

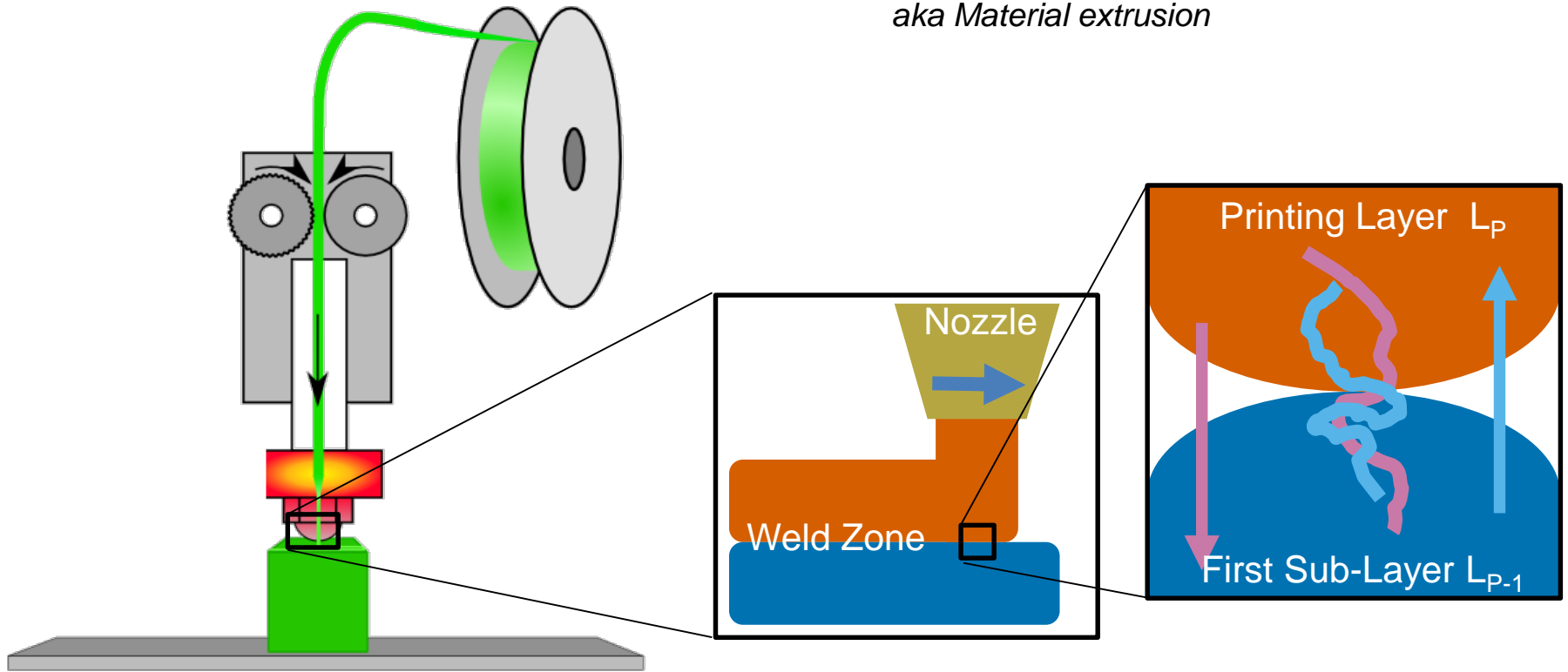
Thermal and fracture characterization of welding zones produced by polymer extrusion 3D printing

*Jonathan E. Seppala, Kaitlyn E. Hillgartner,
Chelsea S. Davis, and Kalman B. Migler*

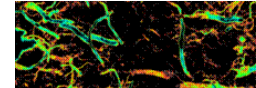
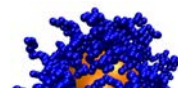
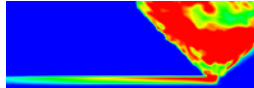
*Polymer & Complex Fluids Group
National Institute of Standards and Technology (NIST)*

FDM/FFF Process

Fused deposition modeling (FDM)TM
aka Fused filament fabrication (FFF)
aka Material extrusion

