Dynamics of Explosives Residues

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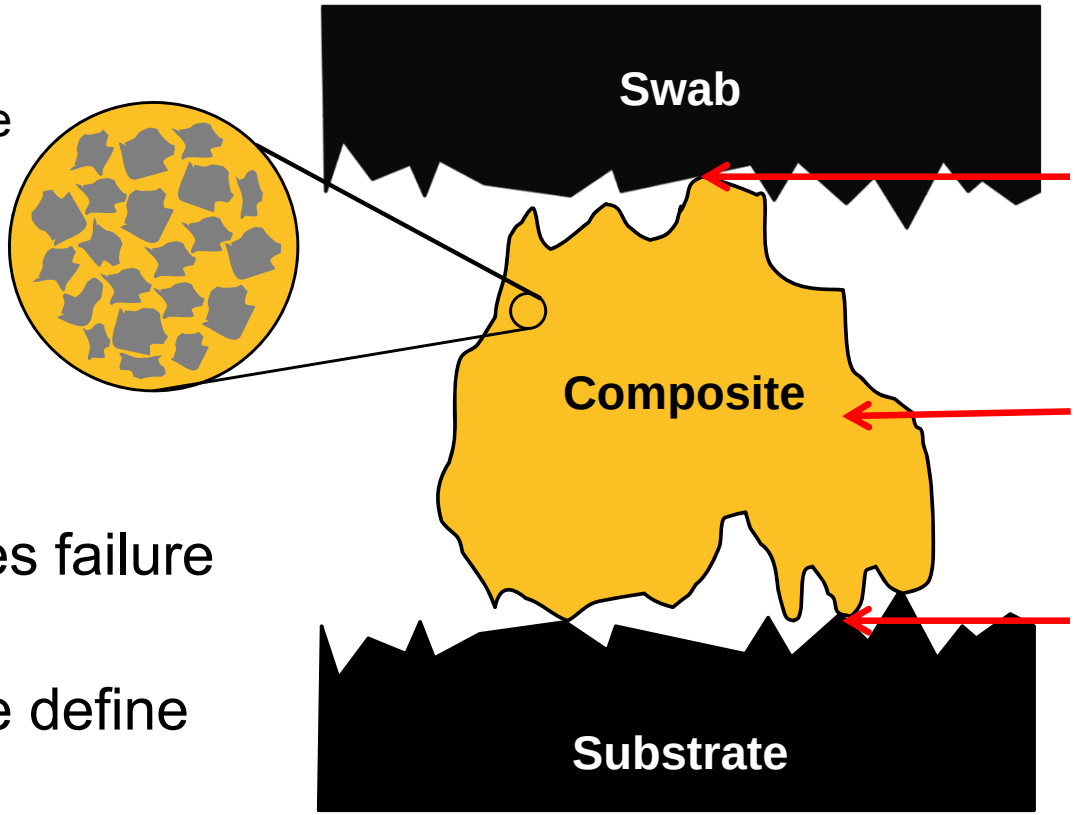
Granular system

~80-90% particle
~10-20% binder



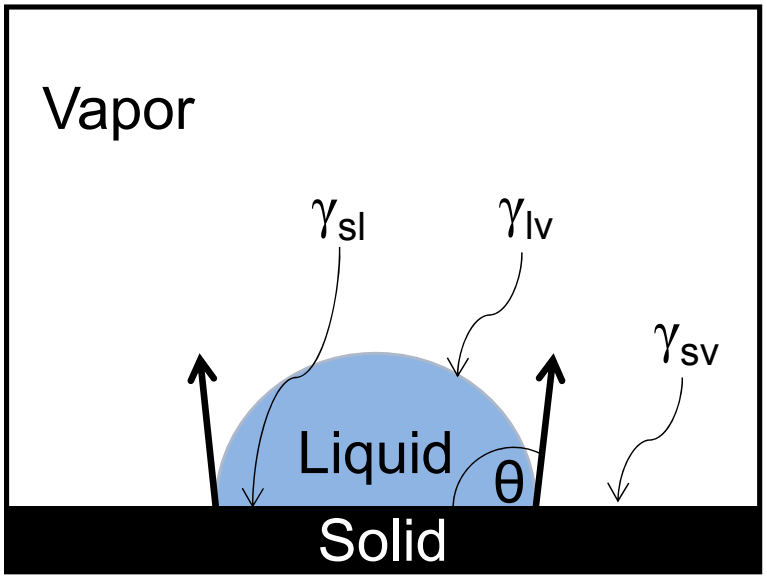
Swab/particle interaction
Swab/binder interaction

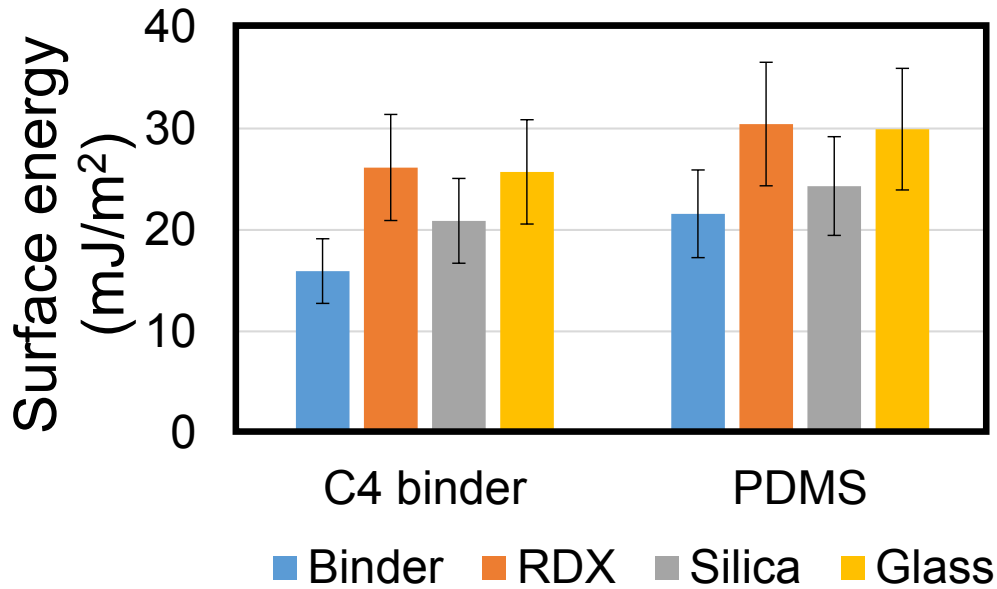
Particle/particle interaction
Particle/binder interaction
Binder/binder interaction

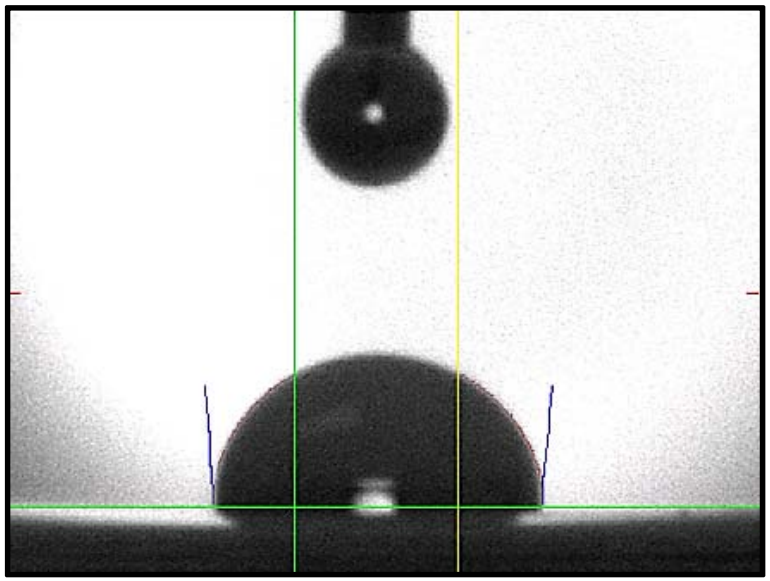
Substrate/particle interaction
Substrate/binder interaction

- Where does failure occur?
- How do we define “failure”?

Surface Energies





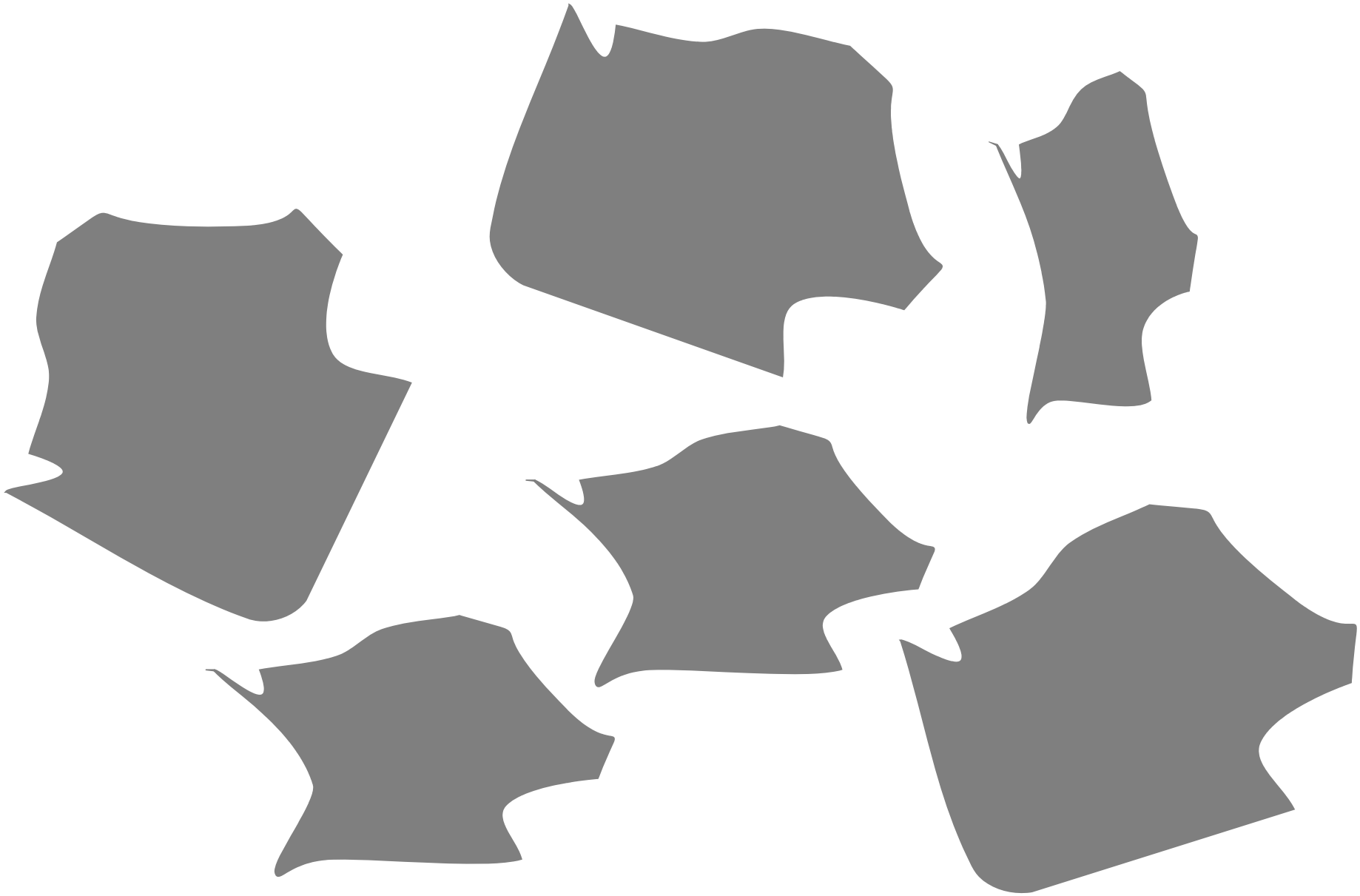


$$\cos\theta\,\gamma_{lv} = \gamma_{sv} - \gamma_{sl} - \pi_e$$

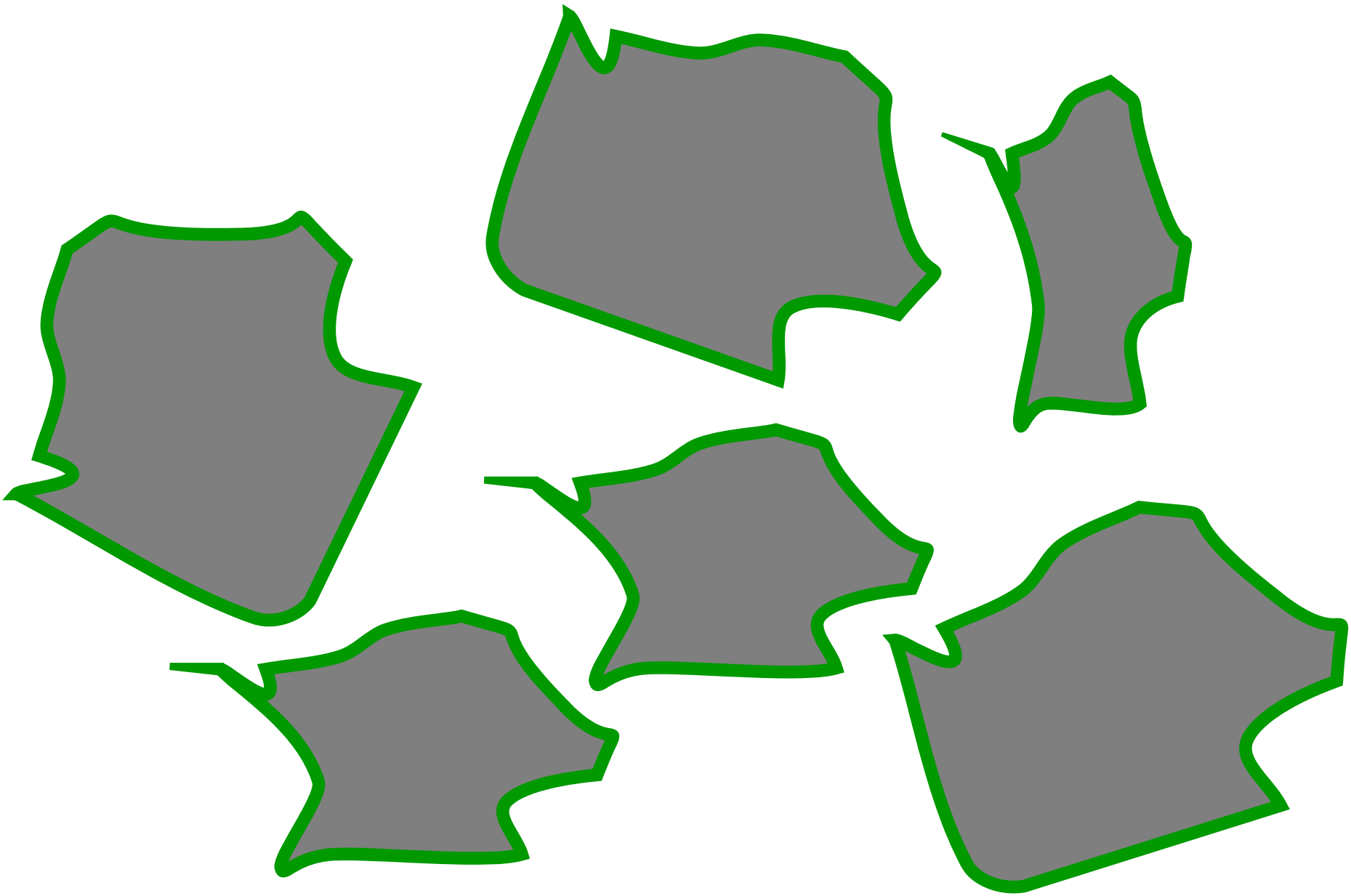
$$\gamma_{ii} = \gamma_{ii}^{d} + \gamma_{ii}^{p}$$

