glycerol poly(oxyethylene) poly(oxypropylene) ether
- Tests were run by varying concentrations of each component individually within the range specified in the MSDS. This was done to identify which component(s) was/were the main cause of ESC.

| Test No. | Comp. 1 | Comp. 2 | Comp. 3 | Comp. 4 |
|---|---|---|---|---|
| 1A | 1700 g | 100 g | 100 g | 100 g |
| 6A | 1800 g | 100 g | 50 g | 50 g |
| 10A | 1800 g | 20 g | 90 g | 90 g |
| 11A | 1800 g | 0 g | 100 g | 100 g |
| 12A | 1800 g | 100 g | 0 g | 100 g |
| 13A | 1800 g | 100 g | 100 g | 0 g |

- Area measurements were done by assuming the samples were rectangles. Three areas were calculated for each. ESC area was calculated by calculating area of polygon drawn around the ESC region using imageJ software and percentages were calculated.
- Corrosion Resistance Experimentation
  - 2" long carbon steel wire submerged in coolant.
  - Samples were inspected at 4, 7, 11 and 14 days.
- Optical Microscopy Procedure
  - Samples analyzed utilizing Dino-Lite digital microscope (fig.3).
  - Birefringence utilized to display stress gradients resulting from ESC.

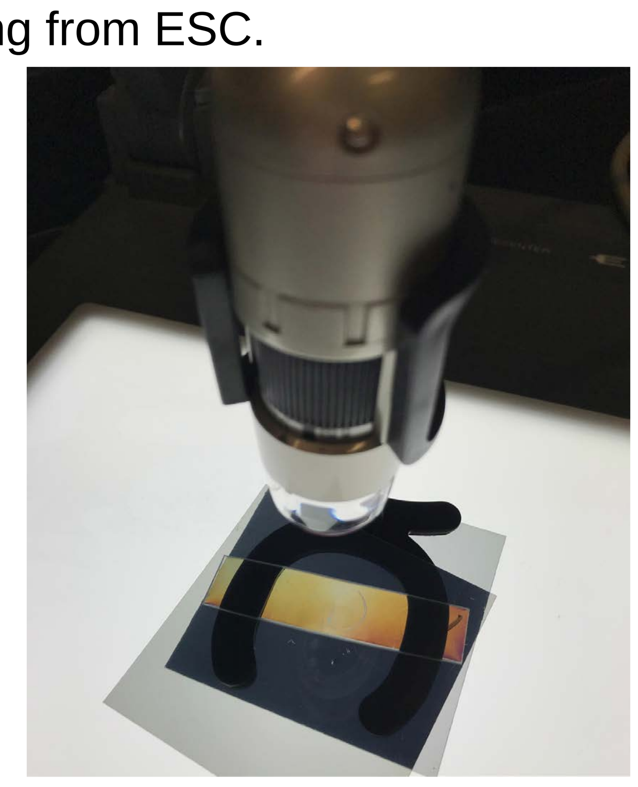

*Figure 3: Imaging of tested samples using Dino-lite microscope and cross-polarizers.*

- Intensity of ESC was quantified using a blind experiment where three of the four group members looked at tested samples that were newly labeled by the fourth group member to avoid bias. The three members then rated intensity of ESC for each sample on a scale of 1-5 with 5 being the most intense.

## Results and Discussion

Area Quantification:

- Components 2 and 3 were identified as ones responsible for ESC.
- An alternate to component 2 in Cool 3 was identified and tests were done with both of them to see if any difference in ESC was observed. Fig. 4 shows 60 minute test results for the two component 2 options tested in a water solution.