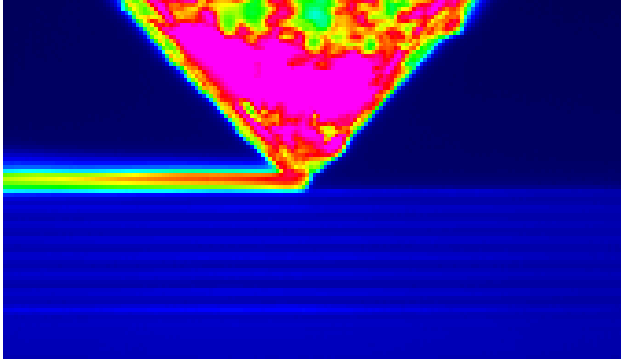


reprap.org

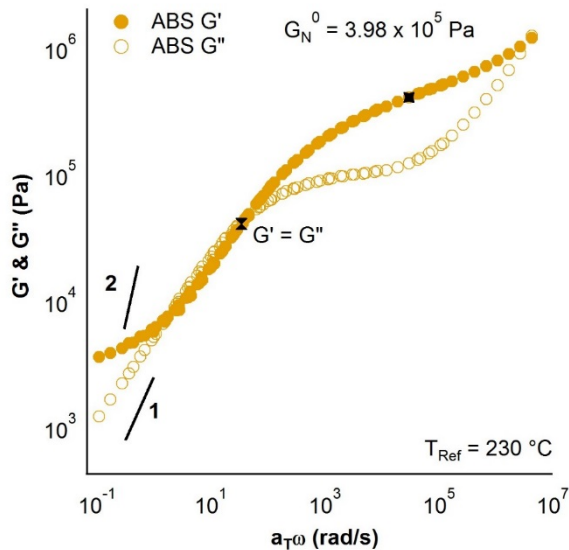


Outline

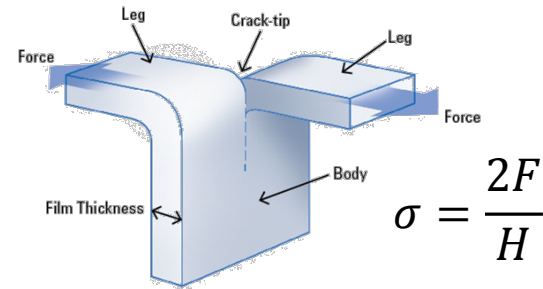
I. Thermography



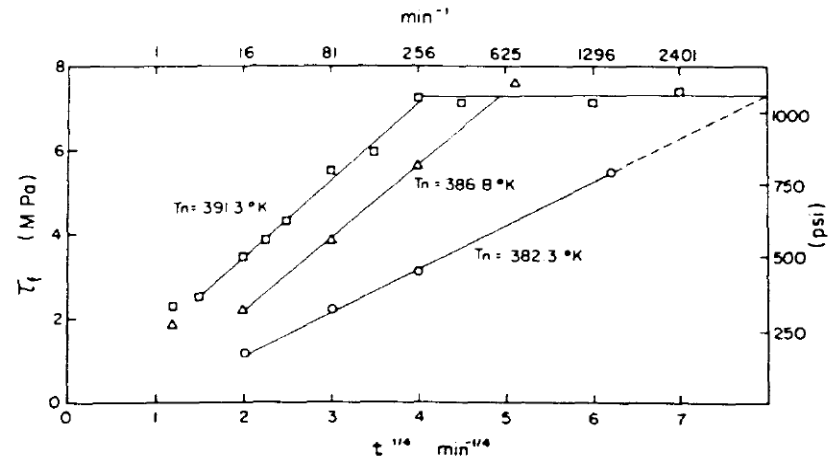
II. Rheology



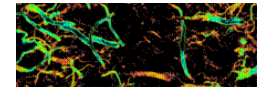
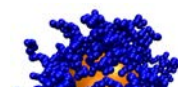
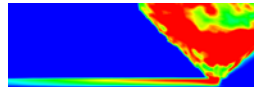
III. Fracture Strength



