Atomic Force Microscopy-based Mechanical Testing Reveals the Mechanisms of Plasticity in Disordered Nanoparticle Packings

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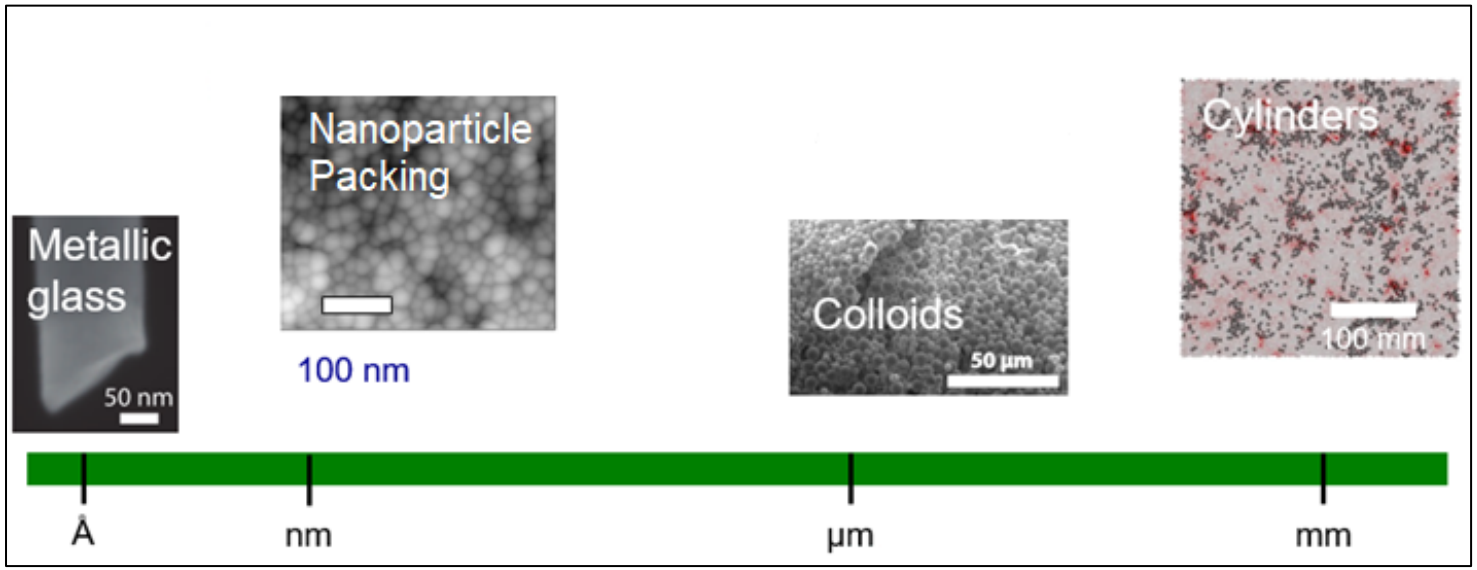
Why study the mechanics of plasticity of disordered nanoparticle packings?

DNPs: Model system of disordered solids

- Length scale of DNP constituents
  - small enough that interparticle forces are still relevant
  - large enough that the constituents can be imaged



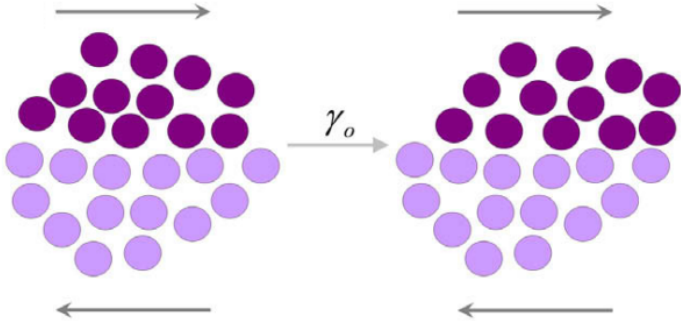
Courtesy of Joel Lefever

Lefever, J. A., et al. *Nano Lett.* **2016**, *16*, 2455–2462.

