ELECTRIC FIELD INDUCED GELATION IN SOFT COLLOIDAL CLAY SUSPENSIONS

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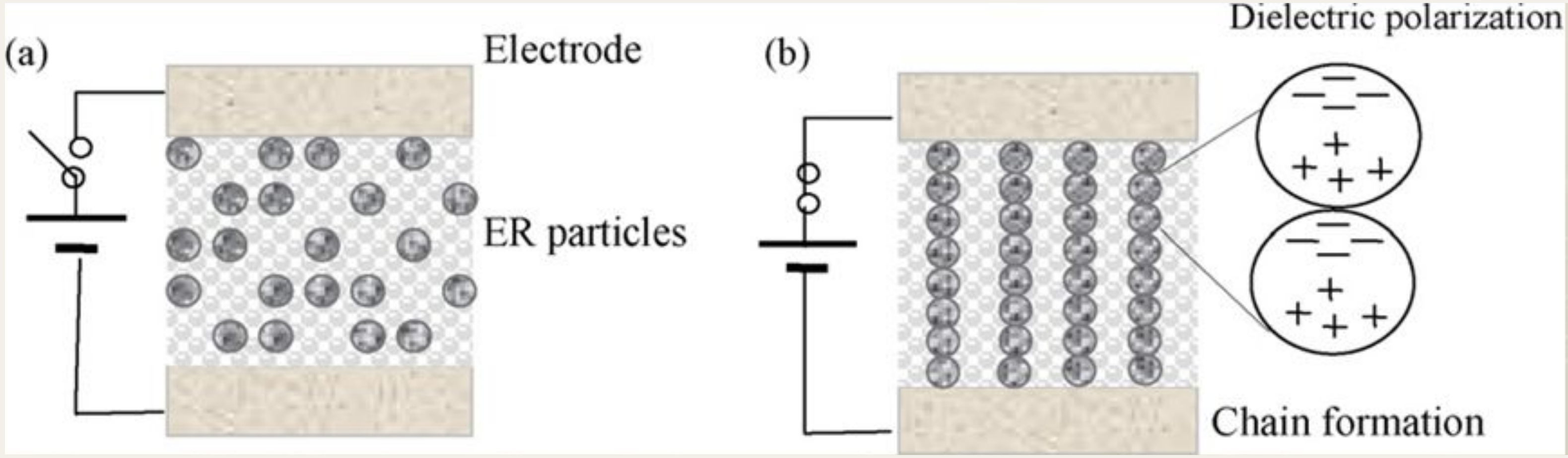
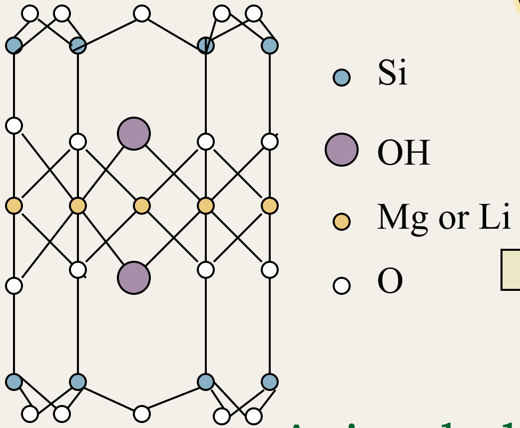
Electrorheological (ER) fluids



Applications of ER fluids:

1) Viscosity can increase by 100000 times in response to an electric fields (shock absorbers, vibration control of structures, dampers in car clutches)
2) Response times ~ 1 millisecond (the Winslow effect, patented in 1947 by Willis Winslow)
3) Reversible liquid to solid phase transitions

