Environmental Stress Cracking of Polymer Hoods of Abrasive Cutter in a Coolant-Rich Environment

PURDUE MATERIALS ENGINEERING

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Buehler has had issues with environmental stress cracking (ESC) of the polycarbonate (PC) hoods of their abrasive cutters after switching to a new coolant. MALDI was used to identify the components of the coolant in order to study their effects on degradation of PC and PETG polymers were studied. An alkanol amine was identified as the likely cause of ESC in the hoods. PETG was found to be more suitable than PC in the presence of coolant.

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

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Environmental Stress Cracking

- Environmental Stress Cracking (ESC) is the creation and propagation of crazes and cracks within a solid polymer exposed to liquid chemicals.
- 15%-40% of polymer failure is due to ESC.
- The stress required for crack formation is lowered by environmental exposure, as the solid-liquid interfacial tension is lower than that of the solid-air interface, as described by the equation $\gamma_{SL} = \gamma_S - \gamma_L \sin(\theta)$ where γ_{SL} is the solid-liquid interfacial tension, γ_S is the solid–air surface tension, and γ_L is the solid–liquid surface tension.
- The diffusion of penetrants into polymers, resulting in an osmotic pressure within the plastic also contributes.

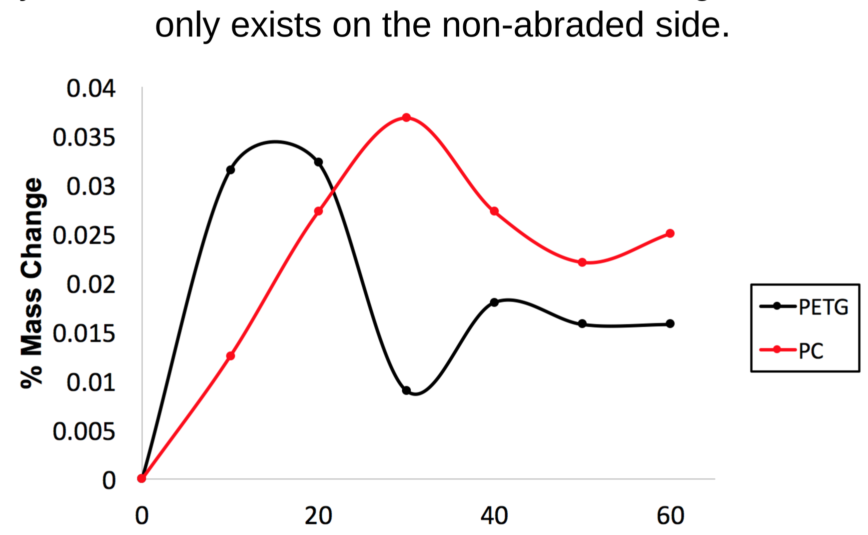
Environmental stress cracking induced in PETG during a continuous strain test soaking in Cool 3, 1 to 5 dilution, for 5 days.

Abrasive Testing

Abrasive testing was performed to simulate the environment that the hoods are exposed to during use in an abrasive cutter.

- 400 gallons/hour of swarf bearing water impinged samples of PC and PETG (similar to below). Neither polymer showed adverse effects.
- Both materials slightly gained mass, shown in the graph below, but at most a .04% increase.
- Neither material changed dimension, eliminating swelling as a potential source for stresses.

PC (left) and PETG (right) both failed to display abrasive wear from the test. Any scratches seen are a relic of the mounting mechanism, and only exists on the non-abraded side.



Both materials gained mass, though at only .02-.03% of total sample mass, the results are negligible. The up and down behavior shown for the PETG sample is likely a result of measurement error at small mass scales.

Conclusion: PETG and PC have adequately similar abrasive resistance, such that switching between the two will not cause unwanted side effects with regard to abrasion.

Continuous Strain Testing

Continuous strain testing was performed to simulate the stresses present at the points where the hood is connected to the frame or lifting handles.

