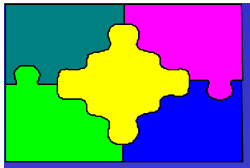


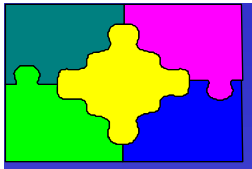
Combinatorial Investigations of Polymer Adhesion

Alfred J. Crosby

Alamgir Karim

Eric J. Amis

Polymers Division
National Institute of Standards and Technology



Combinatorial Investigations of Polymer Adhesion

Motivation

- Adhesion influences numerous industries
- Myriad of variables control adhesion
- Existing techniques have disadvantages

- Surface Energy
- Molecular Weight
- Time
- Temperature
- Humidity
- Roughness
- Geometry

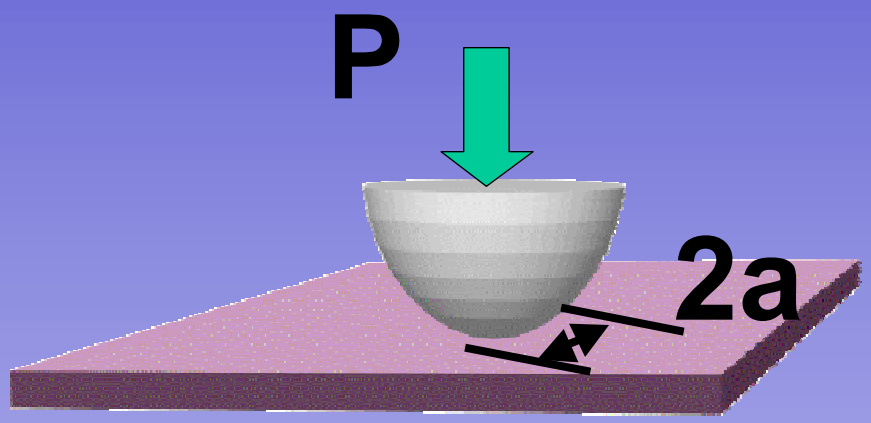
Objective

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

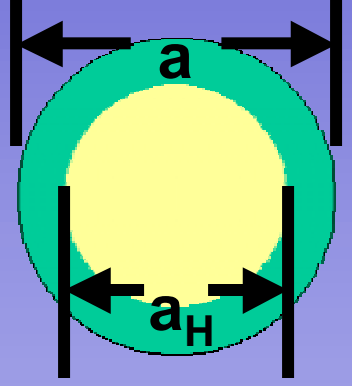
Combinatorial Methods Group

How do we study polymer adhesion?

JOHNSON, KENDALL, & ROBERTS (JKR)



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

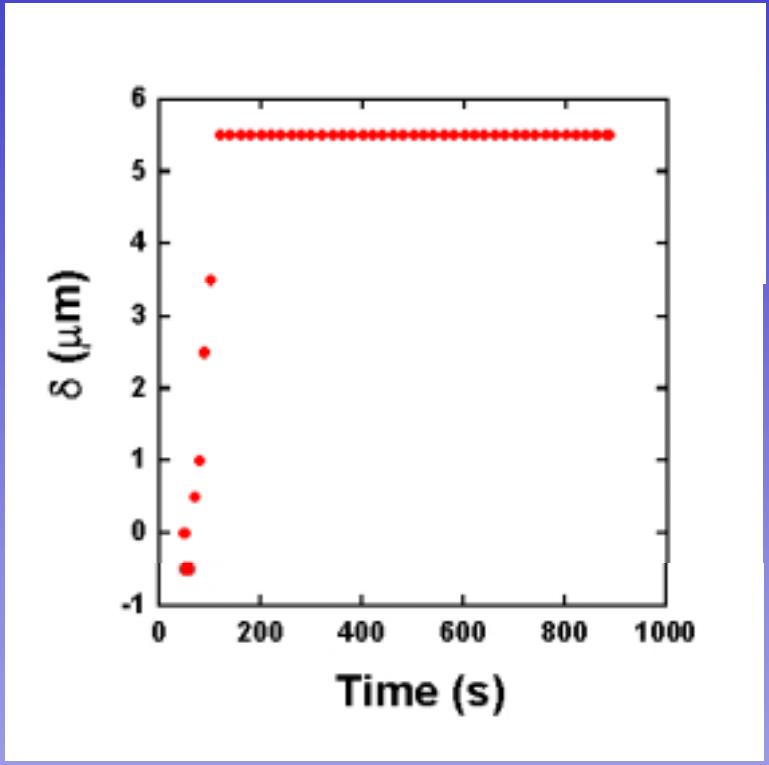


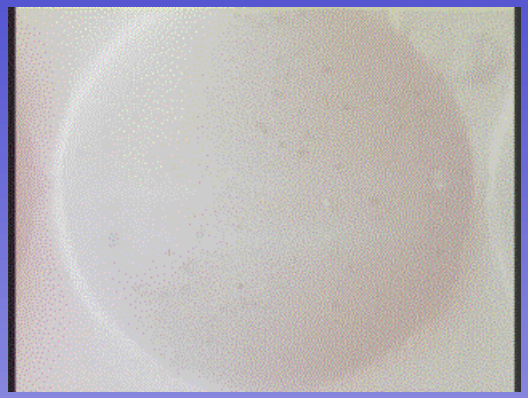
$$a^3 = \frac{9R}{16E}\left[P + 3\pi GR + \sqrt{6GRP + (3\pi GR)^2}\right]$$

Design

Combinatorial Methods Group

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

Combinatorial Methods Group

Why choose JKR?

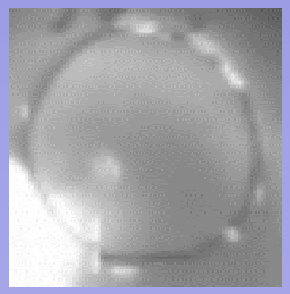
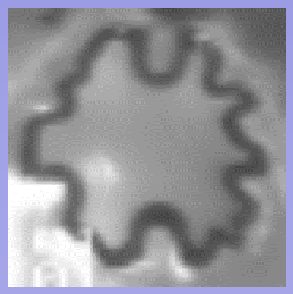
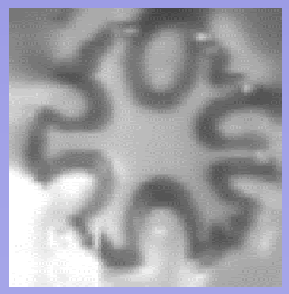
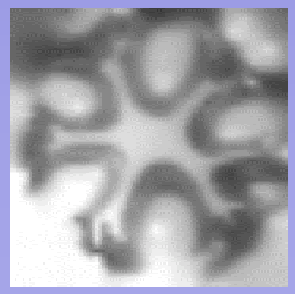
Recent Developments have allowed JKR to be applied to a wide range of issues

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.