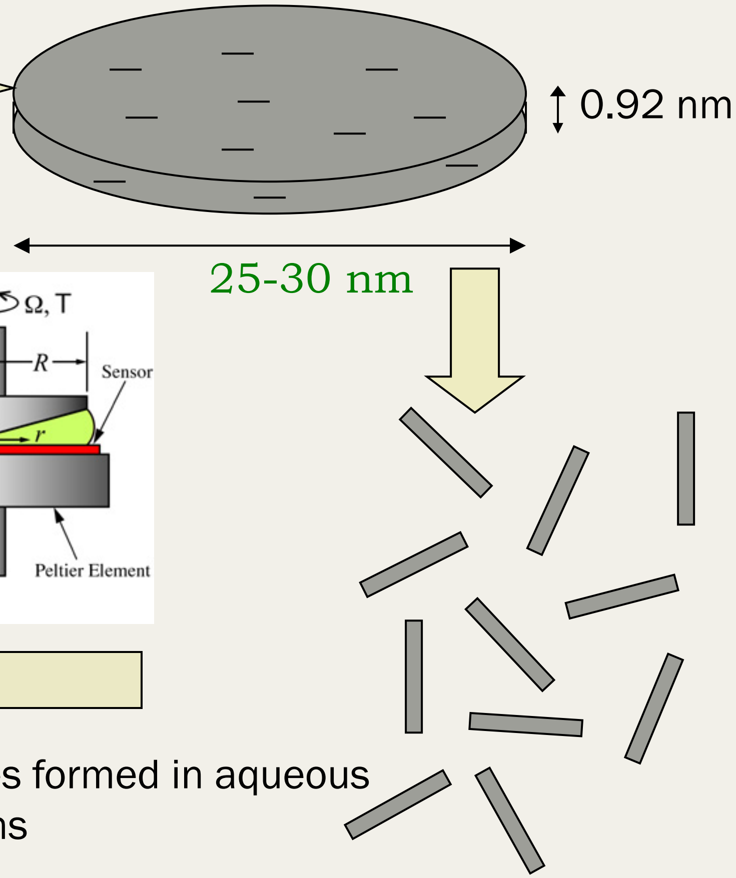
Colloidal glasses of clay



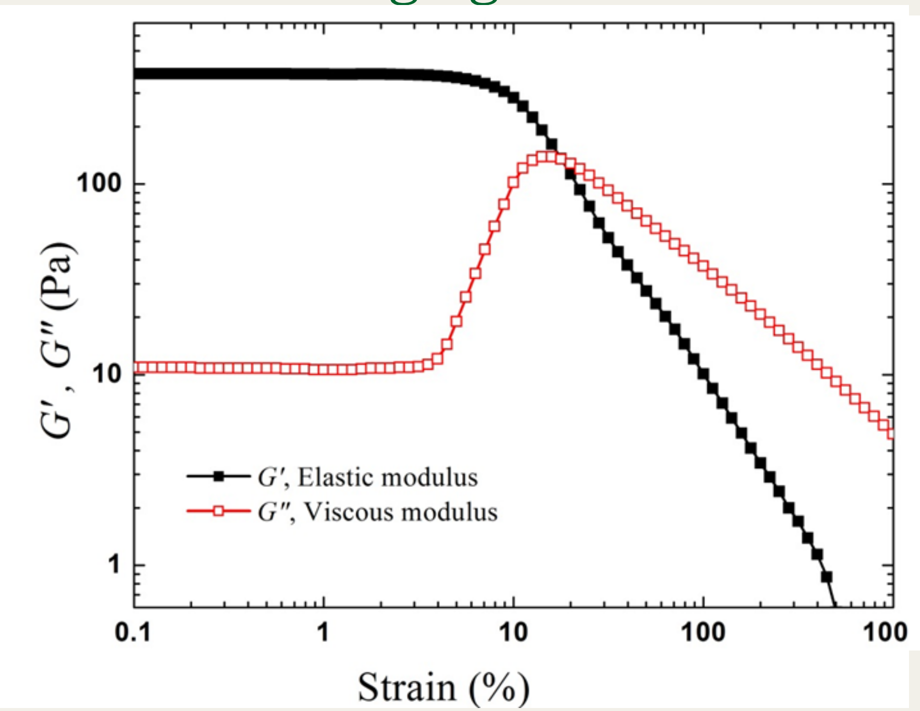
LAPONITE RD: a model glassformer

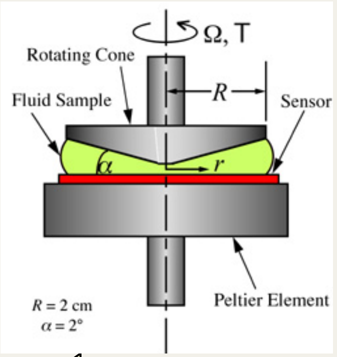
$Na_{0.7}^{+}[Si_8Mg_{5.5}Li_{0.3}H_4O_{24}]_{0.7}^{-}$

Charged disks



Aging behavior





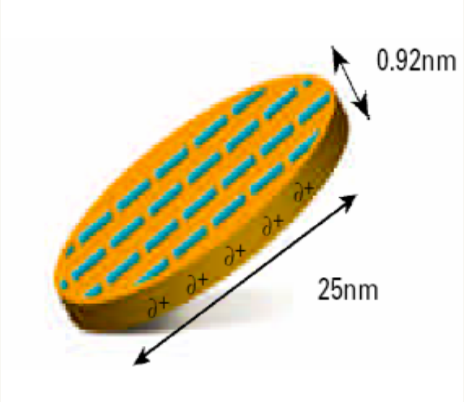
Soft glasses formed in aqueous suspensions

