Combinatorial Investigations of Polymer Adhesion

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Combinatorial Methods Group

Combinatorial Investigations of Polymer Adhesion

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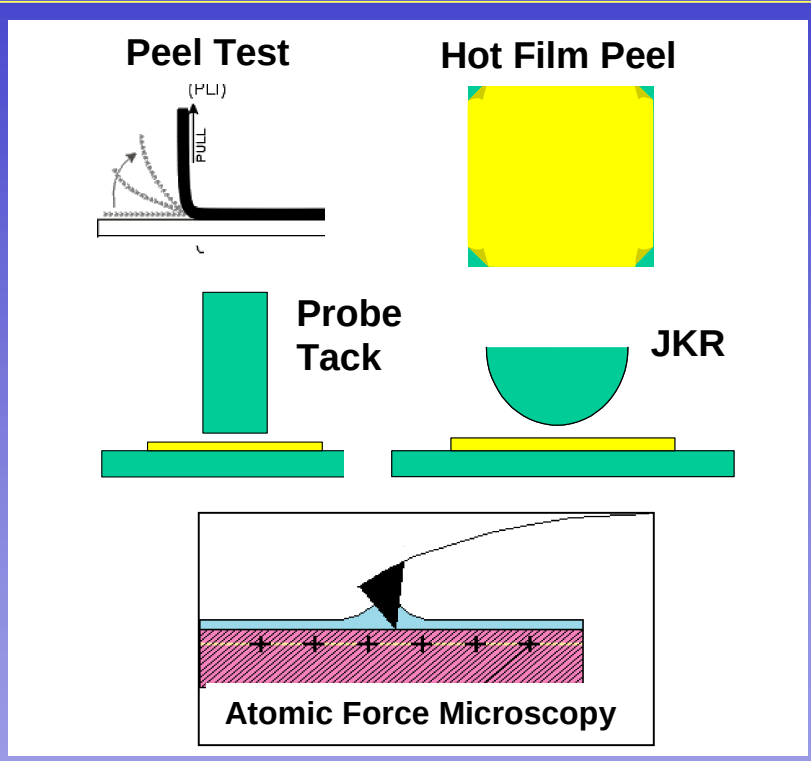
Motivation

- $10 billion annual U.S. sales

"Bolts and screws can be modeled with software... , but glue makers have yet to come up with a predictive model", **Forbes, 10.29.01**

- Myriad of variables control adhesion
- Existing techniques



Objective

- Develop methodology for quantitative high-throughput measurements of adhesive strength of polymer interfaces

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How do we study polymer adhesion?

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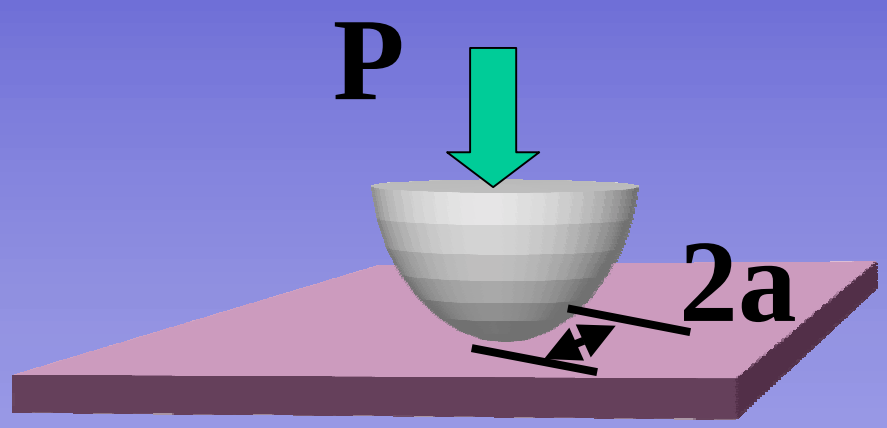
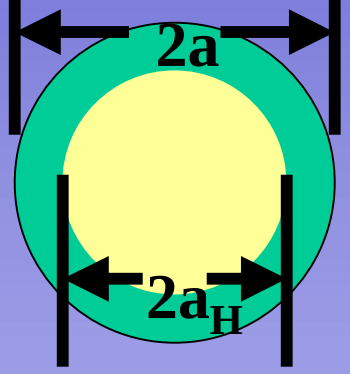
JOHNSON, KENDALL, & ROBERTS (JKR)



$$a_H^3 = \frac{9RP}{16E}$$



$$a^3 = \frac{9R}{16E}\left[P + 3\pi GR + \sqrt{6GRP + (3\pi GR)^2}\right]$$

Design

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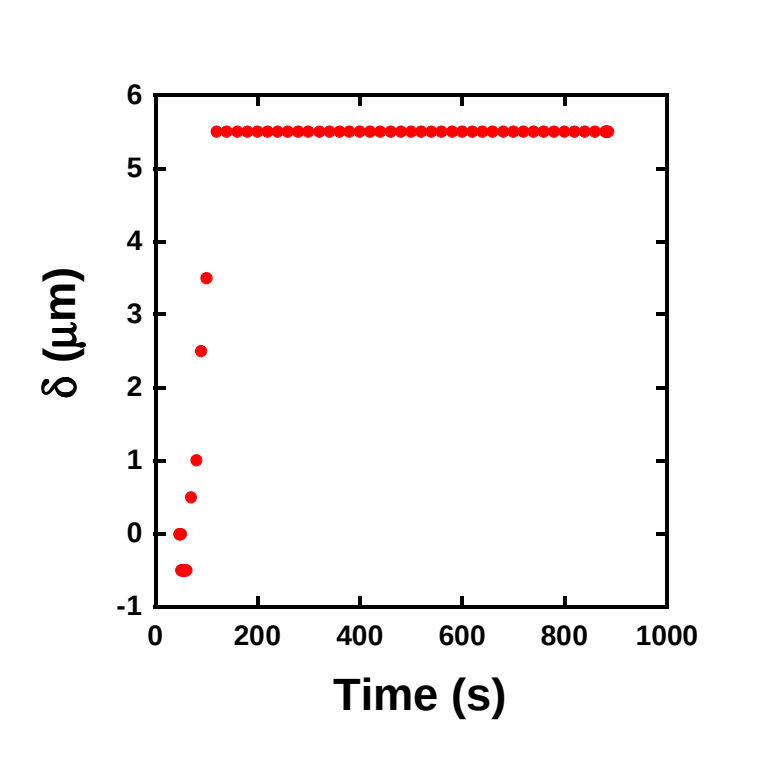
Why choose JKR?



PDMS contacting glass

Classical Use:

- Fundamental studies of adhesion of soft polymers
- Limited to elastic materials and geometries where a << h, R

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Why choose JKR?