$$\gamma_{ij} = \sqrt{\gamma_{ii}\gamma_{jj}}$$

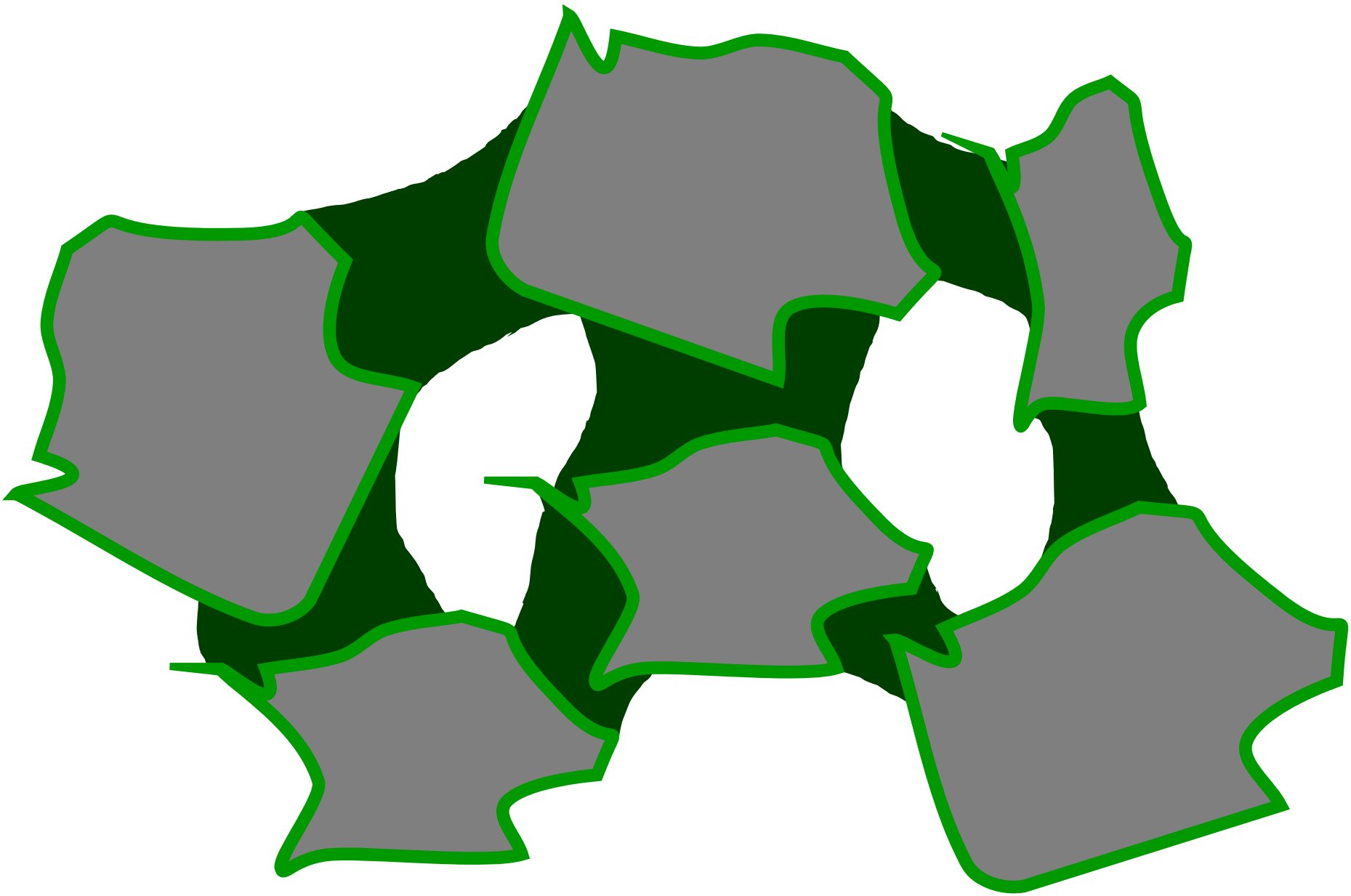
New Proposed Schematic



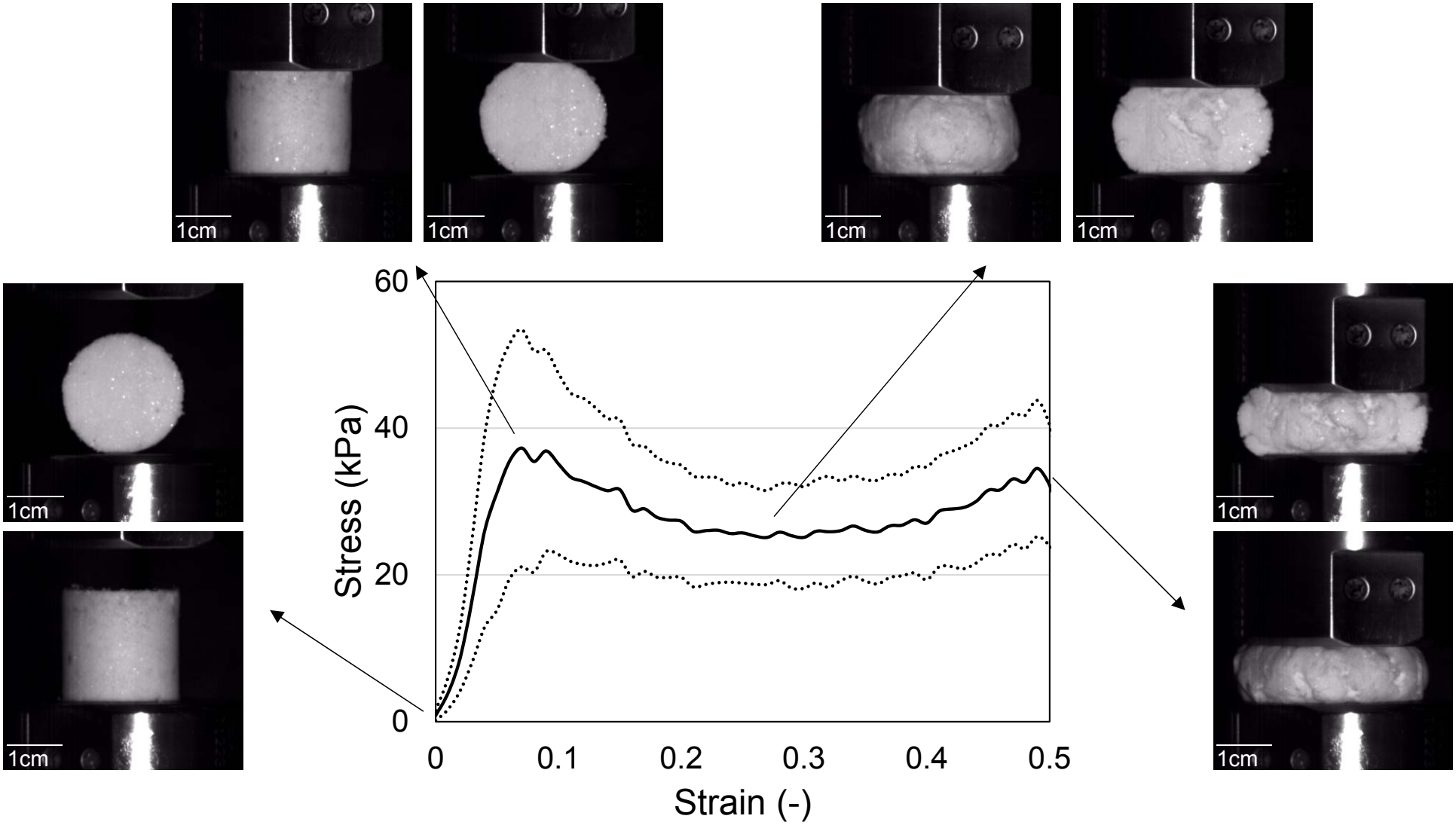
New Proposed Schematic



New Proposed Schematic

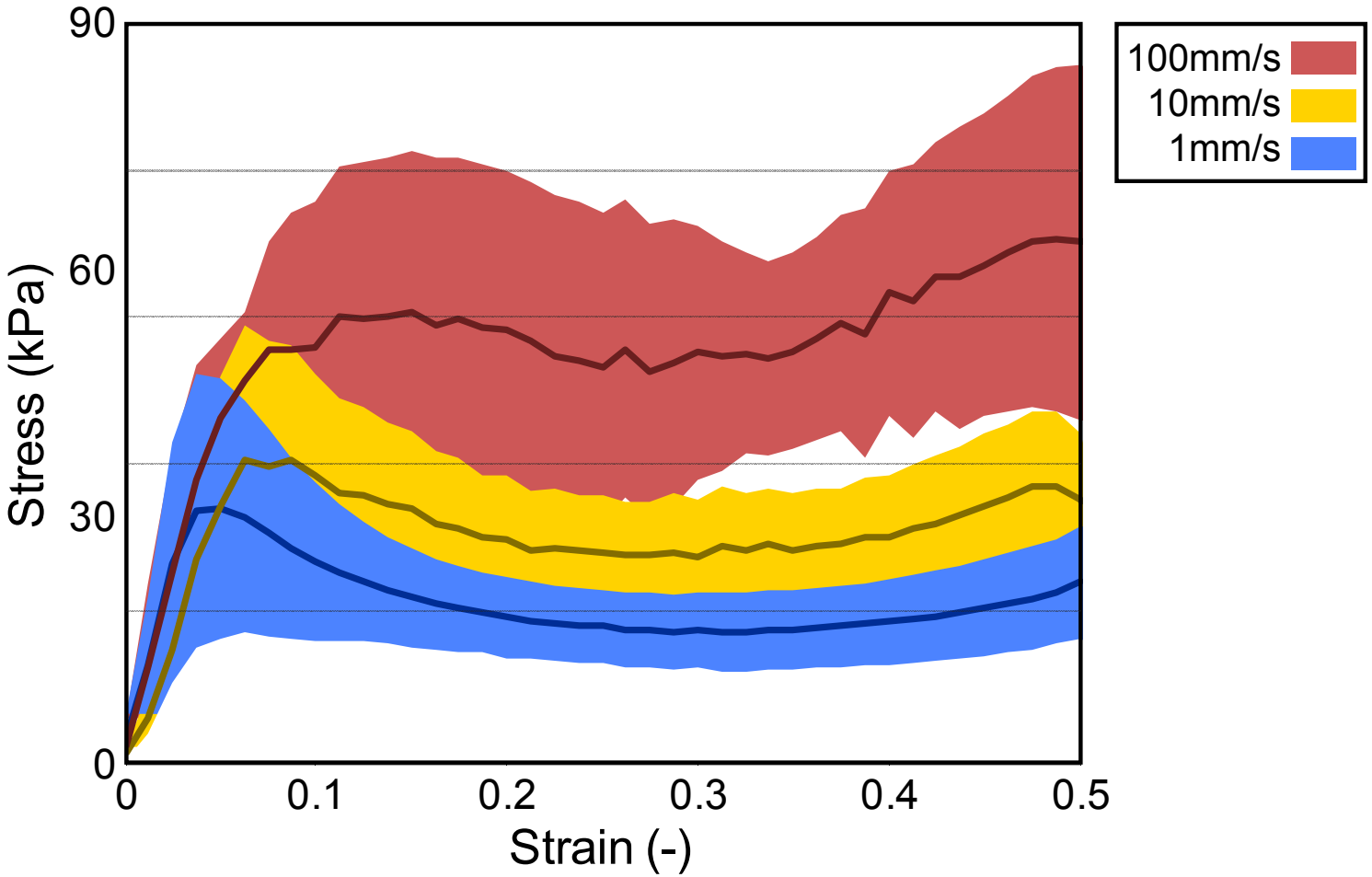


Stress-Strain Results: Live C4 at 10mm/s



Stress-strain curve (with error regions) live C4 at 10mm/s compression rate. Axial images shown bottom and left; diametrical are top and right.

Live C4 Results



Stress-strain curves (with error regions) live C4 at 1mm/s, 10mm/s, 100mm/s compression rates.

Historical model

Viscous effects

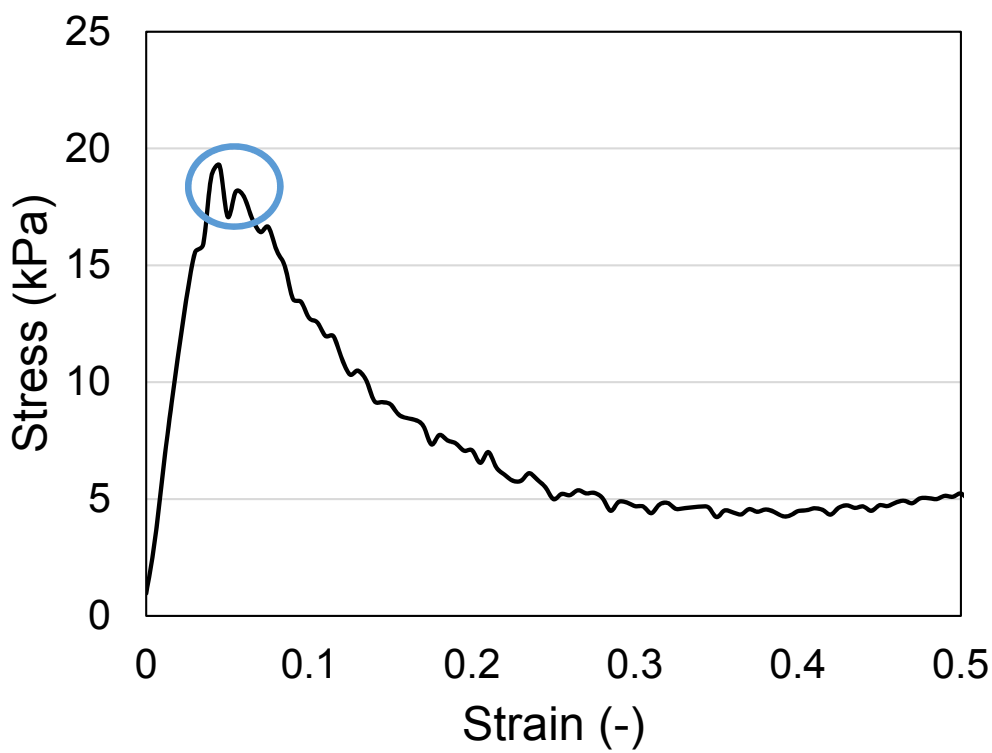
$$Ca = \frac{\mu \dot{\varepsilon}_a d_{32}}{\gamma \cos\theta}$$

Surface effects

Peak flow stress

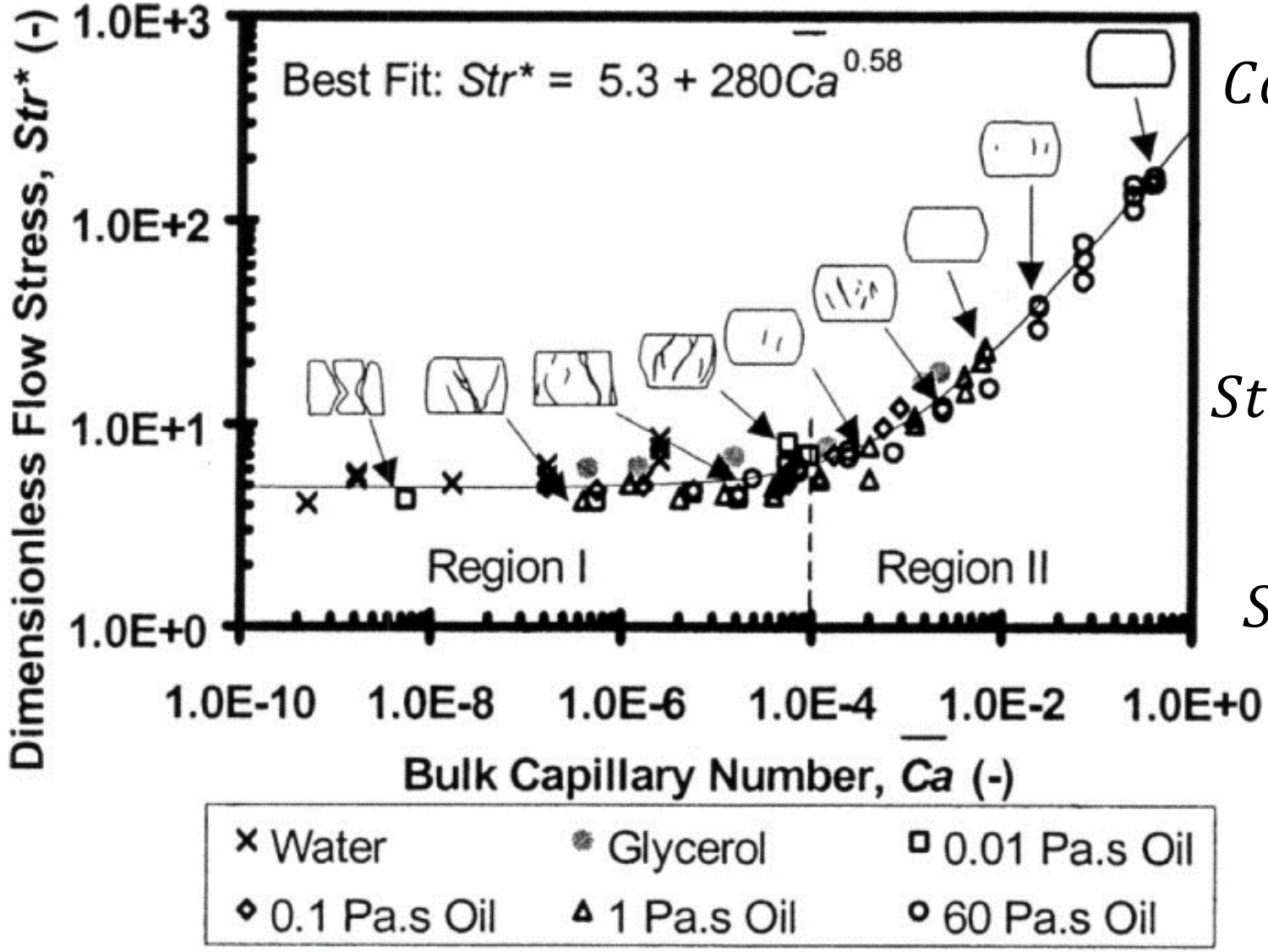
$$Str^* = \frac{\sigma_p d_{32}}{\gamma \cos\theta}$$

Surface effects



Stress-strain curve for silica particles (40-150mesh) in PDMS (600,000 cSt viscosity) at 10mm/s compression rate.

Historical model



Viscous effects

$$Ca = \frac{\mu \dot{\varepsilon}_a d_{32}}{\gamma \cos\theta}$$

Surface effects

Peak flow stress

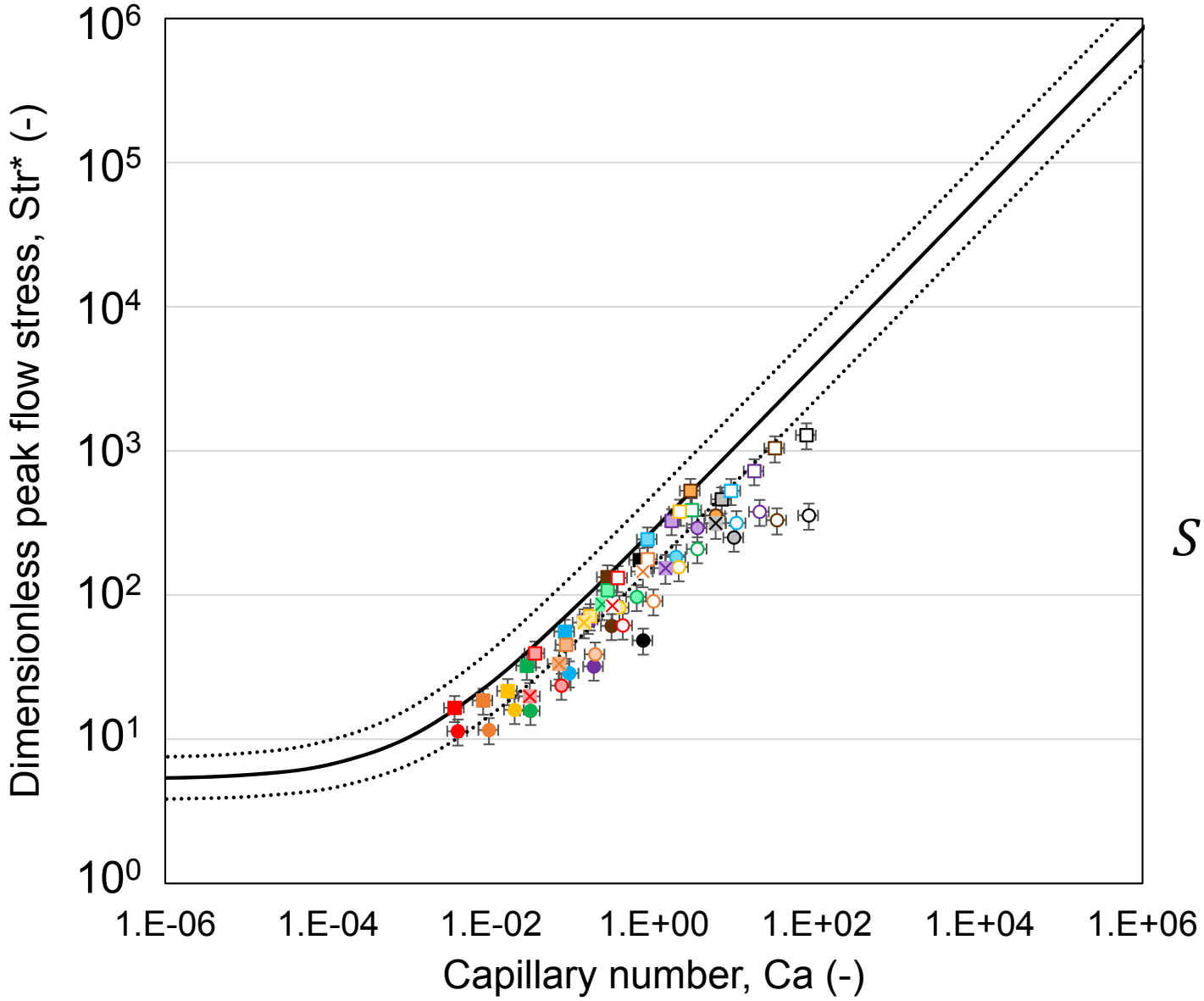
$$Str^* = \frac{\sigma_p d_{32}}{\gamma \cos\theta}$$

Surface effects

$$Str^* = k_1 + k_2 Ca^n$$

Iveson, S. M., & Page, N. W. (2004). Brittle to Plastic Transition in the Dynamic Mechanical Behavior of Partially Saturated Granular Materials. *Journal of Applied Mechanics*, *71*(4), 470–475.