3 wt% LRD, Age t_w= 2 Days

G' : energy stored in the material

G˝: energy dissipated by the material

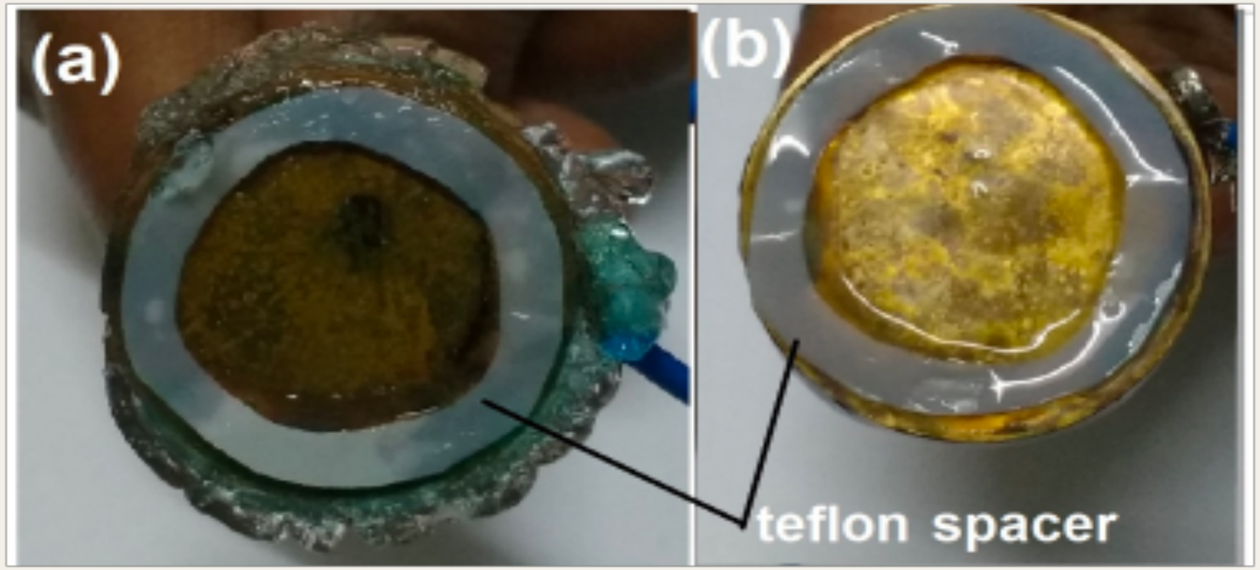
Clay water systems can also form structures



- In an aqueous medium the faces of the Laponite disks are charged negatively
- Depending on the solution pH, the charges on the edges can be positive

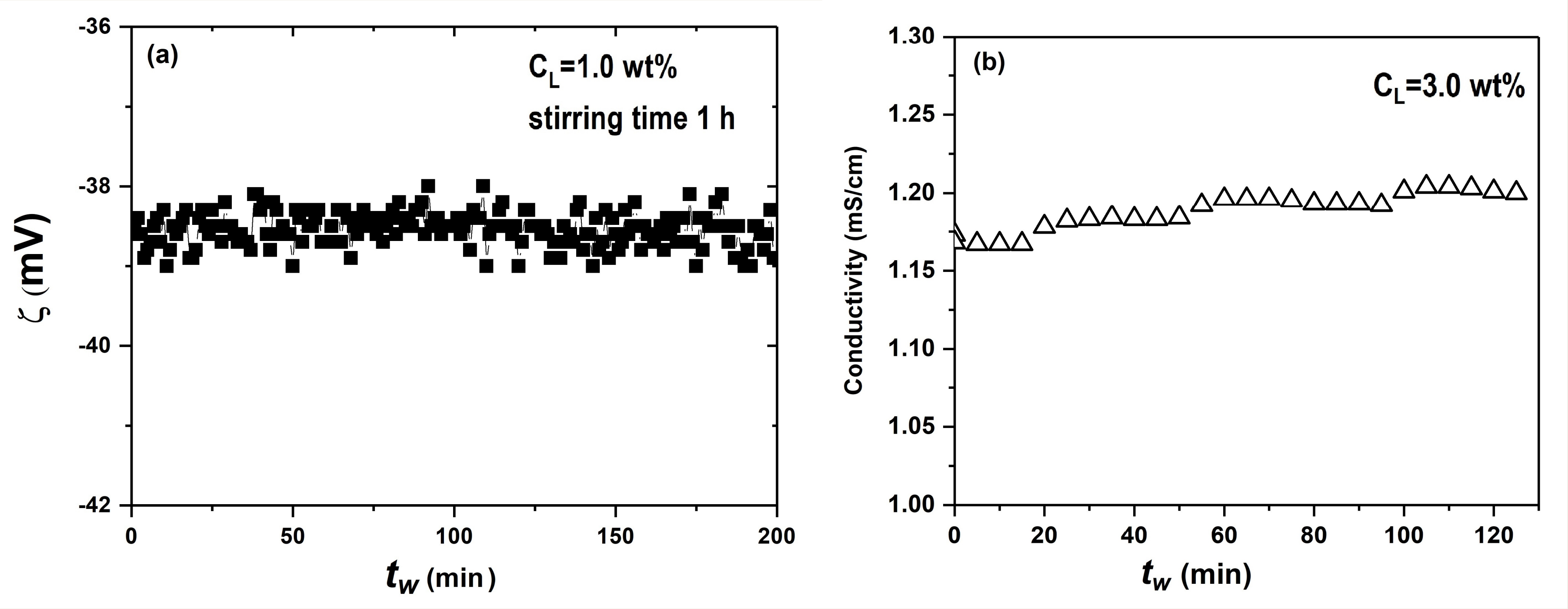
- Houses of cards structures are possible (and predicted in computer simulations due to electrostatic attraction between the faces and rims).

