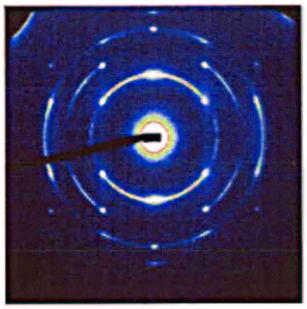
Shear-banding phenomena
Examples in ordered mesophases

Erika Eiser
Laurence Ramos

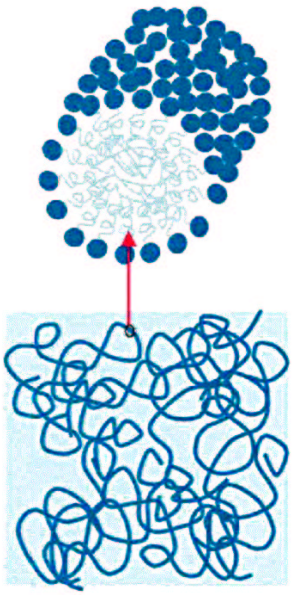
Jean-François Berret
Olivier Diat
Peter Lindner
François Molino
Gregoire Porte
Xavier Pithon

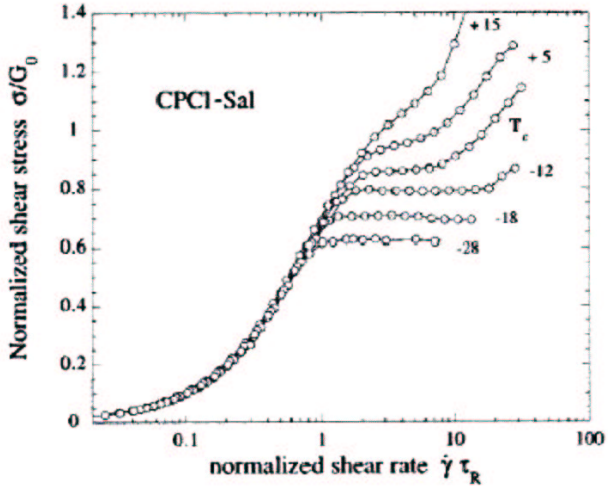


GDPC Montpellier

Living polymers : structure and non-linar rheology

J.F. Berret
G. Porte



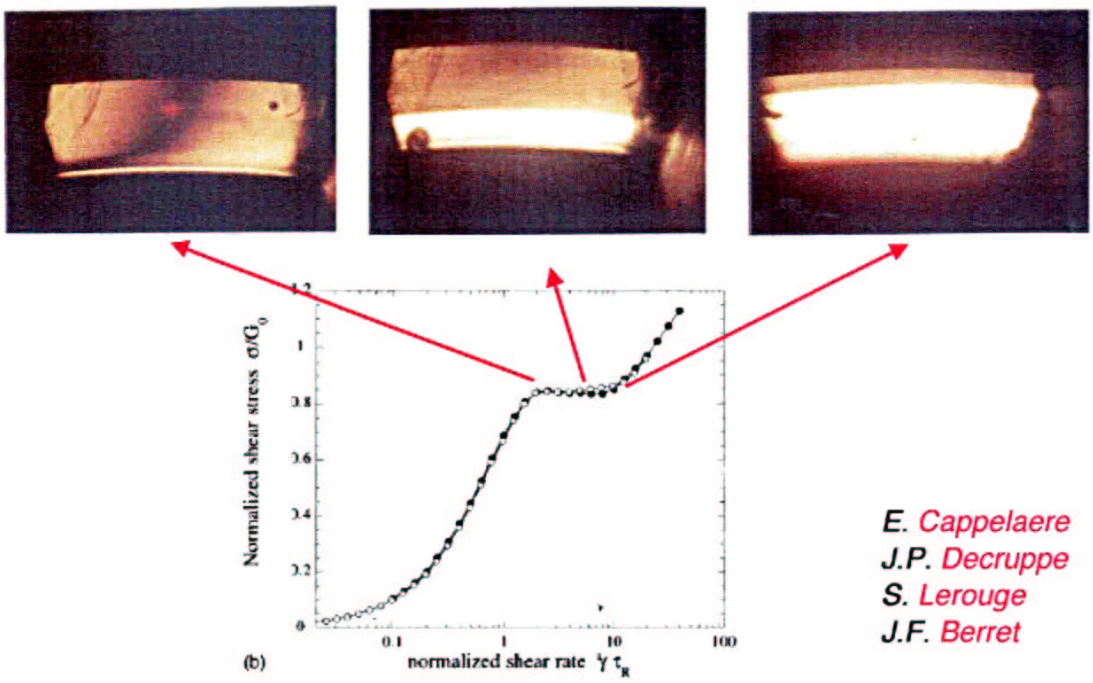


Φ (6 % - 12%) *semi-dilute \ concentrated*

Berret et al. 1997

3

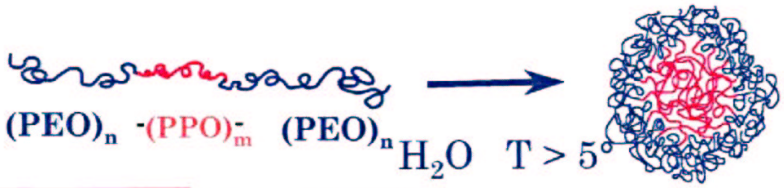
Structural transition under flow : the simple view