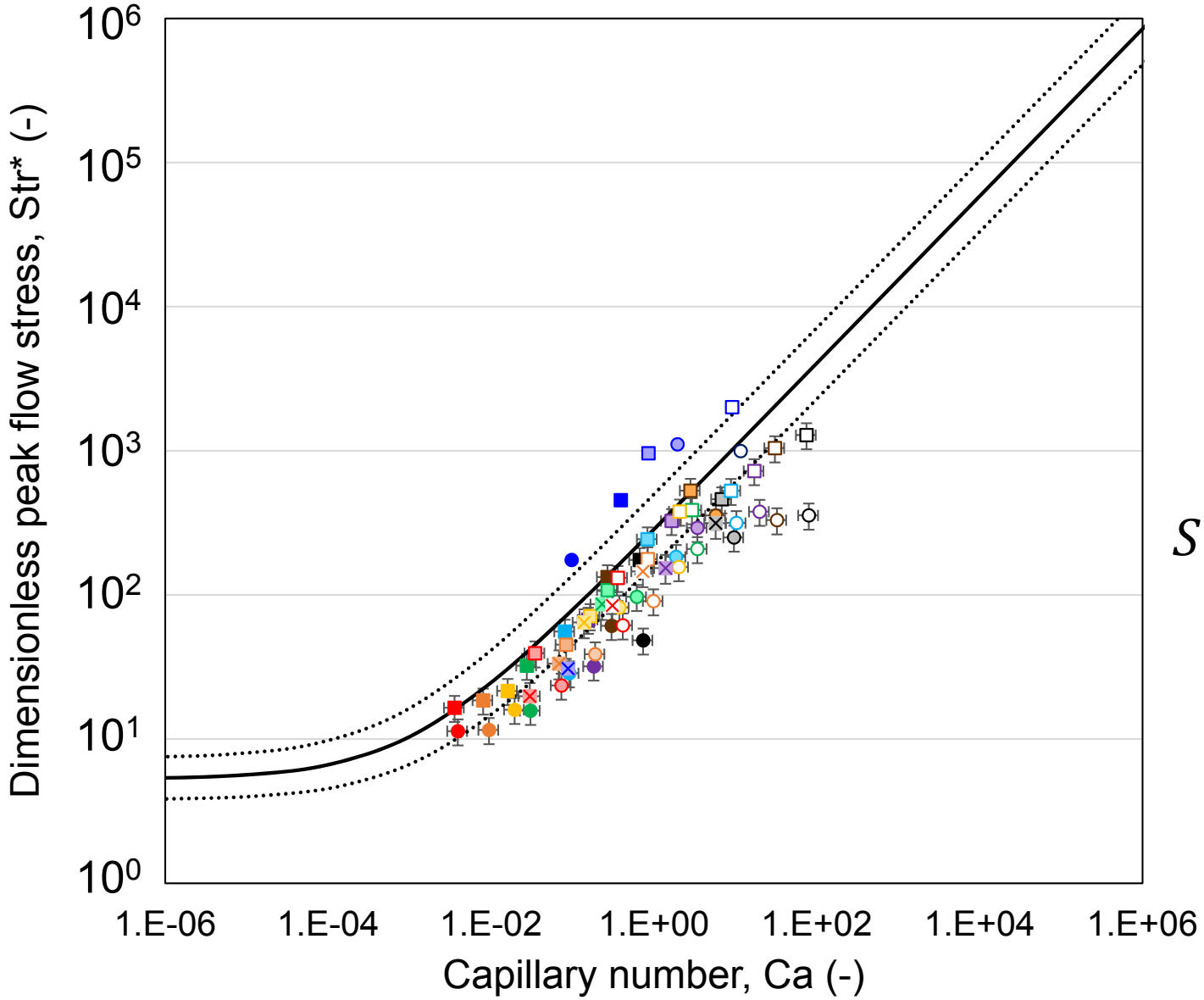
Historical model



$$Ca = \frac{\textit{viscous effects}}{\textit{surface effects}}$$

$$Str^* = \frac{\textit{peak flow stress}}{\textit{surface effects}}$$

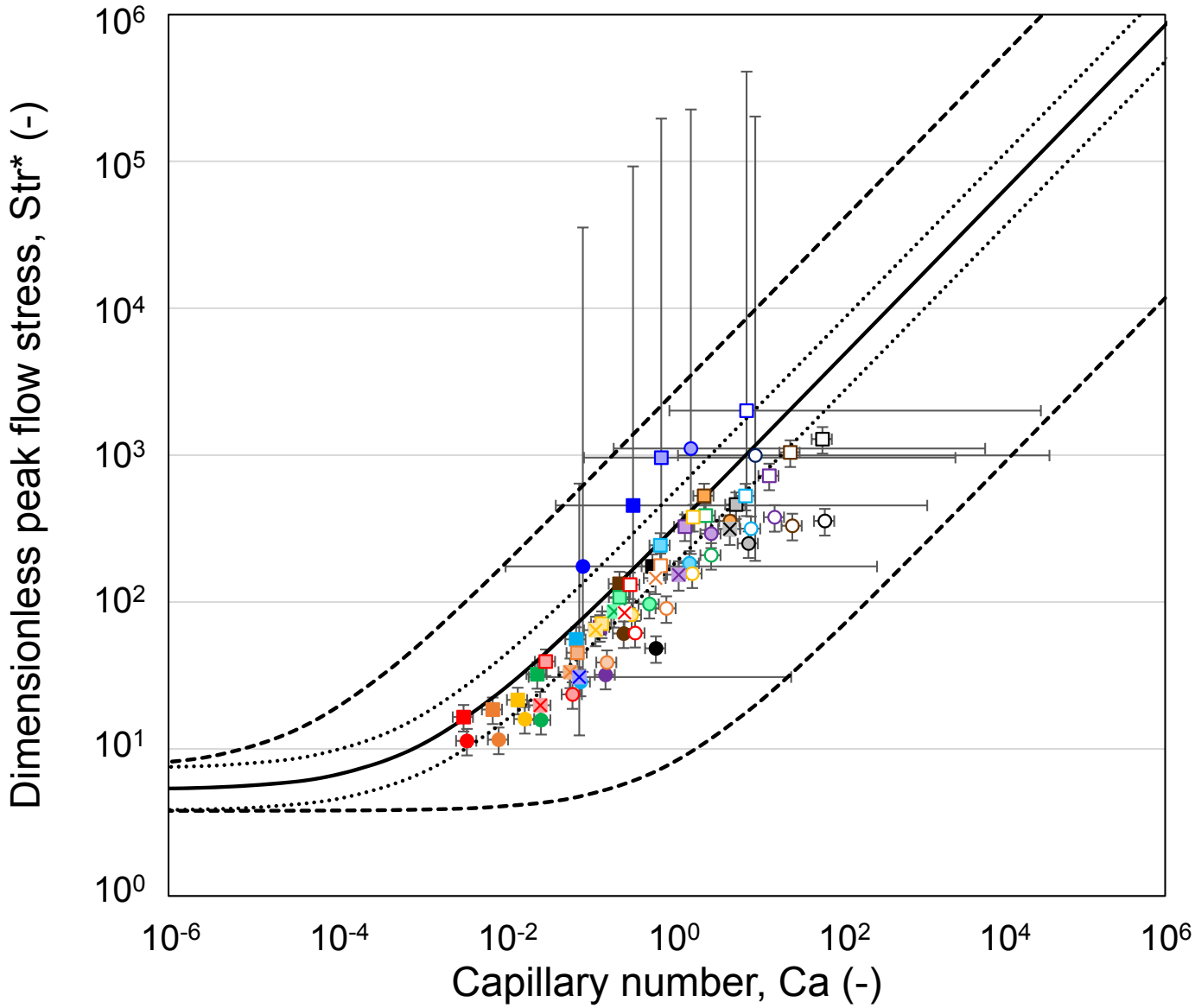
Historical model



$$Ca = \frac{\textit{viscous effects}}{\textit{surface effects}}$$

$$Str^* = \frac{\textit{peak flow stress}}{\textit{surface effects}}$$

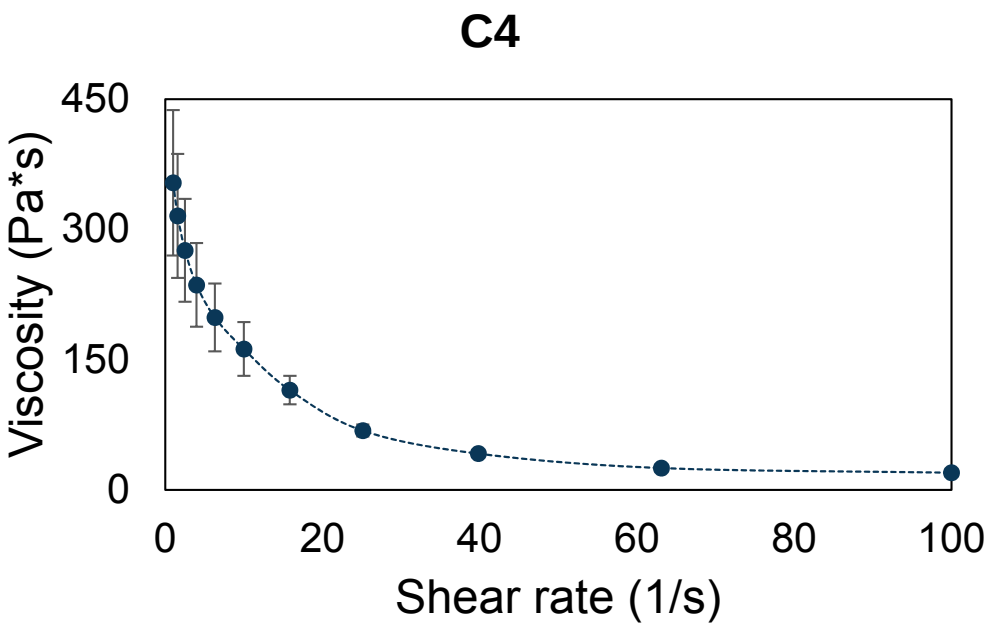
Historical model

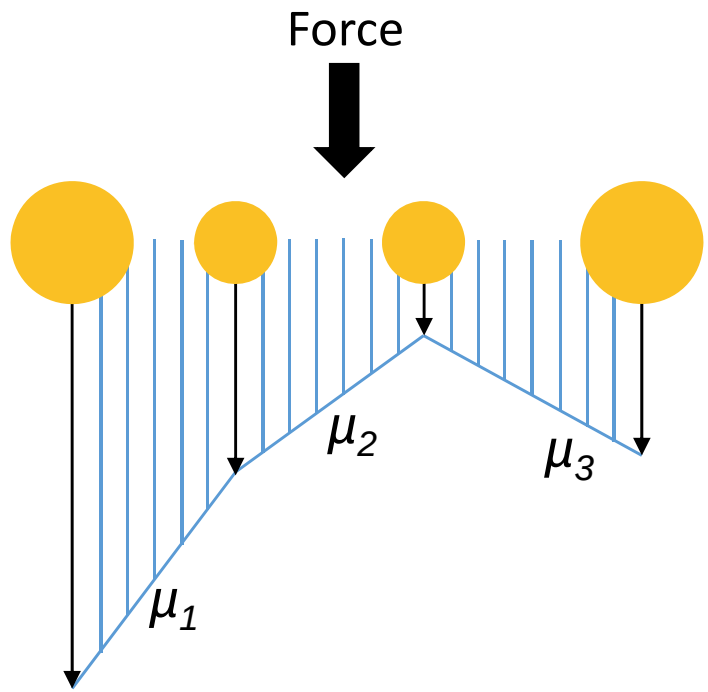


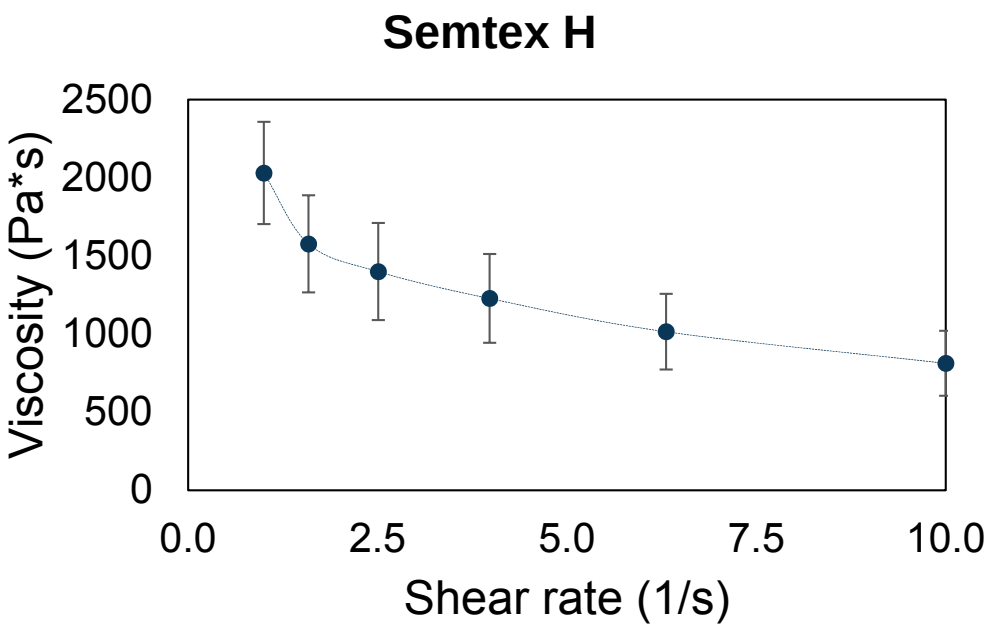
$$Ca = \frac{\textit{viscous effects}}{\textit{surface effects}}$$

$$Str^* = \frac{\textit{peak flow stress}}{\textit{surface effects}}$$

Viscosity profiles

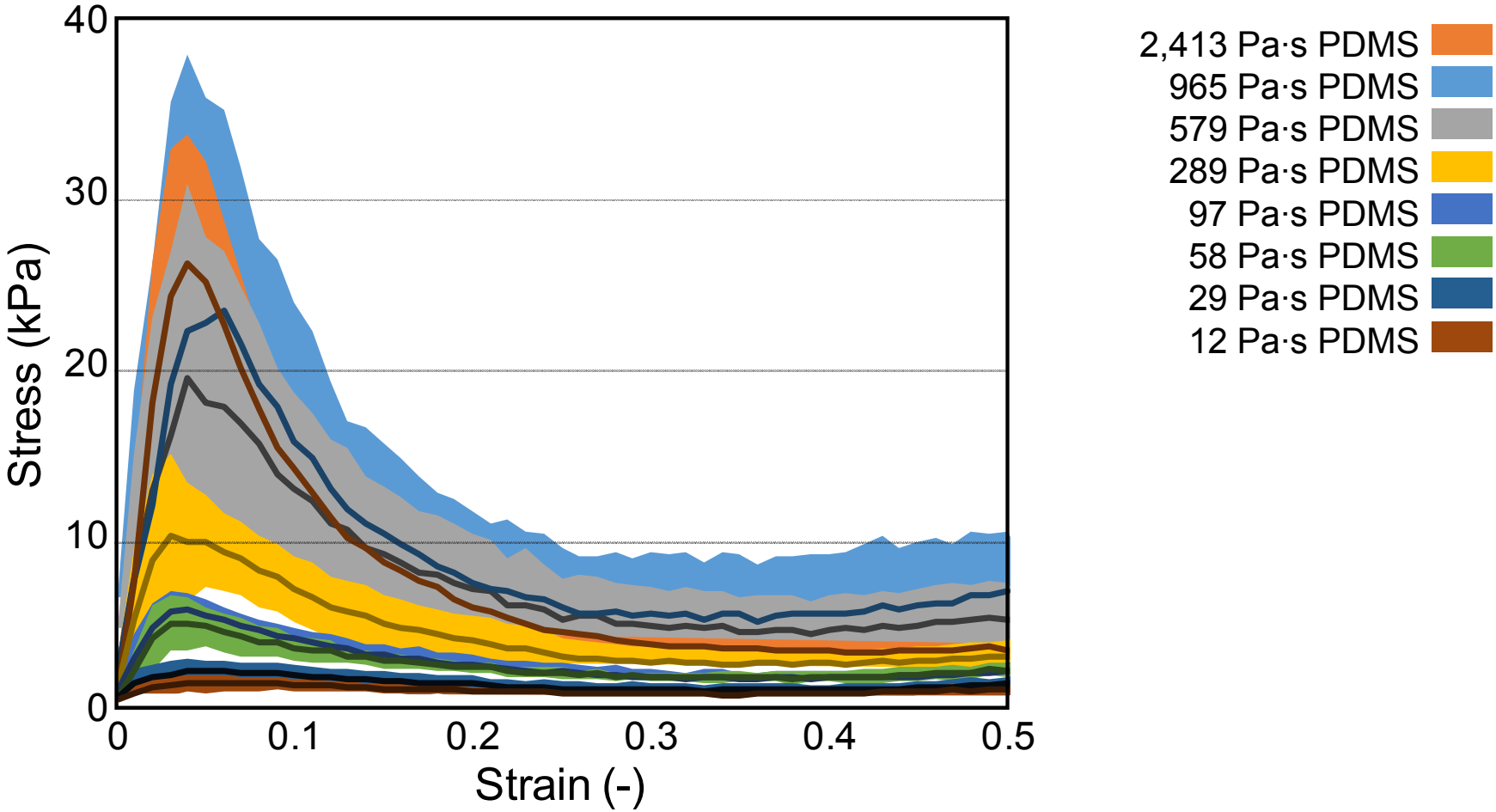






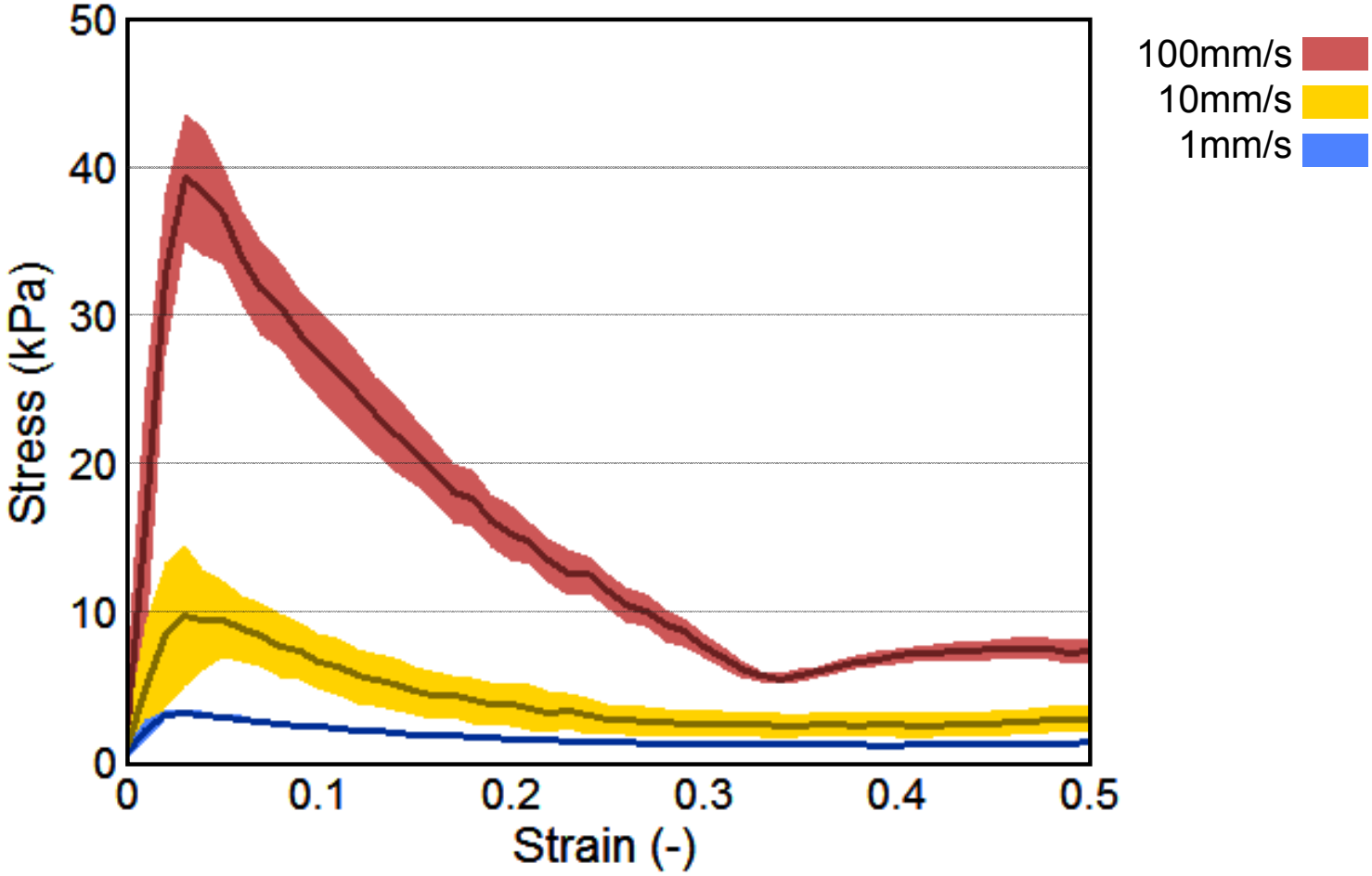
Viscosity profiles for simulated C-4 binder (top left) and simulated Semtex H (bottom left). Top right image is a simple schematics for binder viscosity effects in a granular mixture under applied force.

Viscous effects



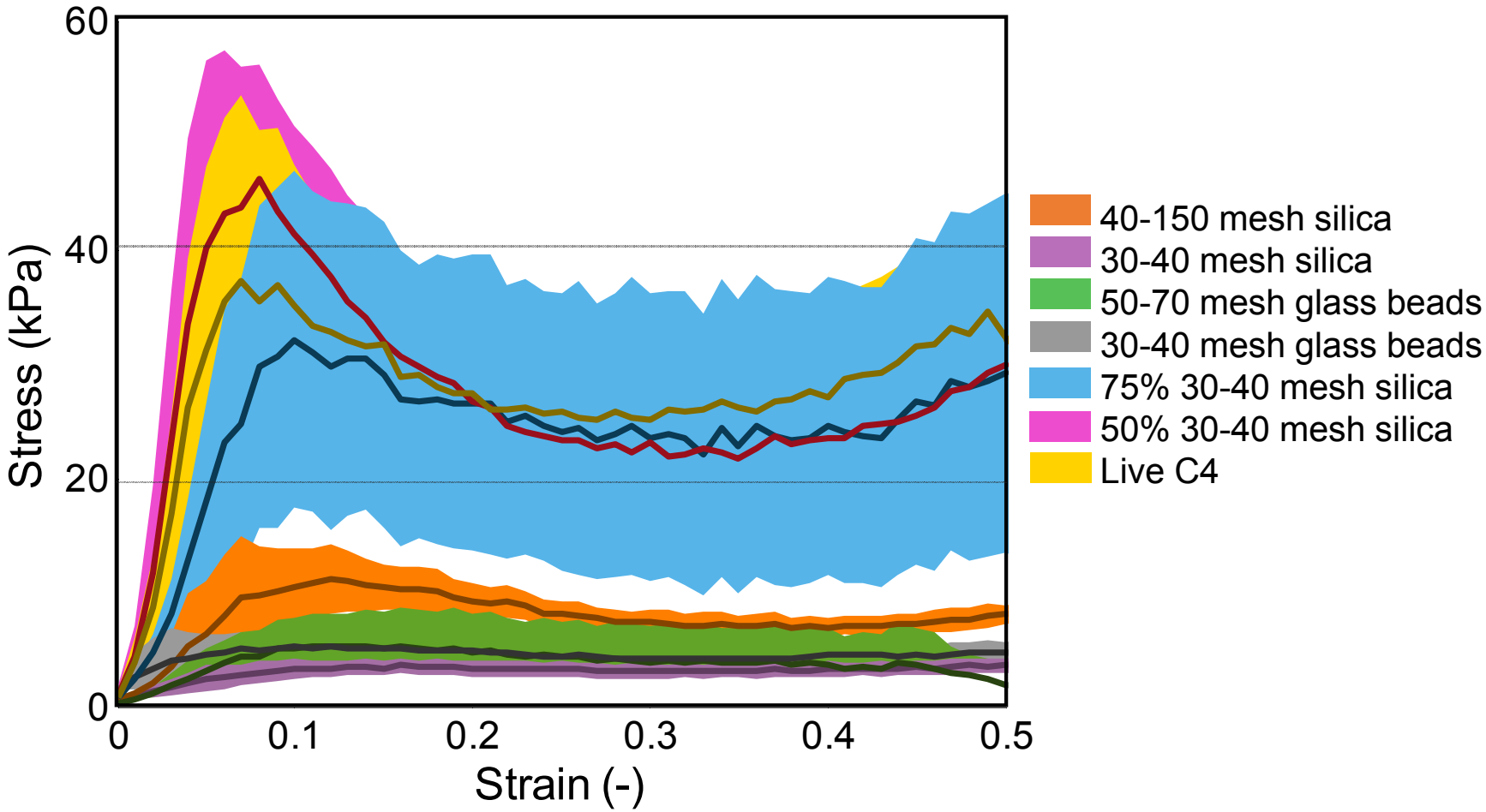
Stress-strain curves (with error regions) for silica particles (40-150mesh) in PDMS at 10mm/s compression rate.

Strain rate effects



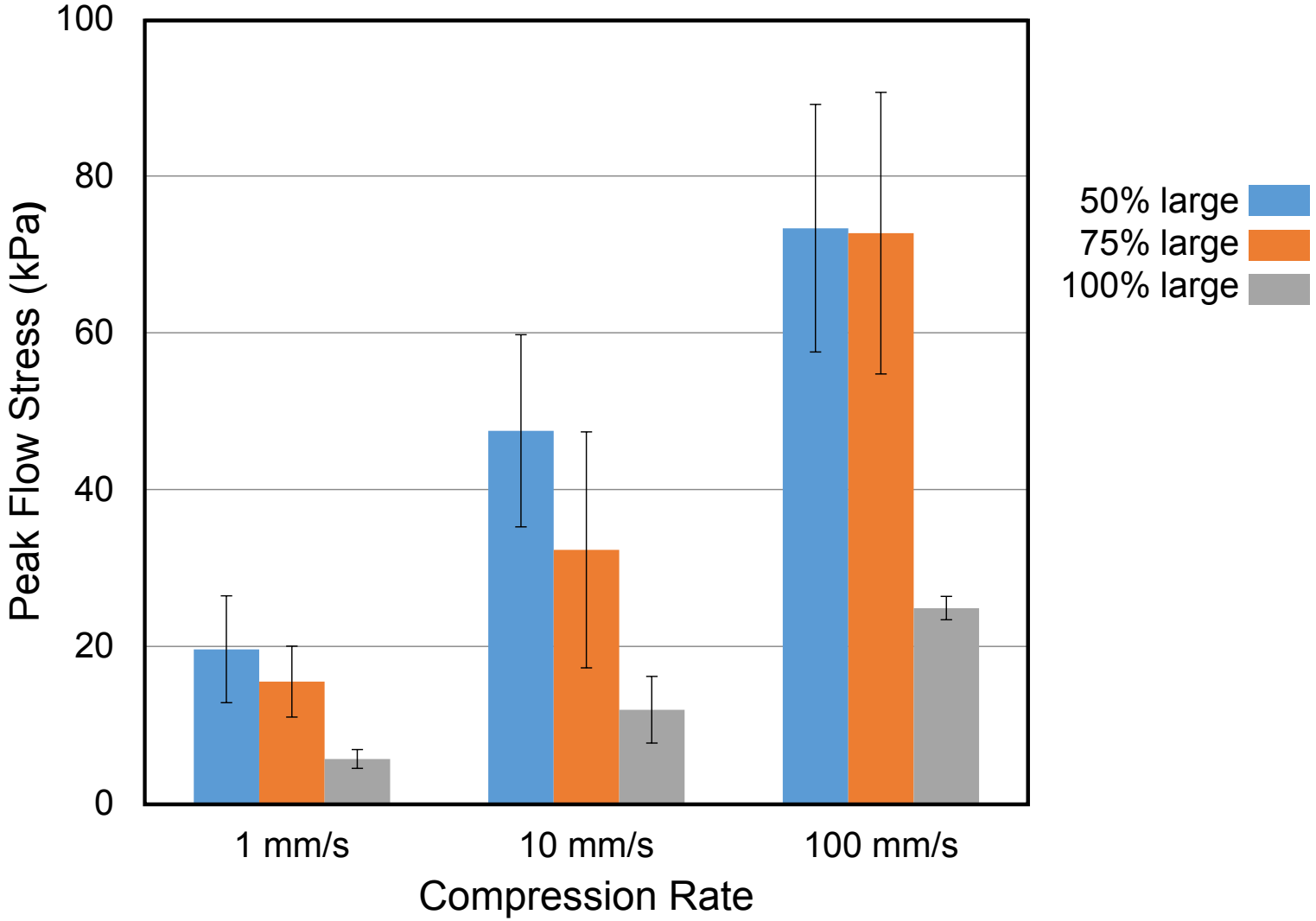
Stress-strain curves (with error regions) for silica particles (40-150mesh) in 289 Pa·s PDMS at 1mm/s, 10mm/s, and 100mm/s compression rates.

