Response and Failure Mechanisms of HDPE and UHMWPE Under Chemical Environment

Andrea Lu, Kevin LoGiudice, Zahra Ahmed, Venkatsai Bellala, Vikas Srivastava
School of Engineering, Brown University, Providence, Rhode Island 02912, USA

Background

High Density Polyethylene

- HDPE is a thermoplastic polymer with a mixed crystalline and amorphous structure commonly used in applications from plastic bottles to transport pipelines.

Ultra High Molecular Weight Polyethylene

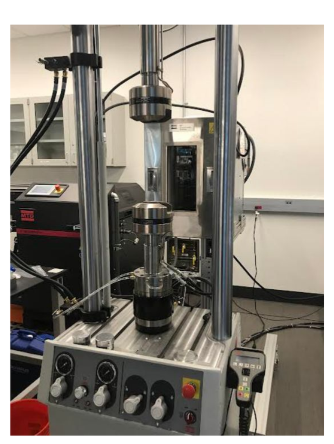
- UHMWPE is a thermoplastic polymer with a highly crystalline structure commonly used in biomedical applications from implants to prosthetic devices.

Failure Mechanism in Polyethylene

- Both polymers are susceptible to failure due to crack growth which can be aggravated by chemical environment and temperature.
- Failure process:
  - Lamellae start to pull away due to creep in amorphous phase.
  - Tie molecules are stretched tight and untangle.
  - Clean break of lamellae.

Methods

Uniaxial Tension Tests



- Performed using servohydraulic MTS test system.
- Notched and unnotched dogbone samples according to ASTM D638 Type V.
  - Notched samples run to complete fracture.
  - Unnotched samples run to 100% strain.
- Chemical treatments over 14 days of phosphate buffered saline (PBS) or 10% Igepal CO-630.
- Test temperatures of 22ºC (room), 37ºC (body), and 50ºC (industrial).
- Run at strain rates of 0.3 s^{-1}, 0.03 s^{-1}, 0.003 s^{-1}, and 0.0003 s^{-1}.

Scanning Electron Microscopy (SEM) Imaging

- Images captured of the failure surface of all notched samples.
  - Entire crack surface captured at 52x.
  - Crack surface captured at 1000x near the initial notch and the final failure.