III. Comparison to Classical Weld Theory



Wool Poly. Eng. And Sci. 1988



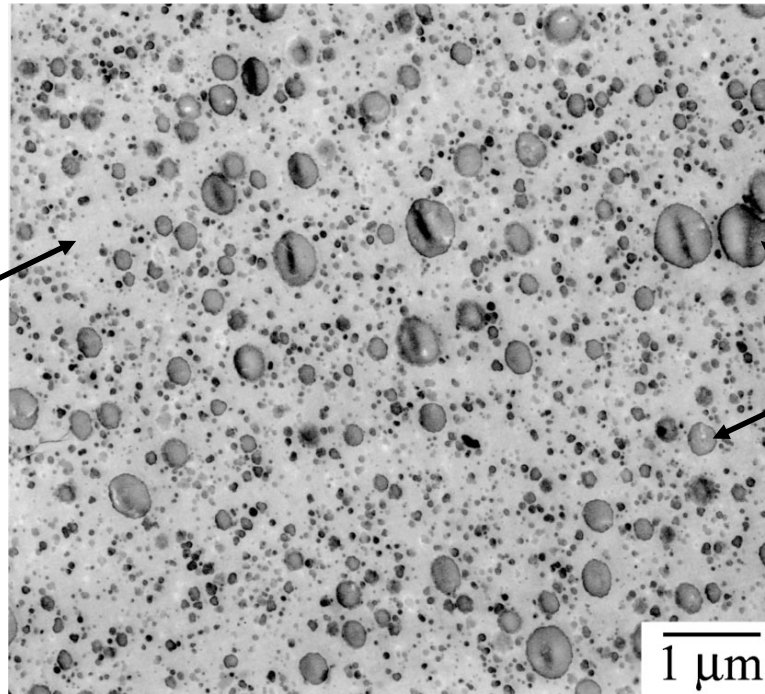
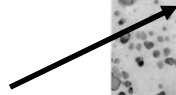
Materials

Acrylonitrile butadiene styrene (ABS)

Butadiene-*g*-Styrene Acrylonitrile/Styrene Acrylonitrile (BgSAN/SAN)

TEM micrograph ABS

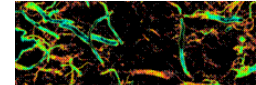
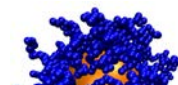
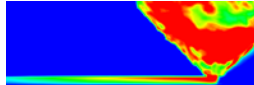
Styrene
Acrylonitrile
Matrix



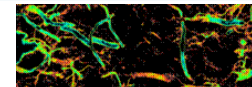
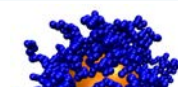
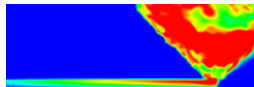
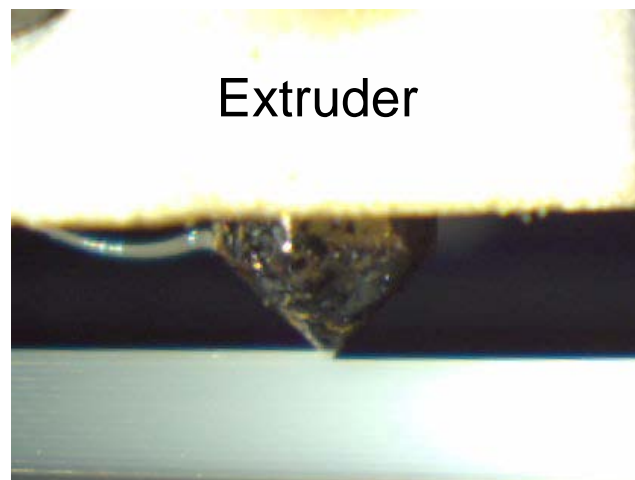
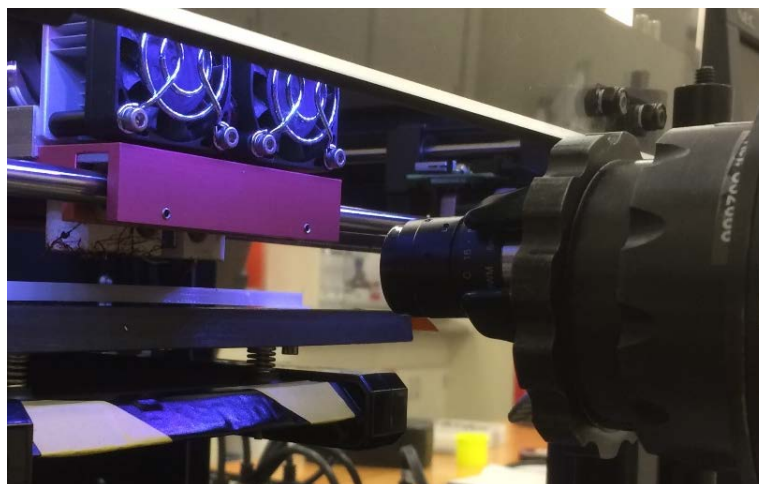
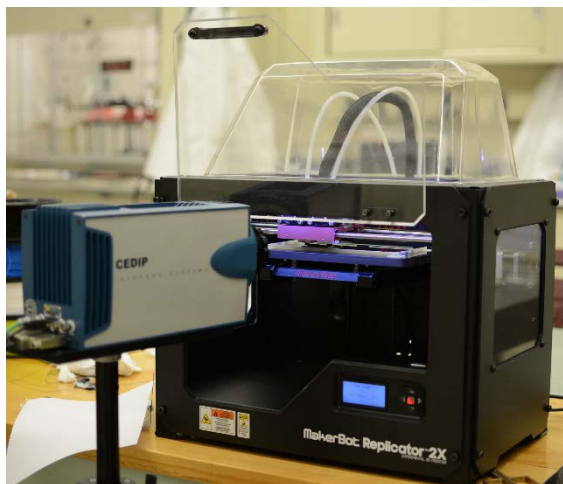
Butadiene
Spheres