E. Cappelaere
J.P. Decruppe
S. Lerouge
J.F. Berret

4

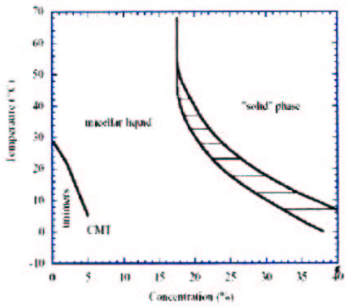
Cubic phase of tribloc copolymers

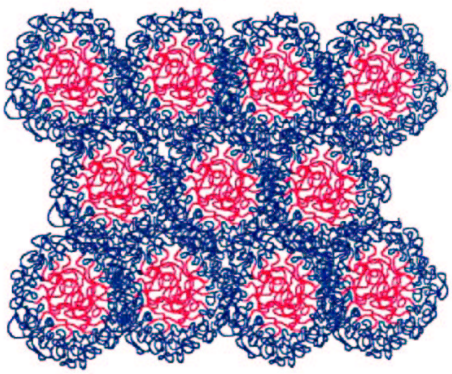


N_{aggr} fixed

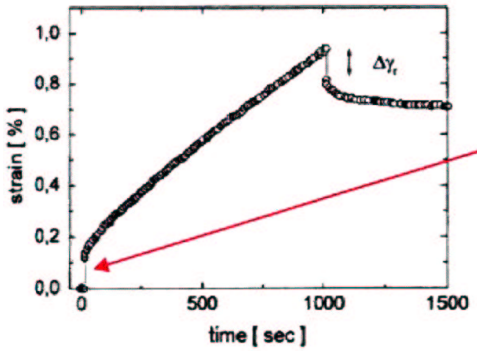
n=76	n=127
m=29	m=48
N_{aggr}=10	N_{aggr}=50
BCC a=75 A	*FCC* a=300 A