Size and shape effects



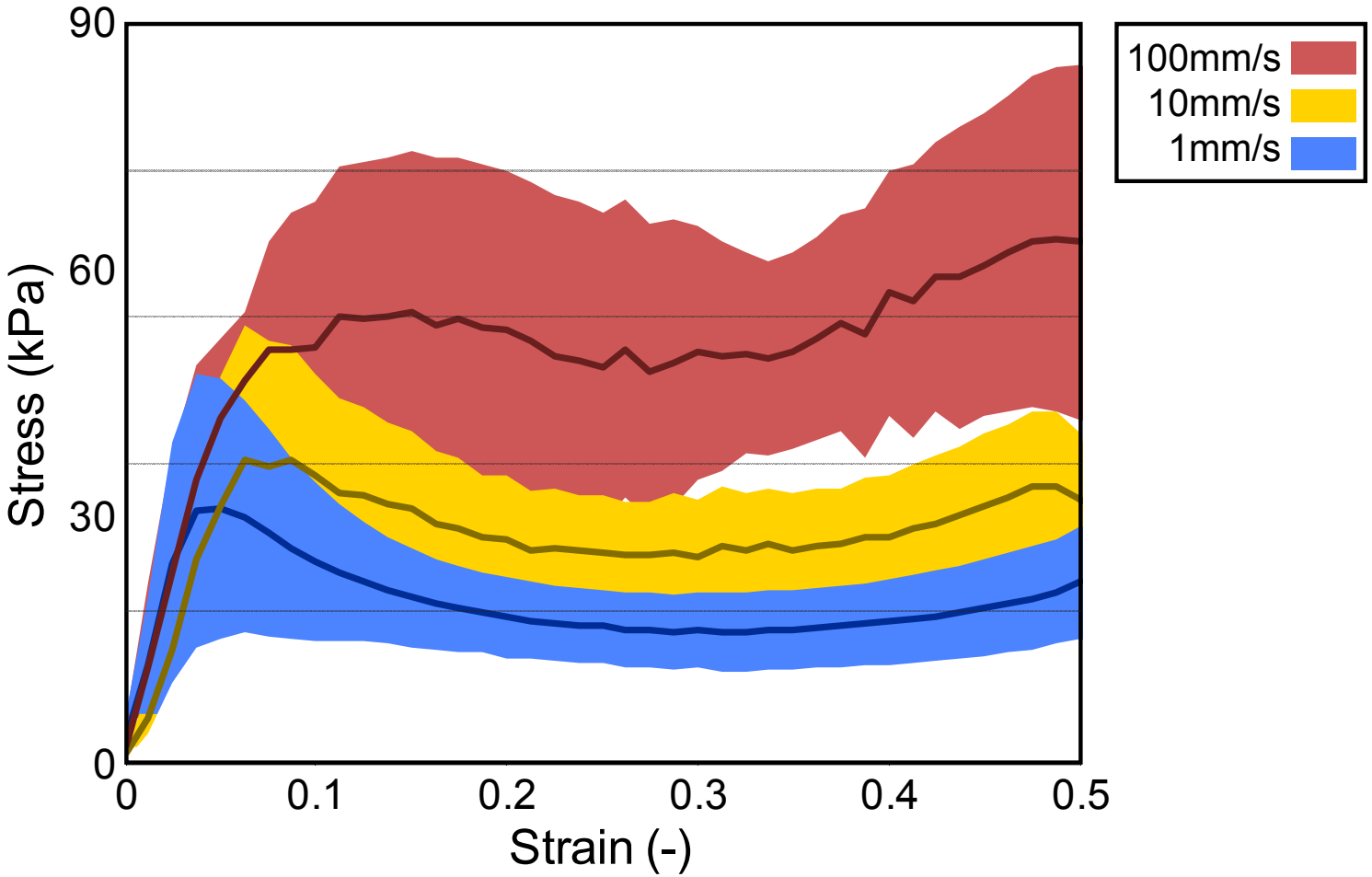
Stress-strain curves (with error regions) for monomodal silica particles (40-150mesh and 30-40 mesh), monomodal glass beads (50-70 mesh) and bimodal silica (75 wt% 30-40 mesh, 25 wt% >230 mesh and 50 wt% 30-40 mesh, 50 wt% >230 mesh) in simulated C4 binder, and live C4 at 10mm/s compression rate.

Peak flow stress



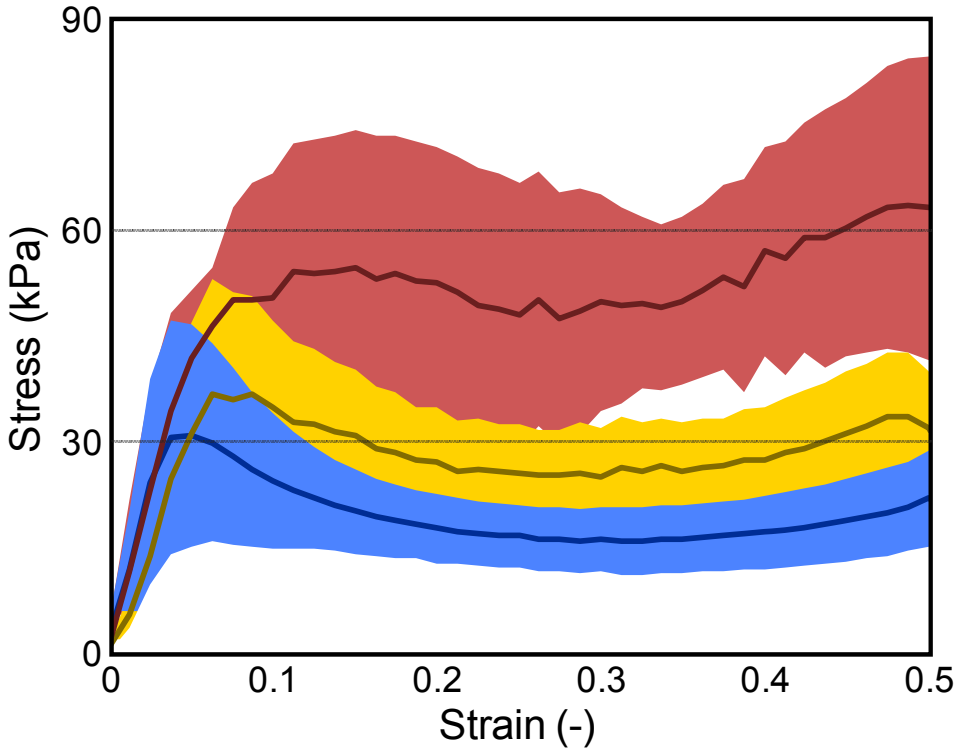
Peak flow stress values for simulated C4 for 1mm/s, 10mm/s, and 100mm/s compression rates. “Large” indicates the percent of granular particulate material from the 30-40mesh silica. The remaining “small” is >230mesh silica.

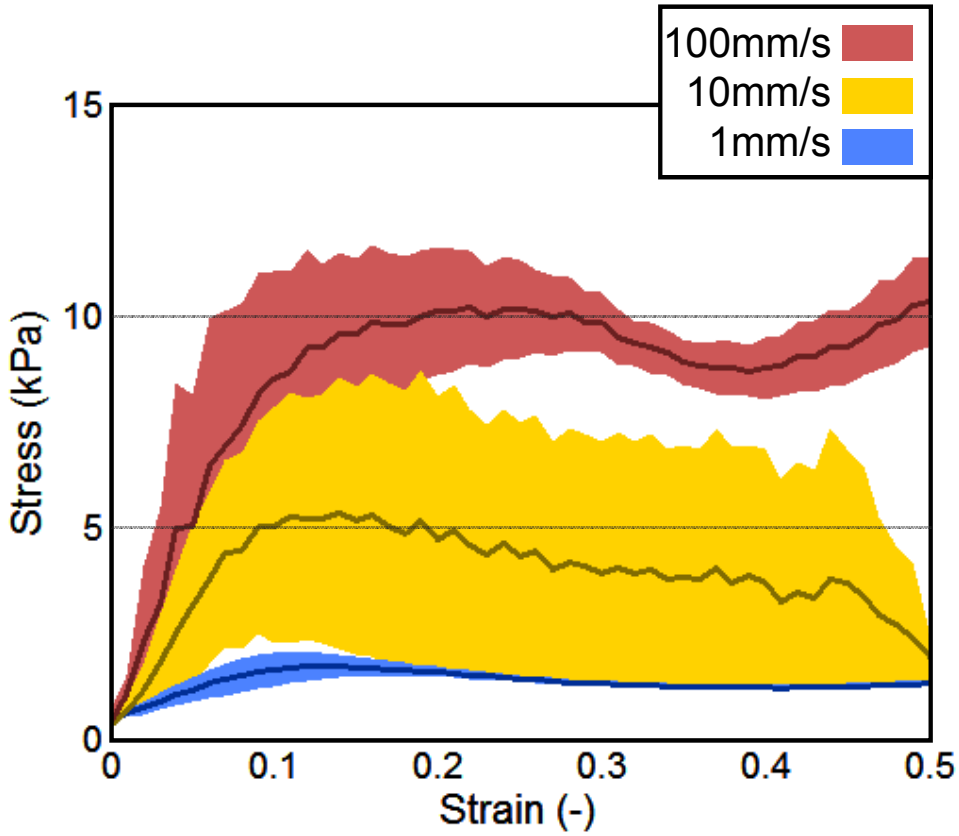
Live C4 Results



Stress-strain curves (with error regions) live C4 at 1mm/s, 10mm/s, 100mm/s compression rates.

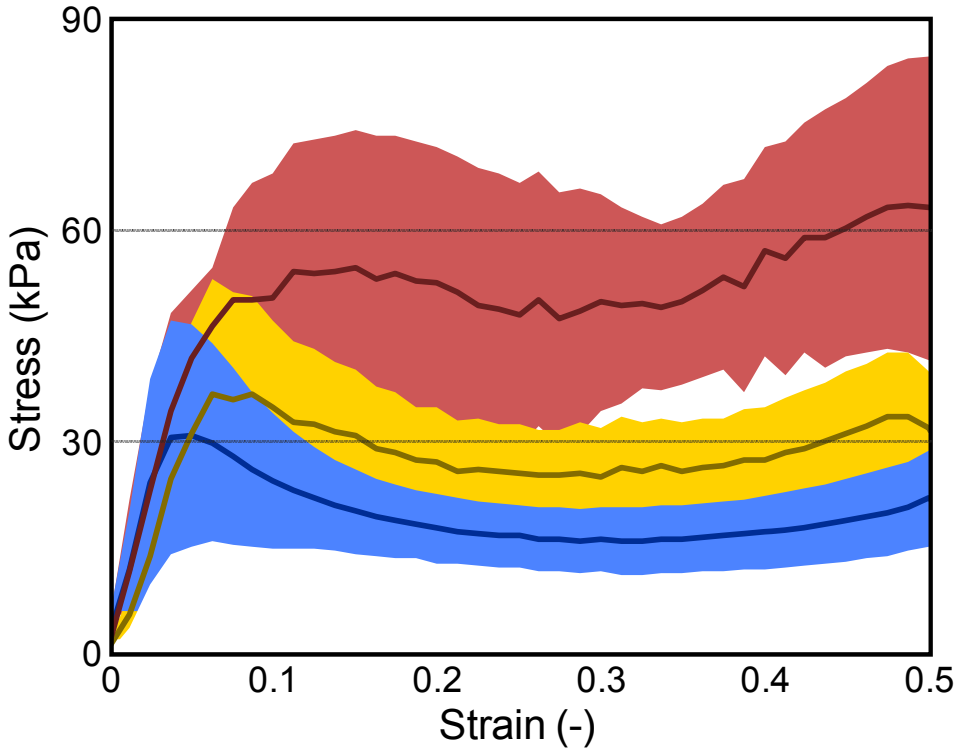
Simulated C4 – effect of particle size

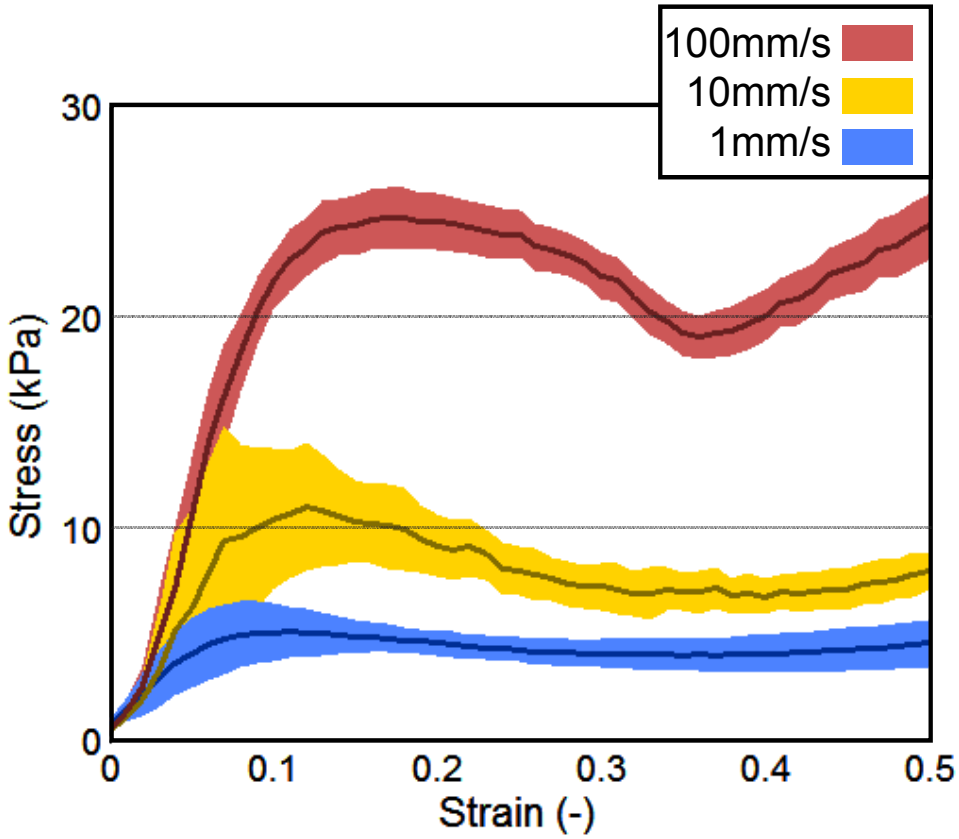




Stress-strain curves (with error regions) for live C-4 (left) and silica particles (40-150mesh) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

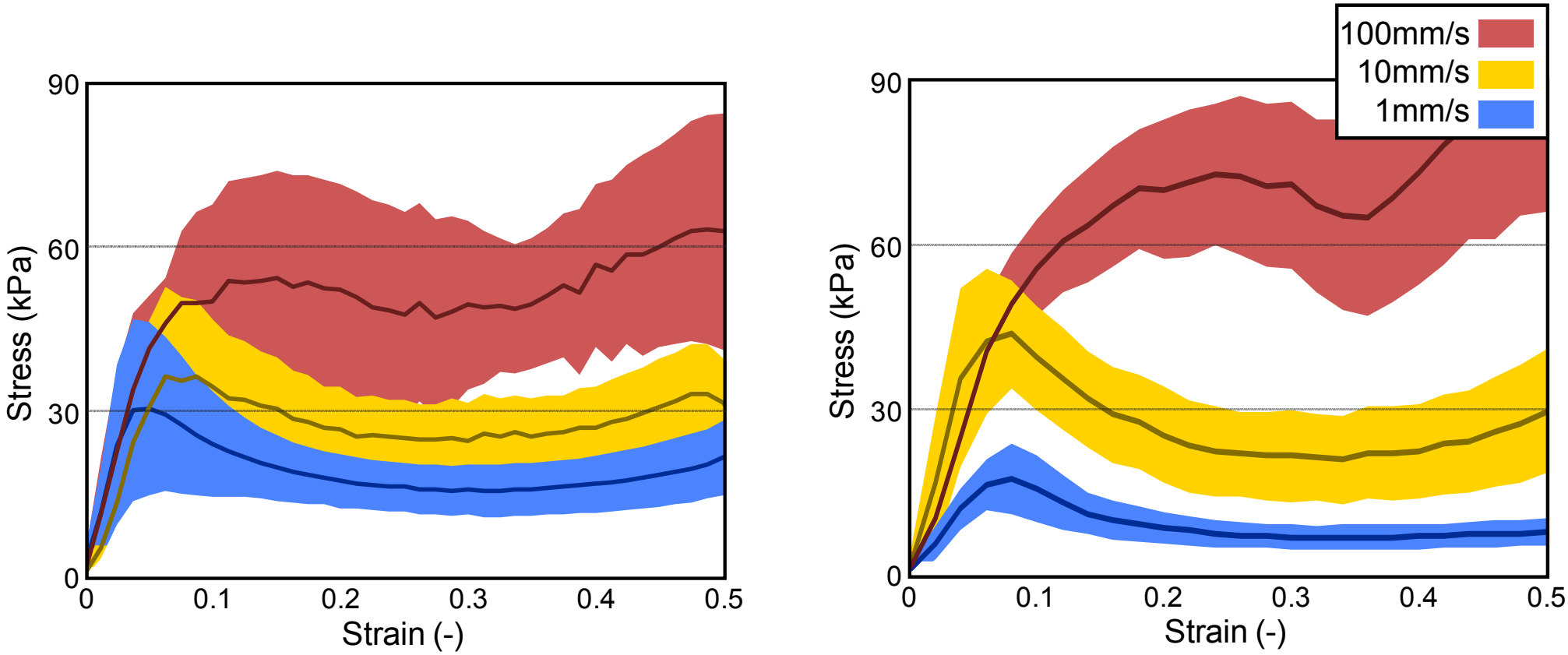
Simulated C4 – effect of particle size





Stress-strain curves (with error regions) for live C-4 (left) and silica particles (30-40mesh) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

Simulated C4 – effect of particle size



Stress-strain curves (with error regions) for live C-4 (left) and silica particles (50% from 30-40mesh silica, 50% from >230mesh silica) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

Summary and Next Steps

Comprehensive Approach to Compressive Behavior

- Historical Approach
- Characterize Granular Behavior
  - Viscous effects
  - Strain rate effects
  - Size/shape effects
- Benign Analog Development
  - *Complete*
- Live Material Characterization
  - *Complete*
- Evaluation of Slip/Peel Tester: Simulated Residue
  - *Work ongoing*

Acknowledgements

Circled:

- Melissa Sweat
  - Dec. 2015
- Leonid Miroshnik
  - 2018/2019

Not pictured:

- Johanna Smith
  - Grad. May 2014
  - Employed at General Mills
- Chris Browne
  - Grad. May 2017
- Alyssa Bass
  - Grad. May 2017
- Hannah Burnau
  - Grad. H.S. May 2017

Top: Leonid Miroshnik, Sean Fronczak, Jenny Laster, Darby Hoss, Andrew Parker
Bottom: Aaron Harrison, Caitlin Schram, Myles Thomas, Melissa Sweat, Jordan Thorpe