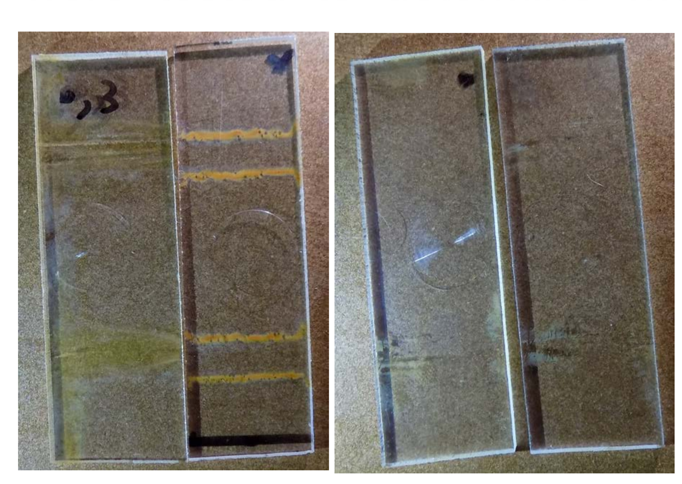
- Constant strain assays were performed on 1" x 3" coupons of PC and PETG, held at constant strain while exposed to ESC-inducing conditions.

Three point continuous strain jig, as provided by Buehler.

- Samples at various stresses were placed in bath for a five-day soak.

PETG (left) and PC (right) samples, displayed from left to right with decreasing strain.

- ESC occurs more strongly in samples at higher stress, low stress samples show no response. This indicates that there is a minimum stress required for ESC to occur.
- Individual chemical components of the new coolant were tested to determine which cause ESC.



Samples after exposure to 2-(2-butoxyethoxy)ethanol (left) and Polyalkylen derivate (right) bathes for five days under strain.

- Coolant components 2-(2-butoxyethoxy)ethanol and Glycerol Propoxylate-b-ethoxylate baths showed no ESC response.
- Samples that had been deformed in 3-pt bend testing and drop tower testing were soaked in coolant bath for 5 days.

3-point bend samples before (left) and after (right) bathing in coolant for 5 days

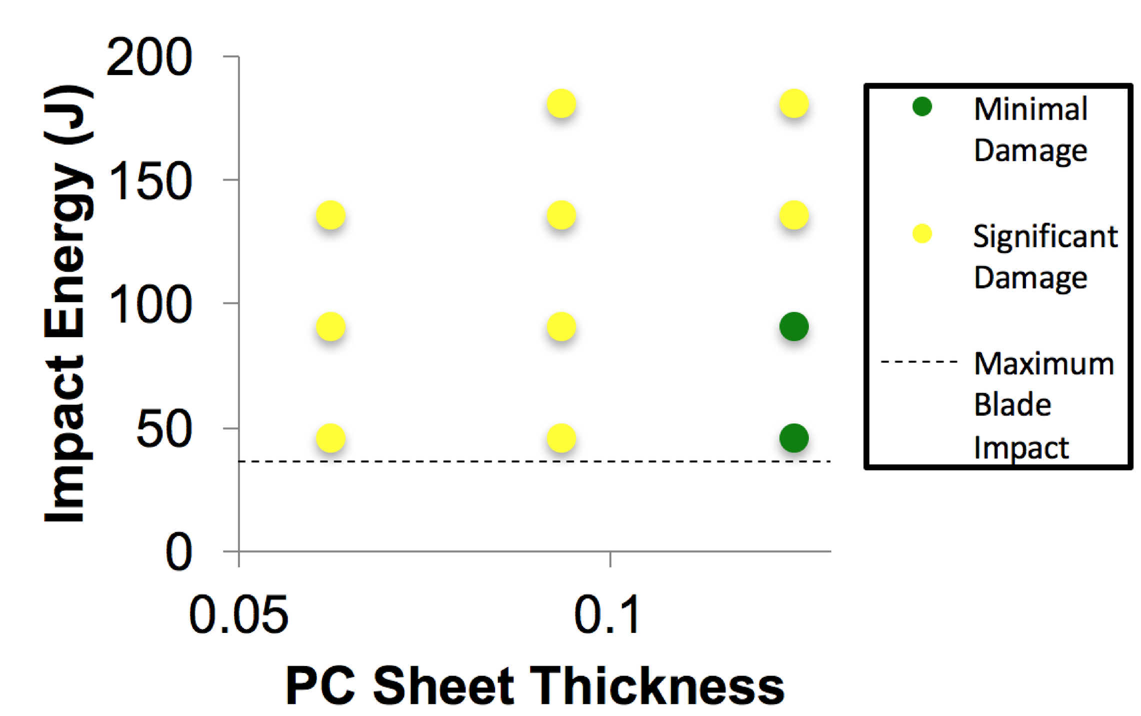
- Residual stress caused ESC to occur in deformed regions and delamination occurred in impacted specimens.