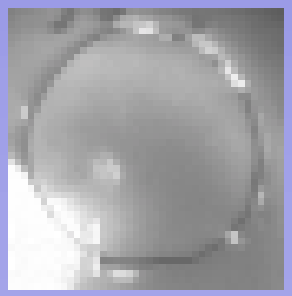
Recent Developments have allowed JKR to be applied to a wide range of issues

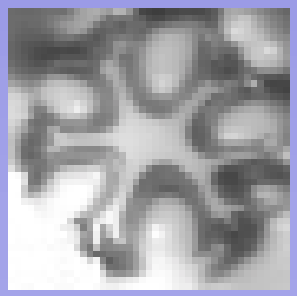
Finite-Size Corrections (for a>h)

Shull, K.R., et al, *Macromol. Chem. Phys.*, 1998, **199**, 489-511.
Crosby, A.J. et al, *Journal of Applied Physics*, 2001, **88**, 2956-2966.

Viscoelasticity Corrections

Lin, Y.Y., et al, *Journal of Applied Physics*, 1999, **32, 2250-2260.**
Johnson, K.L., ACS publication, 2000.





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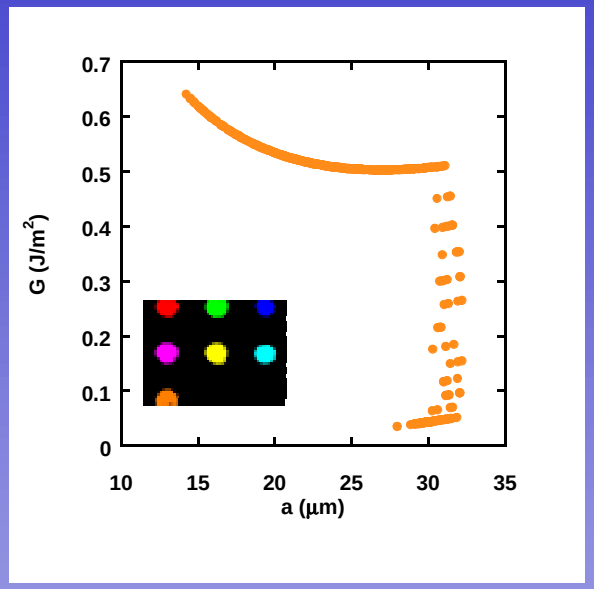
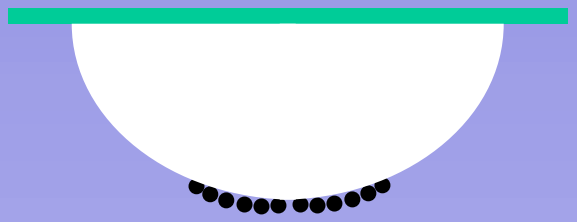
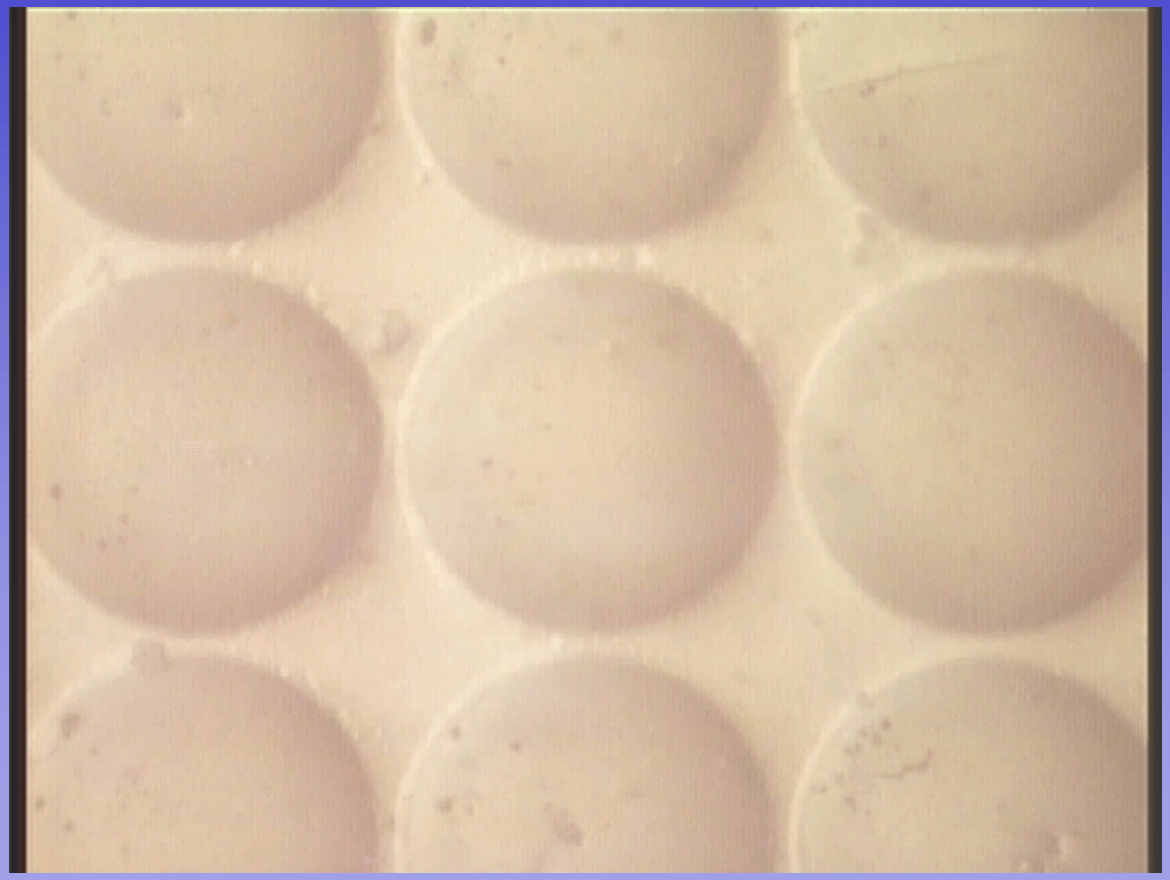
What about an array of lenses?