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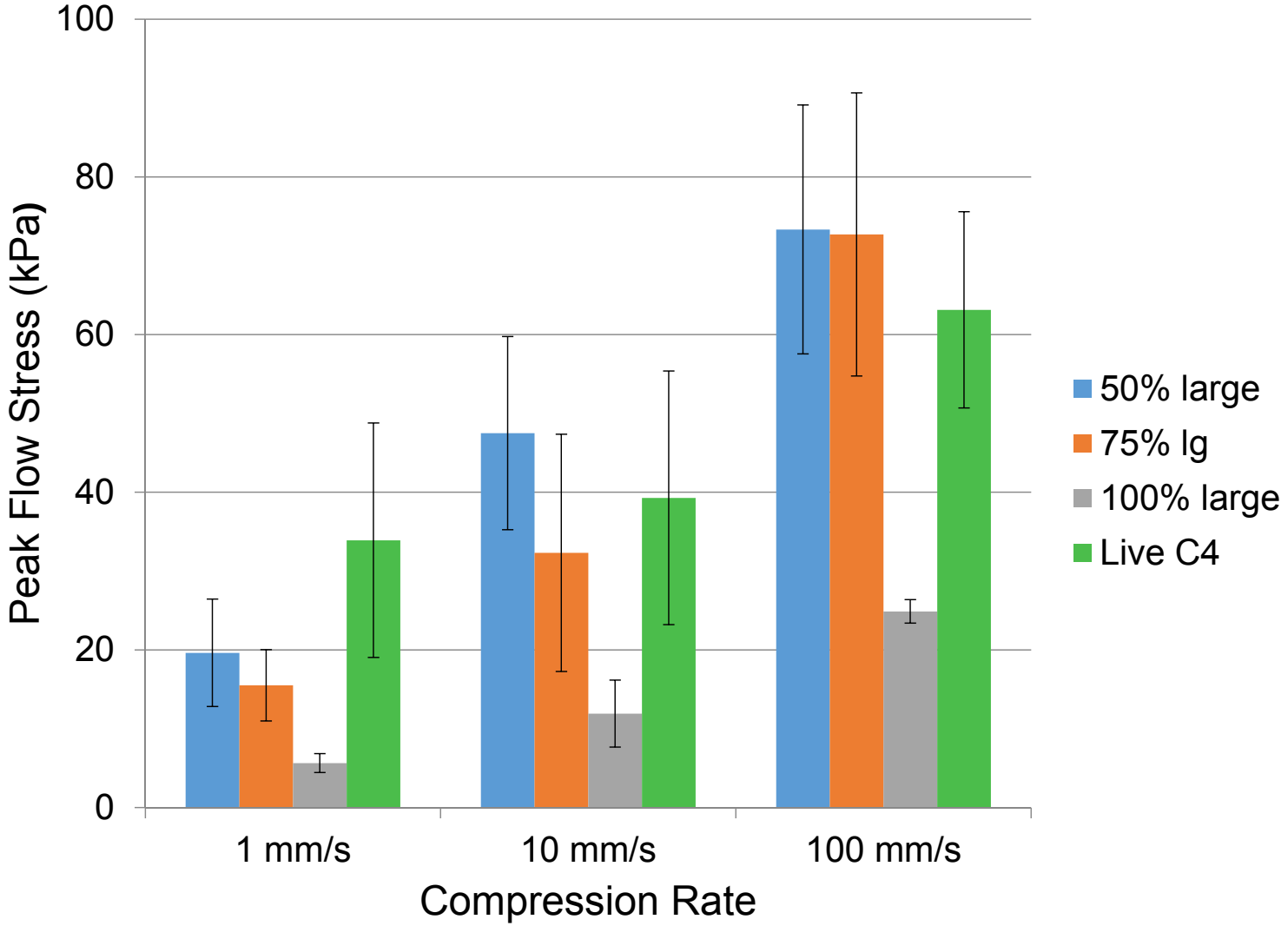
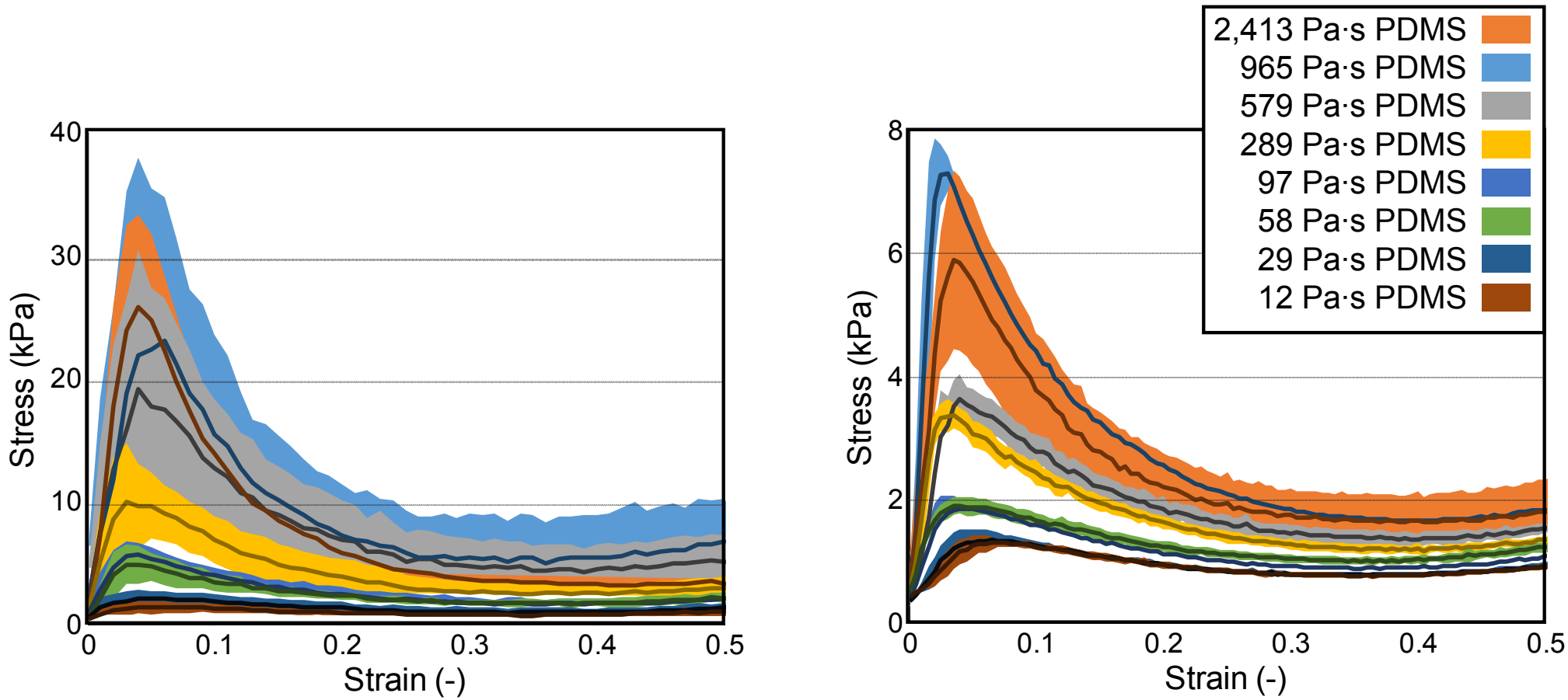
Supplemental slides

Peak flow stress



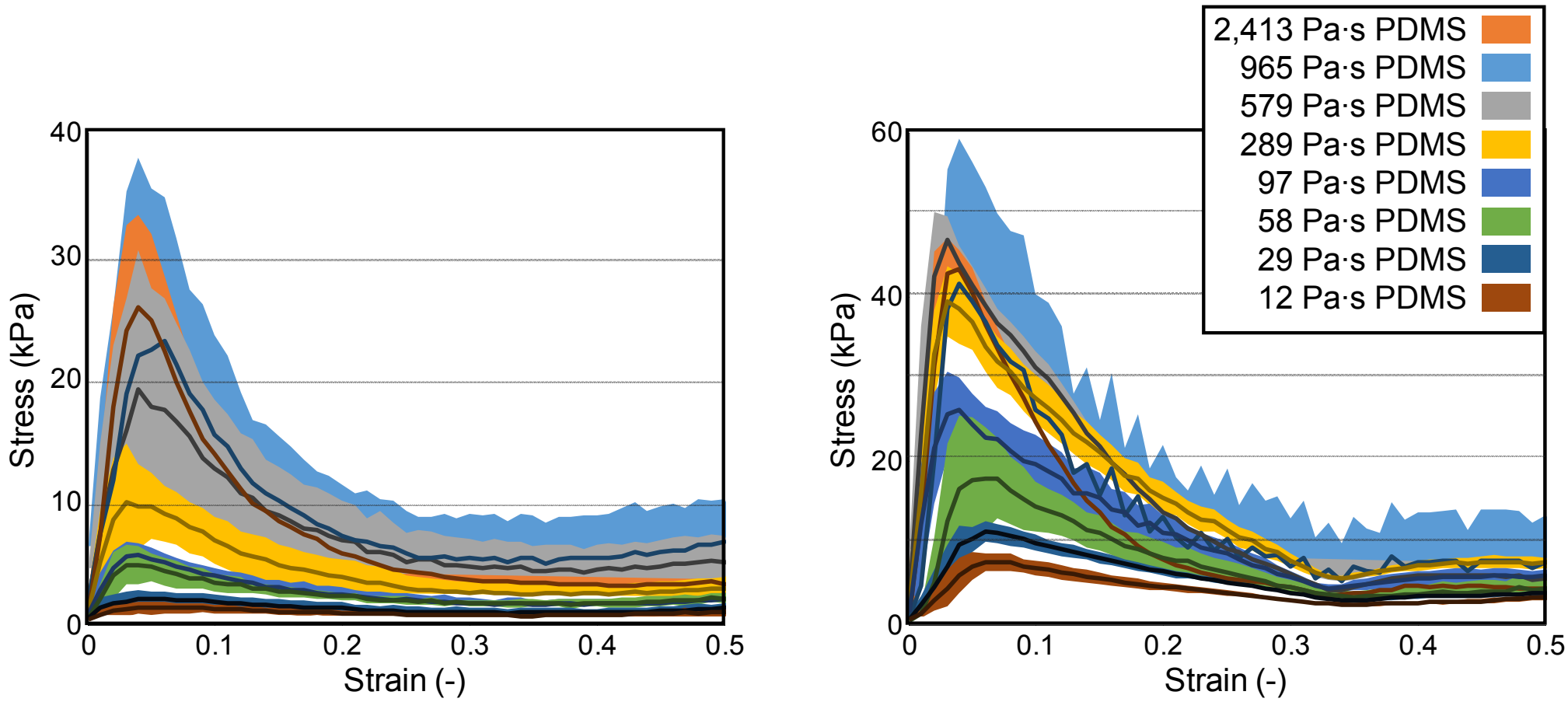
Peak flow stress values for simulated C4 against live C4 for 1mm/s, 10mm/s, and 100mm/s compression rates. “Large” indicates the percent of granular particulate material from the 30-40mesh silica. The remaining “small” is >230mesh silica.

Viscous effects



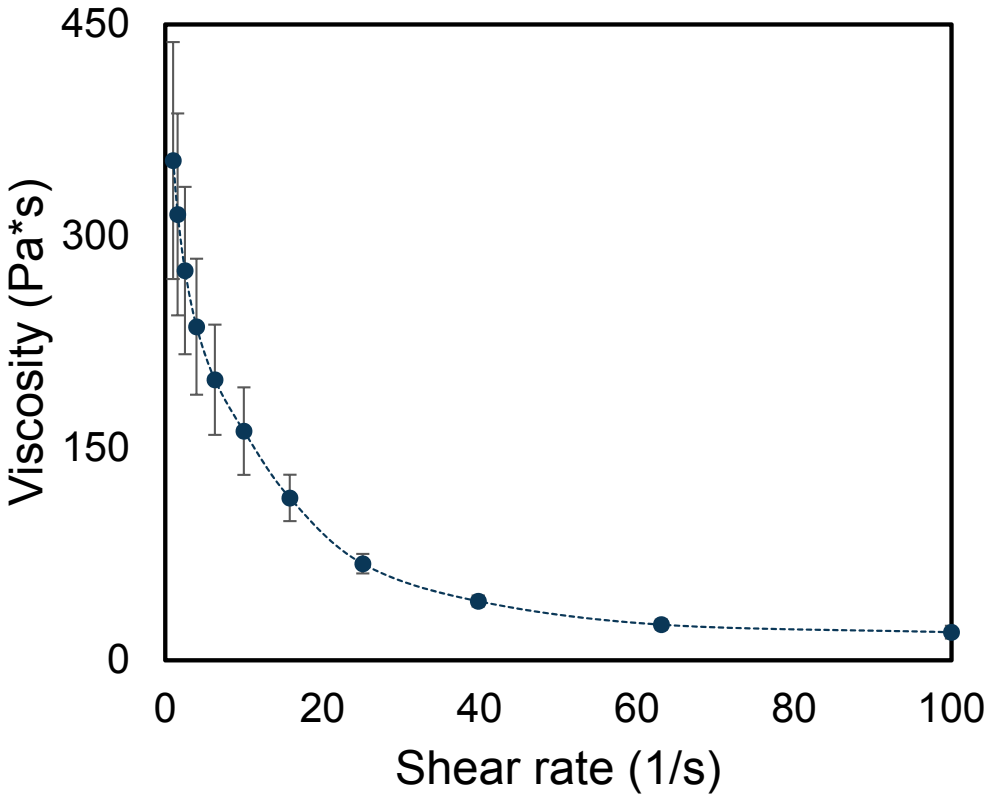
Stress-strain curves (with error regions) for silica particles (40-150mesh) in PDMS at 10mm/s (left) and 1mm/s (right) compression rates.

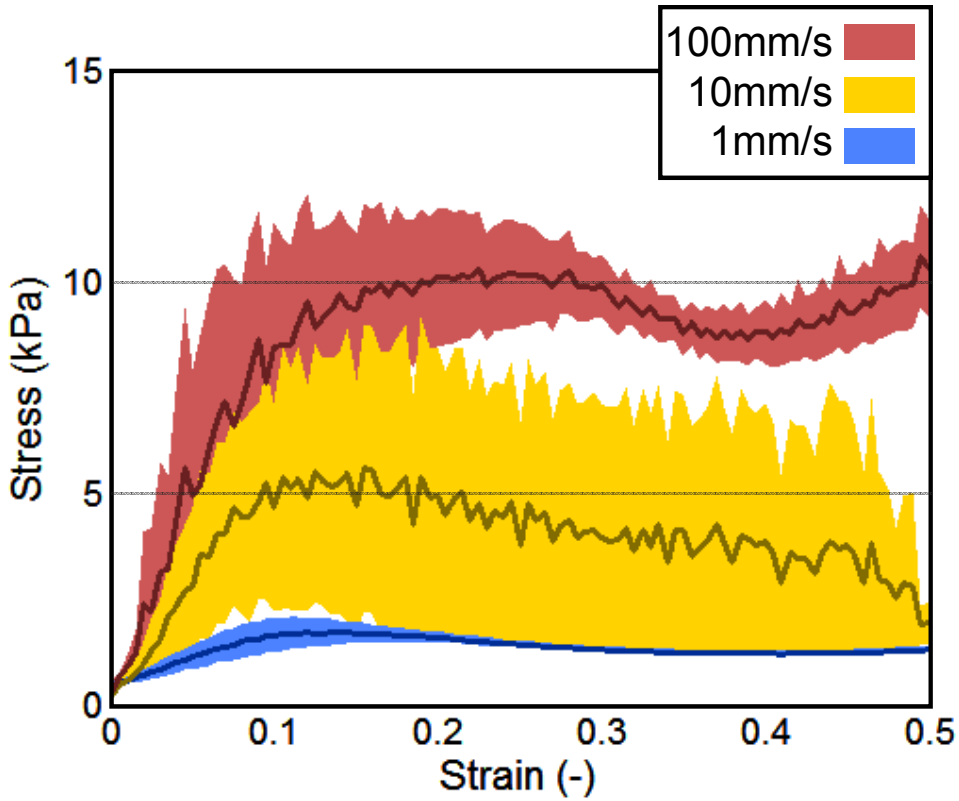
Viscous effects



Stress-strain curves (with error regions) for silica particles (40-150mesh) in PDMS at 10mm/s (left) and 100mm/s (right) compression rates.

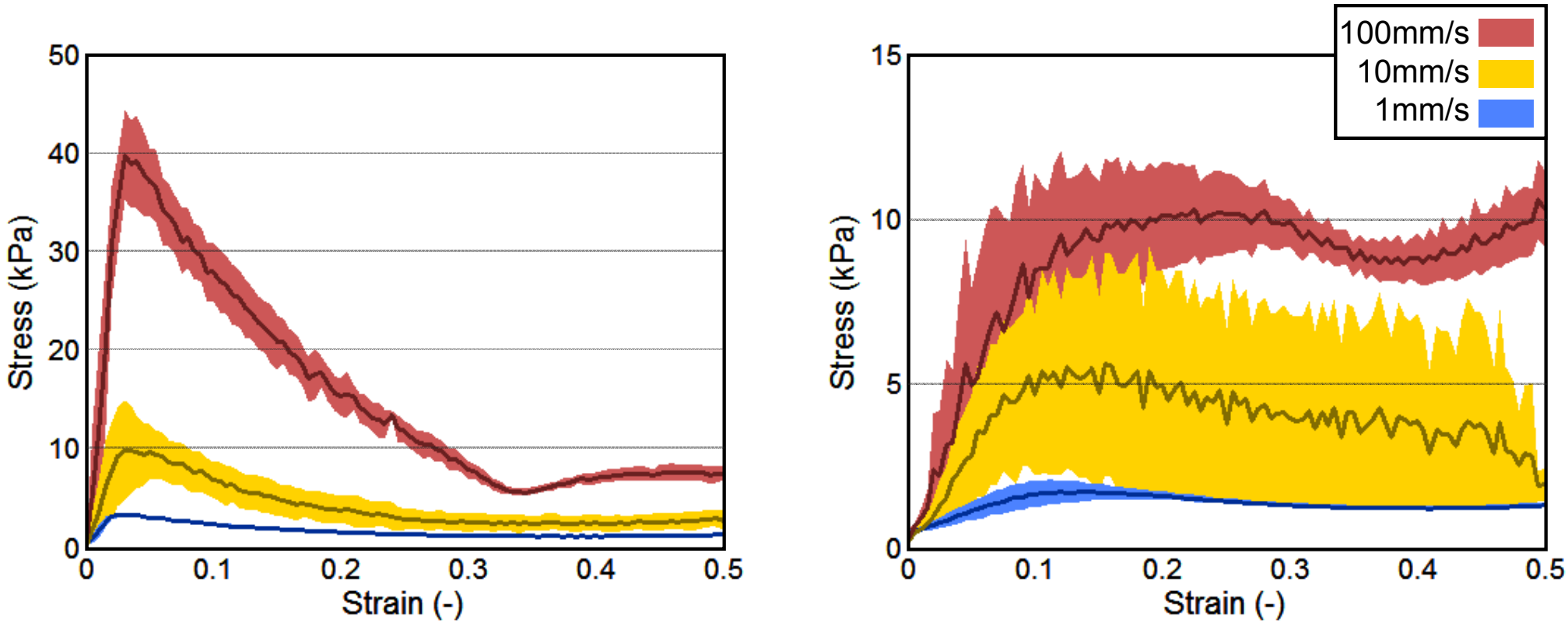
Strain rate effects





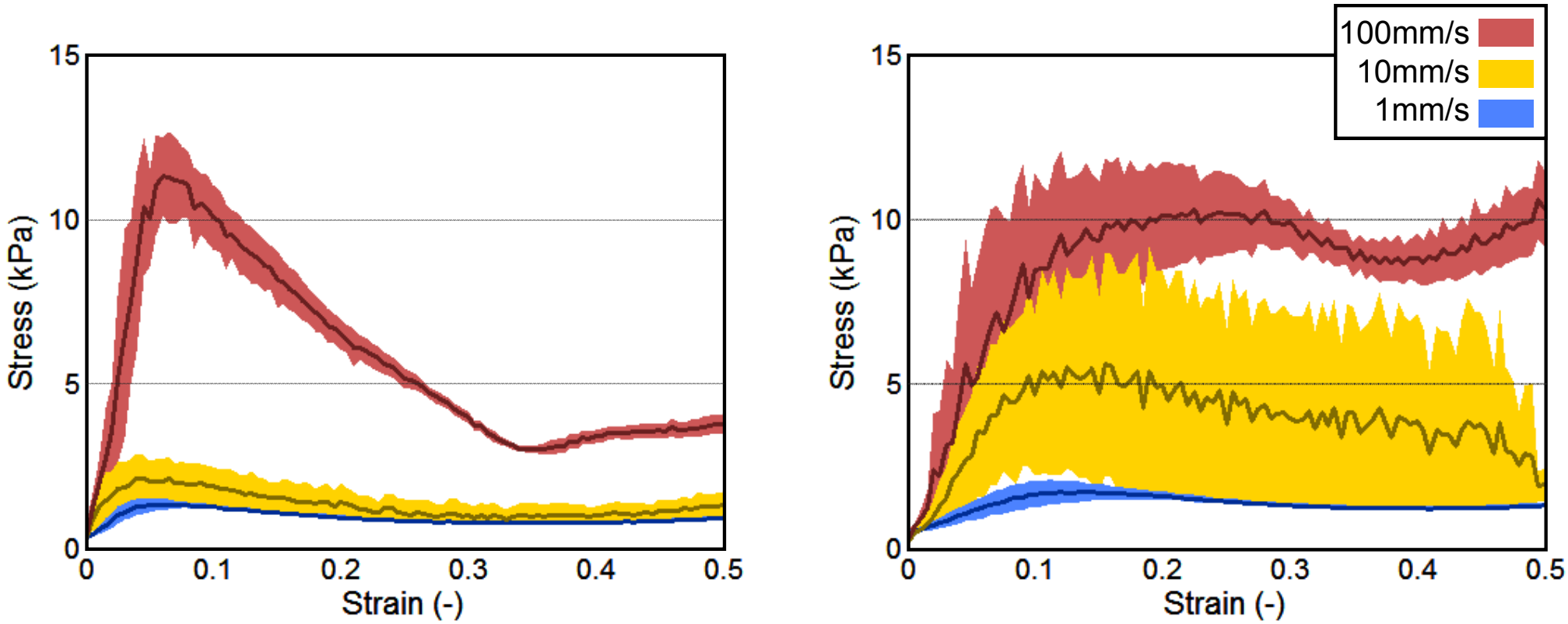
Viscosity of simulated C-4 binder (left) and the associated granular stress-strain curves (with error regions) for silica particles (40-150mesh) in simulated C-4 binder at 1mm/s, 10mm/s, and 100mm/s compression rates (right).