DC electric fields induce the formation of soft solids



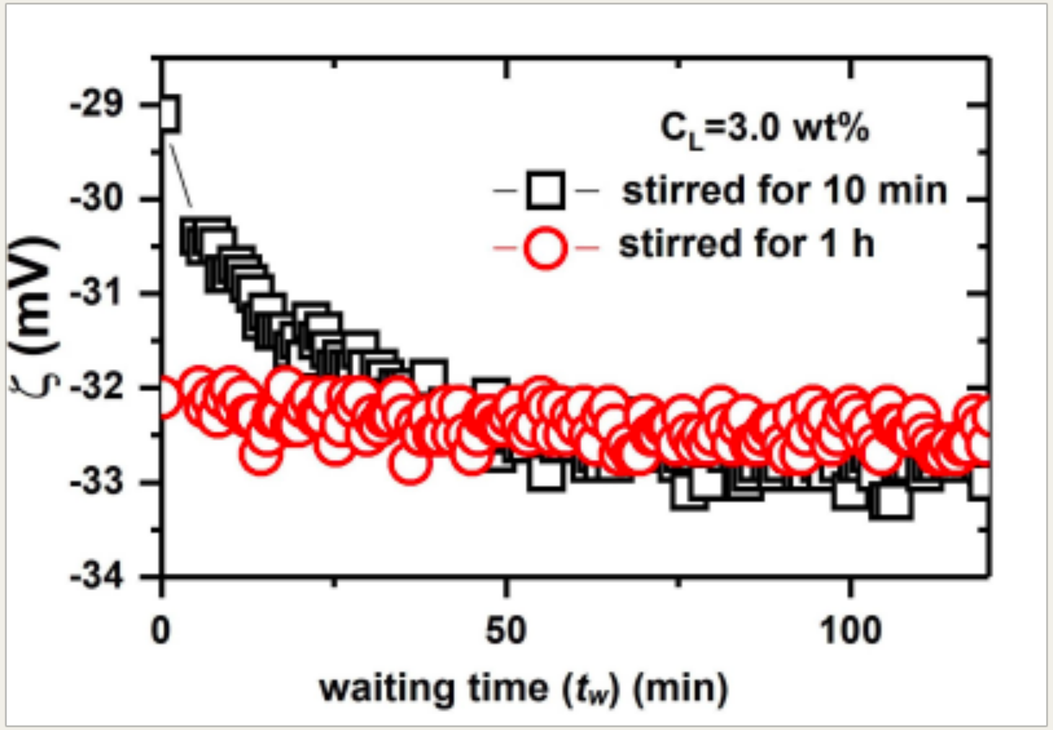
- Two 10 mm brass disks were used as electrodes with a 300 micrometer Teflon spacer
- The electrode setup was immersed in a freshly prepared Laponite suspension.
- Small DC voltages (0.8V-3V) were applied using an Agilent power supply for 15 minutes (E=2.5 kV/m to 10kV/m)
- Soft solids were formed on the positive electrode when DC was applied (figure a).
- When AC fields were applied, no soft solid formation was detected (figure b).