Concentration

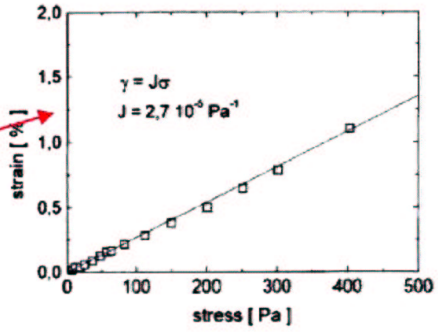




BCC phase under small stresses I
Elastic modulus

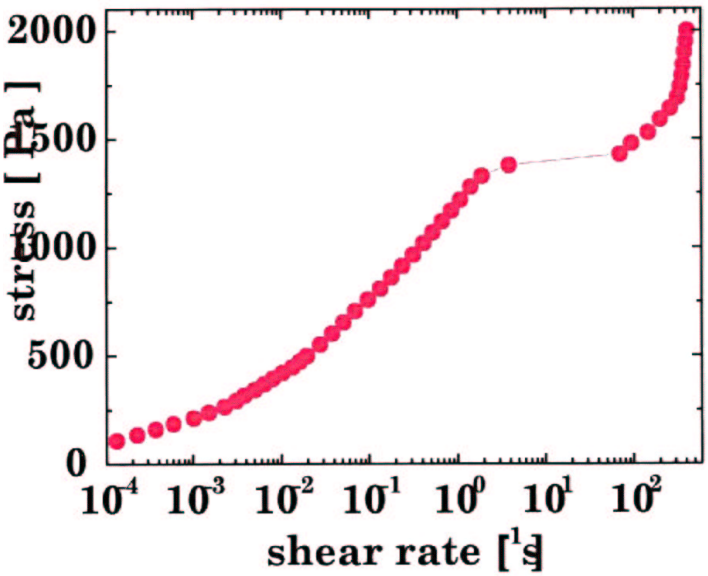


Creep test 50 Pa



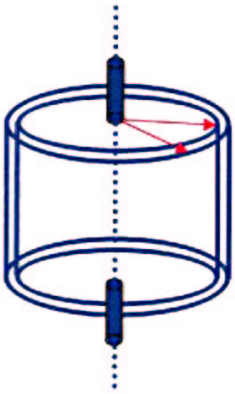
Elastic modulus 4 10^4 Pa

BCC soft crystal flow curve

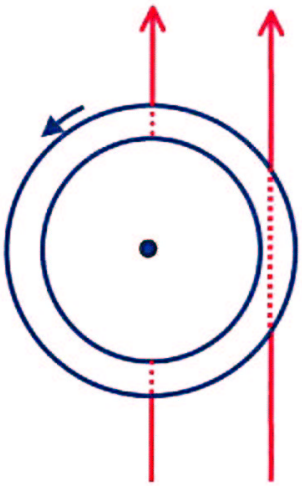


[*F68* $\phi = 46\%$ $T = 18°$]

Neutrons/X rays under shear



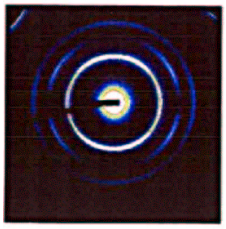
Rheology/structure
Same geometry

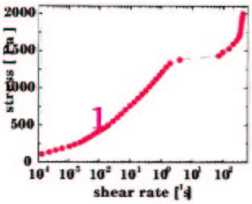


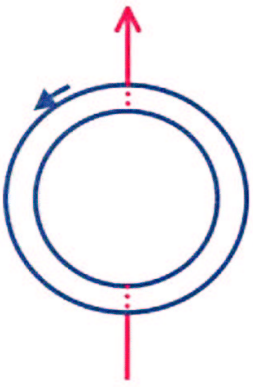
Peter Lindner, **ILL**
Olivier Diat, **ESRF**