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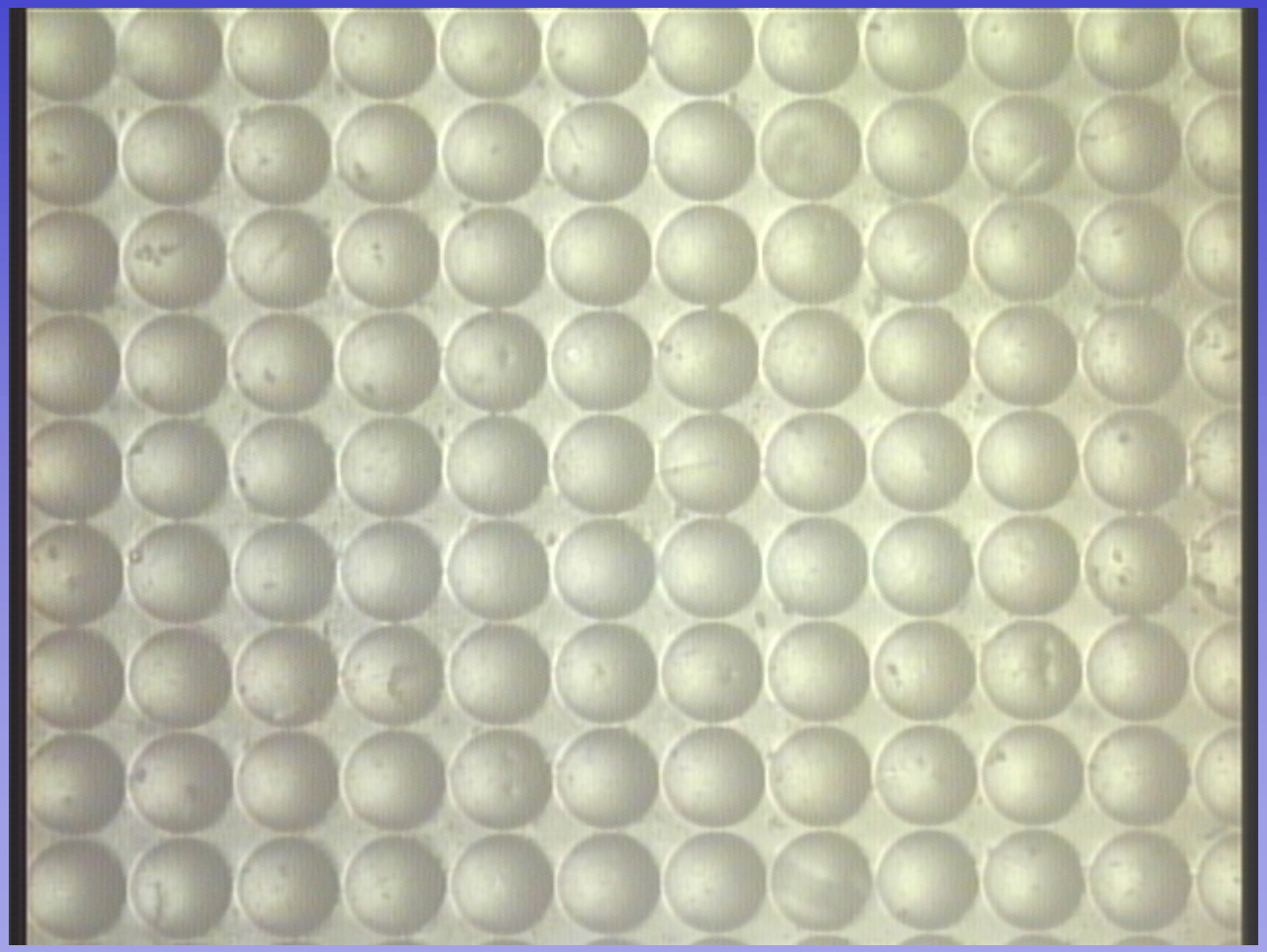
Why not more?



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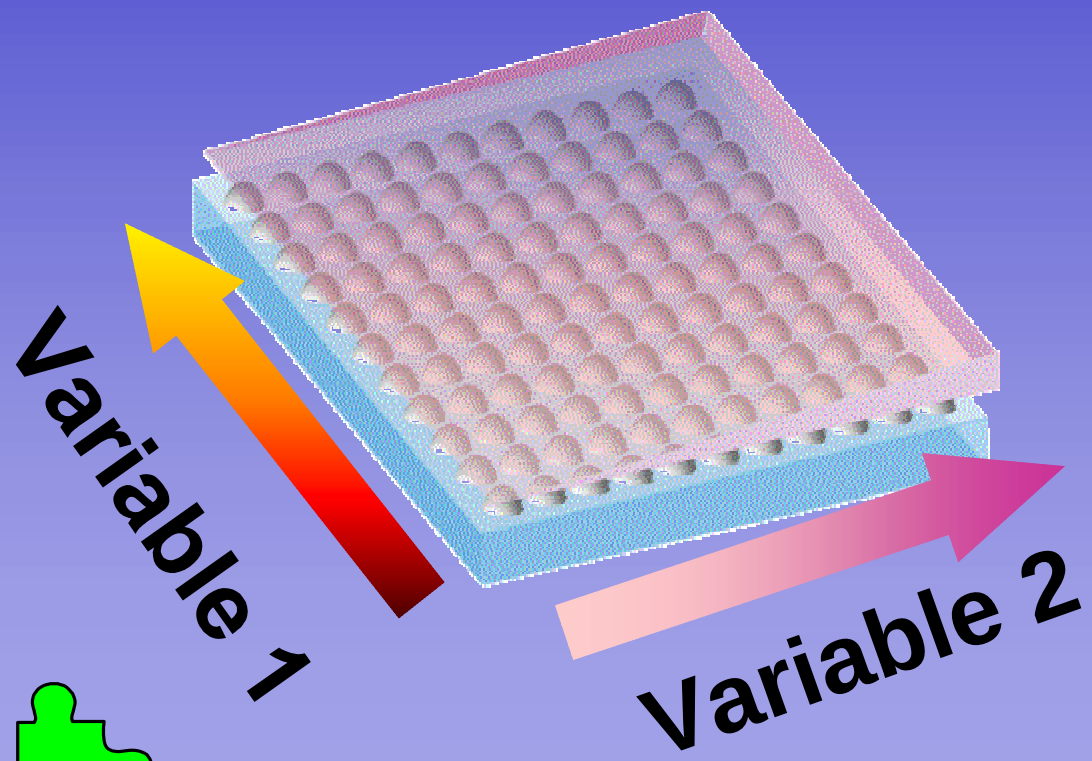
How do we design a *combinatorial* JKR test?



- **Measure a, δ**
- **Determine *G***

- **Possible Variables:**
  - **Temperature**
  - **Thickness**
  - **Strain**
  - **Surface Energy**

Design

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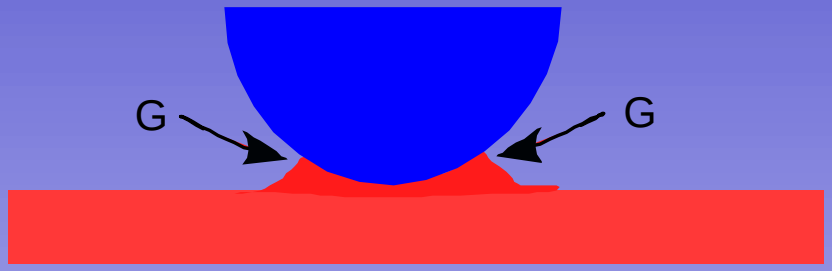
How do we calculate *G* ?

$$a^3 = \frac{9R}{16E}\left[P + 3\pi GR + \sqrt{6GPR + (3\pi GR)^2}\right]$$

$$G = \frac{3\left(P' - P\right)^2}{32\pi E \bullet a^3} \cdot f_P(a,h)$$

$$C = \frac{3}{8Ea} = \frac{d\delta}{dP} = \frac{\delta' - \delta}{P' - P}$$



$$G = \frac{2E\left(\delta' - \delta\right)^2}{3\pi a} \cdot f_\delta(a,h)$$

Design

*** K.R. Shull, et al., *Macro. Symp.*, 1997.

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How do we control contact?