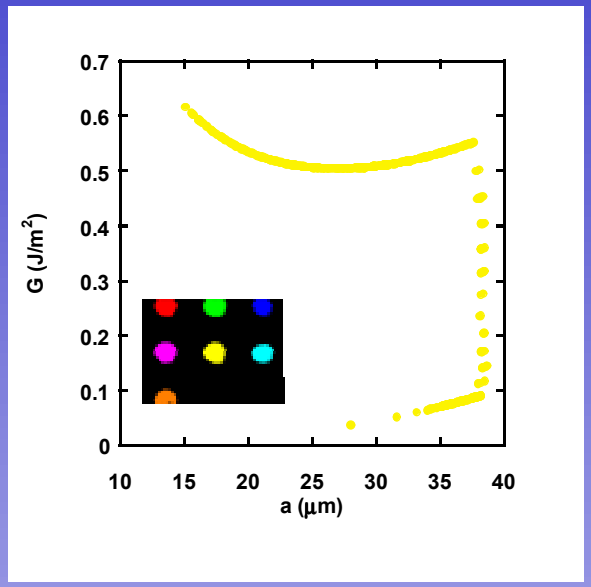
Viscoelasticity Corrections

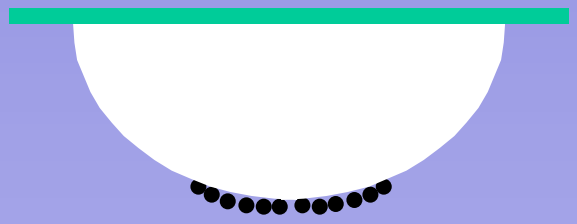
Lin, Y.Y., et al, *Journal of Applied Physics*, 1999, **32, 2250-2260.**
Johnson, K.L., ACS publication, 2000.

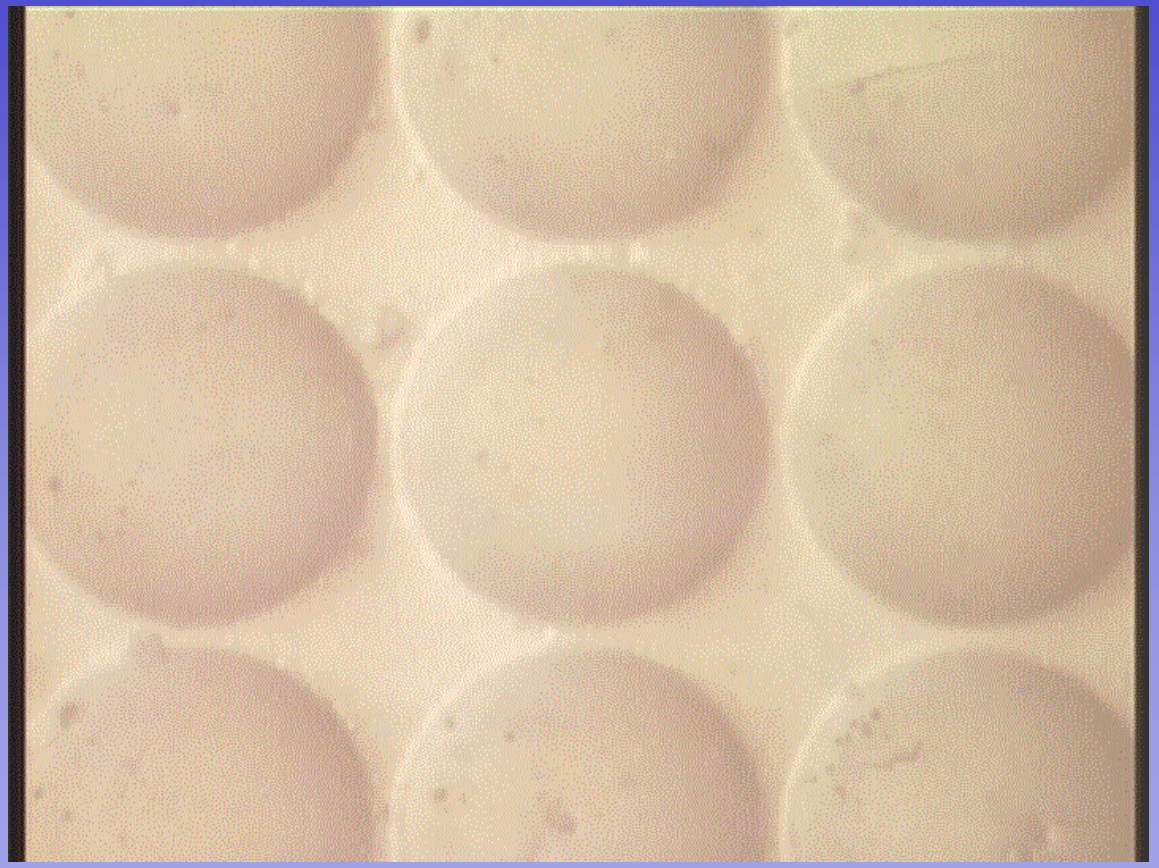





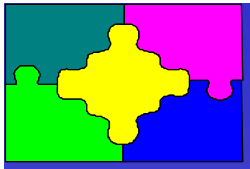
Combinatorial Methods Group

What about an array of lenses?