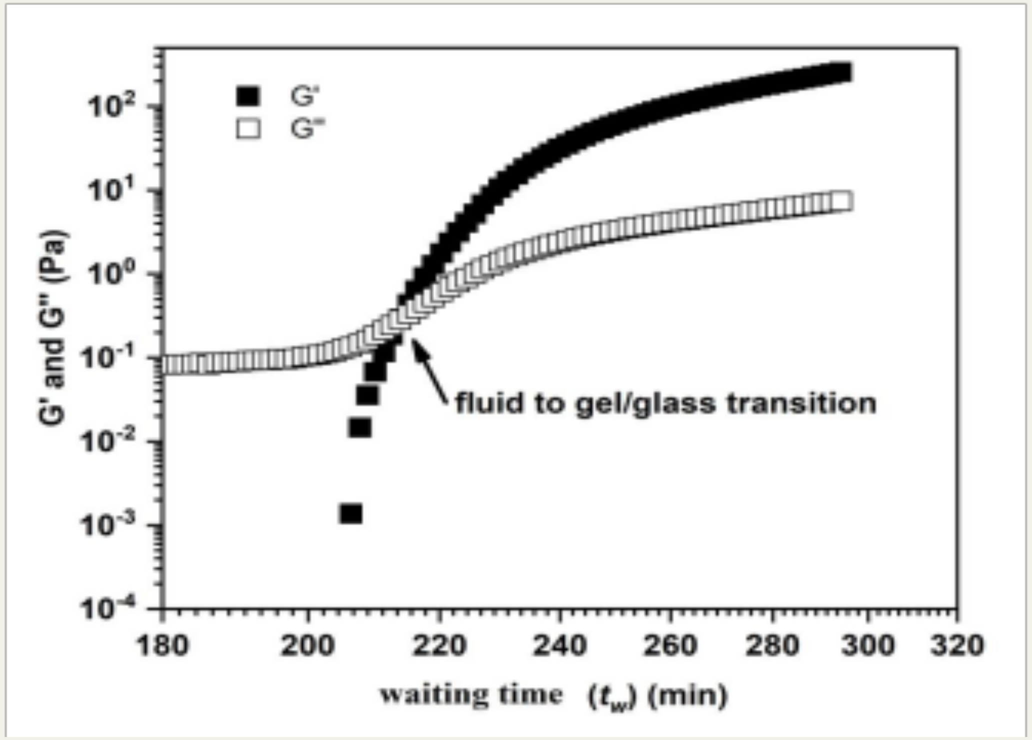
Aqueous Laponite suspensions age due to the delamination of 1D particle stacks and the dissociation of Na^+ ions into the aqueous medium



- ζ potential measurements using an electroacoustic setup show the negative surface potential (-39.5 mV) of Laponite particles in aqueous suspensions.
- Conductivity measured using a 4 probe technique ~ 1.16 mS/cm at t_w = 0 and increases slowly with increasing t_w.

Spontaneously aging suspensions (E=0)