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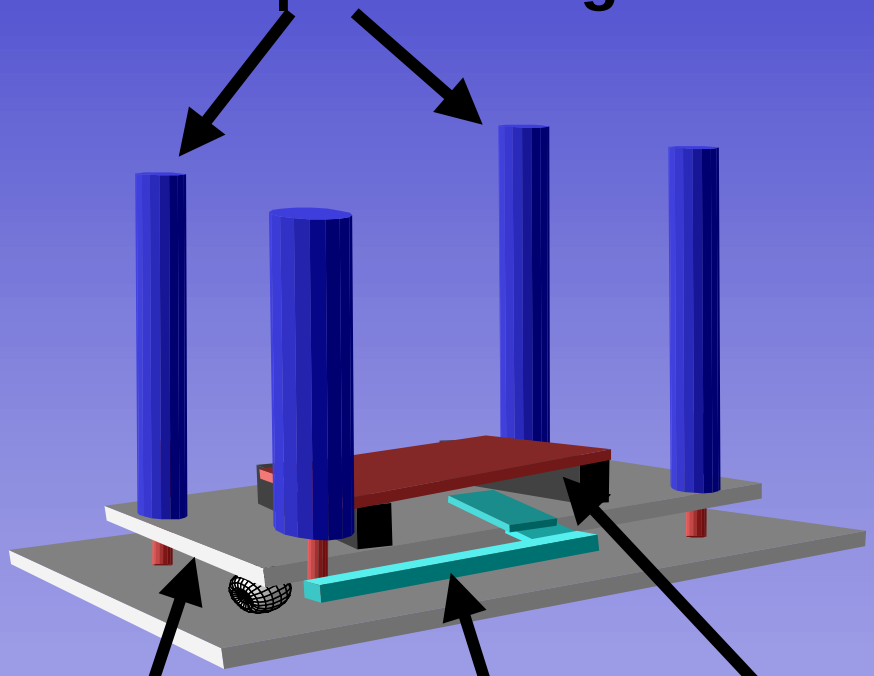
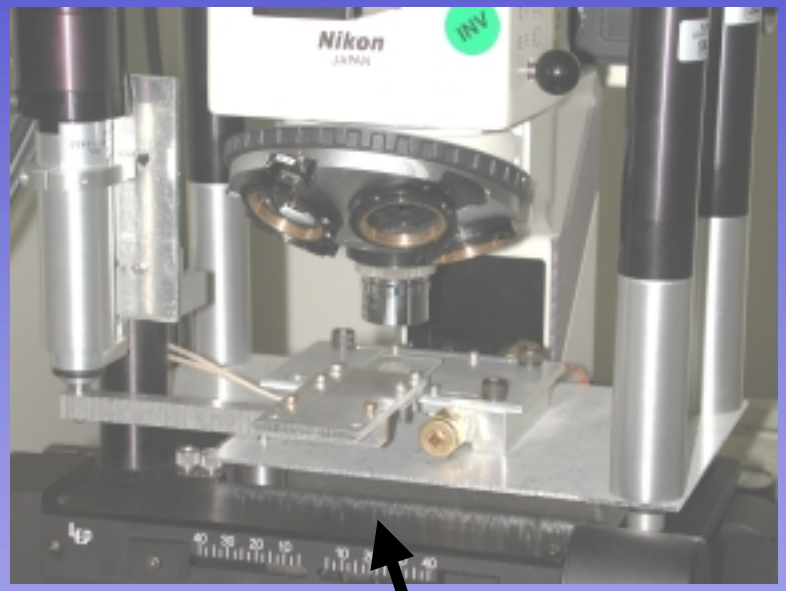
Nanopositioning Actuators





Tip/Tilt Stage

Thermal Gradient Stage

Multilens Probe Holder

Programmable X-Y Stage

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What problem to consider first?

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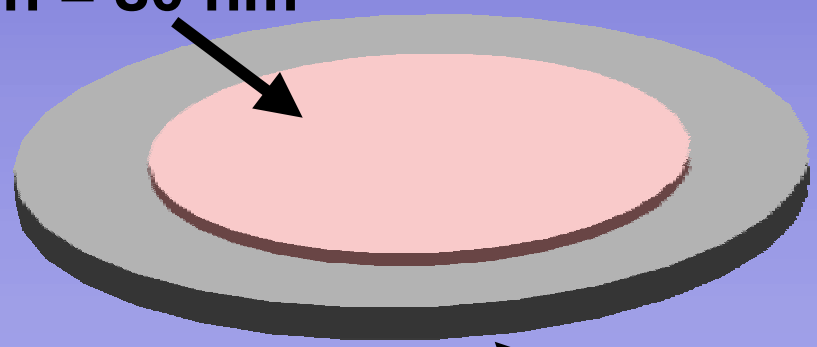
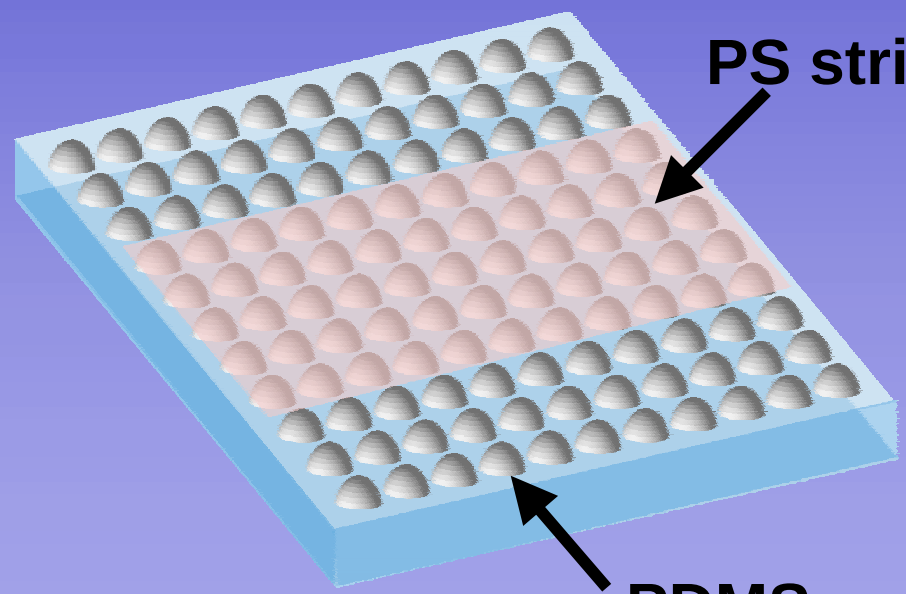
•The Adhesion of Glassy Polymers to Elastomers
- Specifically, PS to PDMS

Our Libraries:

PS film
h = 30 nm



Si substrate



PS strip

PDMS

Library Generation

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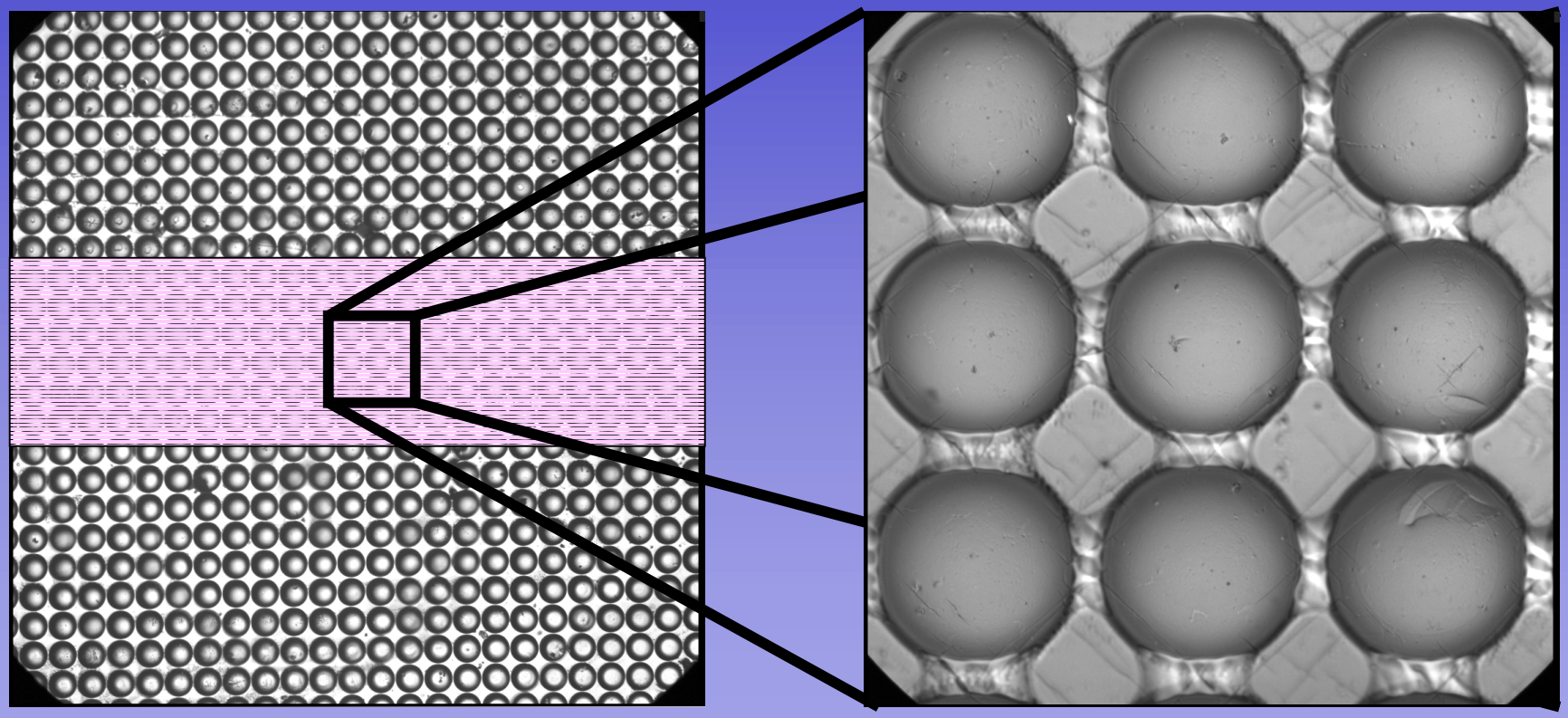
What do our libraries look like?



100 μm

Library Generation

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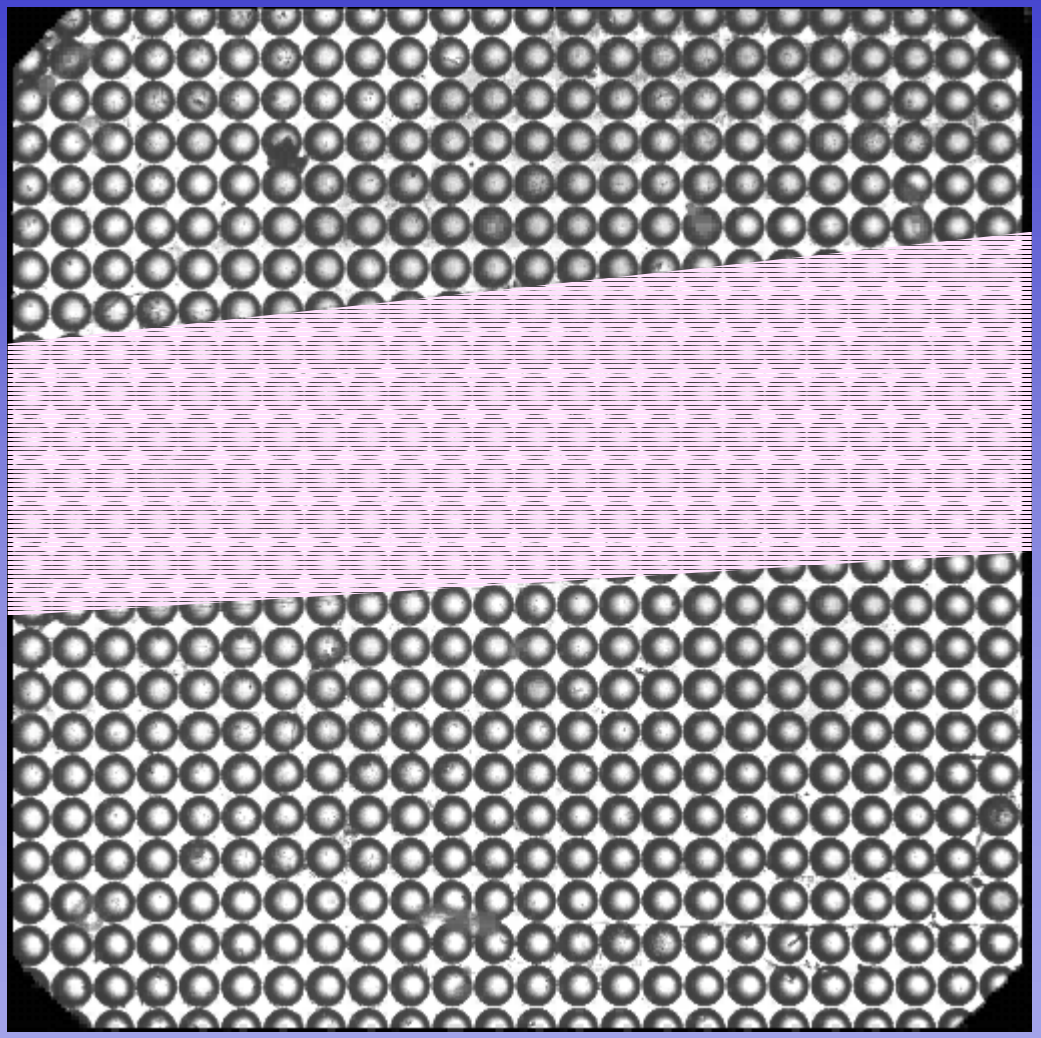
What do we observe?