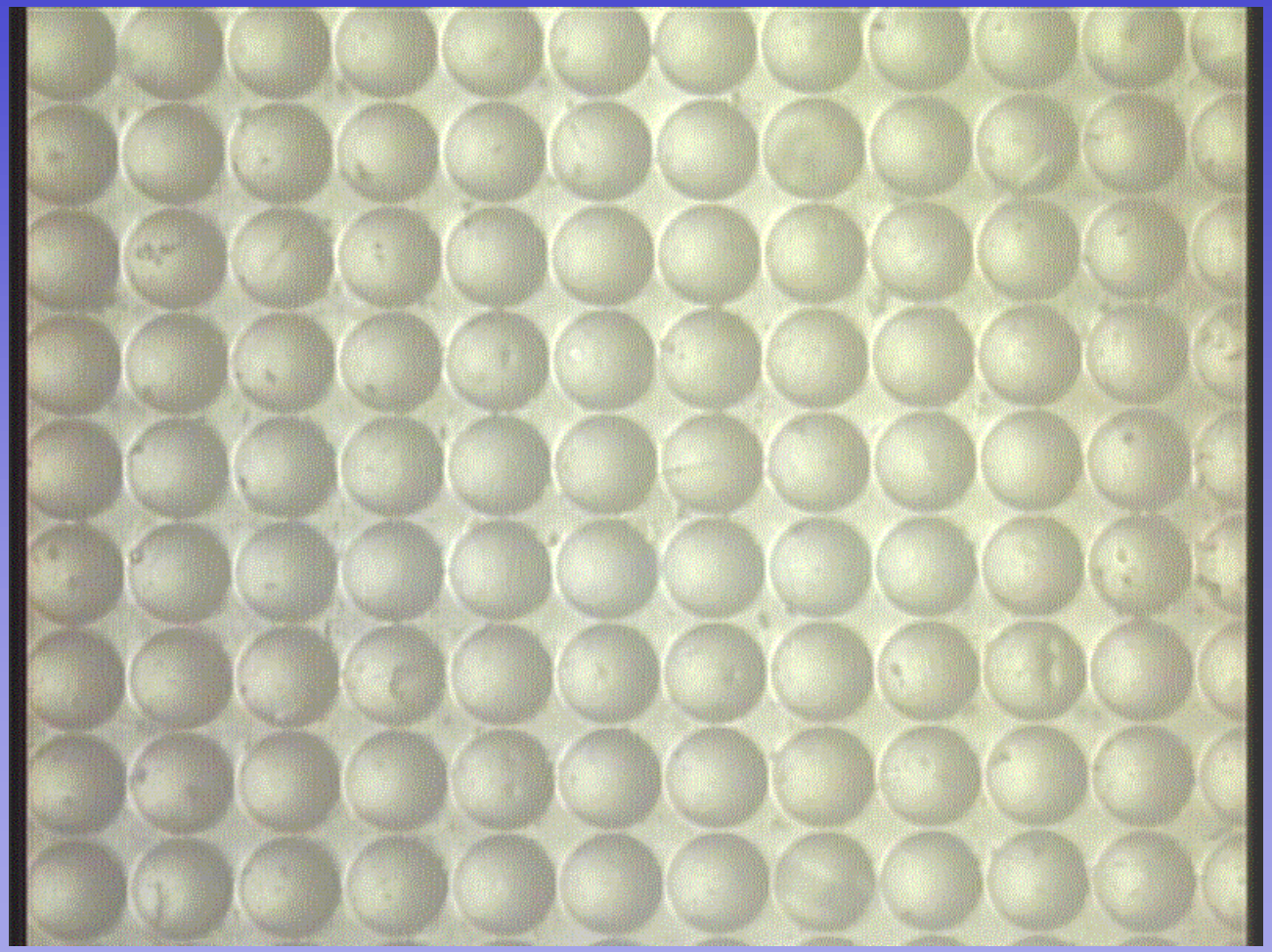






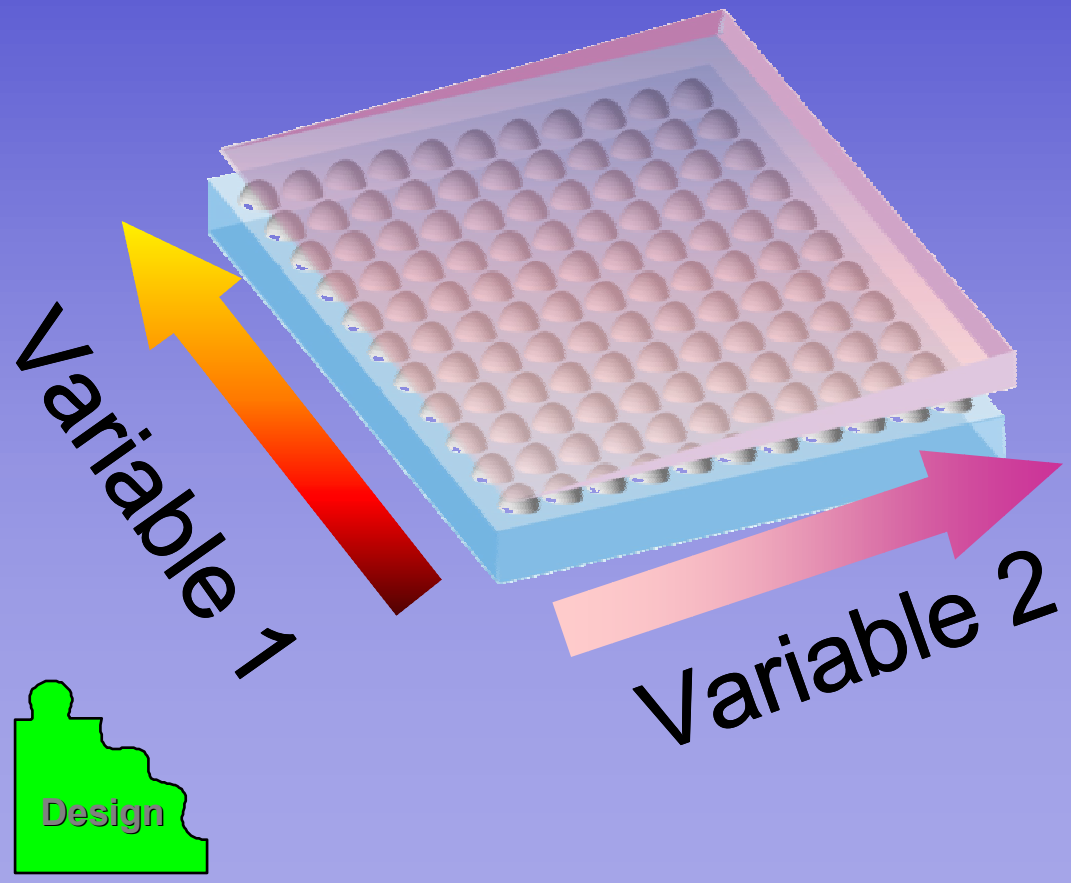


Why not more?



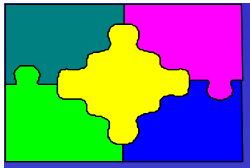
Combinatorial Methods Group

How do we design a *combinatorial* JKR test?



- Measure a, δ
- Determine $\mathcal{G}$

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



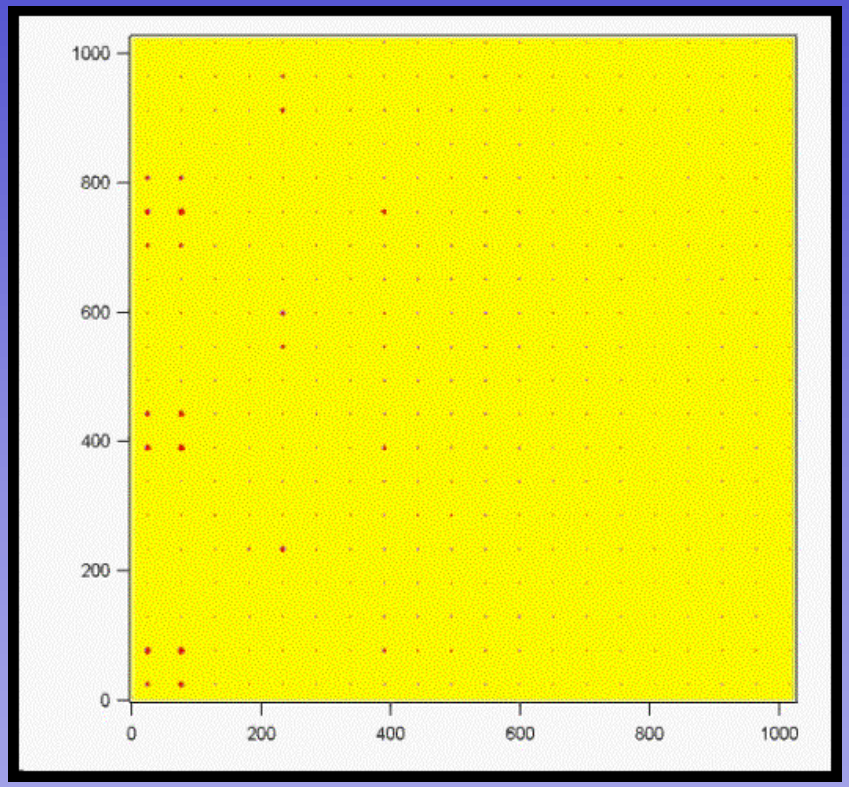
How do we calculate $\mathcal{G}$?