1 μm

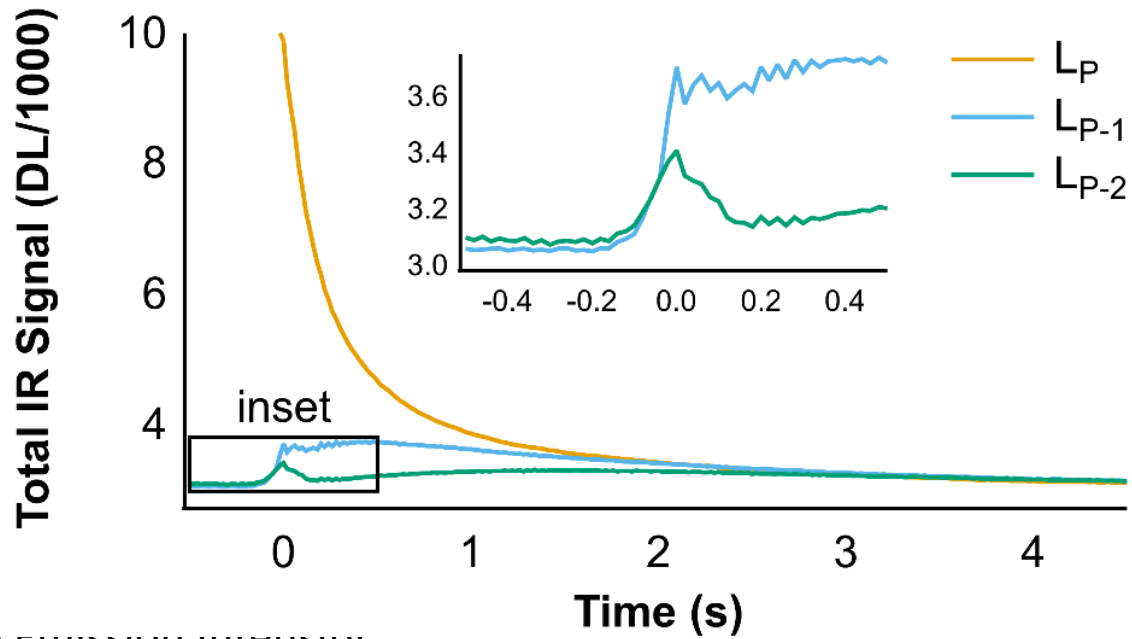
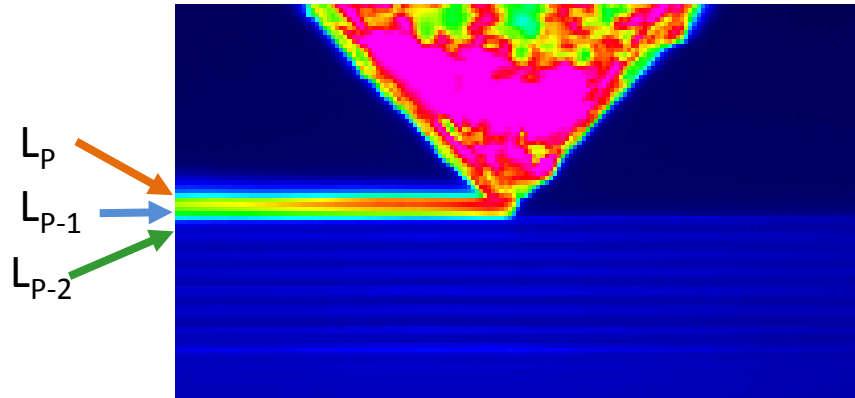
J. Mater. Sci. Lett. **19** (2000) 73-75