Strain rate effects



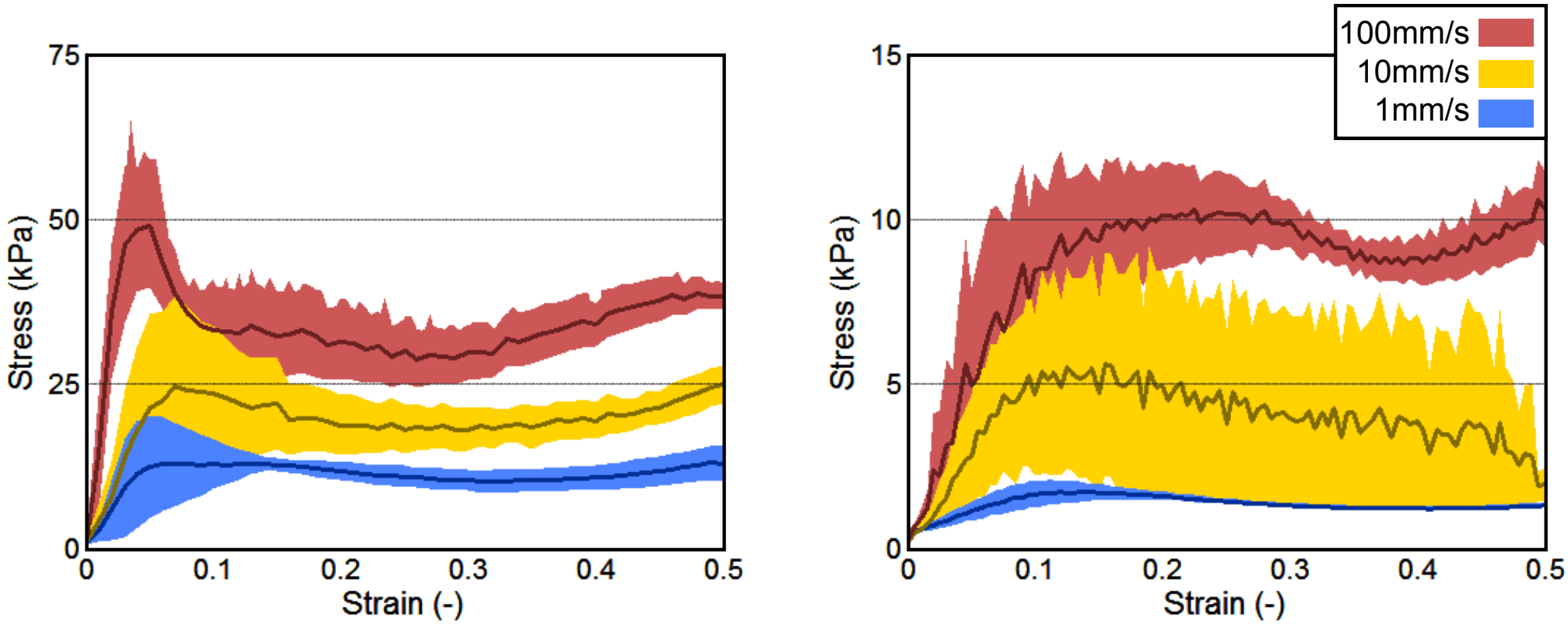
Stress-strain curves (with error regions) for silica particles (40-150mesh) in 289 Pa·s PDMS (left) compared with silica particles (40-150mesh) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

Strain rate effects



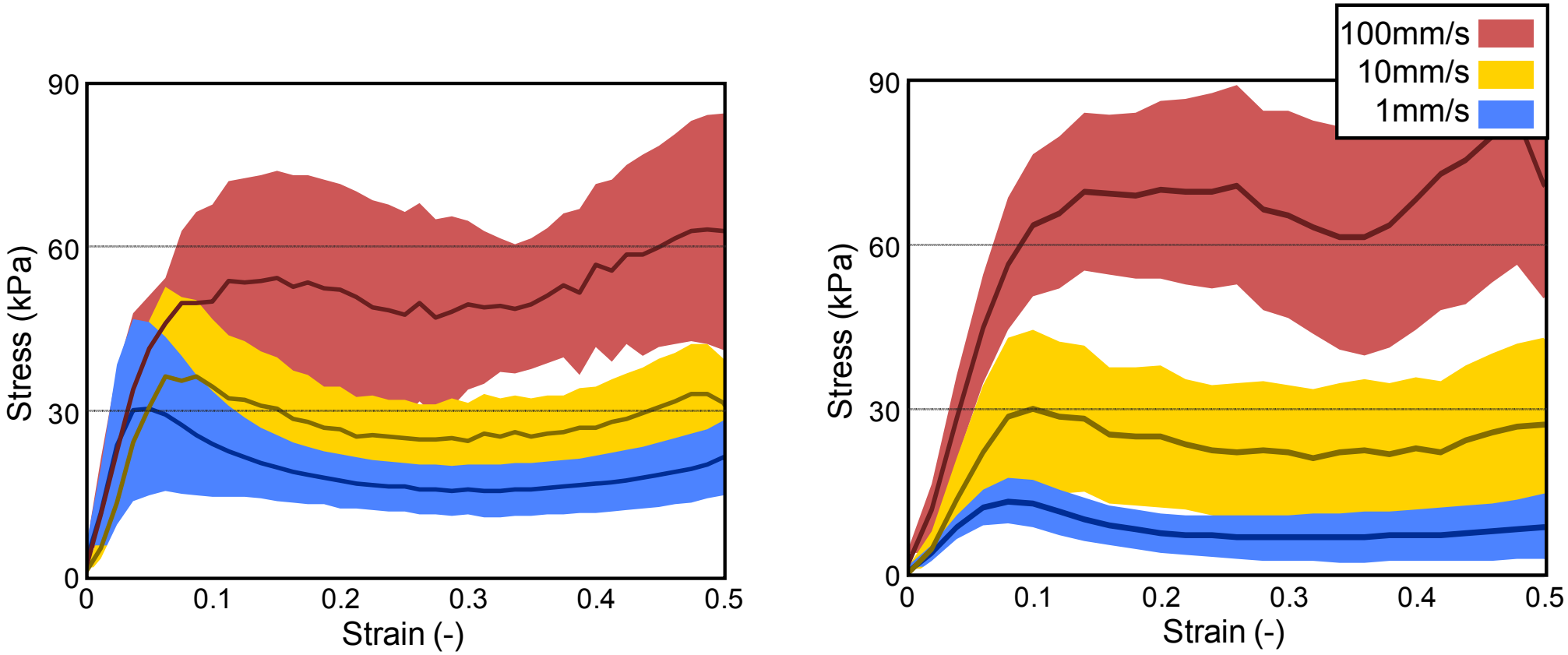
Stress-strain curves (with error regions) for silica particles (40-150mesh) in 29 Pa·s PDMS (left) compared with silica particles (40-150mesh) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

Deformative behavior of C-4



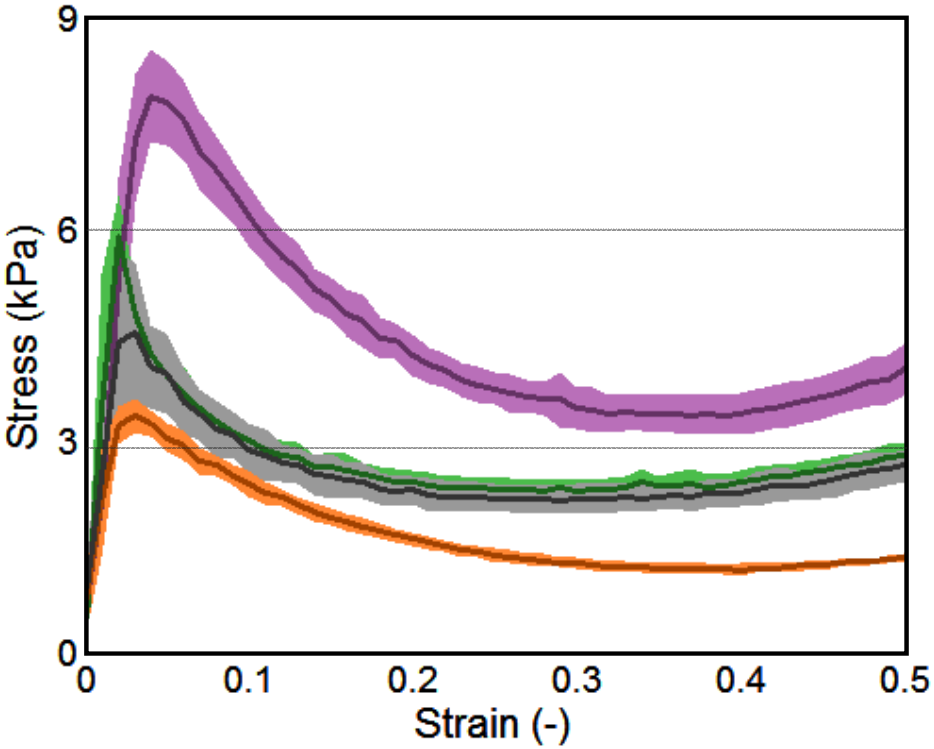
Stress-strain curves (with error regions) for live C-4 (left) and silica particles (40-150mesh) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

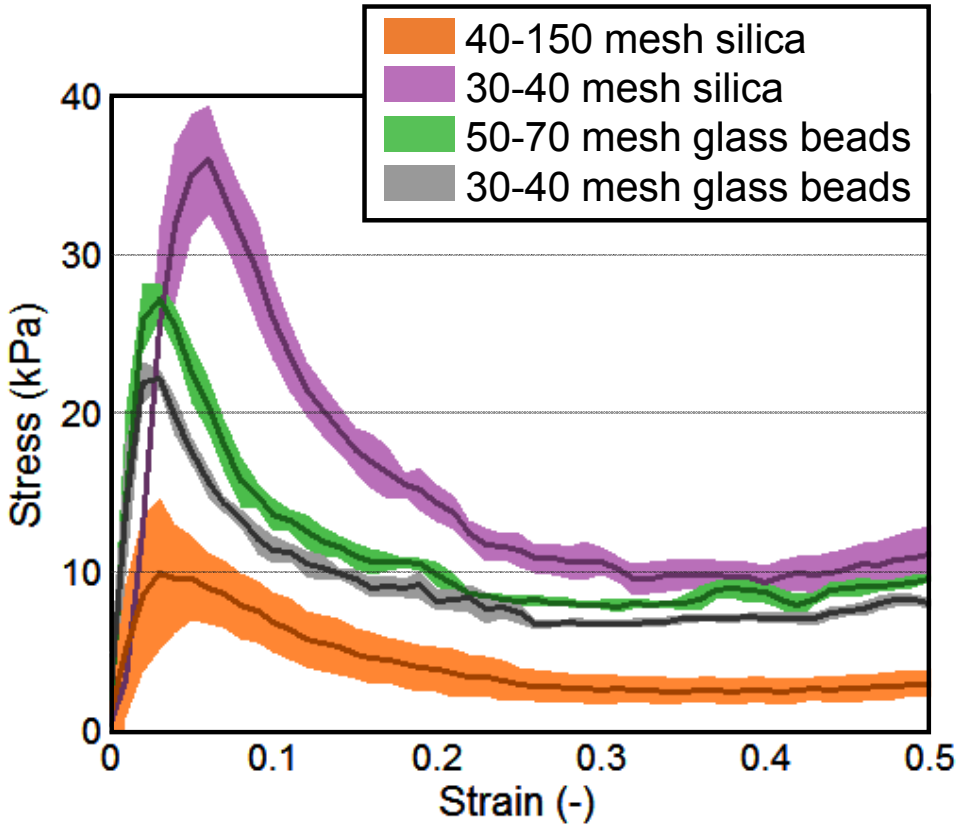
Simulated C4 – effect of particle size



Stress-strain curves (with error regions) for live C-4 (left) and silica particles (75% from 30-40mesh silica, 25% from >230mesh silica) in simulated C-4 binder (right) at 1mm/s, 10mm/s, and 100mm/s compression rates.

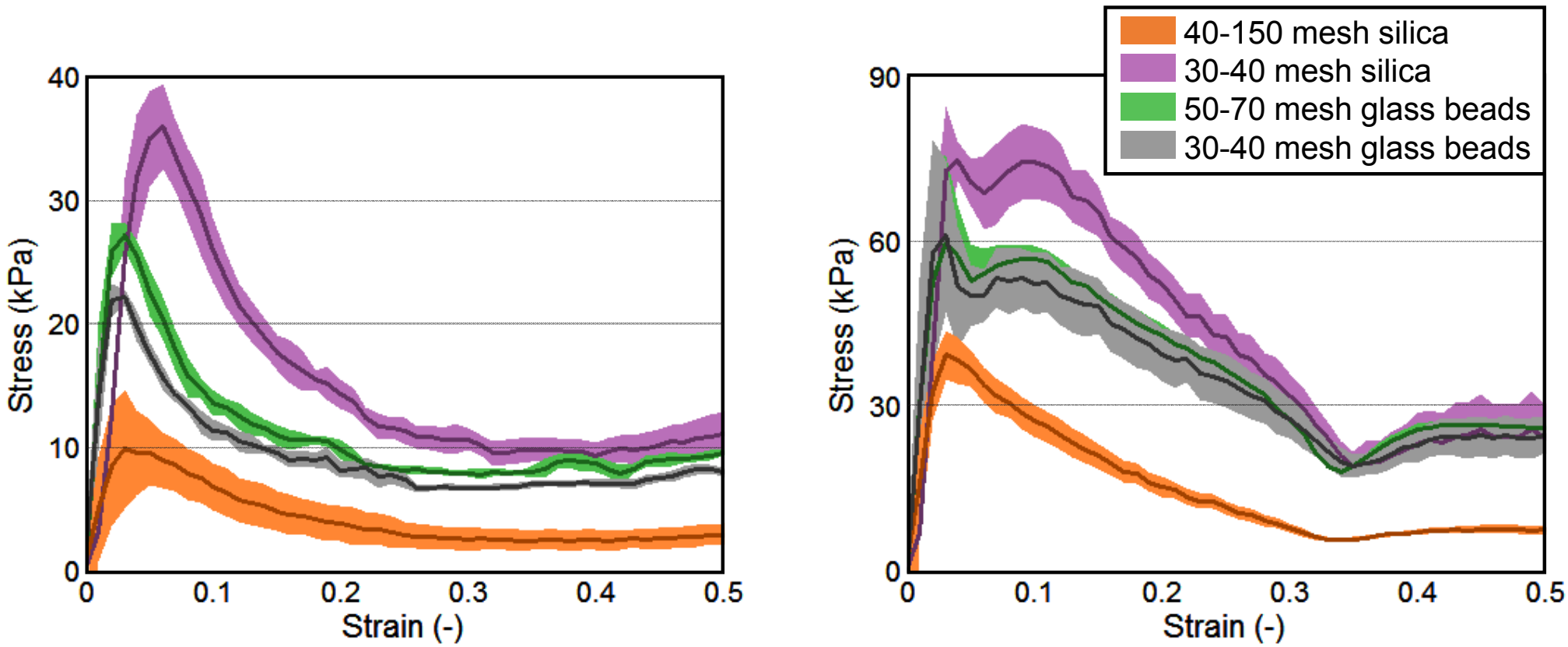
Size and shape effects





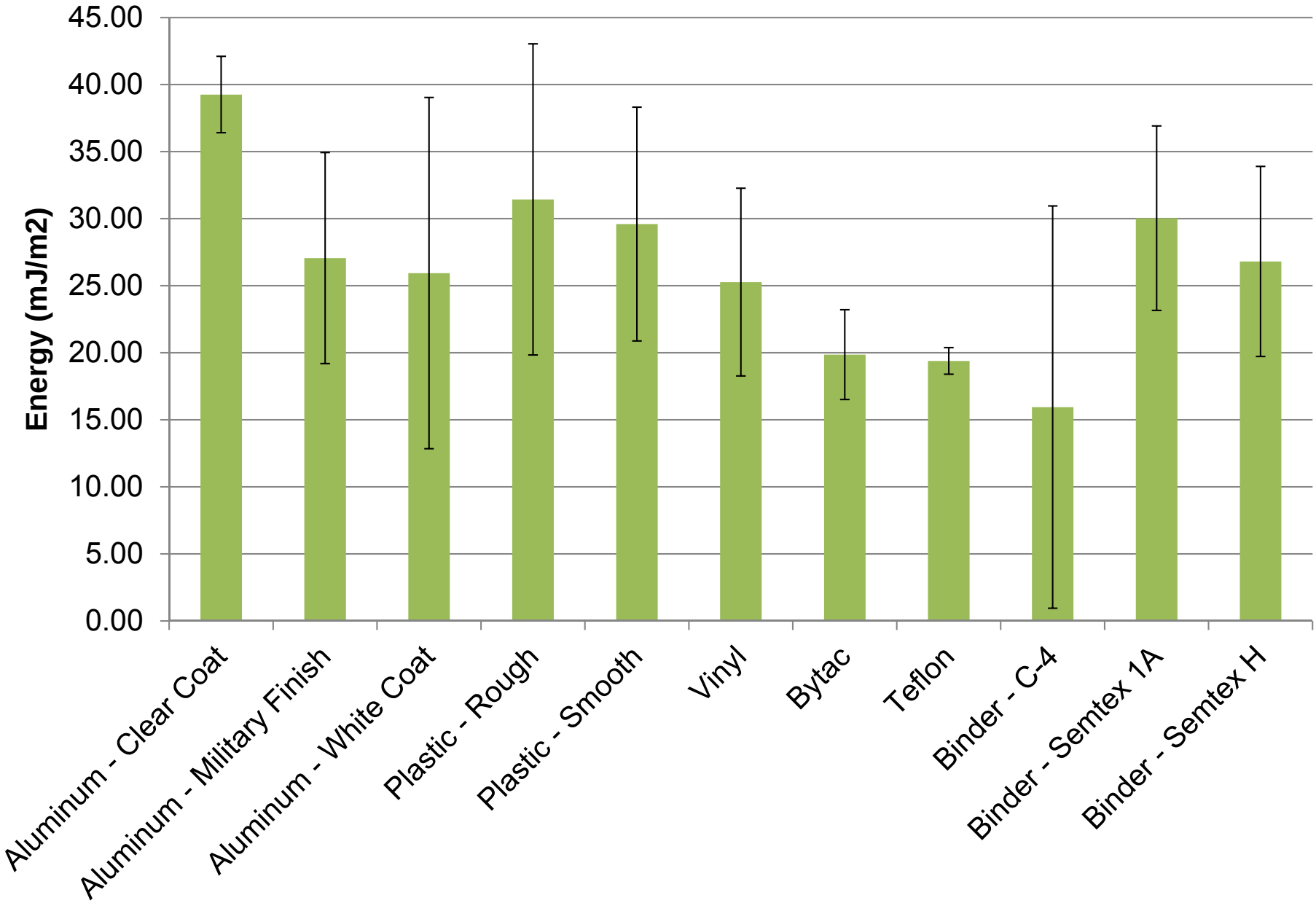
Stress-strain curves (with error regions) for silica particles (40-150mesh and 30-40 mesh) and glass beads (50-70 mesh) in 97 Pa·s PDMS at 1mm/s compression rate (left) and 10mm/s compression rate (right).

Size and shape effects

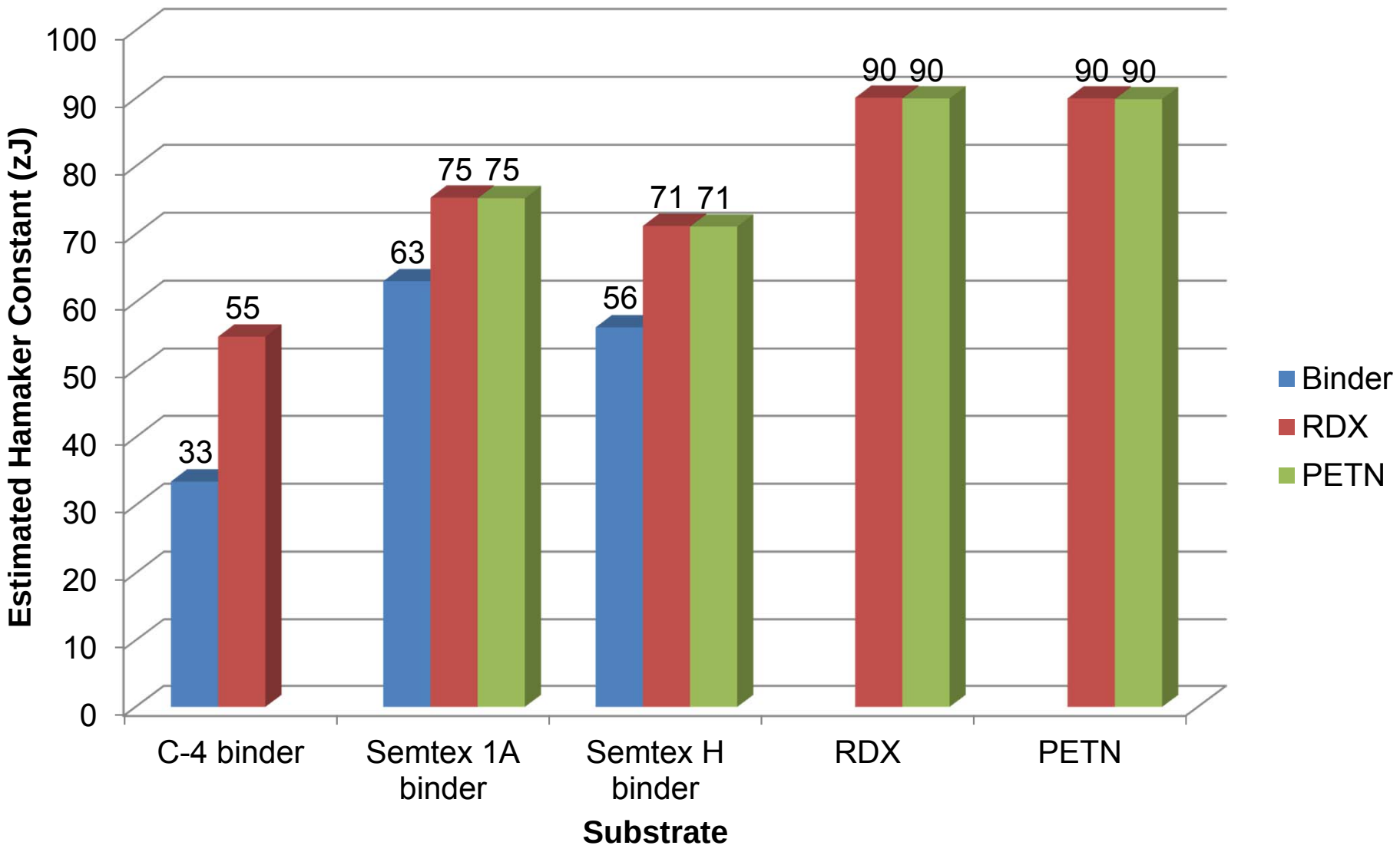


Stress-strain curves (with error regions) for silica particles (40-150mesh and 30-40 mesh) and glass beads (50-70 mesh) in 97 Pa·s PDMS at 10mm/s (left) and 100mm/s (right) compression rates.