Conditions:

$d\delta/dt = 1\ \mu m/s$

$h_{PS\ strip} = 30$ nm

Temperature = 25°C

Library Evaluation

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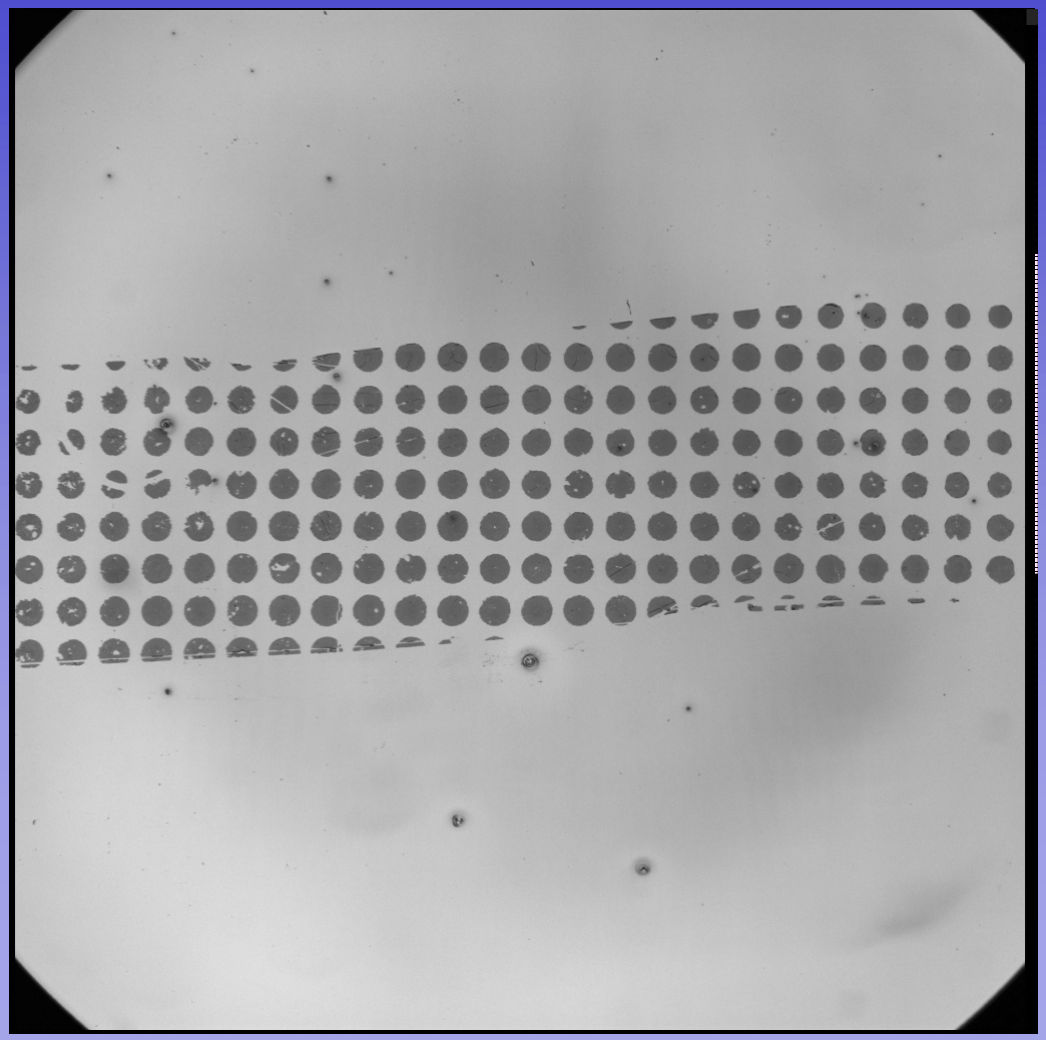
What happens at elevated temperature?



Conditions:

$d\delta/dt = 1\ \mu m/s$

$h_{PS\ strip} = 30$ nm

Temperature ~ 80°C

Library Evaluation

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What is the critical temperature for PS welding?

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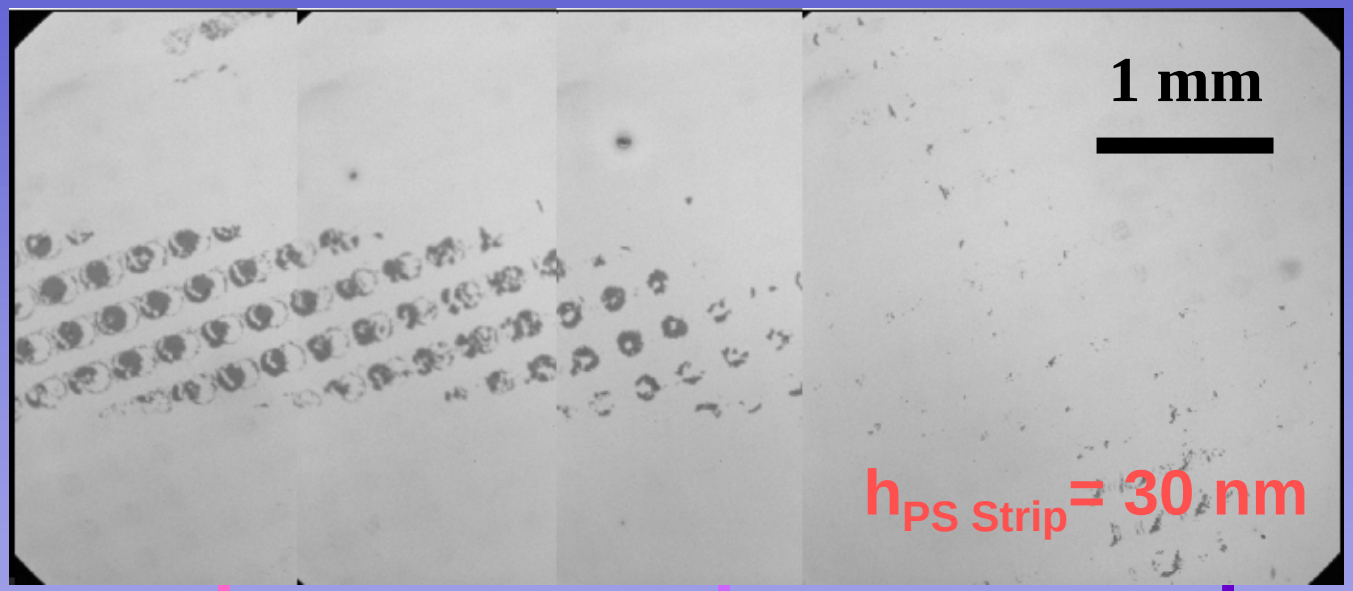
Let's use combi!