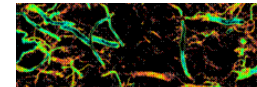
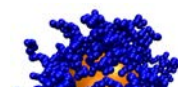
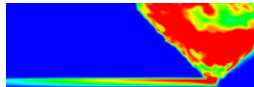
Process Characterization: Thermography



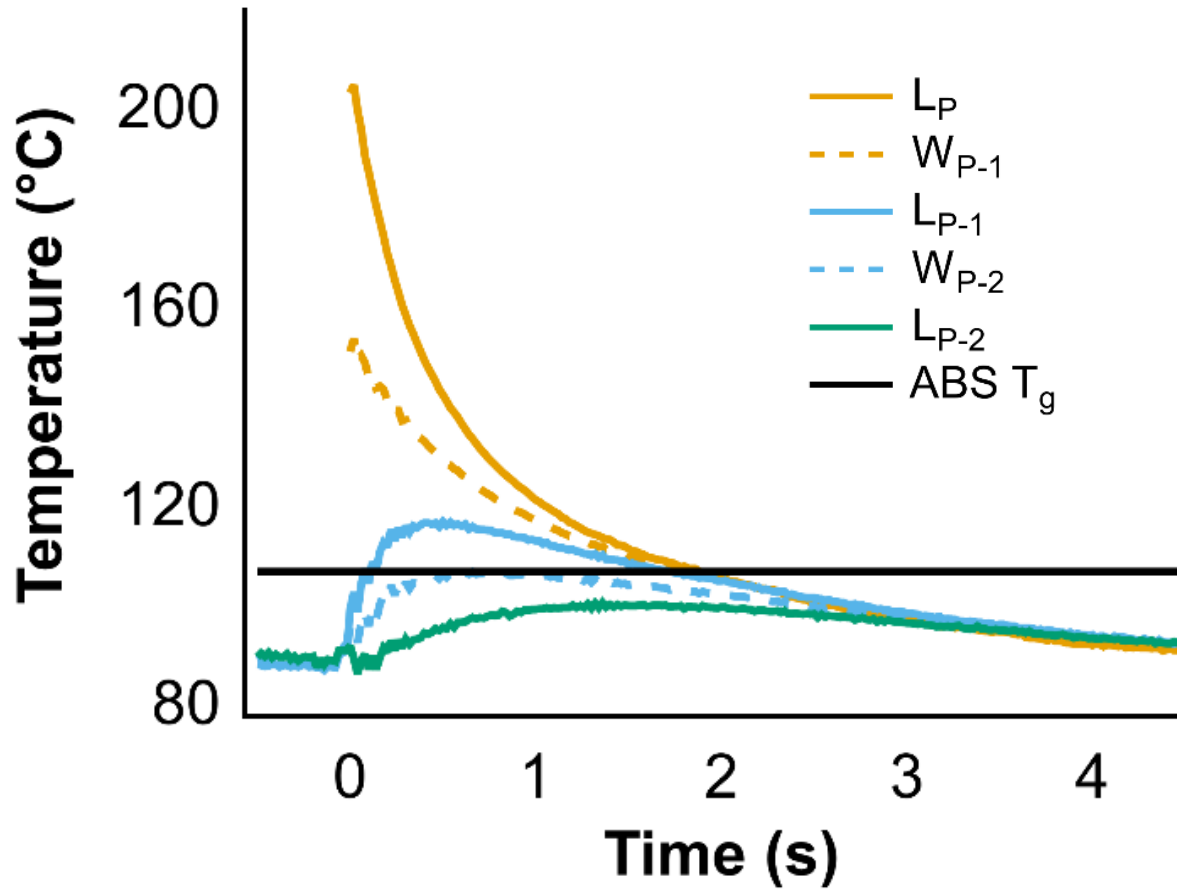
IR Intensity Profiles



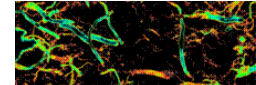
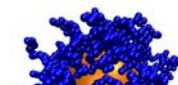
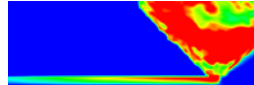