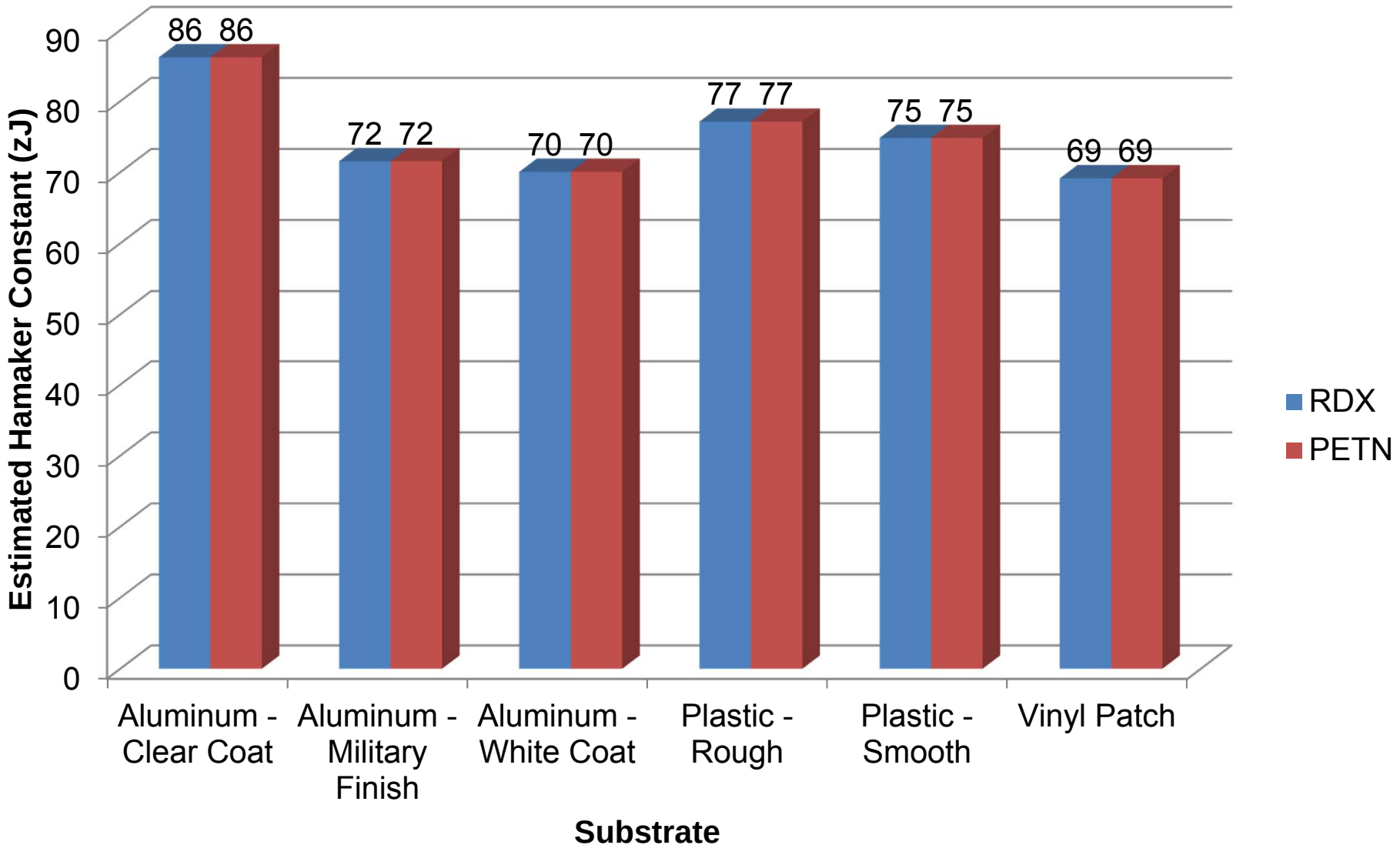
Surface energy



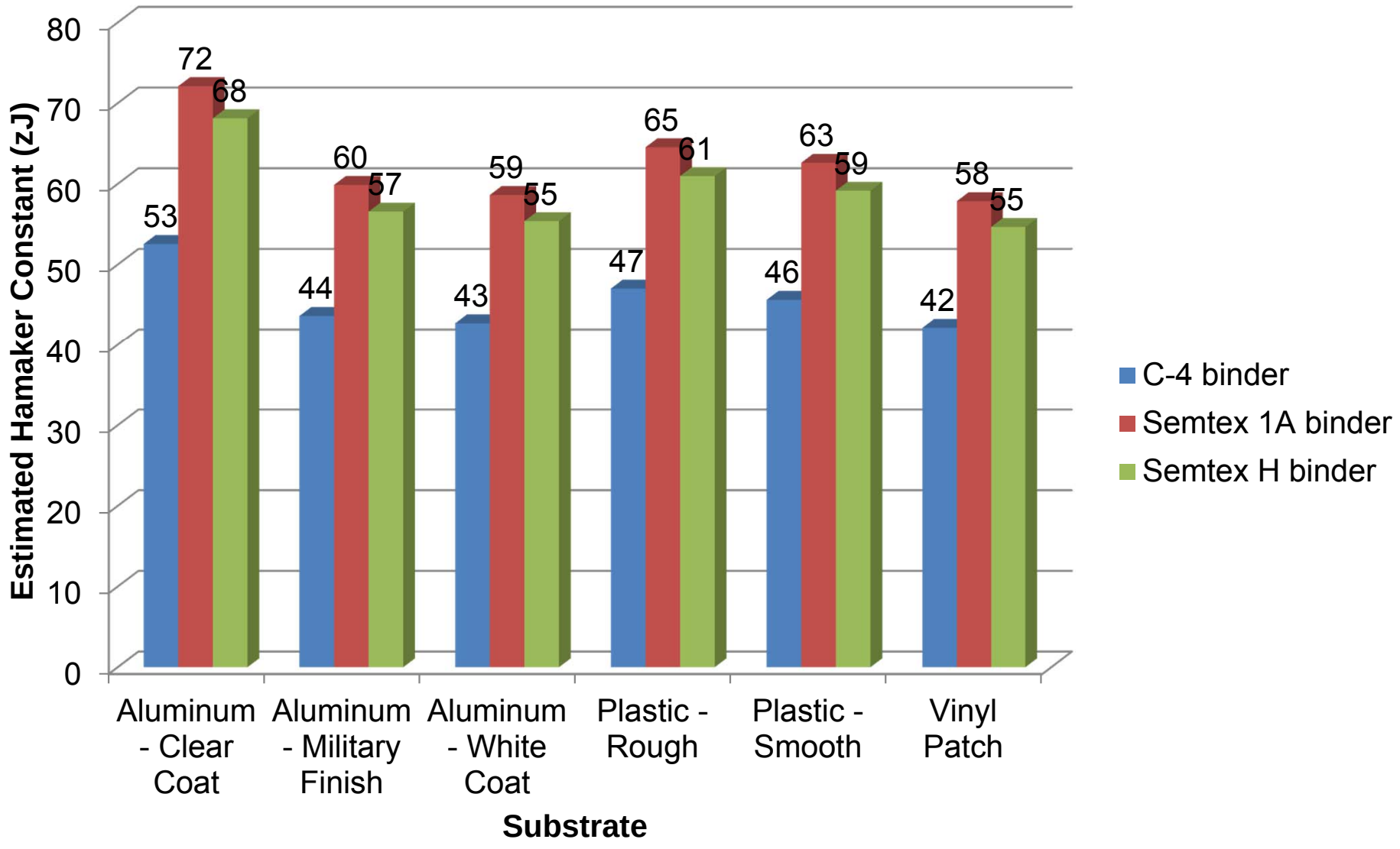
Hamaker constants – within composite



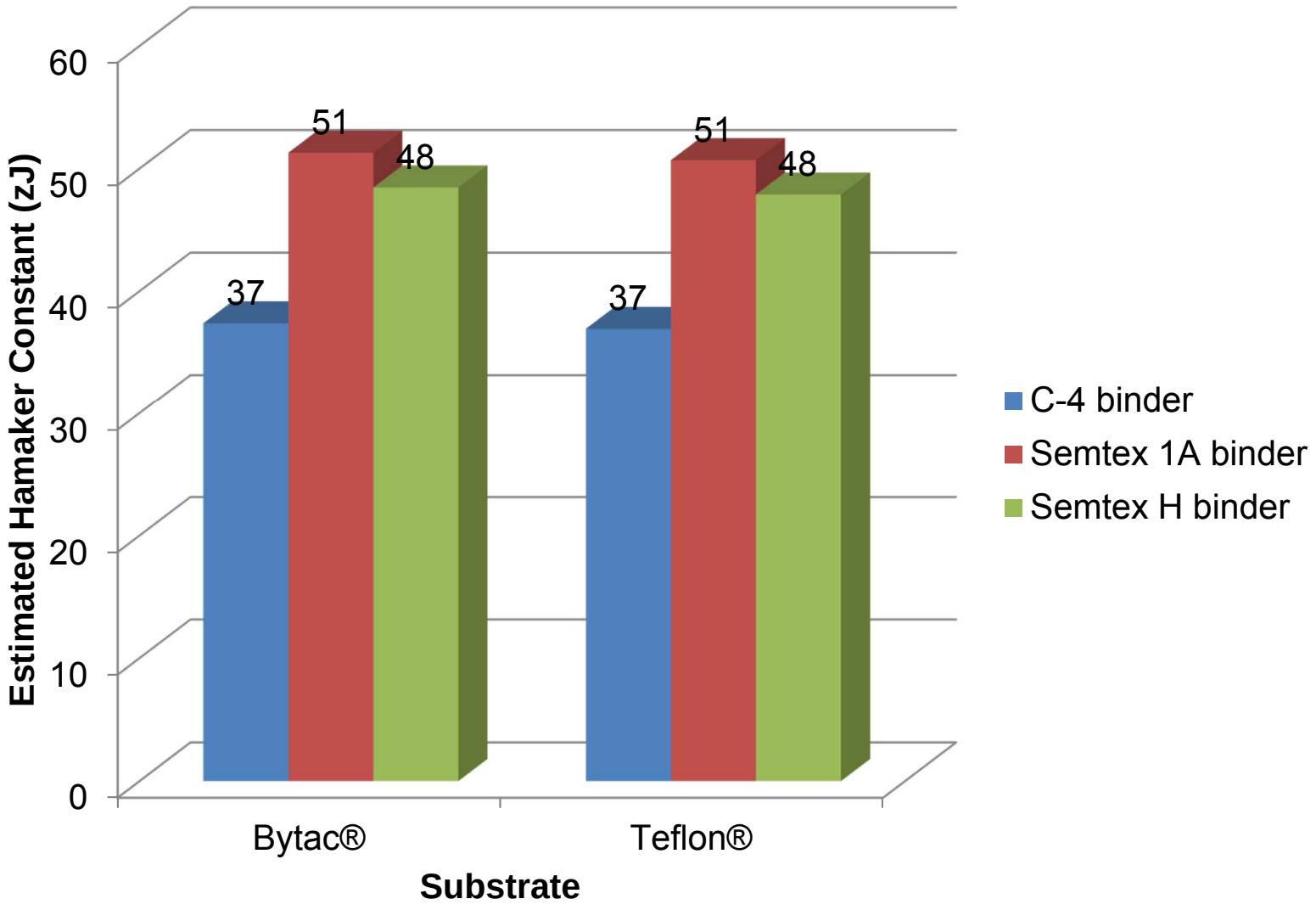
Hamaker constants – particle/substrate



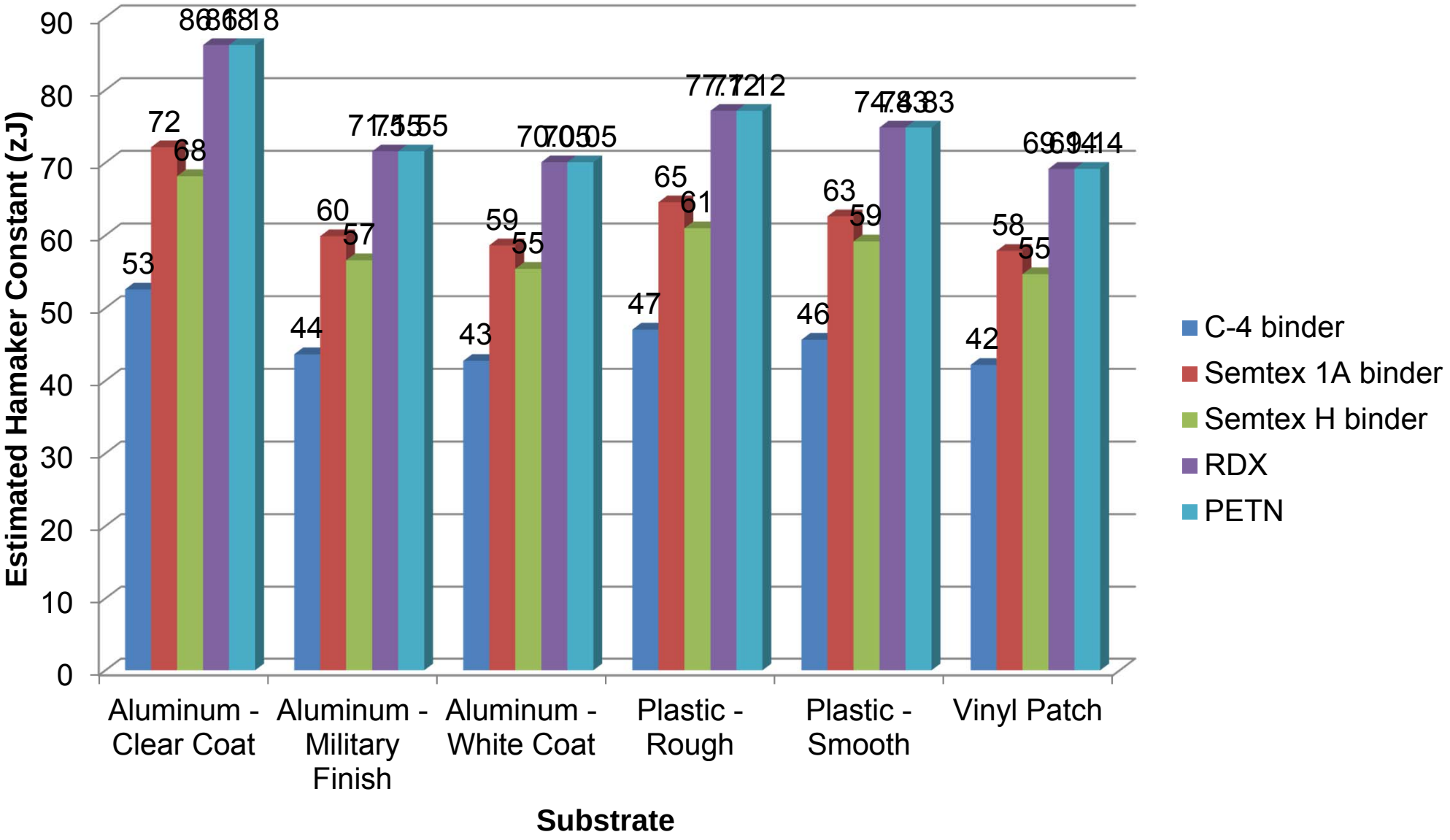
Hamaker constants – binder/substrate



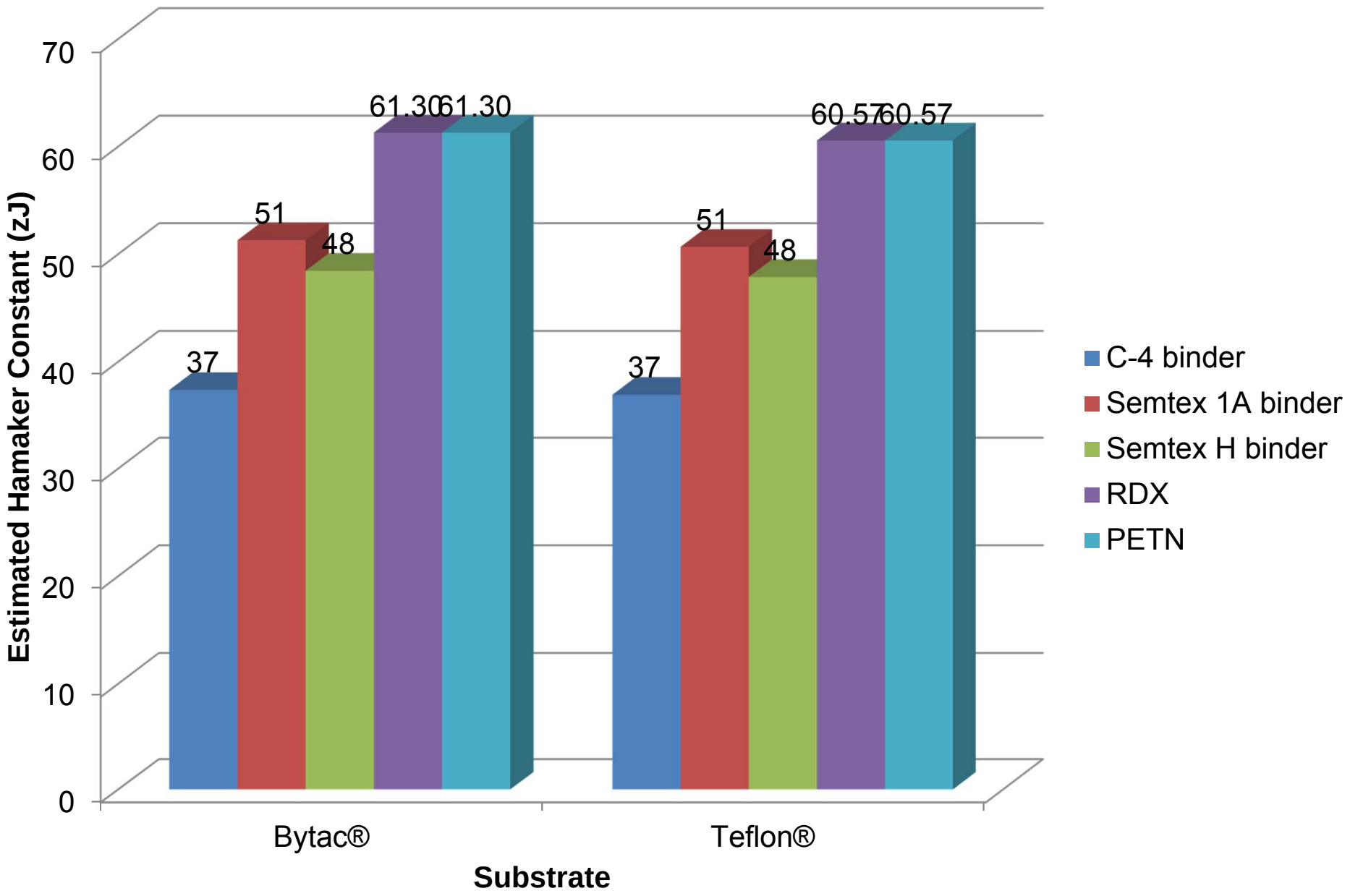
Hamaker constants – swab/binder



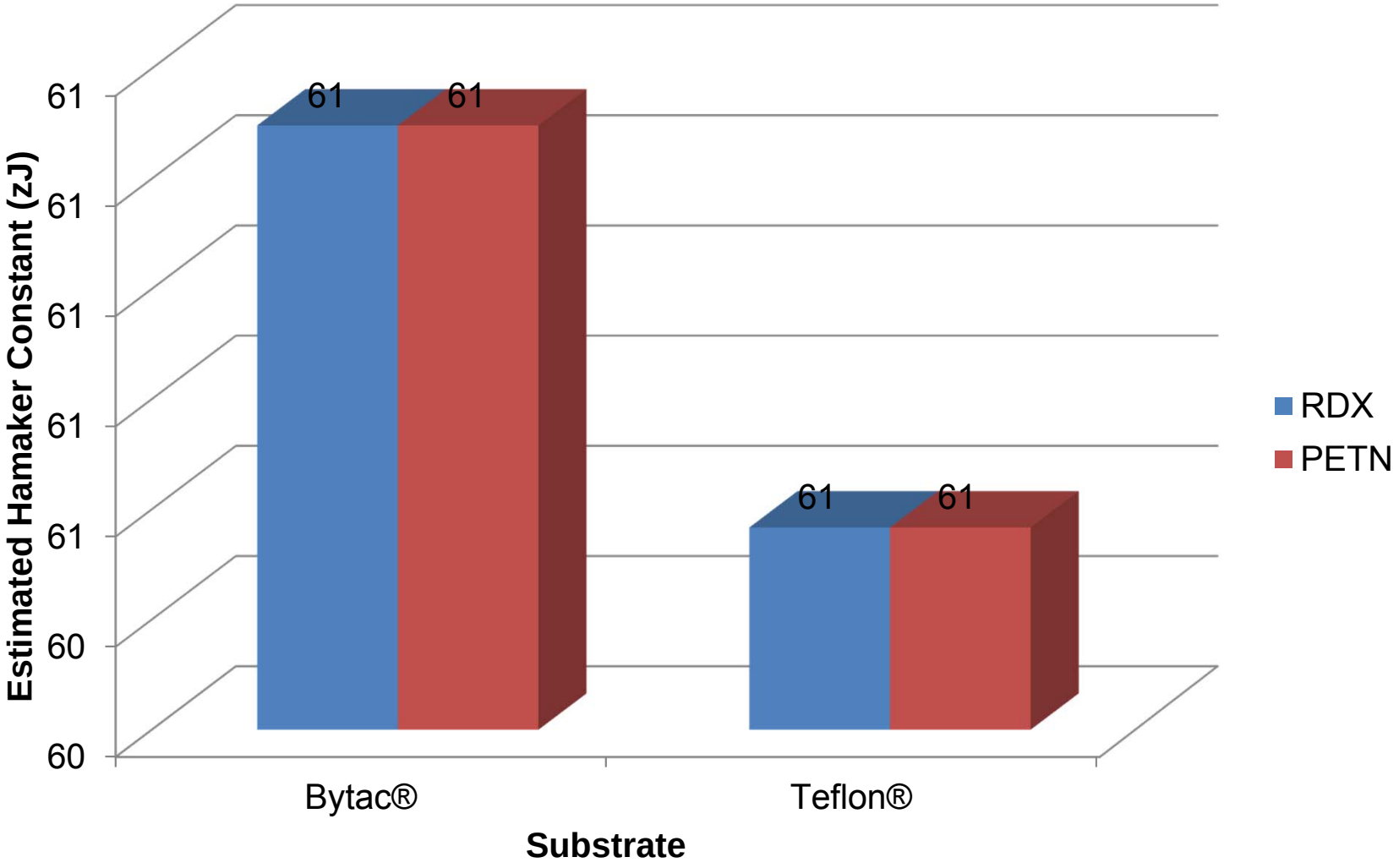
Hamaker constants – substrate/composite



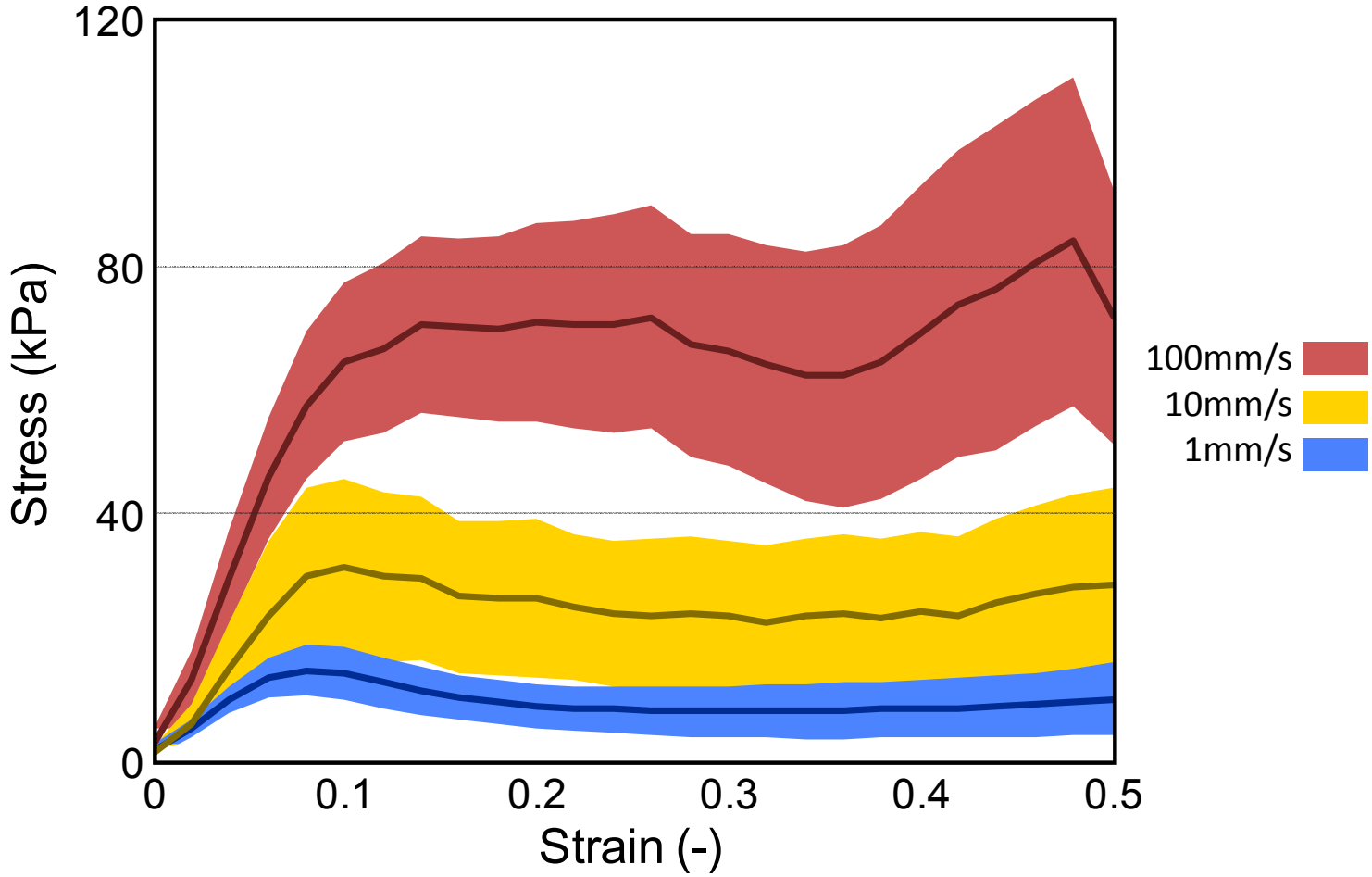
Hamaker constants – swab/composite



Hamaker constants – Swab/particle



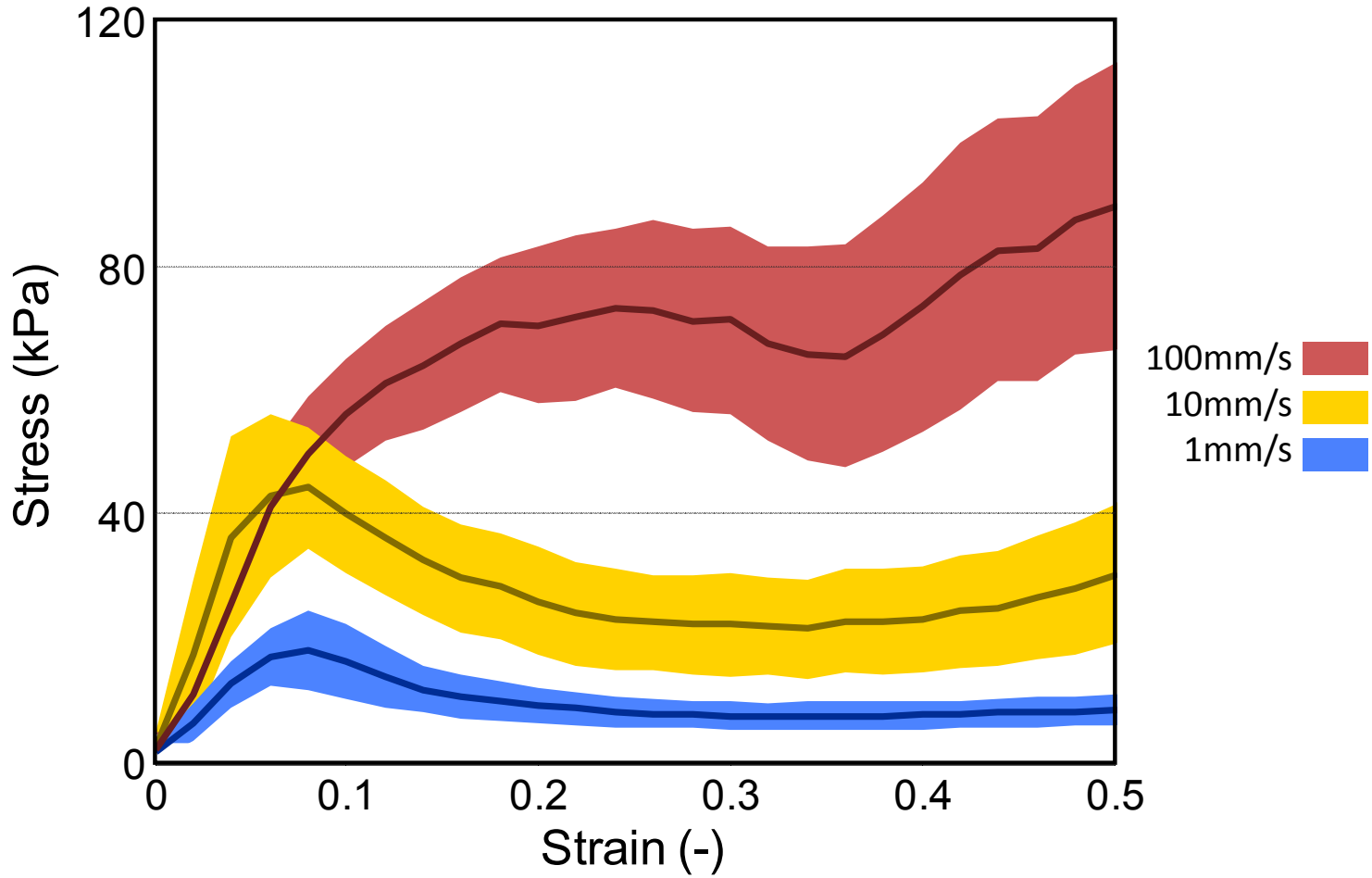
Stress-Strain Results: Bimodal SiO_2 in Simulated C-4 binder



Stress-strain curves (with error regions) for silica particles (75 wt% 30-40mesh, 25wt% >230 mesh) in simulated C-4 binder at 1mm/s, 10mm/s, and 100mm/s compression rates.

MSweat

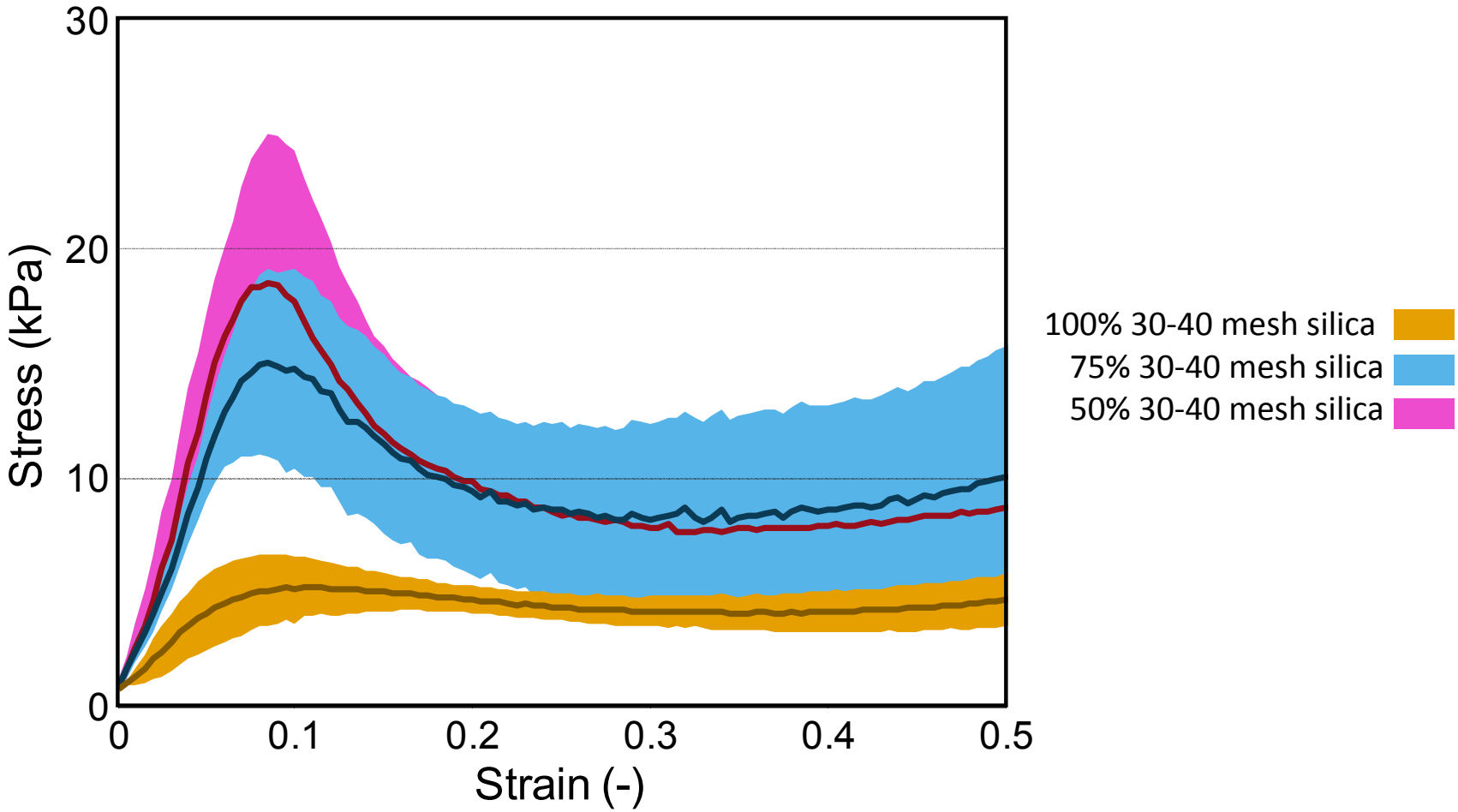
Stress-Strain Results: Bimodal SiO_2 in Simulated C-4 binder



Stress-strain curves (with error regions) for silica particles (50 wt% 30-40mesh, 50wt% >230 mesh) in simulated C-4 binder at 1mm/s, 10mm/s, and 100mm/s compression rates.