80°C 75°C 70°C

Library Evaluation

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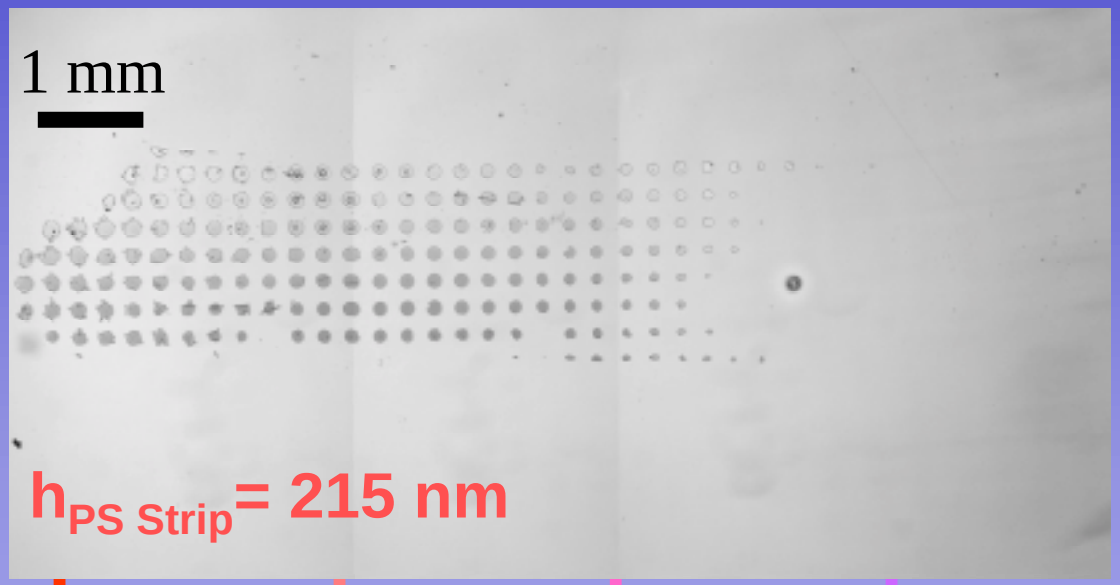
Does the critical temperature depend on thickness?



100°C 95°C 90°C 85°C

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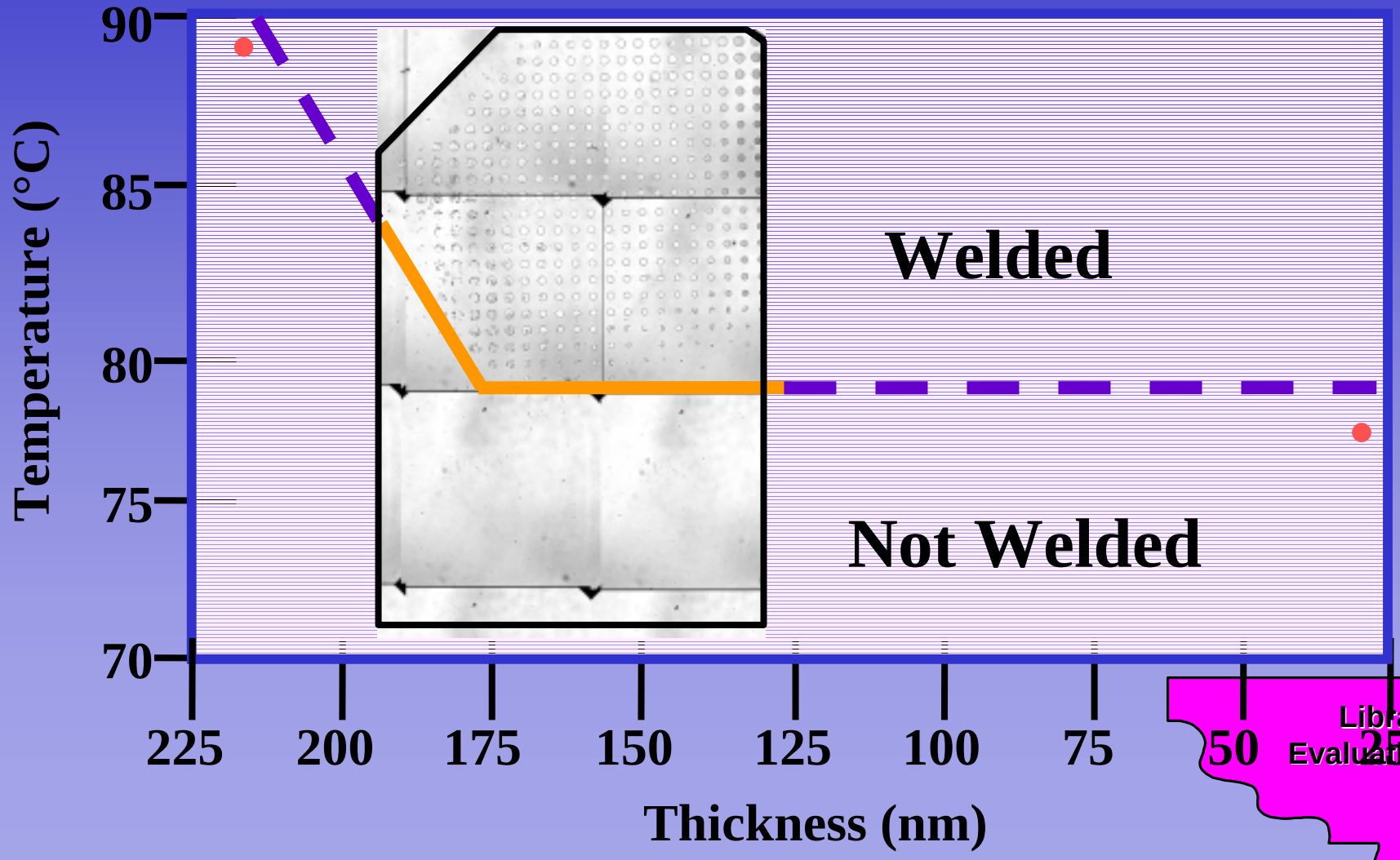
Does the critical temperature depend on thickness?



Library Evaluation

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What does the data look like?