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

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

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

Design

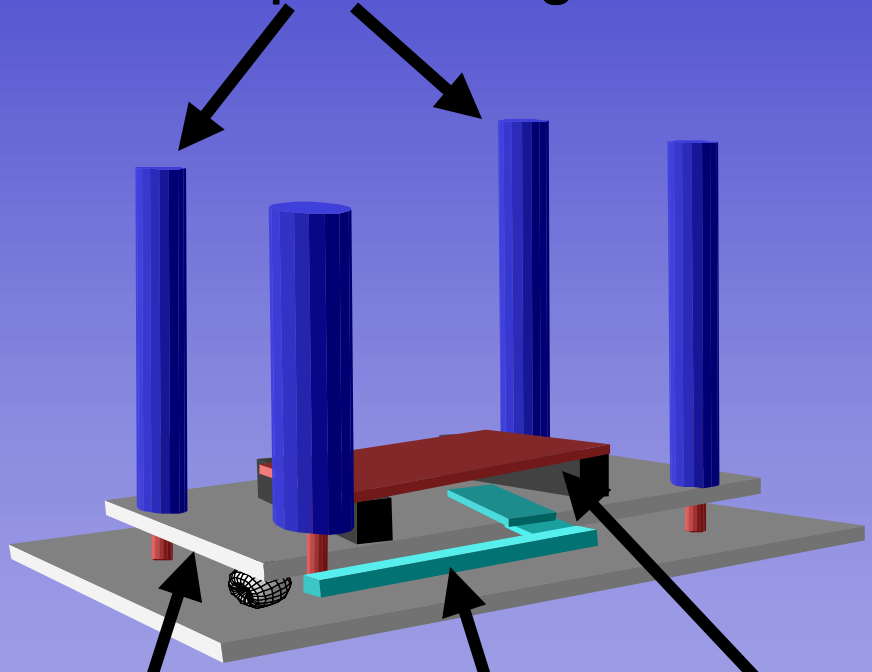


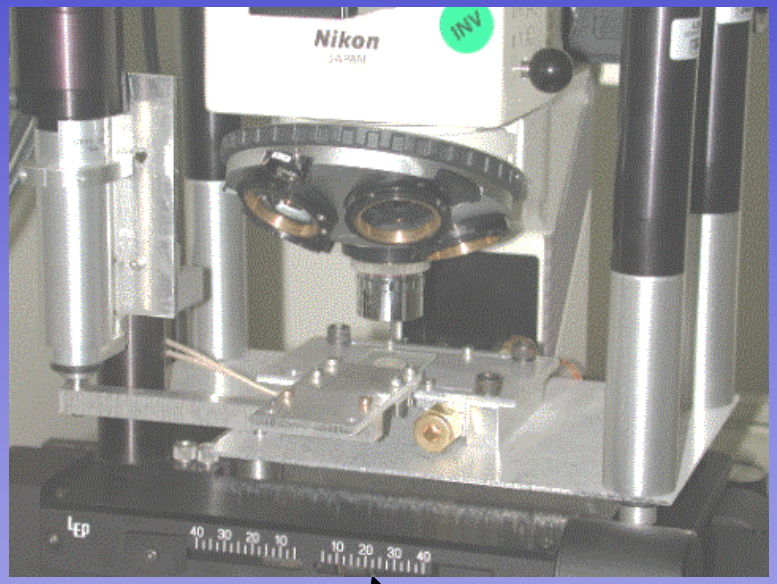
*** K.R. Shull, et al., *Macro. Symp.*, 1997.

Combinatorial Methods Group

How do we control contact?

Nanopositioning Actuators





Tip/Tilt Stage

Multilens Probe Holder

Thermal Gradient Stage

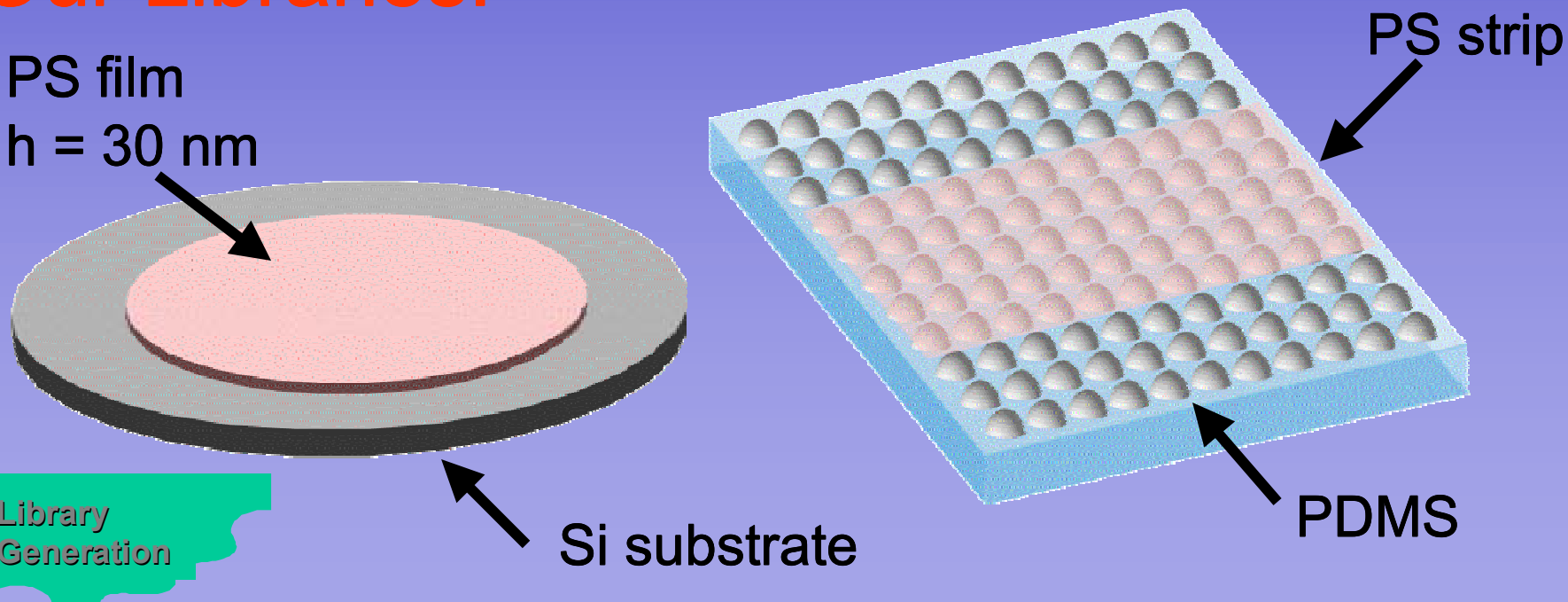
Programmable X-Y Stage

Combinatorial Methods Group

What problem to consider first?