MSweat

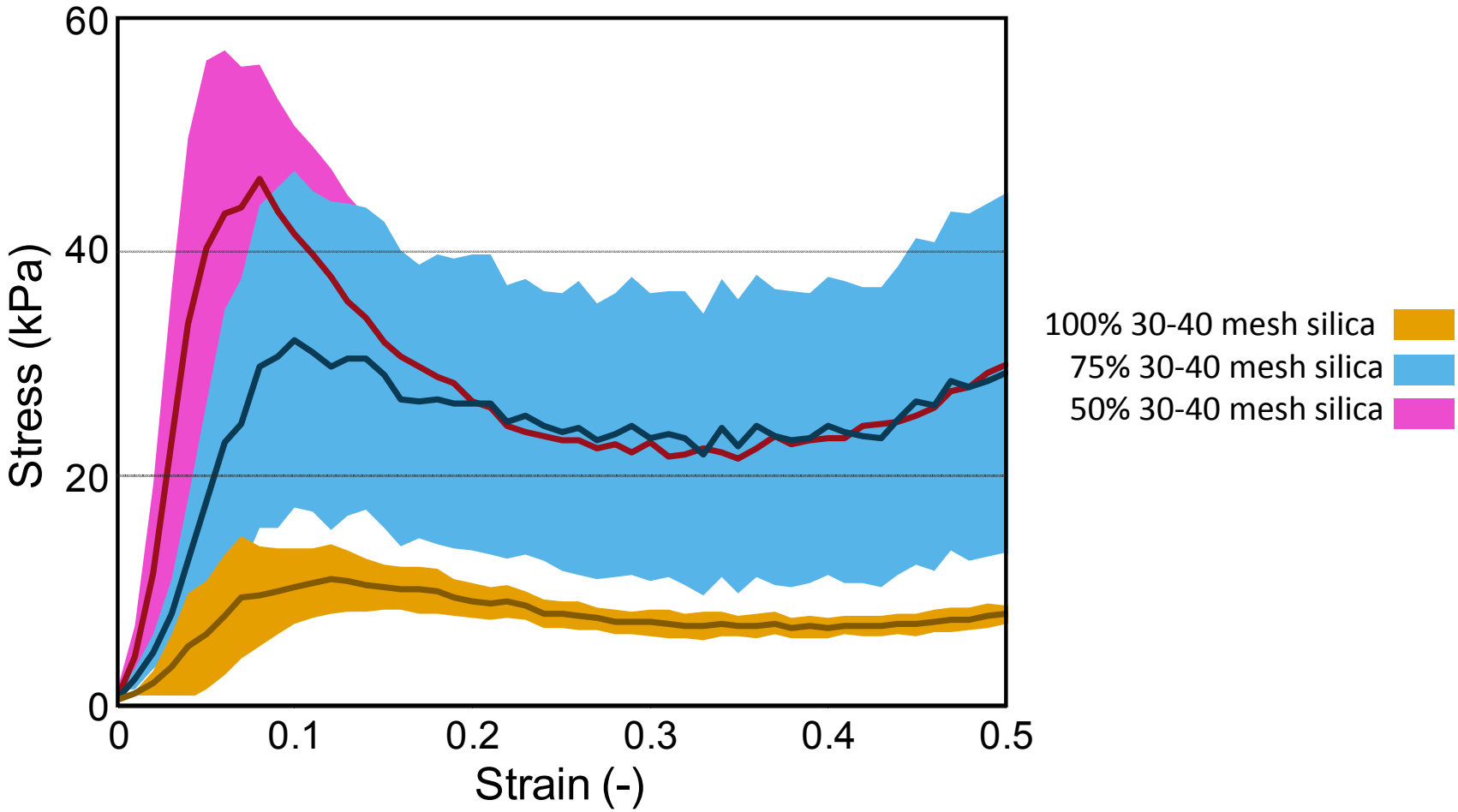
Stress-Strain Results: Bimodal SiO_2 in Simulated C4 Binder



Stress-strain curves (with error regions) for silica particles (100 wt% 30-40 mesh, 0 wt% >230 mesh; 75 wt% 30-40 mesh, 25 wt% >230 mesh; and 50 wt% 30-40 mesh, 50 wt% >230 mesh) in simulated C4 binder at 1mm/s compression rate.

MSweat

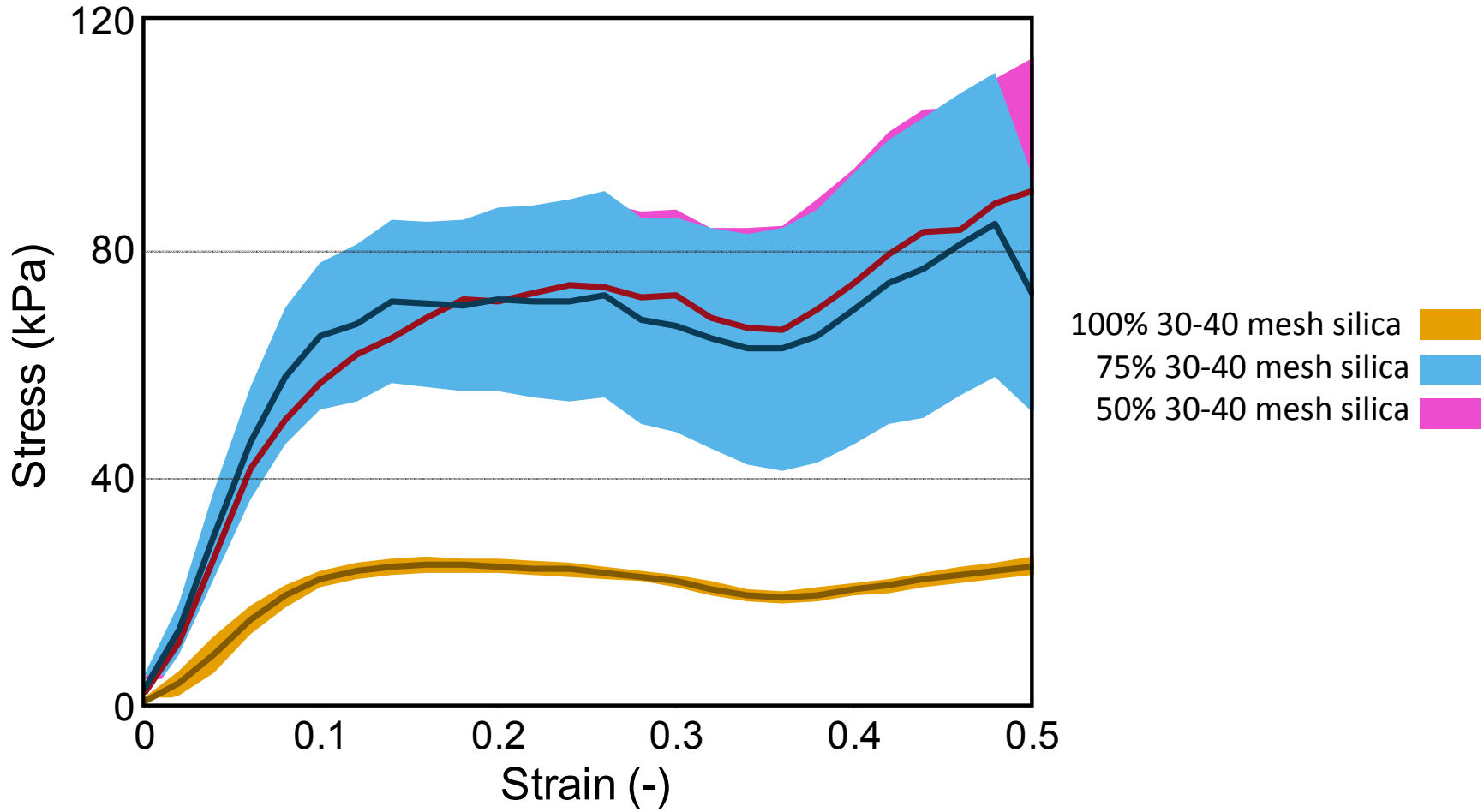
Stress-Strain Results: Bimodal SiO_2 in Simulated C4 Binder



Stress-strain curves (with error regions) for silica particles (100 wt% 30-40 mesh, 0 wt% >230 mesh; 75 wt% 30-40 mesh, 25 wt% >230 mesh; and 50 wt% 30-40 mesh, 50 wt% >230 mesh) in simulated C4 binder at 10mm/s compression rate.

MSweat

Stress-Strain Results: Bimodal SiO_2 in Simulated C4 Binder



Stress-strain curves (with error regions) for silica particles (100 wt% 30-40 mesh, 0 wt% >230 mesh; 75 wt% 30-40 mesh, 25 wt% >230 mesh; and 50 wt% 30-40 mesh, 50 wt% >230 mesh) in simulated C4 binder at 100mm/s compression rate.

MSweat