Reflection + EMISSION Intensity



Temperature Profiles

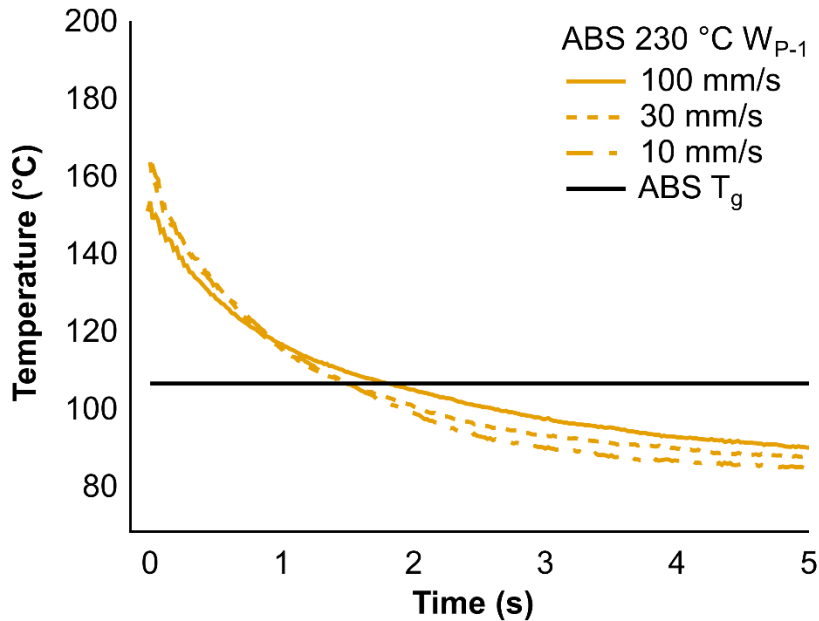


Weld zone:
Average of layer above
and below.

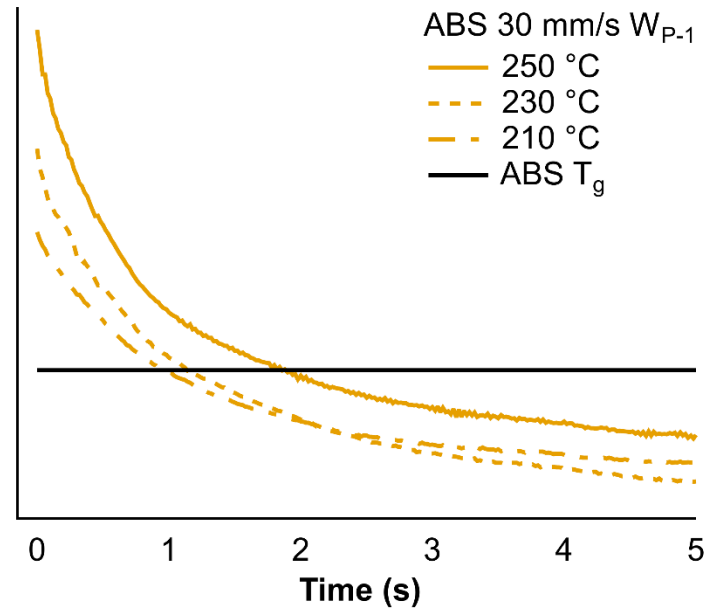


Weld Temperature

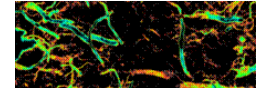
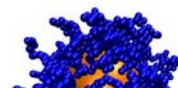
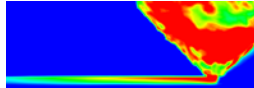
Print Speed