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

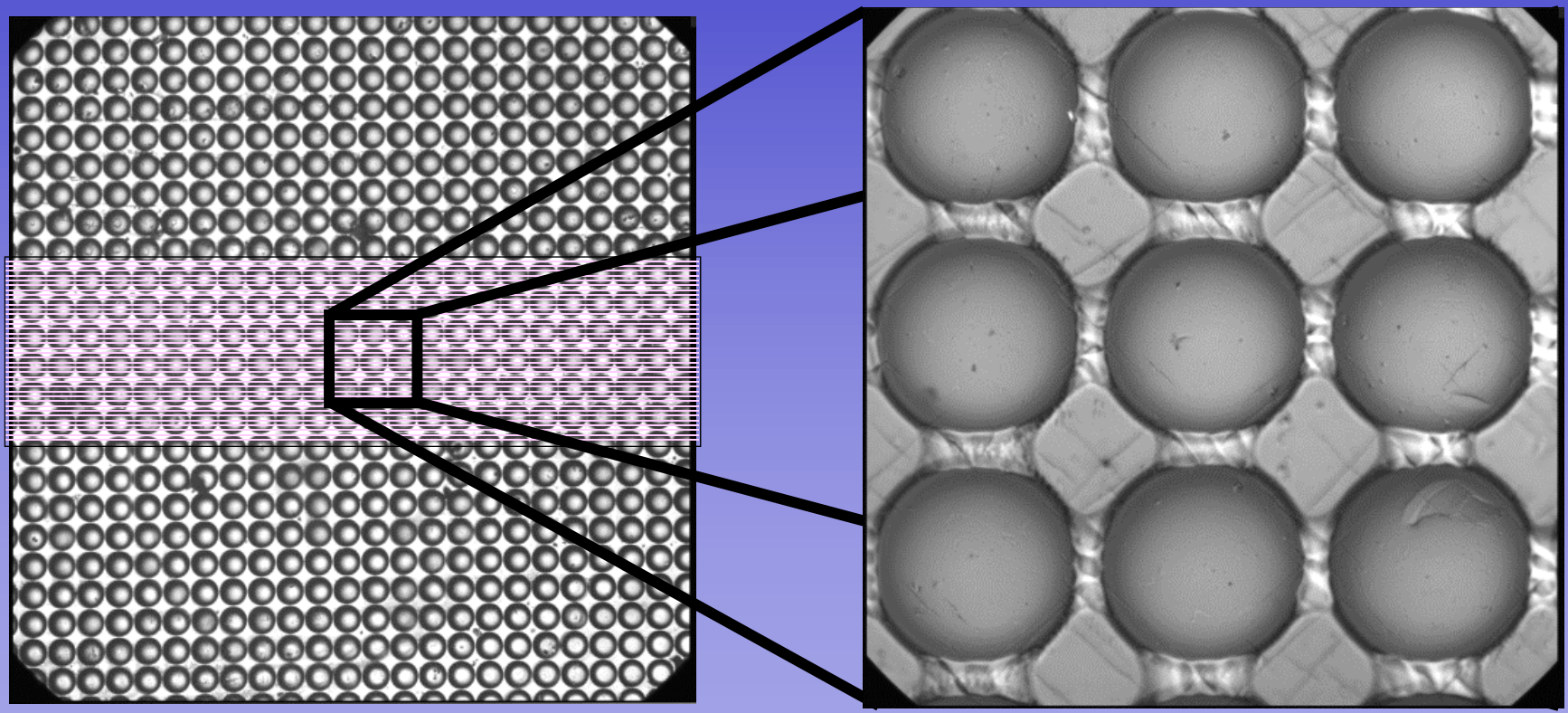
Our Libraries:



Library Generation

Combinatorial Methods Group

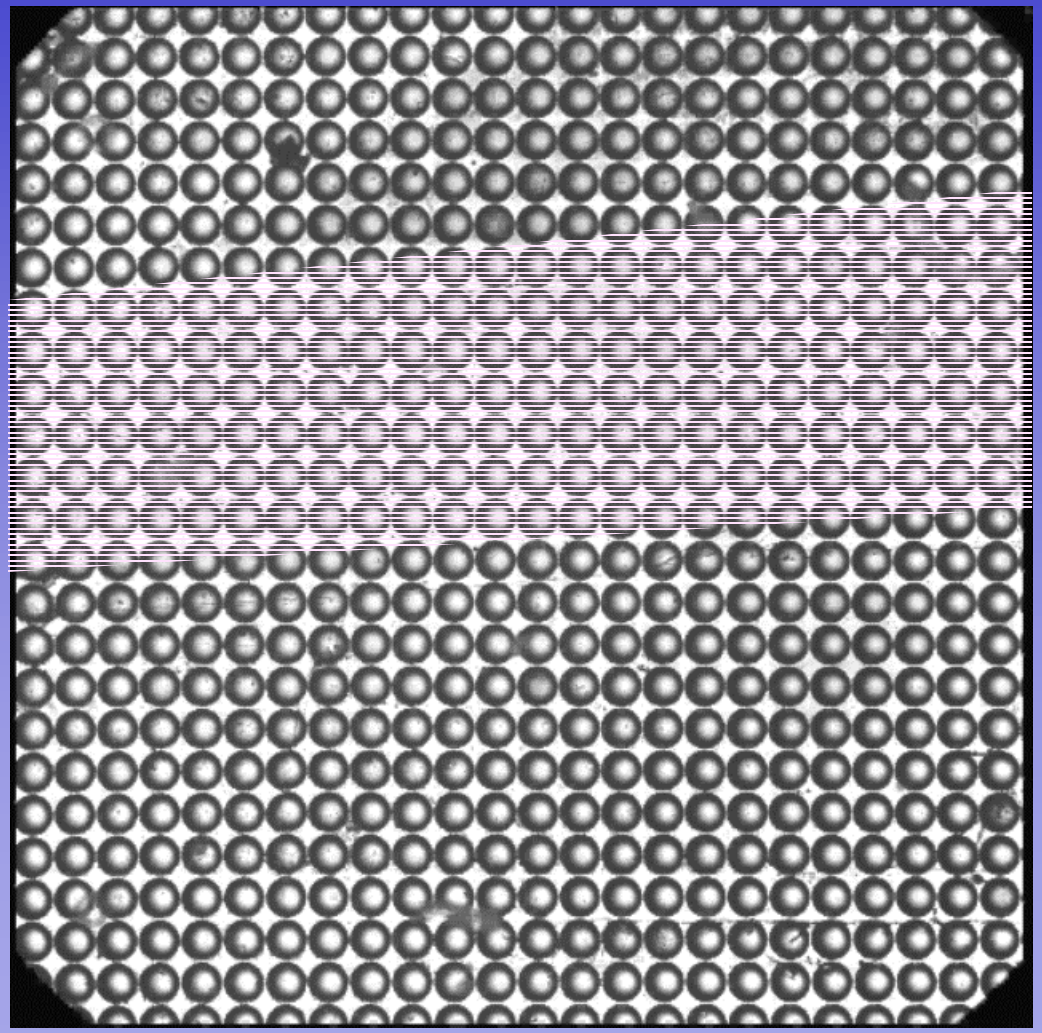
What do our libraries look like?



Library Generation

Combinatorial Methods Group

What do we observe?



Conditions:

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

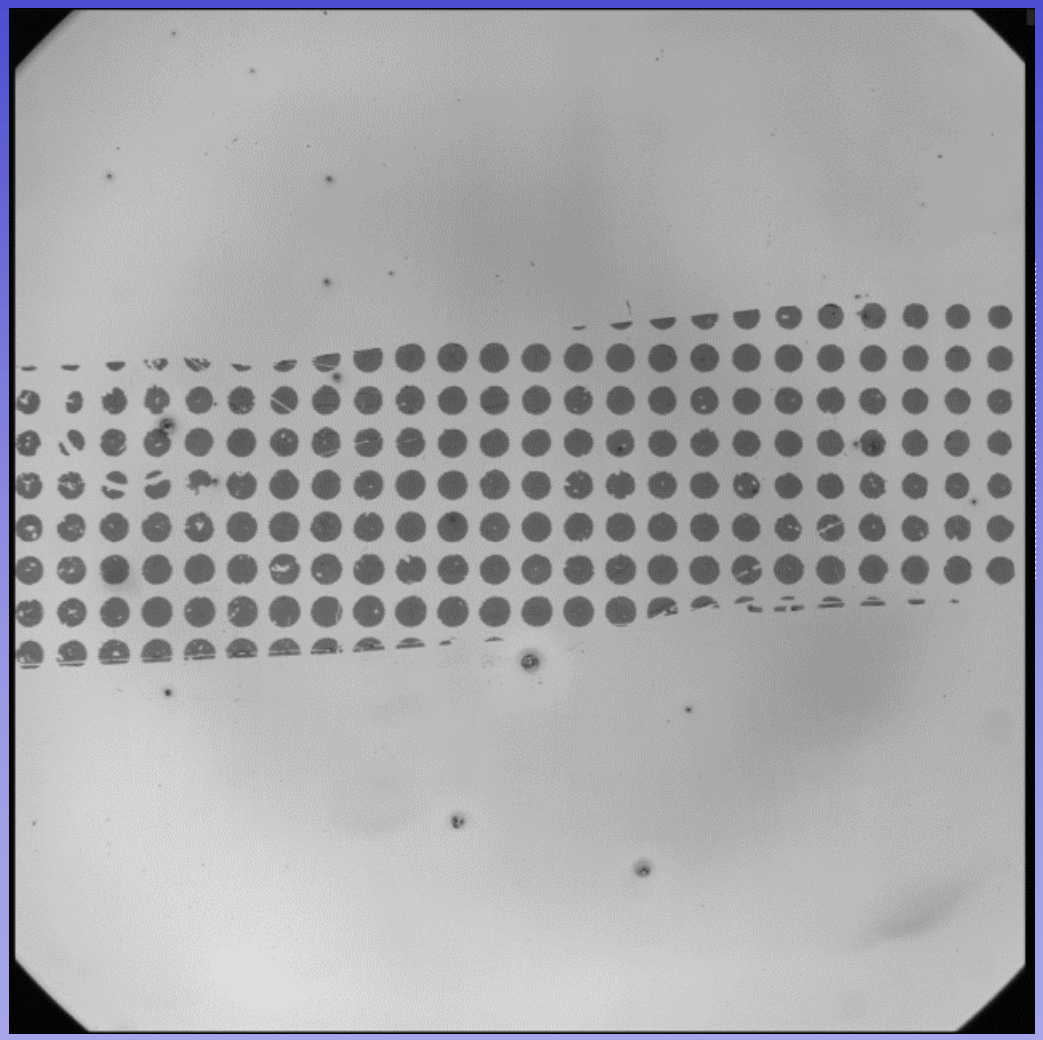
$h_{PS\ strip} = 30\ nm$

Temperature = 25°C

Library Evaluation

Combinatorial Methods Group

What happens at elevated temperature?



Conditions:

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

$h_{PS\ strip} = 30\ nm$

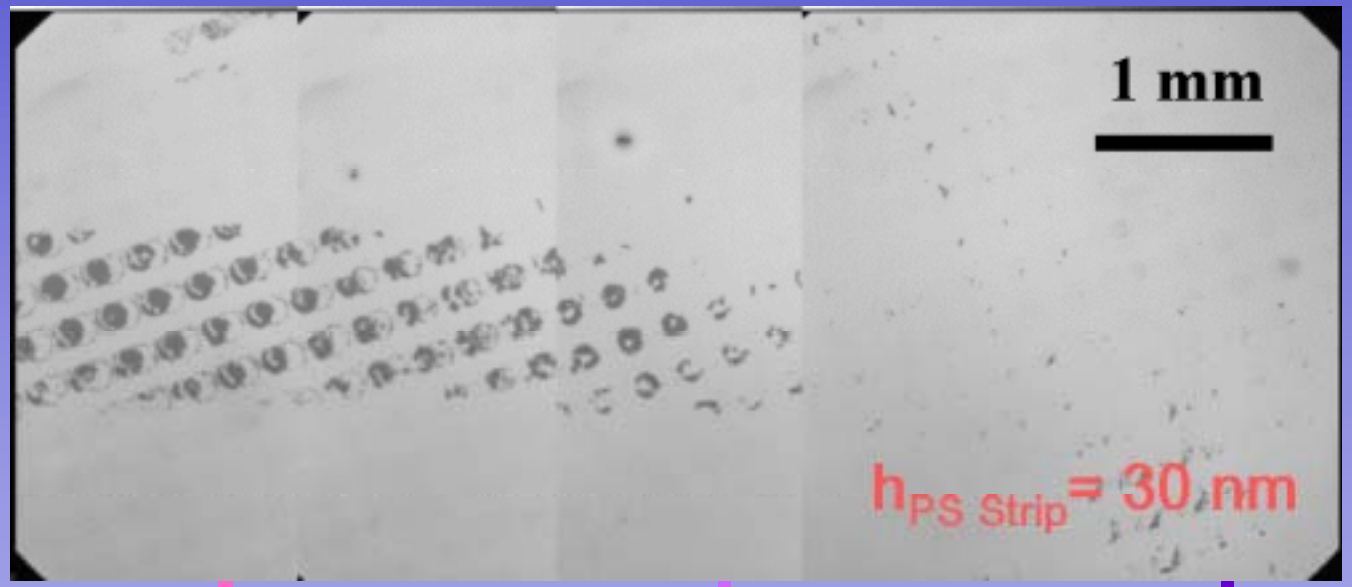
Temperature ~ 80°C

Library Evaluation

Combinatorial Methods Group

What is the critical temperature for PS welding?

Let's use combi!

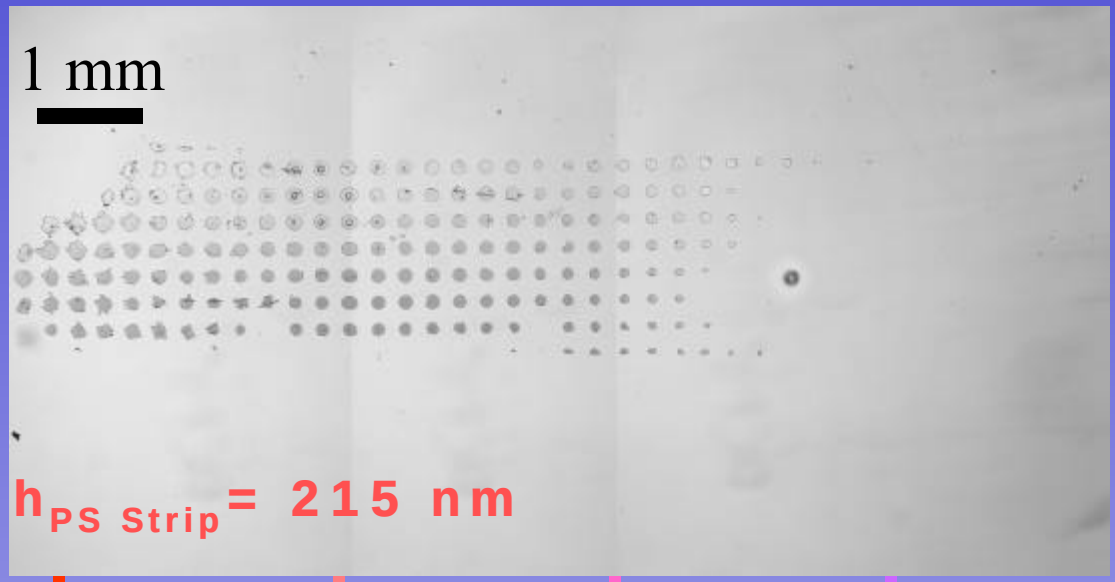


Library Evaluation

Combinatorial Methods Group

Does the critical temperature depend on thickness?