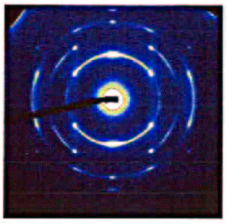
beam

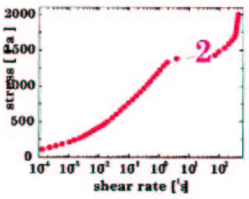
BCC : Structure and Rheology

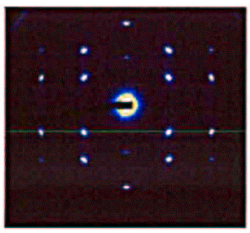


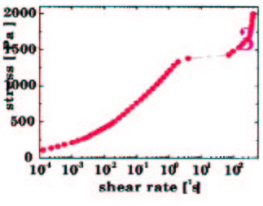






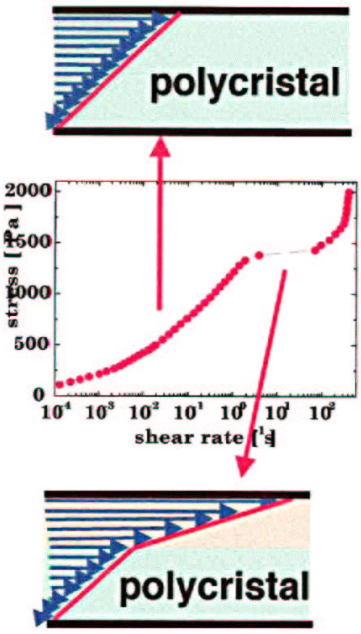


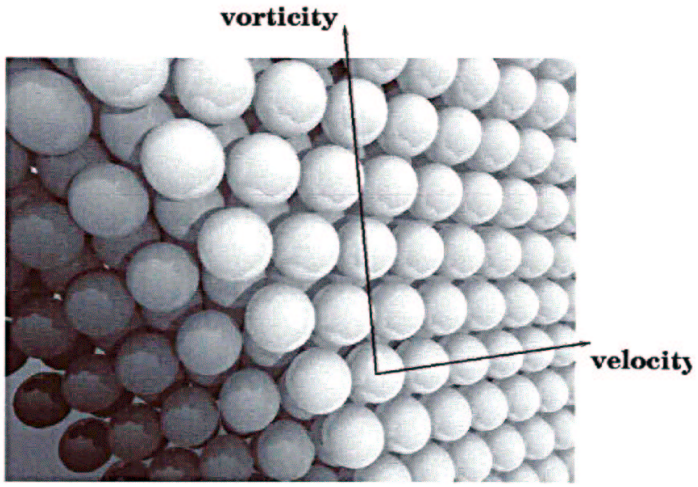




ESRF 1998

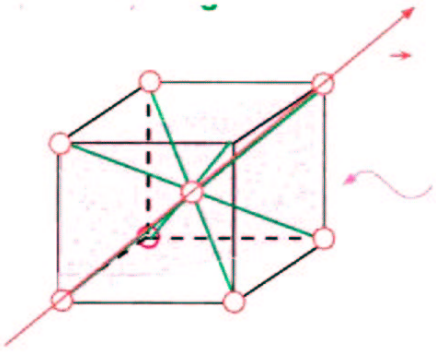
Layer-sliding mechanism

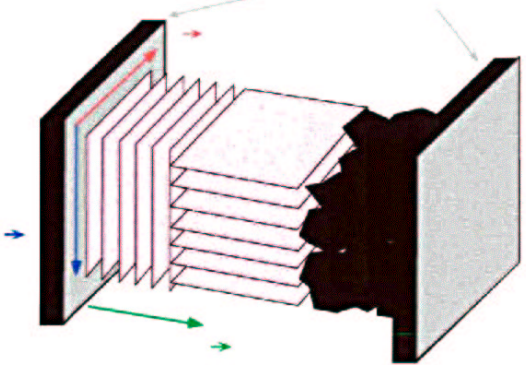




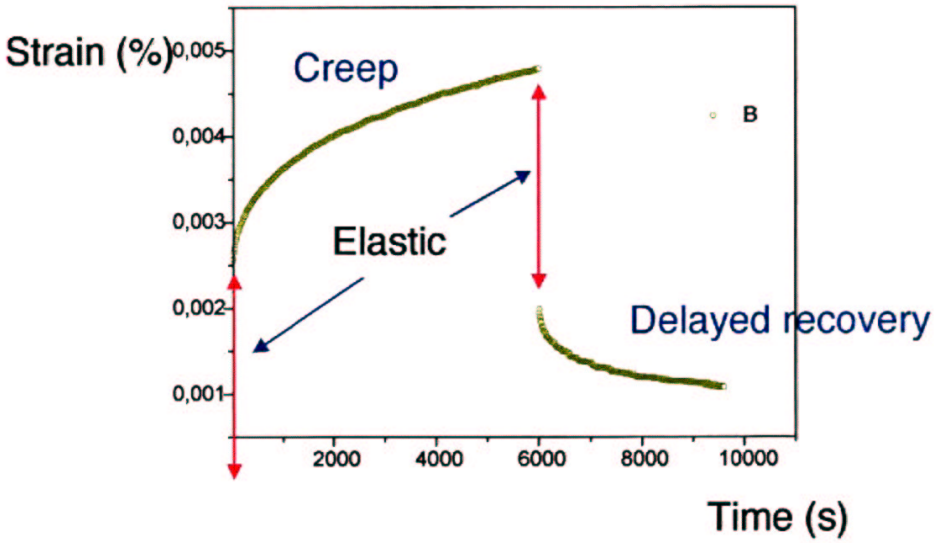
Ackerson 80' Gast 90"

BCC : double layer sliding

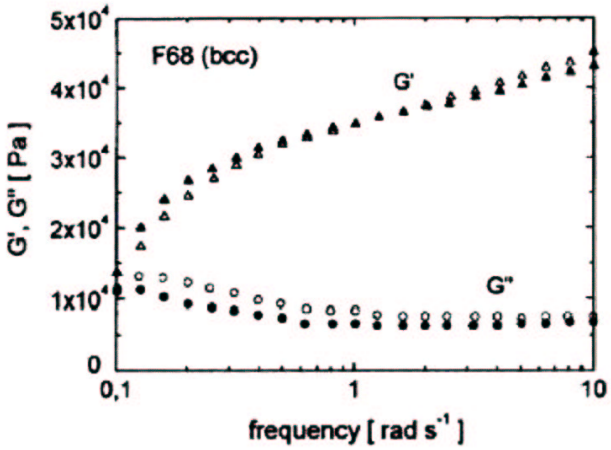




A typical creep test



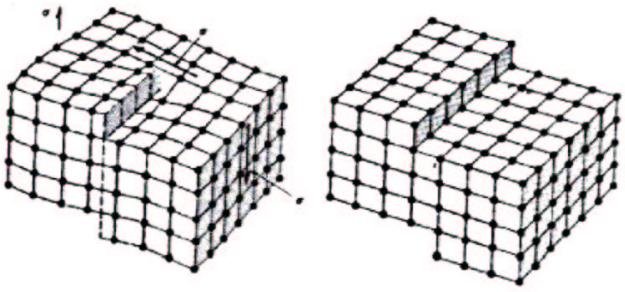
BCC soft crystal : linear regime



γ_{max} 1%

Glassy response

Textural transition: role of defects



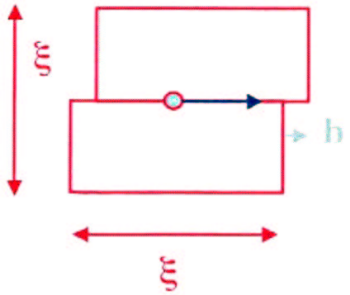
Flow induced by
- dislocations glide/climb
- dislocation proliferation