Extrusion Temperature

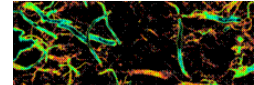
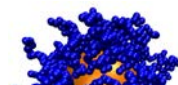
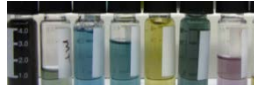
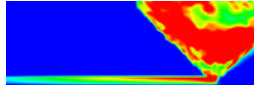
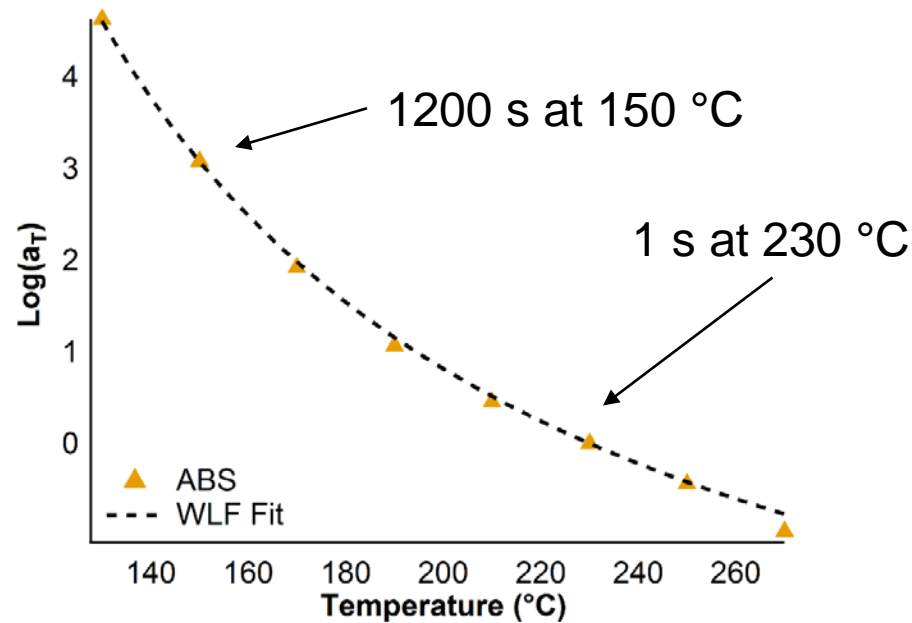