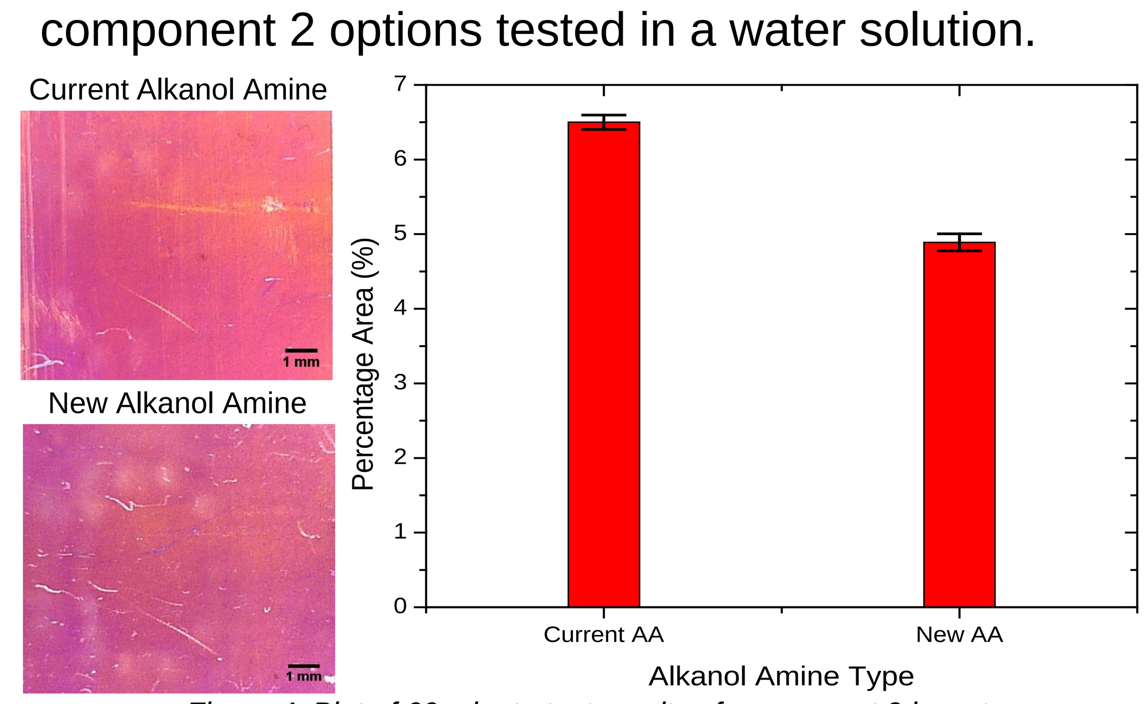


*Figure 4: Plot of 60 minute test results of component 2 in water.*

- Tests were then done with the two component 2 options and ESC area was compared (fig. 5).

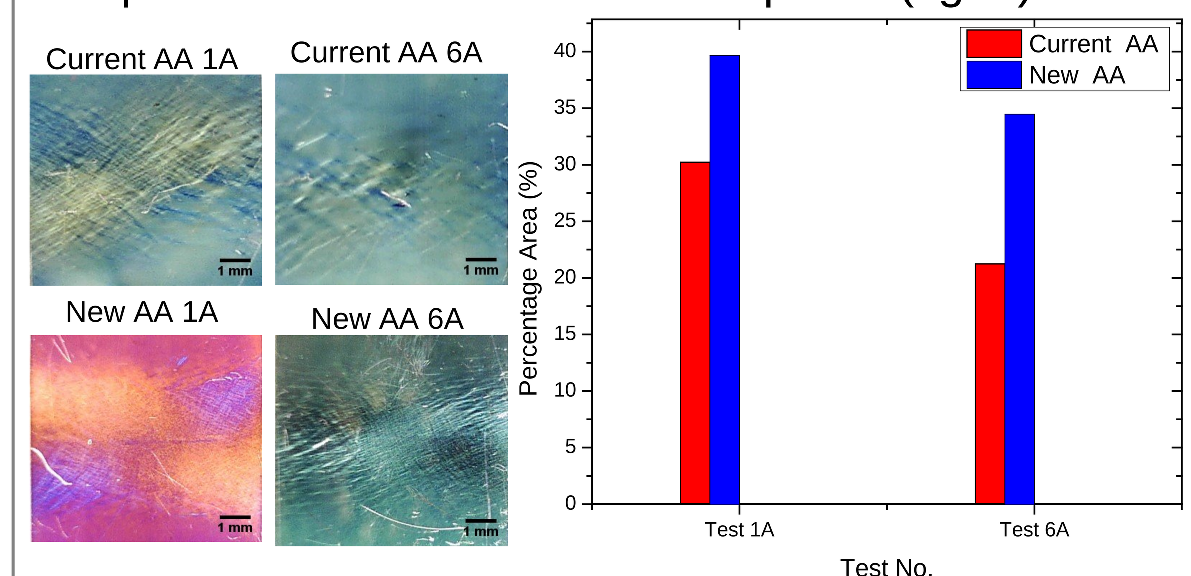


*Figure 5: Plot of 60 min. test results using both component 2 options.*

- An alternate commercially available coolant (Tri-Cool TC-1) was also tested and compared with Buehler's Cool 3. The results were plotted in fig. 6.