Orowan's mechanism

Low shear rate regime
Evidence for dislocation-mediated fow

$$\sigma \propto \dot{\gamma}^{1/3}$$

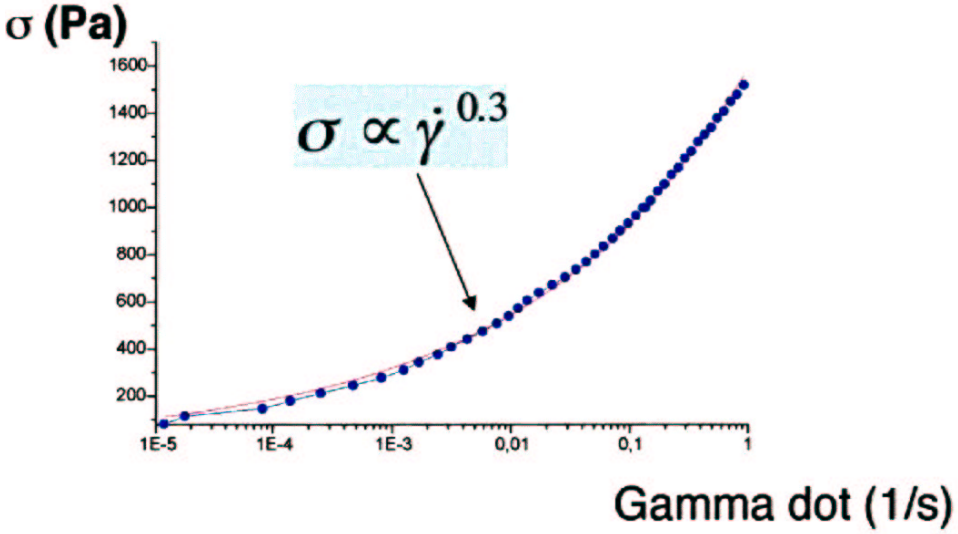
analogy with high temperature creep for metals
' relaxation of the stress by dislocation movements '



$$\left.\begin{aligned} \dot{\gamma} &= \frac{bv}{\xi^2} \\ v &= M\,\sigma_{int} \\ \sigma_{ext} &= \sigma_{int} = \frac{\mu b}{\xi} \end{aligned}\right\} \quad \sigma = \left(\frac{\mu b}{M}\right)^{1/3} \dot{\gamma}^{1/3}$$