Results

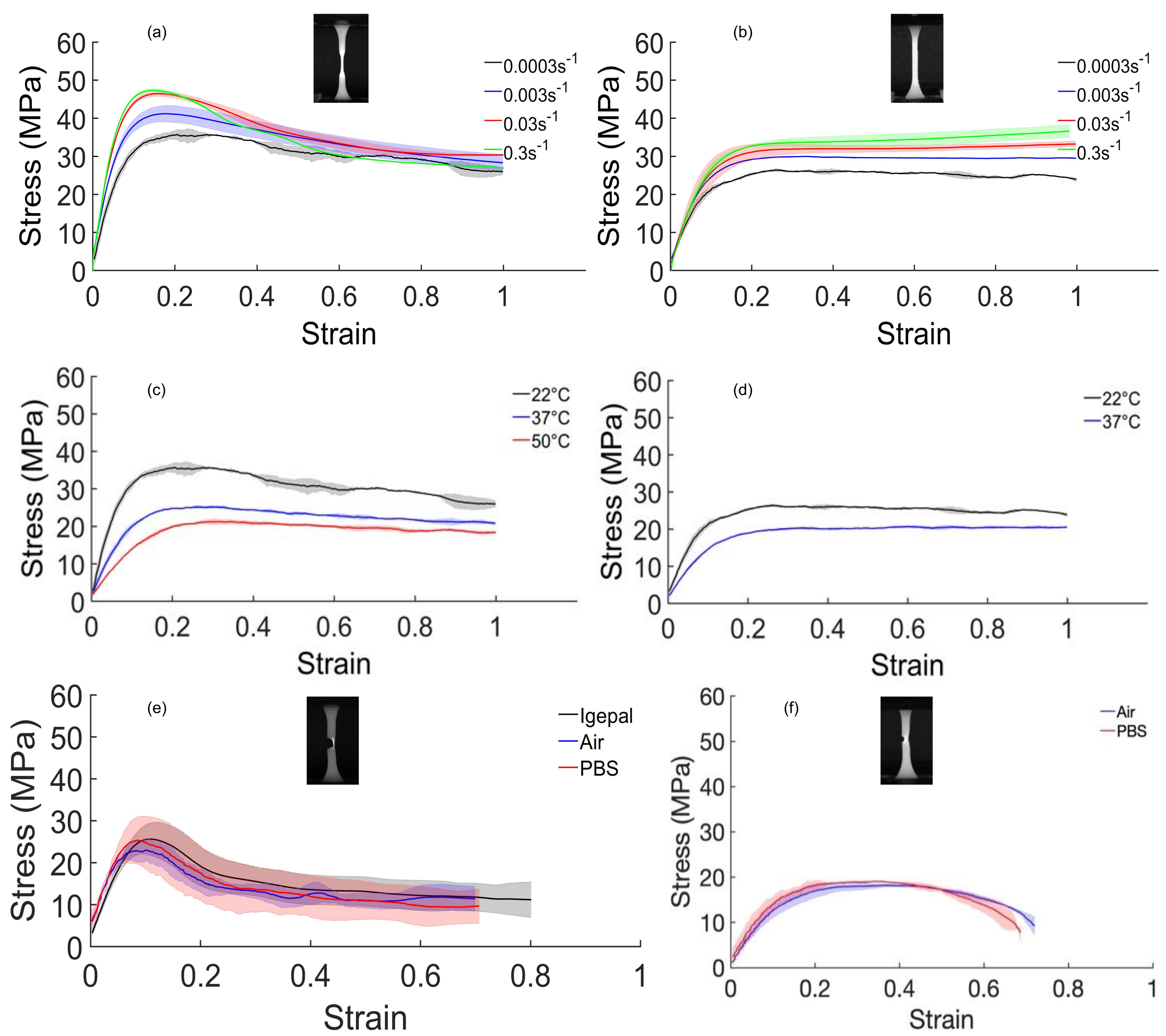


Figure 1. Stress vs. strain curves for selected uniaxial tension tests. **(a)** Strain rate comparison for unnotched HDPE sample at 22ºC with no chemical treatment. **(b)** Strain rate comparison for unnotched UHMWPE sample at 22ºC with no chemical treatment. **(c)** Temperature comparison for unnotched HDPE sample at 0.0003 s^{-1} with no chemical treatment. **(d)** Temperature comparison for unnotched UHMWPE sample at 0.0003 s^{-1} with no chemical treatment. **(e)** Chemical treatment comparison for notched HDPE sample at 0.0003 s^{-1} and 22ºC. **(f)** Chemical treatment comparison for notched UHMWPE sample at 0.0003 s^{-1} and 22ºC.