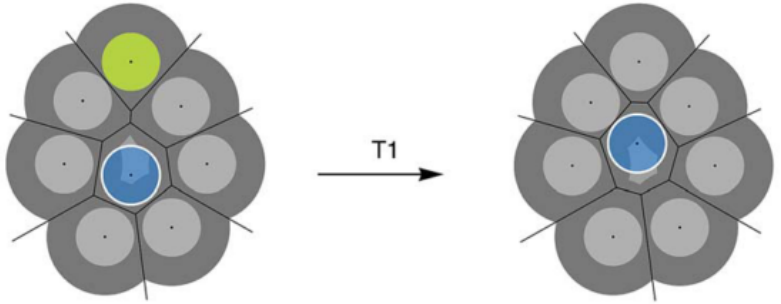
Plasticity in disordered solids is driven by particle rearrangements at soft spots

Soft spot: Region of extra free volume shared among a group of particles[1,2]

Two types of particle rearrangements:



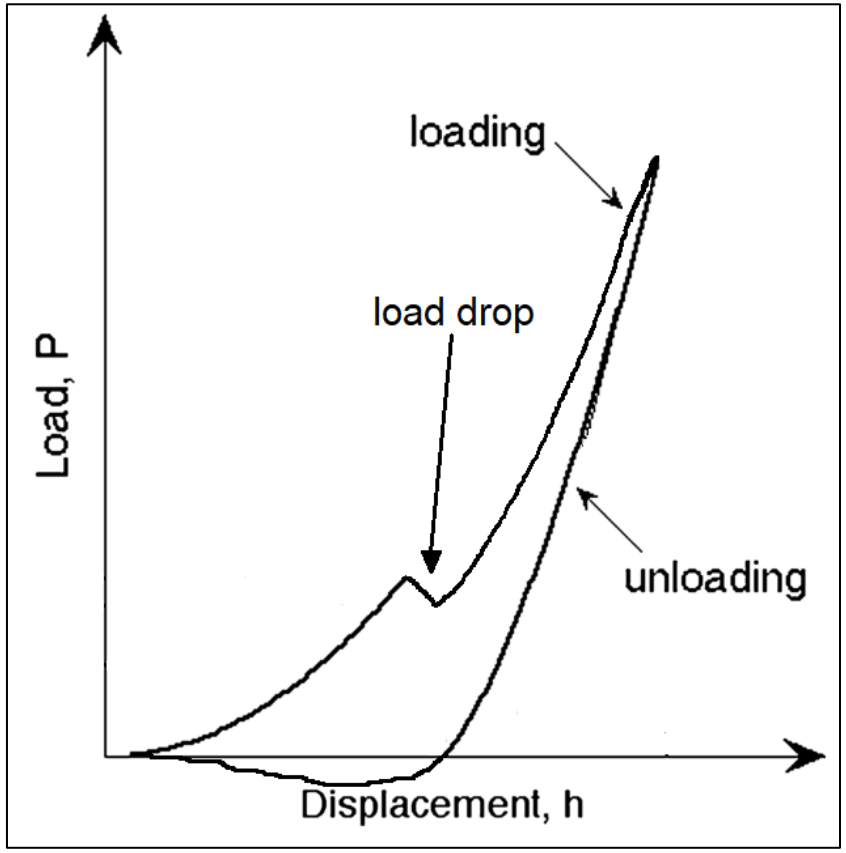
Shear transformation zones[3]



T1 process[4]

Both phenomena cannot be directly imaged in small scale material systems[5] ☹

How do the factors of environmental humidity and bulk volume fraction influence these rearrangement events?



Adapted from ref (6)

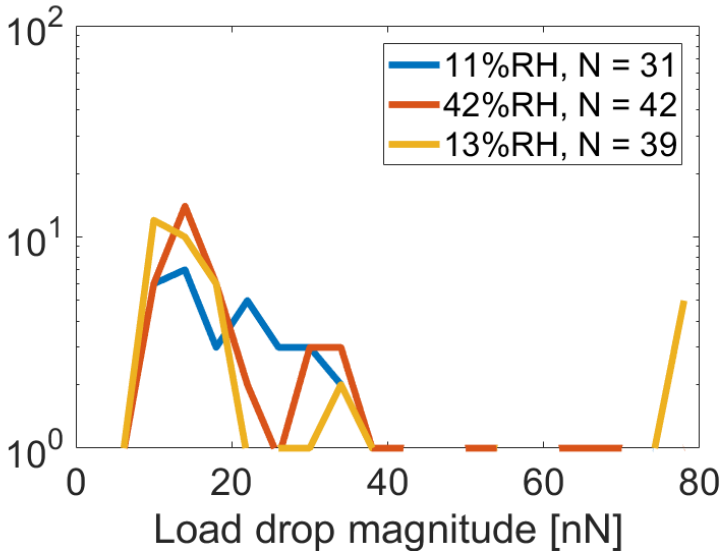
Presence of load drops in the load-displacement curve of a nanoindentation test indicate onset of such rearrangements

Various measures of plasticity can be collected from these tests[6,7]