Conclusion: PETG shows more resistance to ESC than PC as it does not fail catastrophically. However, the optical clarity of PETG becomes impaired under ESC conditions. The alkanol amine component in the new coolant is the likely facilitator for ESC.

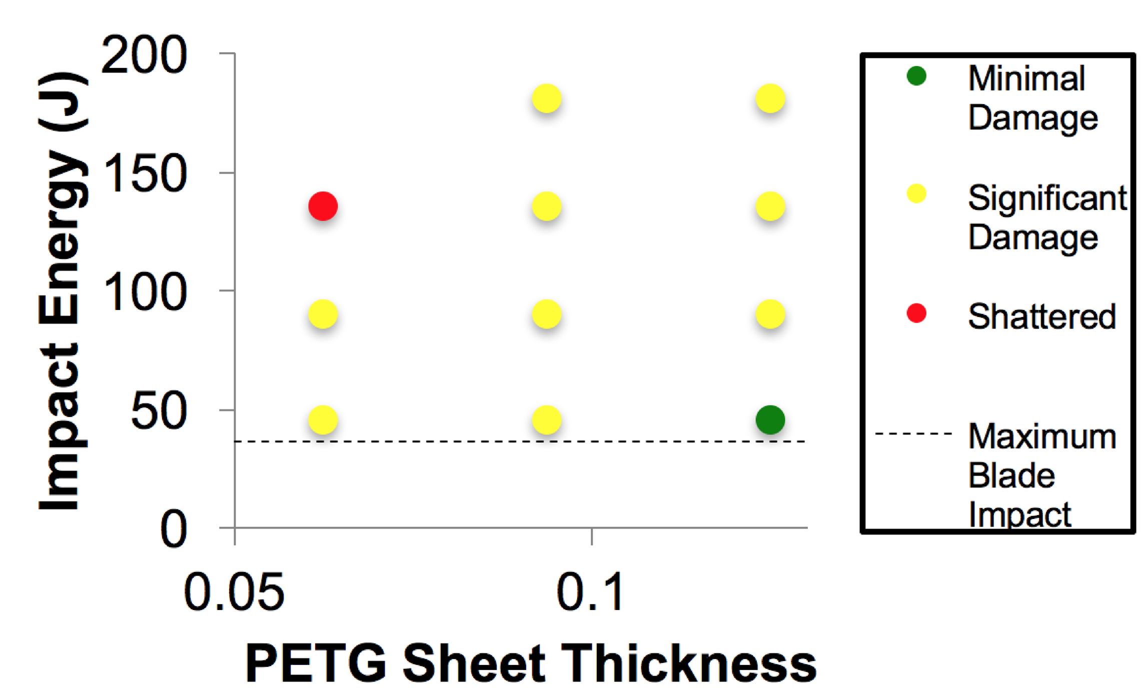
Impact Testing

Impact testing was performed to simulate blade breaks that occur during normal usage, which can then cause flying debris into the abrasive cutter's hood.

- Drop tower impact testing of steel discs from a height of 20 m was used to simulate a broken abrasive blade impacting a hood.
- The minimum thickness of PC and PETG needed to withstand a worst case scenario blade break was established.
- Several tests were performed in the presence of coolant, but no difference in impact strength was found compared to the coolant-free tests.
- The results show that a 1/8" thickness for both PC and PETG is enough to protect against a worst case scenario blade break, and that PC has a greater impact strength than PETG.



Impact strength as a function of thickness for PC sheets.



Impact strength as a function of thickness for PETG sheets.

Conclusion: PC is stronger than PETG in impact, but the difference is not large. For both PC and PETG, a 1/8" thickness is sufficient to survive a maximum blade impact. Additionally, the coolant was not found to significantly affect impact strength.

Recommendations

We recommend the continued usage of PETG that Buehler has begun to implement into their abrasive cutters, due to its suitable impact strength. Additionally, it has high resistance to catastrophic ESC but has demonstrated that it is more likely to form aesthetically problematic cracking. As well, if a coolant change is implemented, we recommend avoiding alkanol amines if possible, as they facilitate ESC. Future work for this project could include researching into alternate materials such as Eastman Tritan.