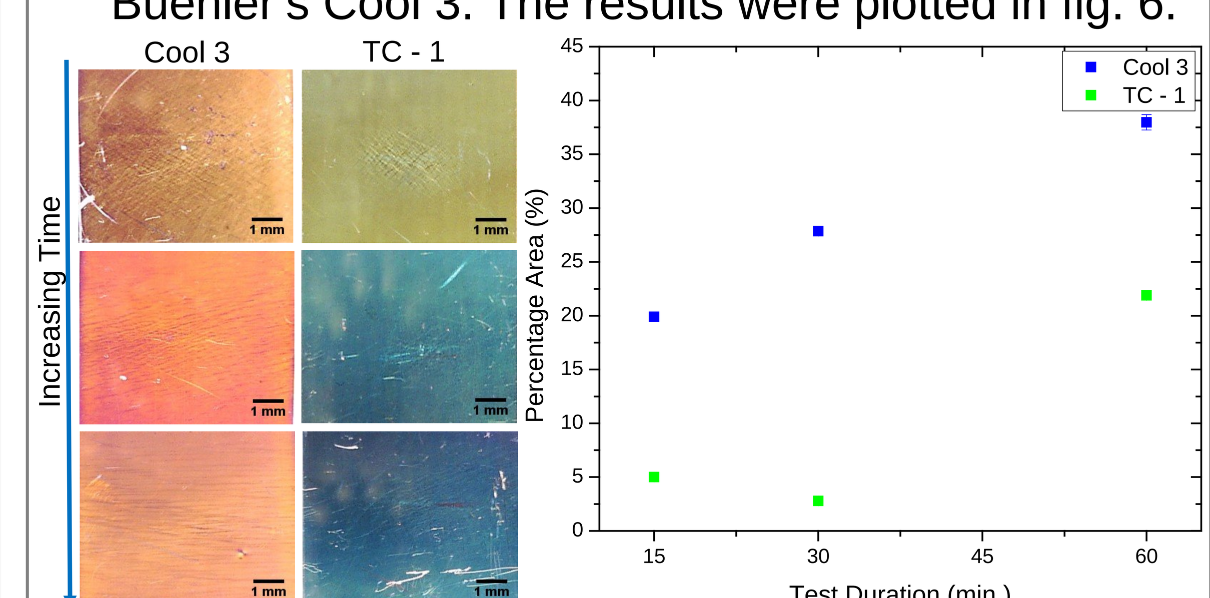


*Figure 6: Comparison between Cool 3 and TC-1 for the three test durations.*

Intensity Quantification:

- Even though fig. 5 shows that the current component 2 was better, ESC observed in its case was much more intense suggesting that the new component gave less intense ESC on a wider area whereas the current option gave more intense ESC on a smaller region. These are supported by the blind test results plotted in fig. 7.

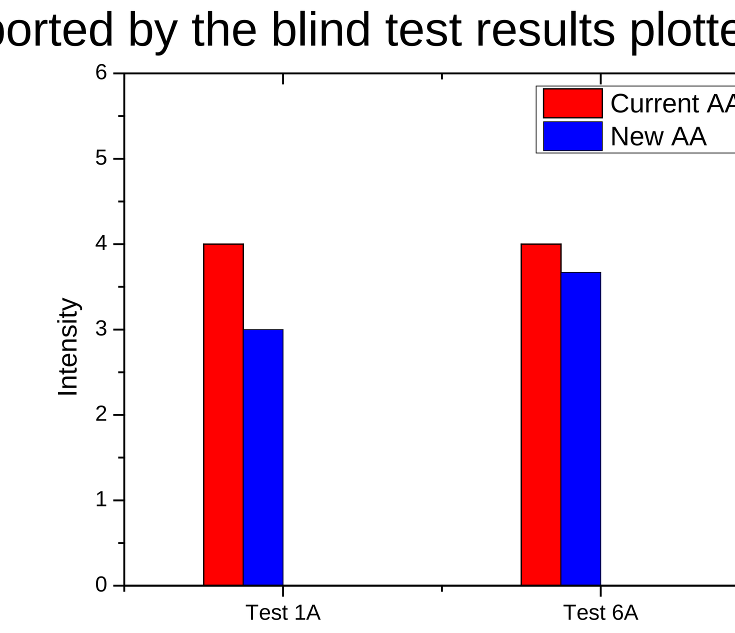


*Figure 7: Intensity comparison for the test results plotted in fig. 5.*

Corrosion Resistance:

- Since component 2 is the corrosion inhibitor in the Cool 3 system, corrosion resistance tests proved that the new alkanol amine was just as effective as the current one over a period of 11 days as shown below. TC-1 was also comparable to Cool 3.


## Recommendations

We recommend the continued use of PETG polymer material but with a change in machine coolant. With current coolant, a change in components 2 (as suggested) and 3 is necessary. TC-1 also provides a good alternative for coolant that is already commercially available. Since component 3 is a more aggressive ESC agent than component 2, future work should focus on looking at alternatives for it.