NIST CENTENNIAL 1901-2001

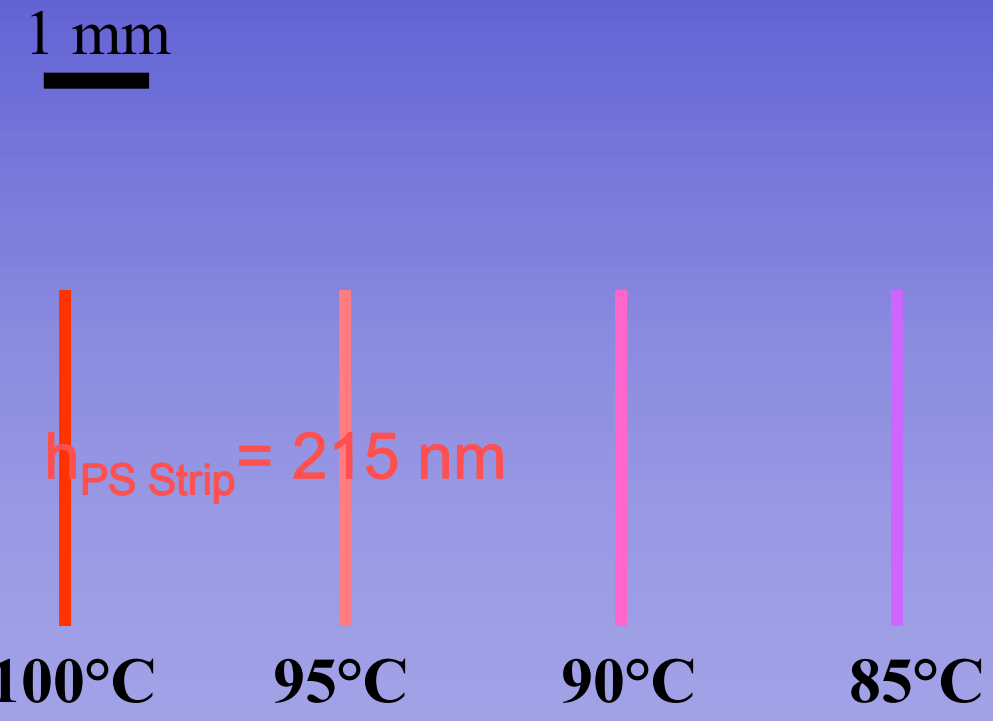


100°C 95°C 90°C 85°C

Library Evaluation

Combinatorial Methods Group

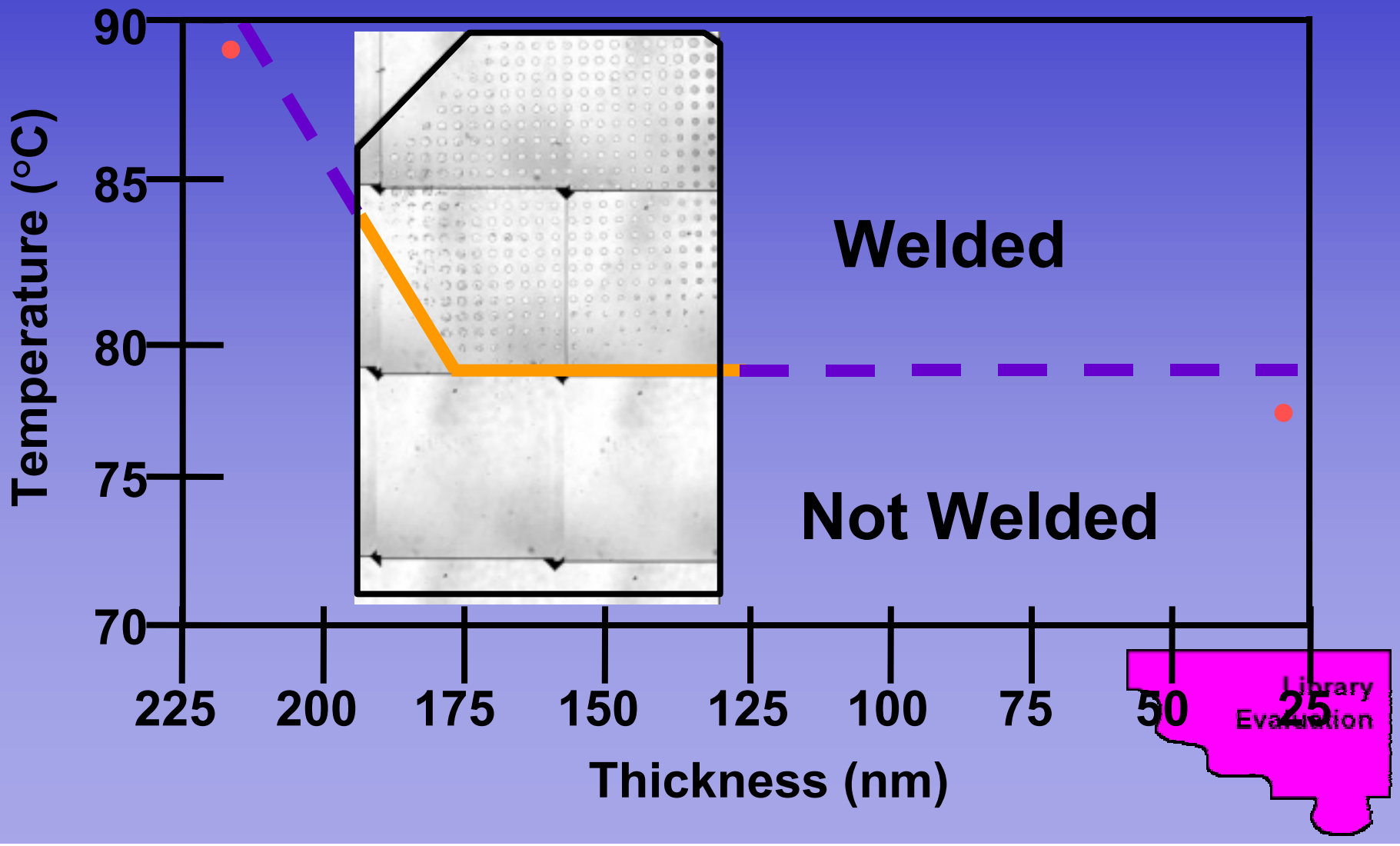
Does the critical temperature depend on thickness?



Library Evaluation

Combinatorial Methods Group

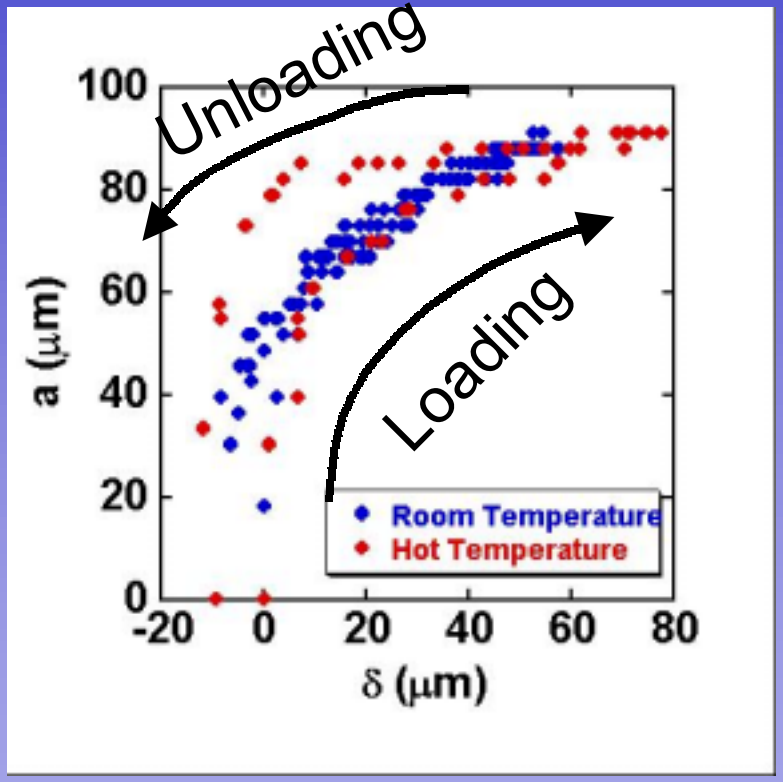
Does the critical temperature depend on thickness?