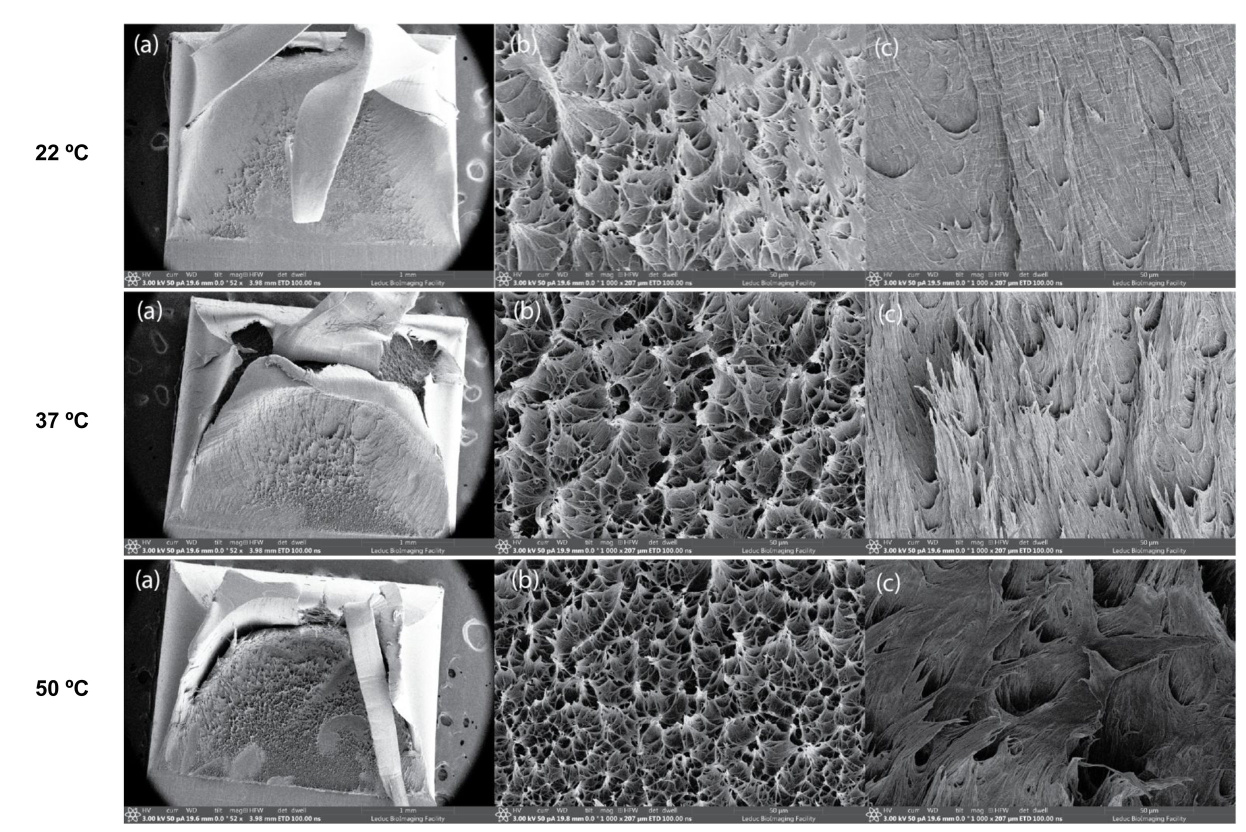


Figure 2. SEM images of fractured HDPE samples at 0.0003 s^{-1} with no chemical treatment. The testing temperature is listed to the left of each row. **(a)** A 52x magnification view of the entire crack surface. **(b)** a 1000x magnification view of the crack surface near to the location of notch initialization. **(c)** a 1000x magnification view of the crack surface near to final sample failure.

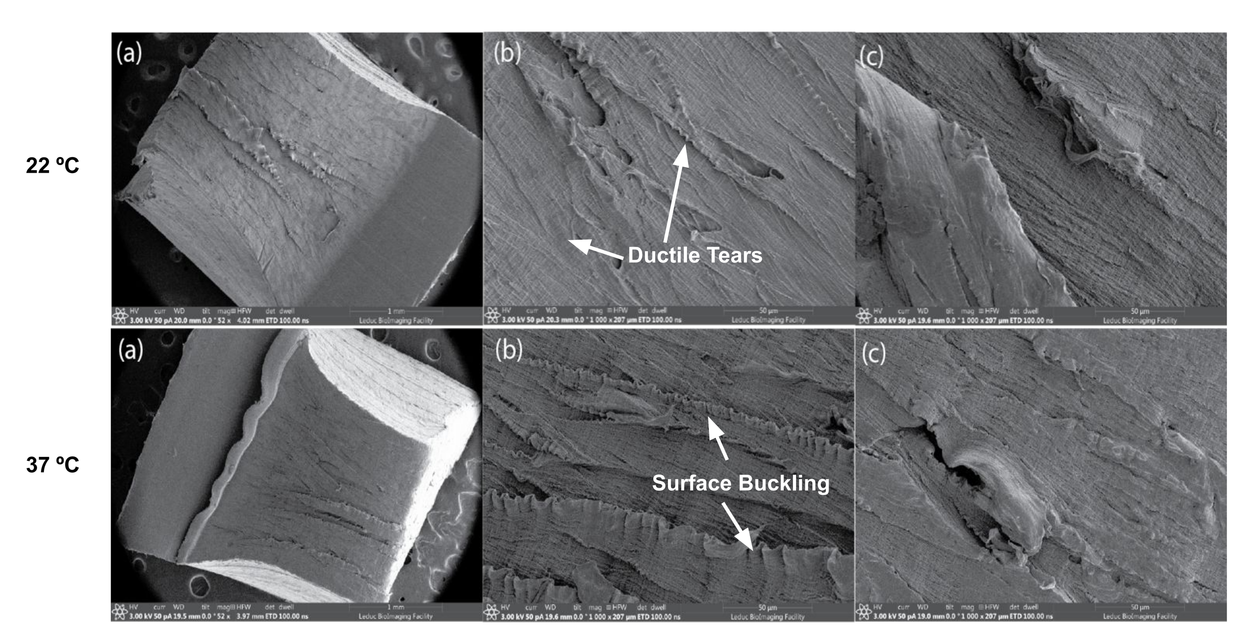


Figure 3. SEM images of fractured UHMWPE samples at 0.0003 s^{-1} with no chemical treatment. The testing temperature is listed to the left of each row. **(a)** A 52x magnification view of the entire crack surface. **(b)** a 1000x magnification view of the crack surface near to the location of notch initialization. **(c)** a 1000x magnification view of the crack surface near to final sample failure.

Discussion

- At very slow strain rates, significantly smaller amounts of stress will lead to onset of plastic deformation.
- HDPE experiences strain softening; UHMWPE experiences strain hardening.
- As the temperature increases, the maximum tensile stress decreases and the polymer becomes more ductile.
- Under current conditions, there is no observed effect of Igepal or PBS on the strain and time to failure observed in HDPE.
- HDPE experiences more brittle failure at higher temperatures.
- UHMWPE experiences more ductile failure at higher temperatures, characterized by tears with criss cross features running at angles in the same direction as crack propagation and surface buckling.

Future Work

- X-ray diffraction of tested samples to observe and analyze changes in polymer crystallinity.
- Characterize viscoelastic slow rate response by conducting tension stress relaxation tests.
- Long term creep tests to characterize the slow crack growth phenomenon observed in polyethylenes.
  - Observe brittle failure under low forces over long periods of time.
  - Model slow crack growth.
- Additional chemical treatments and temperatures to incorporate new variables into polyethylene fracture models.

Acknowledgements

This project was supported through funding provided by the Department of Transportation (DOT) (grant # GR5245077).