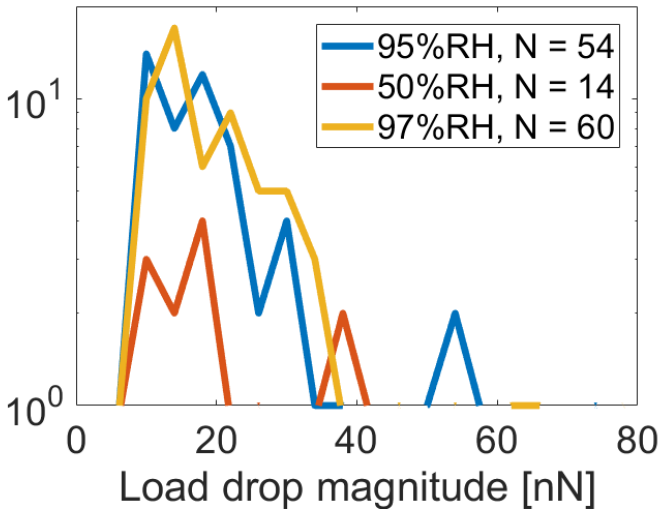
AFM nanoindentation tests were performed to:

- titania-nanodiamond DNP sample in various humidity levels
- multiple samples of silica thin film DNPs of various levels of bulk volume fraction

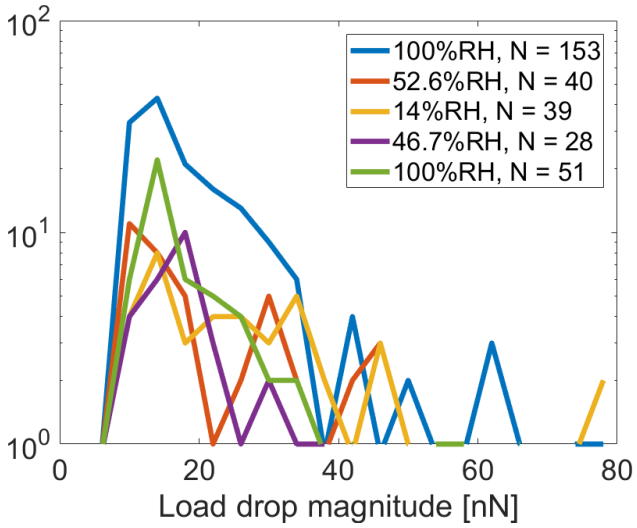
In general, more load drops were observed in the nanoindentation tests performed at higher humidity levels