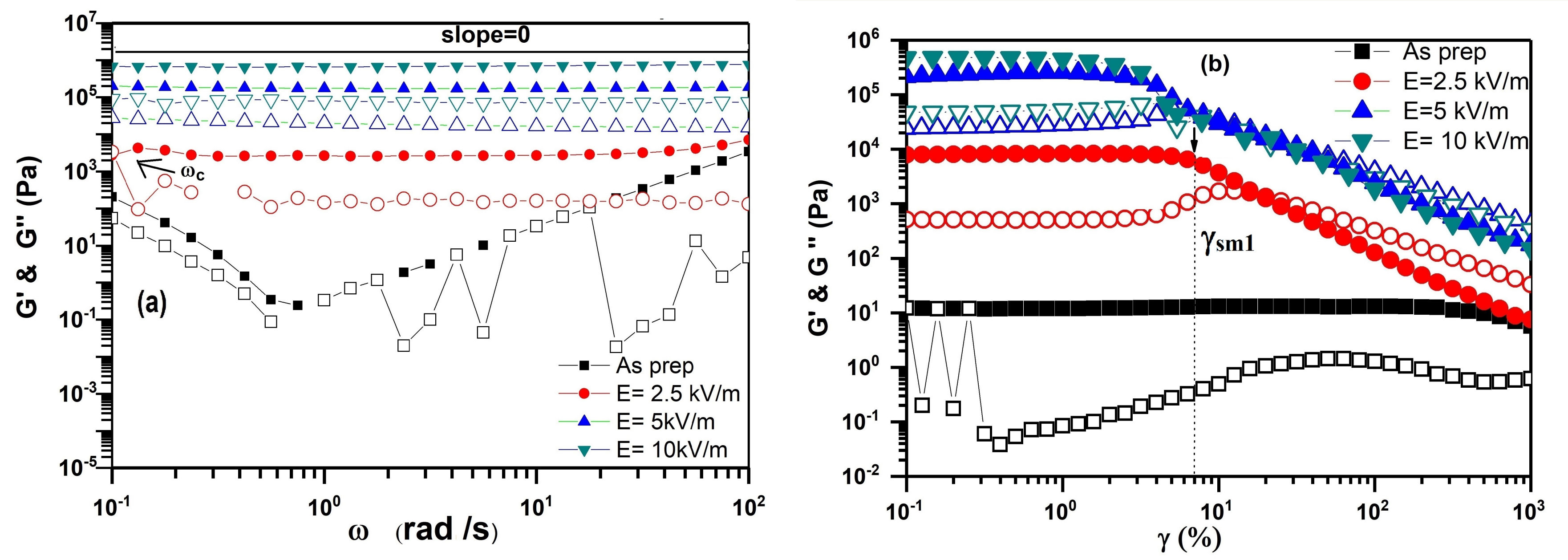




- For short stirring times, the tactoid (stack) exfoliation process is incomplete as the ζ potential continues to evolve

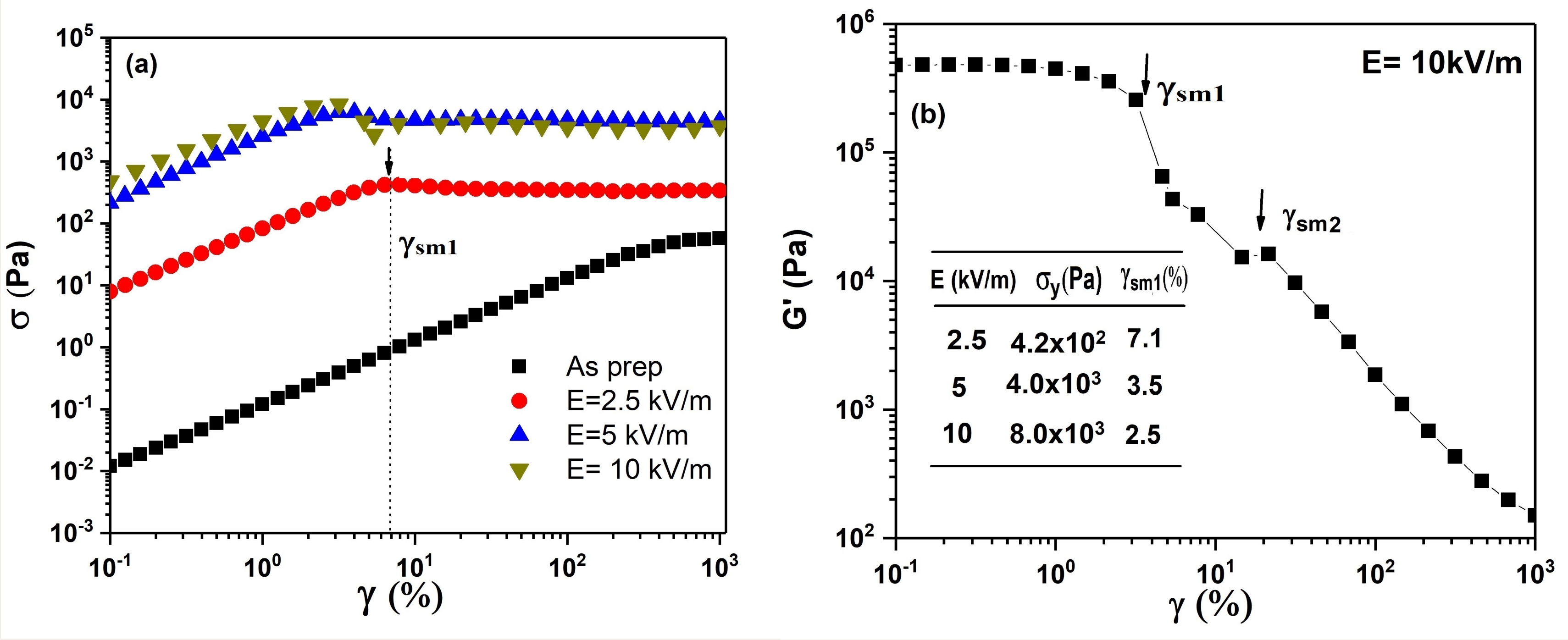
- The sample transforms into a soft solid but much more slowly.
- Electric fields are expected to change the DL (charged double layer structure) around each particle.