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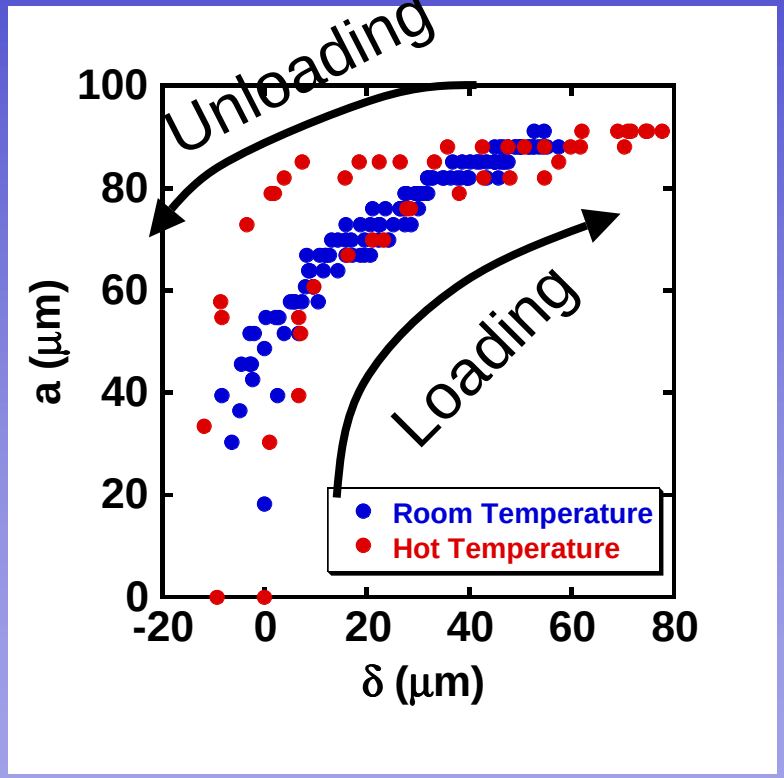
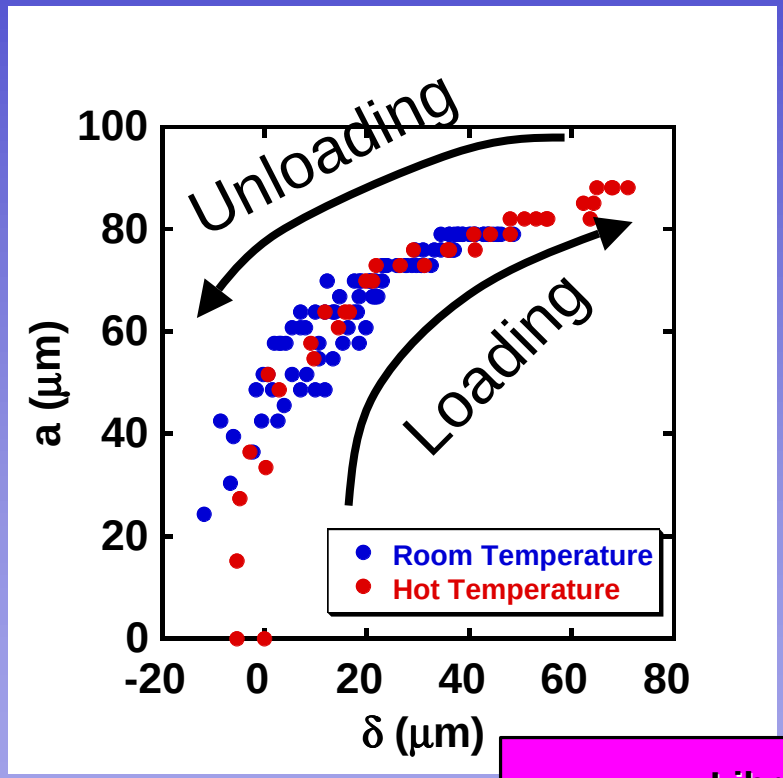
PS/PS Contact History



PS/PDMS Contact History



Same Sample, Same Conditions!

Library Evaluation

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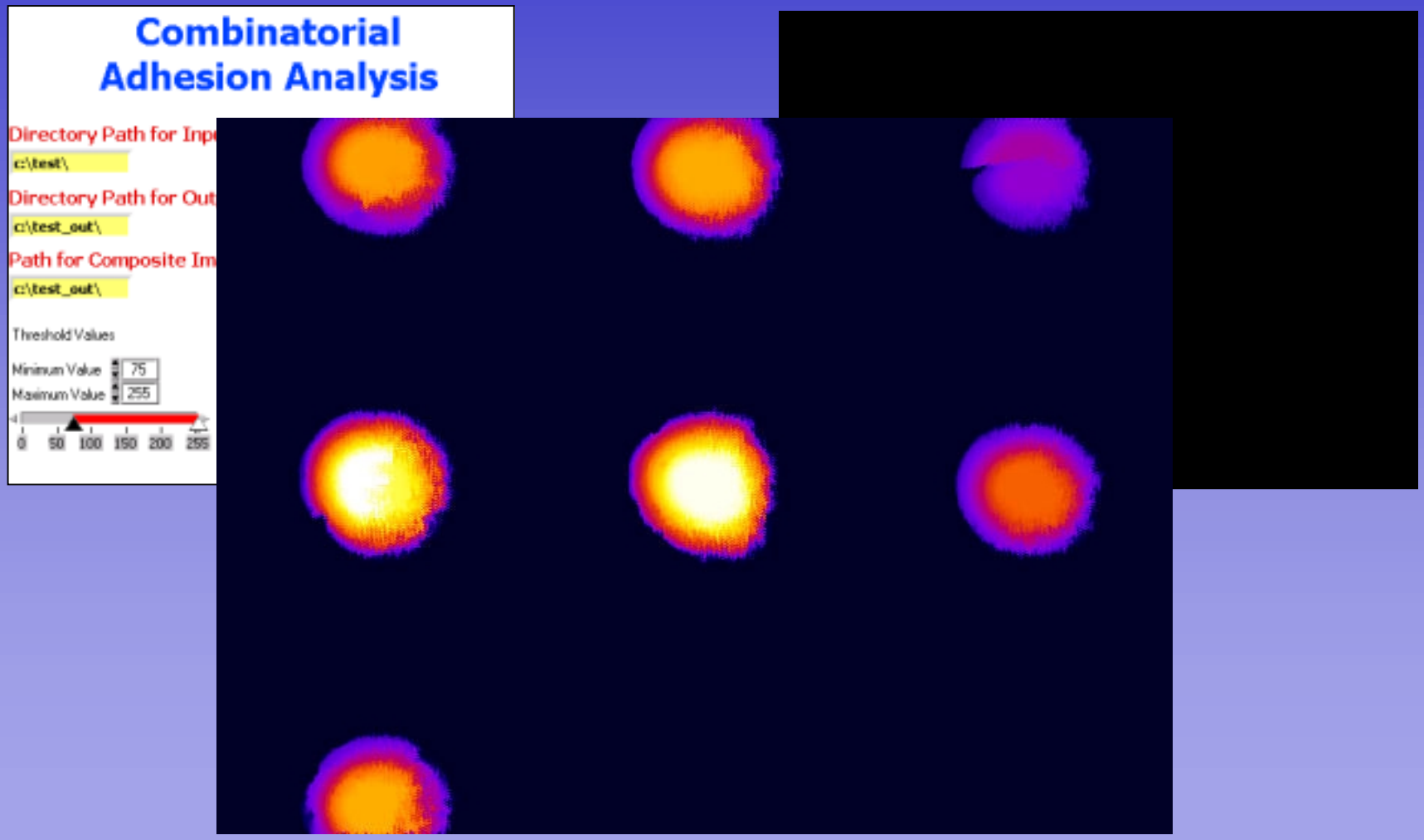
Automated Analysis



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What are the main points?

- **Multilens contact reflects classical JKR results**
- **Combinatorial methods are powerful for studying polymer adhesion**
  - **e.g. 1600 JKR tests within the time of one conventional test**
- **Thickness of glassy polymer affects welding temperature**
- **Adhesion maps provide quick assessment of interfacial properties**

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Acknowledgements

- National Research Council Research Associateship Program

- Many helpful discussions with:
  - Ken Shull
  - Amit Sehgal
  - Kate Beers
  - A. Paul Smith