Trial 1

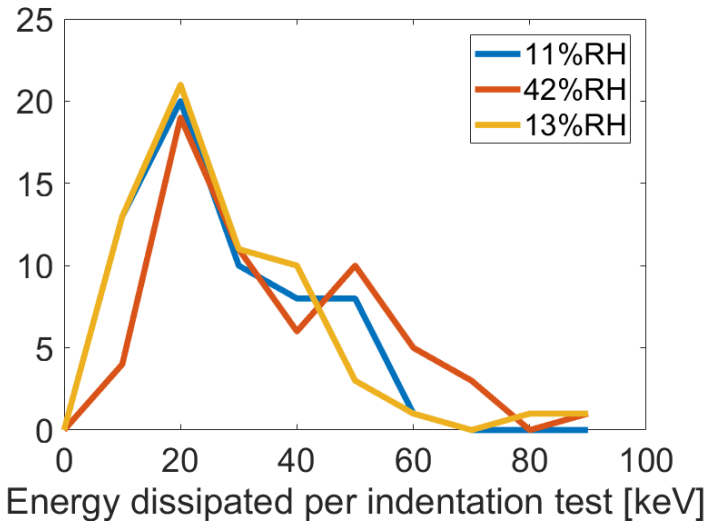


Trial 2

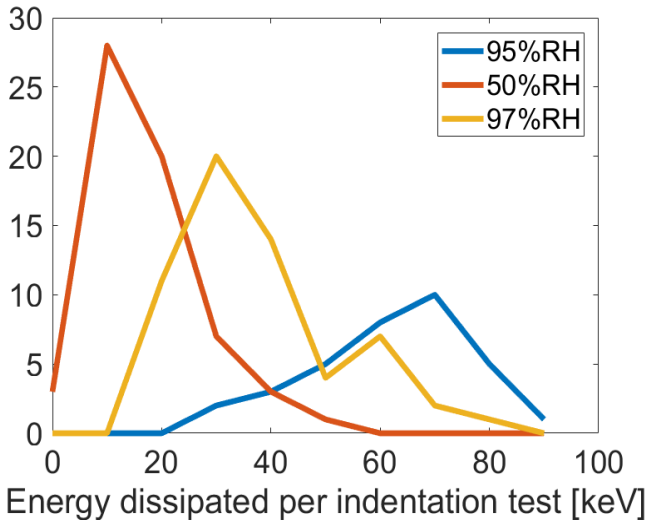


Trial 3

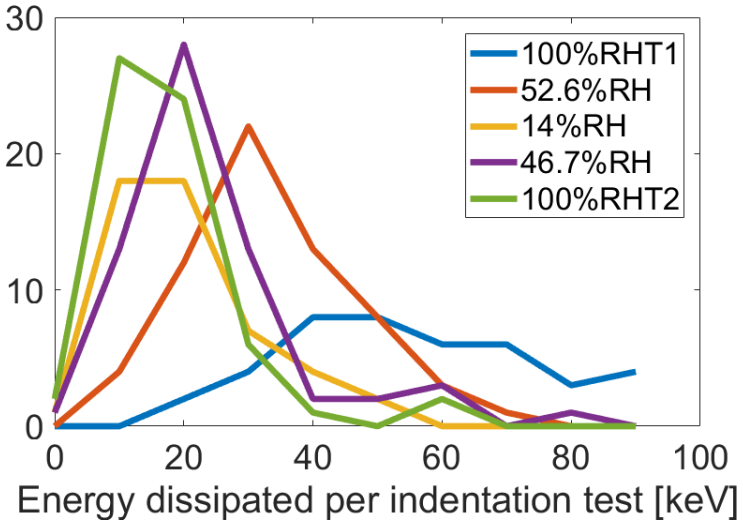
In general, nanoindentation tests at higher humidity levels displayed higher levels of energy dissipated per indentation



Trial 1



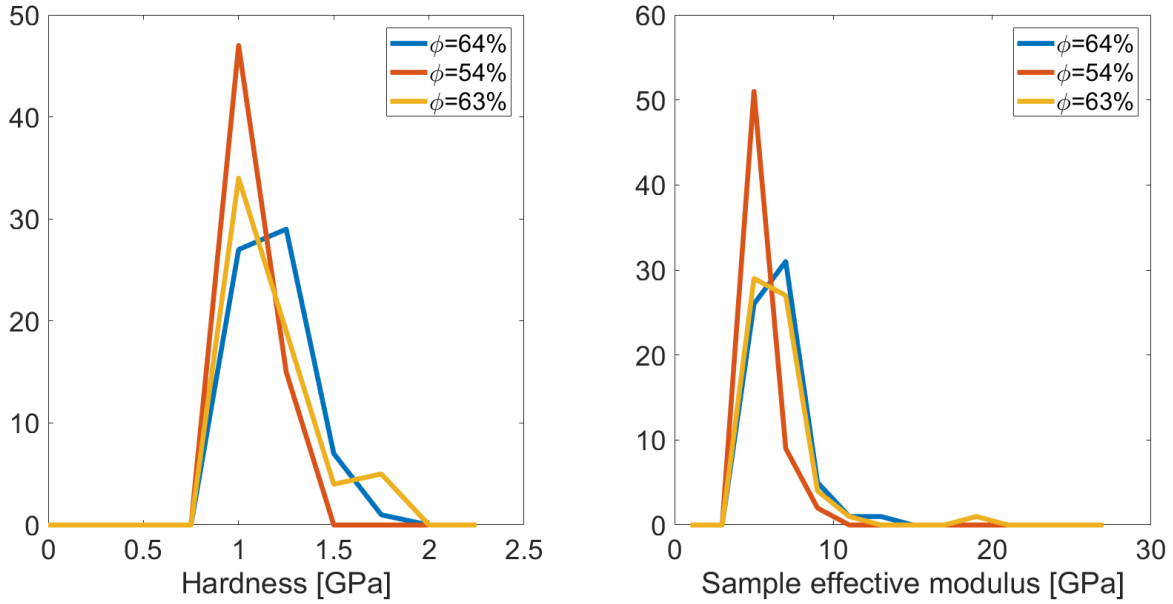
Trial 2



Trial 3

Hardness and sample effective modulus both increased in the nanoindentation tests as bulk volume fraction increased

Statistically significant, with a confidence of $p < 0.05$



Trial 2

Trial 1 displayed the same trends

Conclusions

Environmental humidity and bulk volume fraction influenced the mechanics and plasticity of the DNP samples. These parameters can be used to control particle interaction to make the DNP model system reflect other disordered material systems.

More data needs to be taken in order to reduce hysteresis effects and ensure consistent behavior between data sets.

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