Mechanical properties of the soft solids



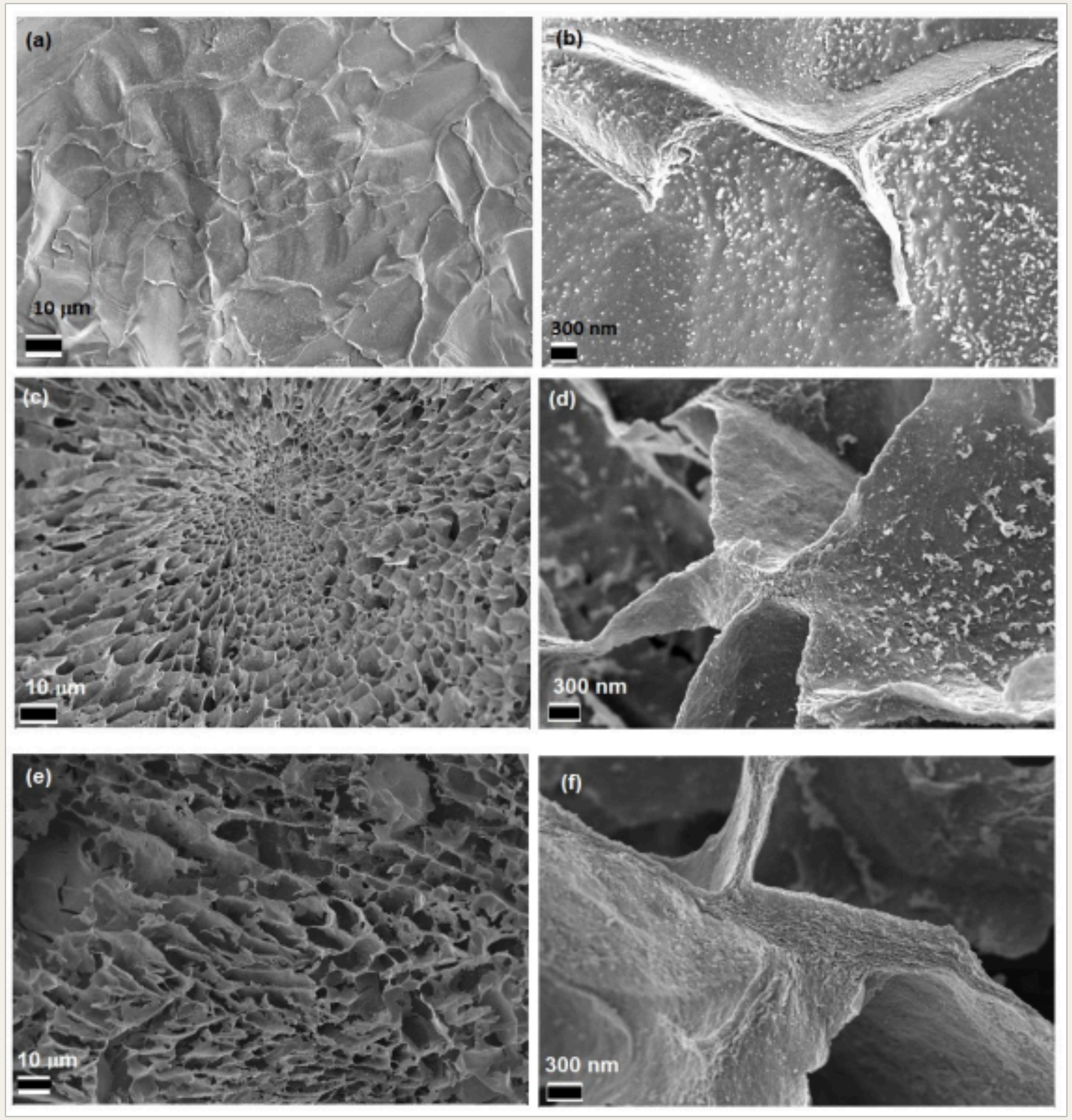
- In the absence of electric fields, the sample is liquid-like (figure (a)).
- Samples are soft solids at E> 0 and resemble materials displaying soft glassy rheology (figure (a) - G’ frequency independent and G” weakly frequency dependent).
- At E>0, crossover frequency lies outside the measurement window (slow dynamics).
- Remarkable acceleration of the solidification process with increasing E (figure (a))
- The shear melting of the samples are studied in amplitude sweep experiments (figure (b)). The linear viscoelastic regime becomes smaller at higher E and yielding is seen.

Two step yielding at high E signifies the formation of highly structured attractive glasses.



