Stresses & strains in drying colloidal films



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McBain Medal for Alex Routh 8th December 2010

'Tough' layered ceramic structures





Making layers by tape-casting





Cracking in aqueous tapes





Any theory of drying cracking must explain

- Why the substrate makes cracking easier
- Why the maximum capillary pressure is so important

Importance of capillary forces



W.P. Lee and A.F. Routh, *Langmuir*, **<u>20</u>**[23] (2004) 9885-9888

Double layer and critical cracking thickness (CCT)



Chiu et al., Journal of the American Ceramic Society, 76[9] (1993) 2257-64

Experimental

- Alumina, AKP-30 (350 nm)
- Sheets made by plastic mixing & burnout of polymer (aqueous PVA gel)

Samples filled with water & dried



Before wetting



5 minutes after wetting



190 minutes after wetting

Young modulus varies with ϕ as predicted



Adhesion to substrate



wet

saturated

Particles bond immediately, but film is still fluid

Through-thickness strain measurement



Lateral drying during height change measurement



 f_i = 0.3, dispersed

Height change after packing front



Height change for weakly attractive slurry



 $f_i = 0.3$, $c_{NaCl} = 0.1$ M, weakly attractive

And in silicas



Silica, 50 nm

Courtesy of Lucas Goehring

DLVO interparticle pair potential, Al₂O₃



Maximum pressure needed for collapse ~ 10⁻⁴ P_{c,max}

What is collapse pressure?



A.F. Routh and W.B. Russell, A.I. Mech. E., <u>44[9]</u> (1998) 2088-2098



Different cracking criteria

- Critical strain-energy release rate due to capillary pressure
- Critical pressure in network causes collapse

Conclusions

- Particles in a network made by plastic processing and burn out of the polymer do NOT crack on rewetting
- Young modulus consistent with that for network of particles held together by surface forces
- Suggests particles are not touching in saturated network
- Collapse strains (3%) occur on drying suspension
- Apparent pressures required ~10⁴ greater than for DLVO
- But collapse over non-DLVO energy hill cannot be associated with cracking, as tapes redisperse