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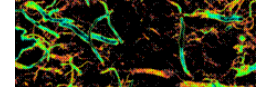
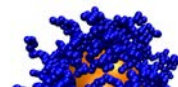
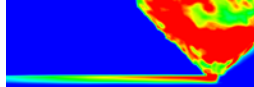
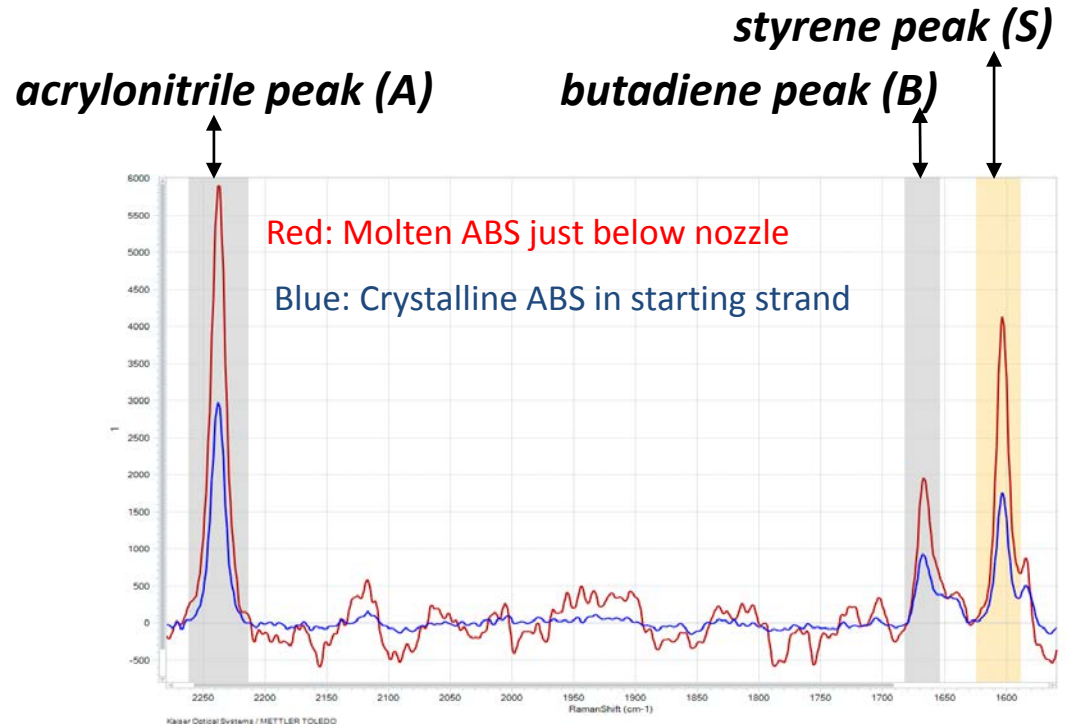
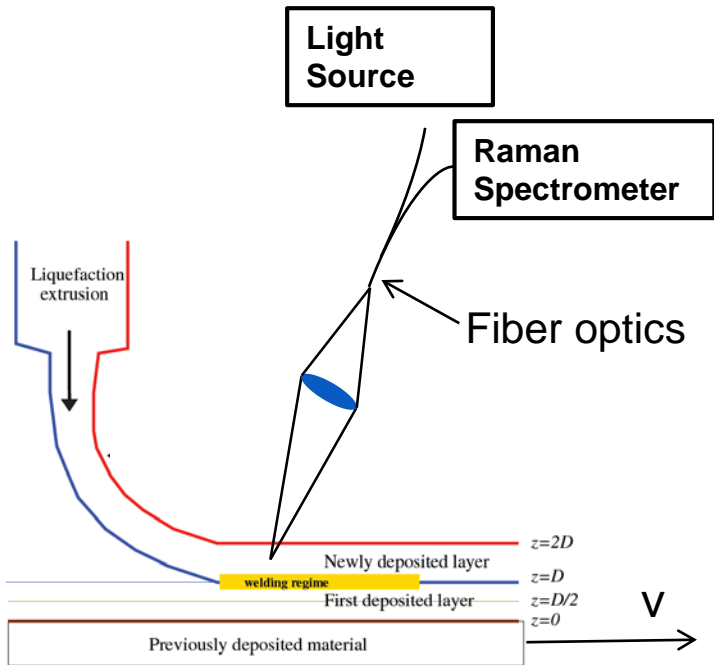


ABS Rheology

- Shift factors from time-temperature superposition
- Provides comparison in molecular mobility between different temperatures



Spectroscopic Monitoring of Fused Deposition Modeling



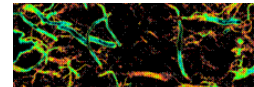
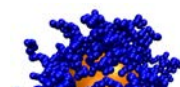
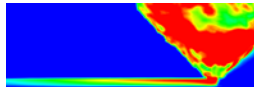
Conclusion

Temperature measurement / thermal imaging is 1st step towards development of physics based model of FDM.

Weld formation in material extrusion occurs over ~ 1 s; most of the interdiffusion occurs over time scale much less than 1s.

Temperature kinetics, rheology and weld theory provide foundation for understanding fracture strength as a function of temperature and feed rate.

In-situ monitoring is achievable. Linking back to real time control is a challenge.



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<http://www.nist.gov/mml/msed/polymers/kalman-migler.cfm>