- Herschel Bulkley yielding in all samples solidified using E>0 (figure (a))
- Two step yielding at E = 10kV/m. Step 1: breakup of clustered network, step 2: breakup of individual clusters (figure (b)).
- Yielding at small strains indicate that samples are mechanically fragile (inset of figure (b)).

Direct visualization using cryogenic scanning electron microscopy



E = 2.5 kV/m

An open network like structure with limited connectivity of chains of Laponite particles

E = 5 kV/m

The chain connectivity increases.

E = 10 kV/m

A dense percolated network with thick network branches emerges. Honeycomb like structure.

Conclusions

- A rapid formation of Laponite clay colloidal gels due to the application of DC electric fields.
- Cryo-SEM corroborates rheological results.
- An electrokinetic effect causing electrophoresis, coupled with electrohydrodynamic flows and a concentration mechanism related to the concentration polarization of the particles.
- Smart fluids

Why do the mechanical moduli of clay suspensions evolve spontaneously with time?

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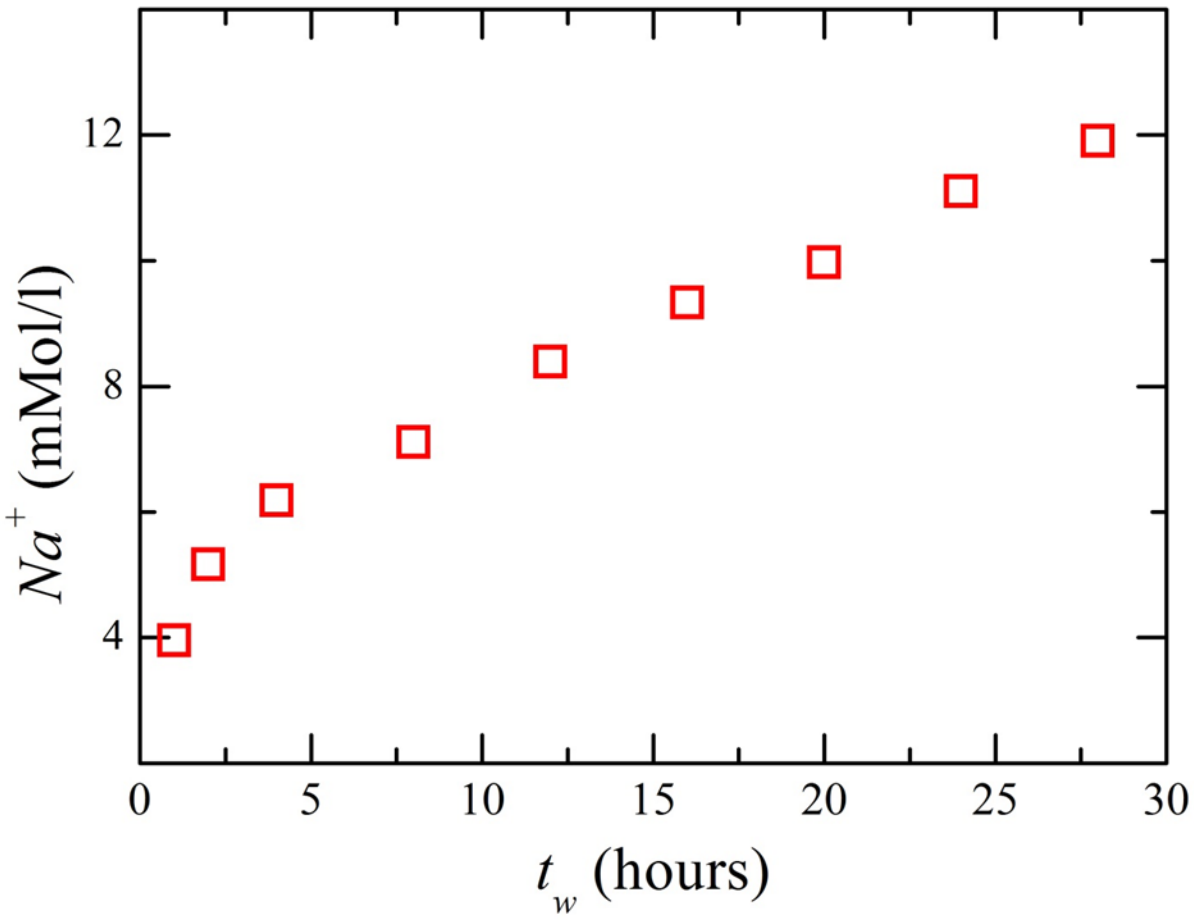

Saha, Bandyopadhyay and Joshi, *Langmuir* 31 (10), pp 3012–3020, 2015