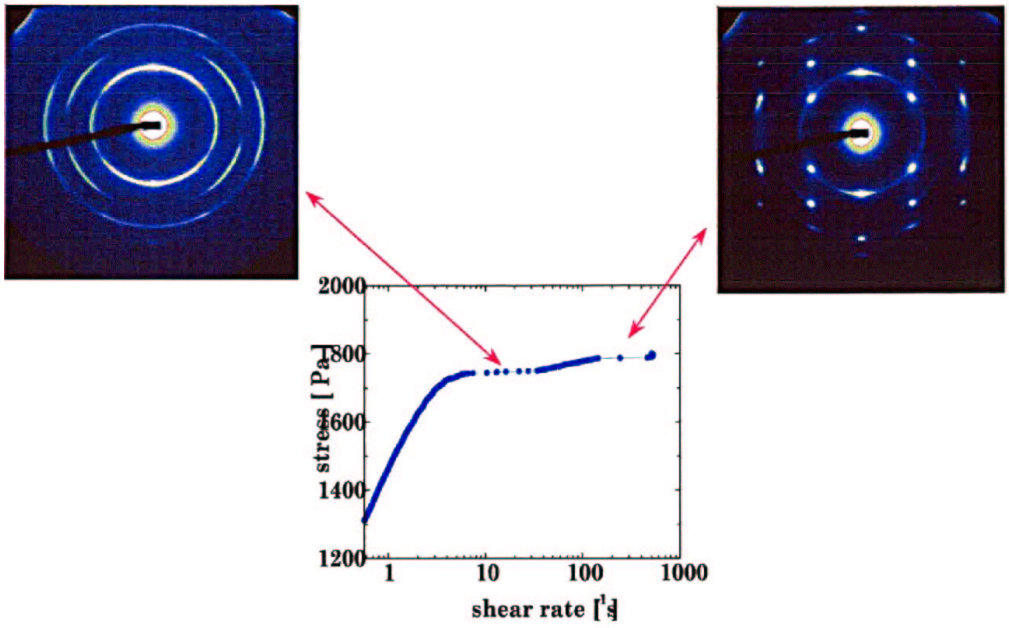
Orowan's argument

BCC phase under small stresses II



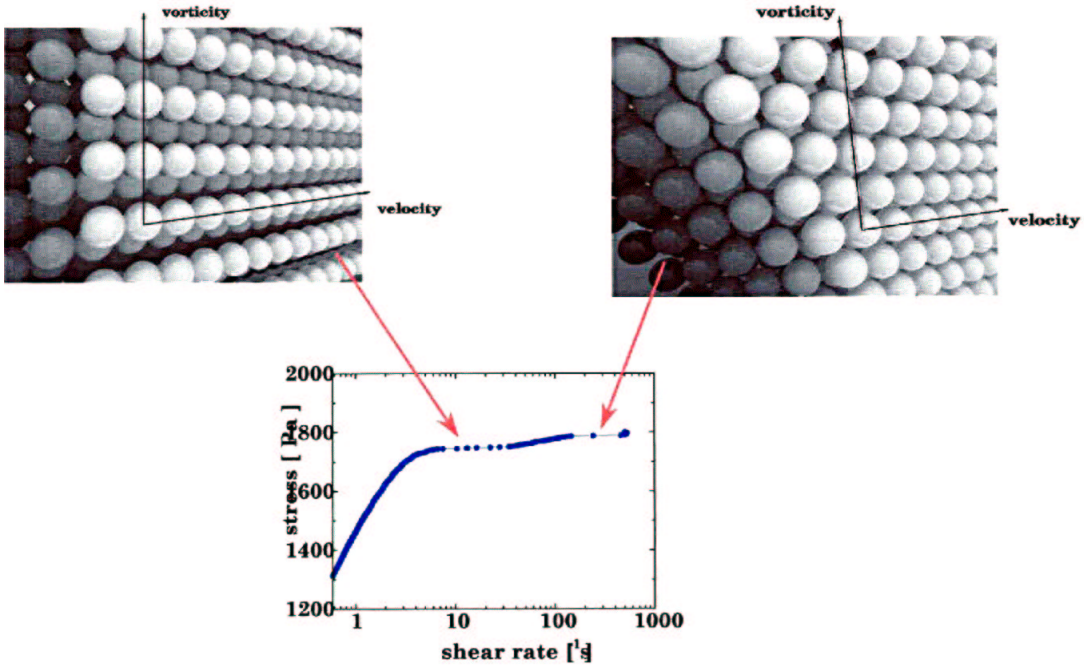
bcc: apparently no yield stress

Double layer-sliding transition

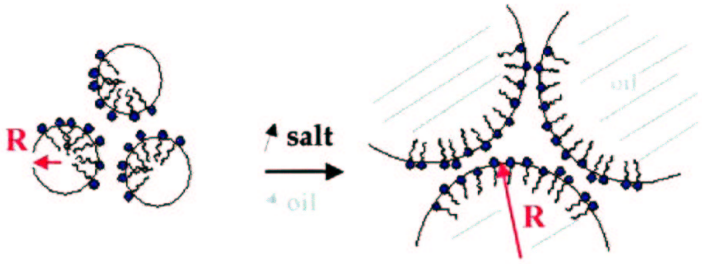


[*F68* $\phi = 46\%$ $T = 17°$]

BCC : double layer sliding



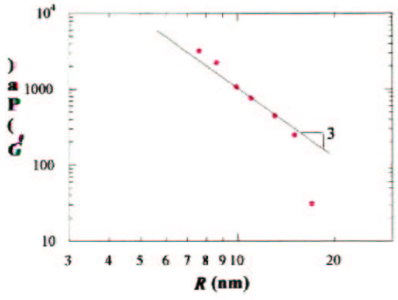
Highly swollen hexagonal phases



$R = 1/C_0$

$1.5 < R < 17$ nm

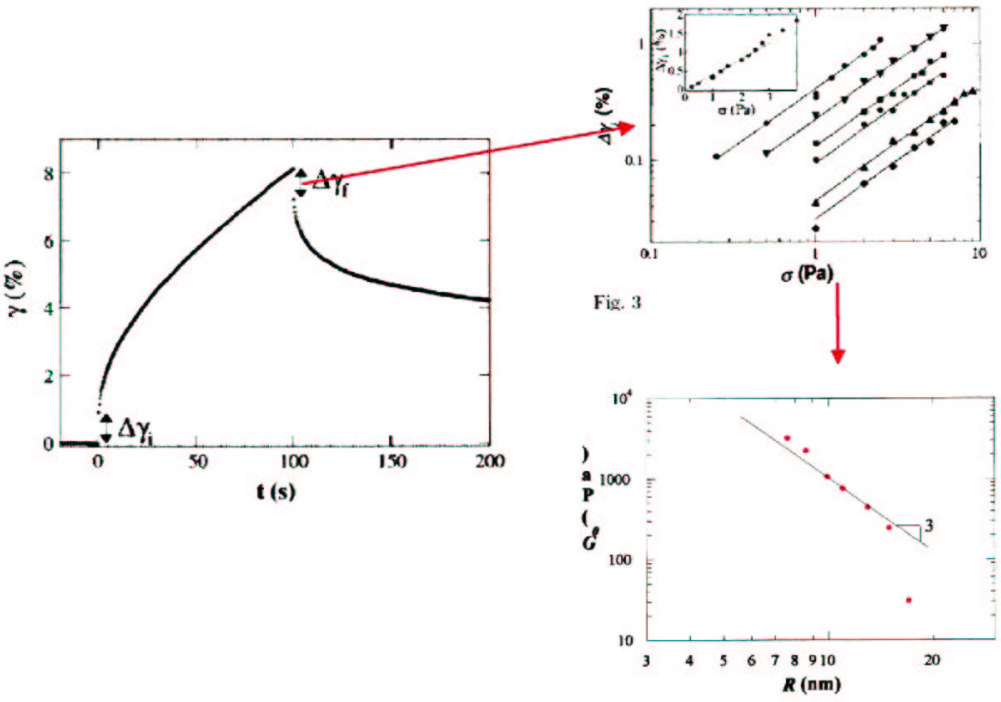
⇒ control of the spontaneous curvature C_0 through ionic strength