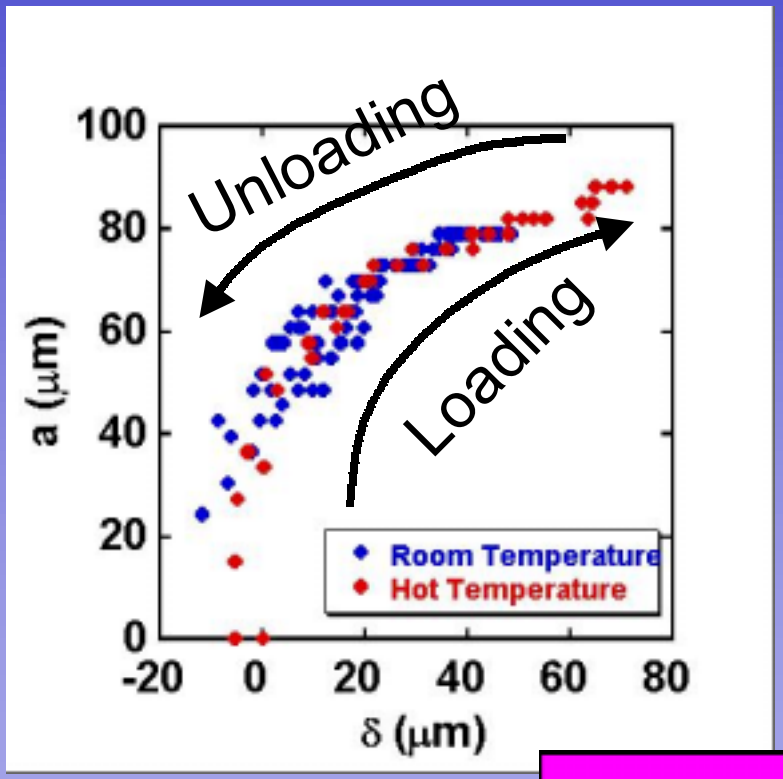
Combinatorial Methods Group

What does the data look like?

PS/PS Contact History



PS/PDMS Contact History

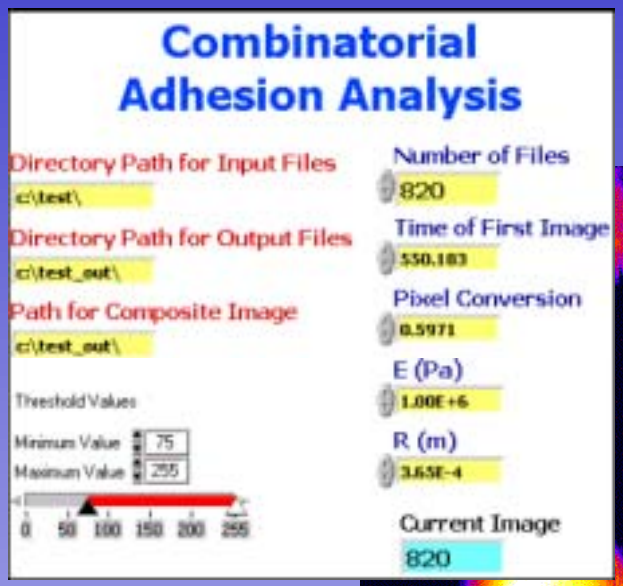


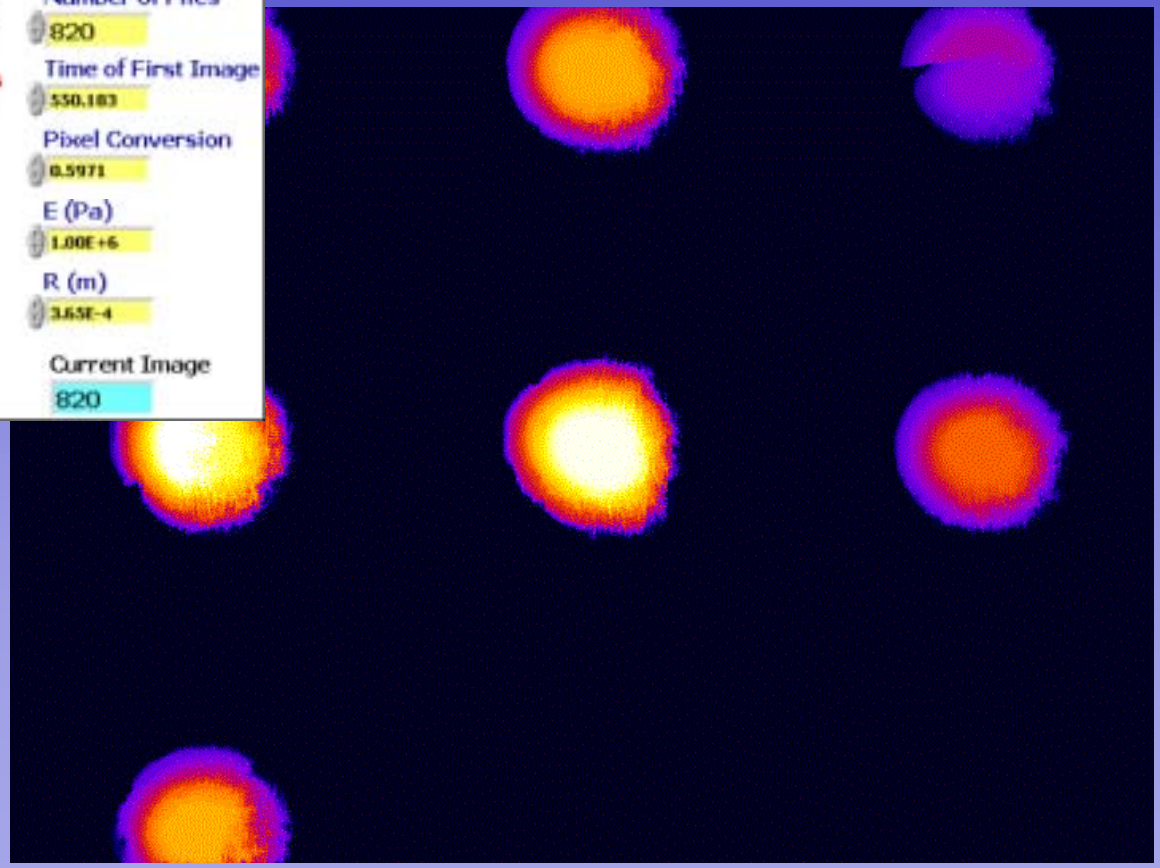
Library Evaluation

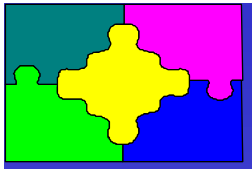
Same Sample, Same Conditions!

Combinatorial Methods Group

Automated Analysis

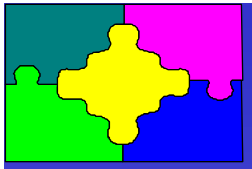






What are the main points?

- 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



Acknowledgements

- National Research Council Research Associateship Program

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