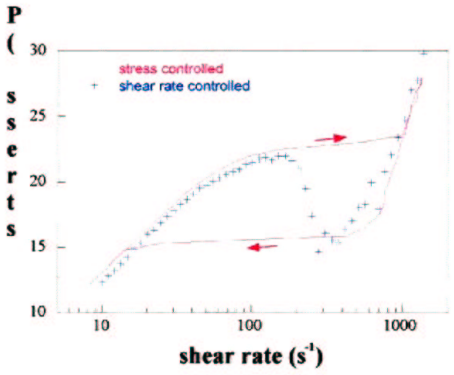
$G_0 \sim 1 / R^3$

⇒ strong softening upon swelling

Creep behaviour of the hexagonal phase



Flow curve of a swollen hexagonal phase

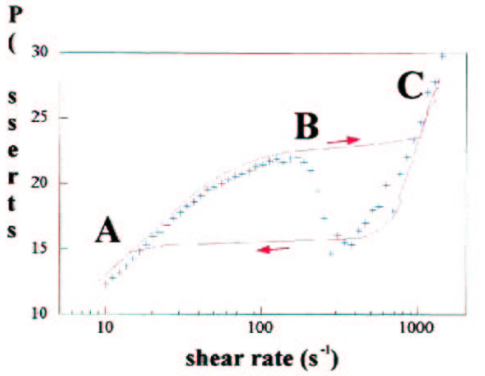


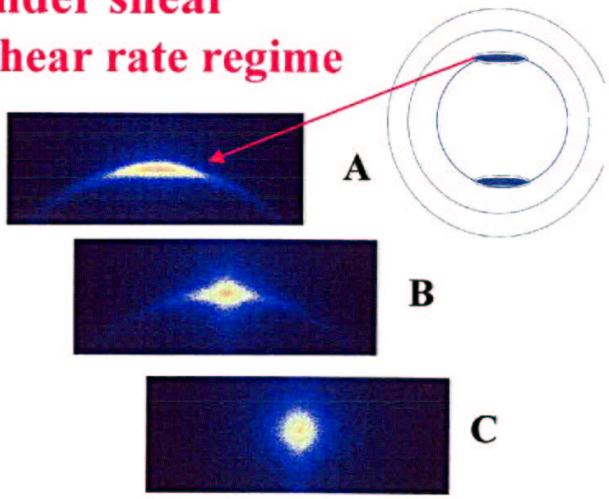
- **low rates** *shear-thinning* for $\dot{\gamma} \leq 30\ s^{-1}$, $\sigma \approx \dot{\gamma}^{1/3}$
- **high rates** ($\dot{\gamma} \geq 1000 s^{-1}$) *Bingham fluid* $\sigma = \sigma_0 + \eta\dot{\gamma}$

($\sigma_0 = 8.8$ Pa, $\eta = 14$ cP)

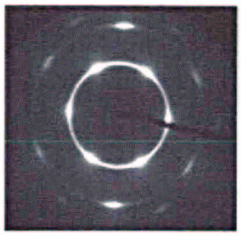
→ **shear-induced transition (structure? texture? ...)**

SAXS under shear
intermediate shear rate regime



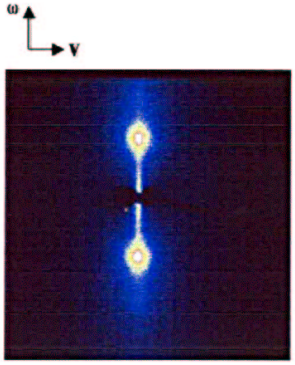


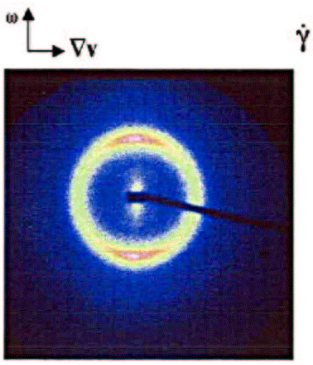
Coexistence of 2 types of structures



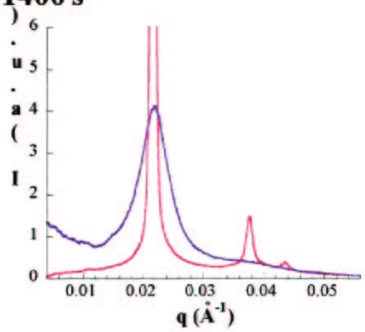
rest after shear at 393 s^{-1}

SAXS under shear - High shear rate regime

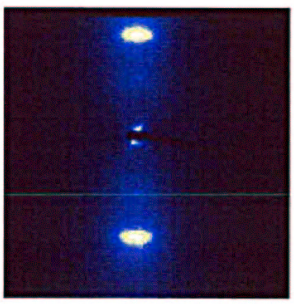


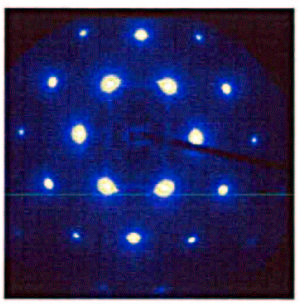


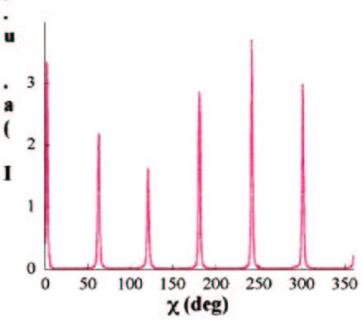
$\dot{\gamma} = 1400\ s^{-1}$



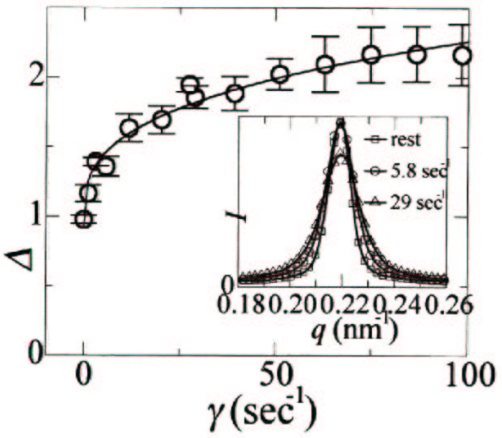
at rest







Low rates regime
Evidence for dislocation proliferation

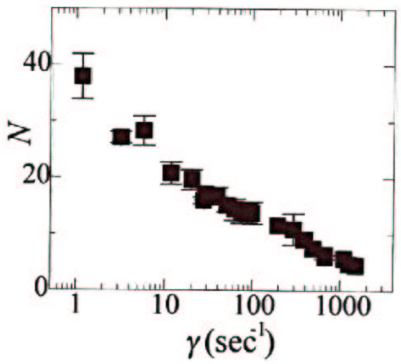


Δq/q :Structure factor width

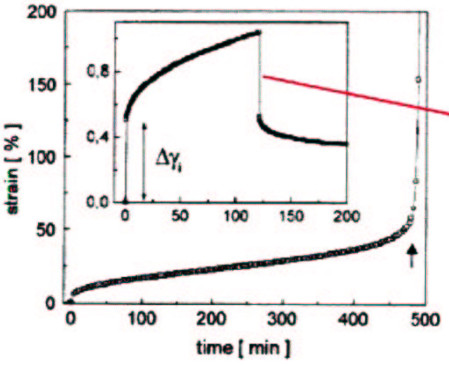
$\Delta q/q \sim \dot{\gamma}^{1/3}$

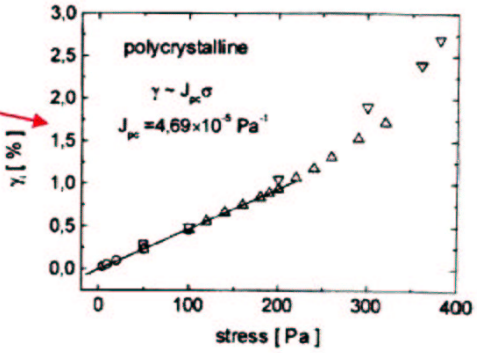
Average distance between dislocations

$\xi \sim \dot{\gamma}^{-1/3}$



FCC phase under small stresses I
Elastic modulus

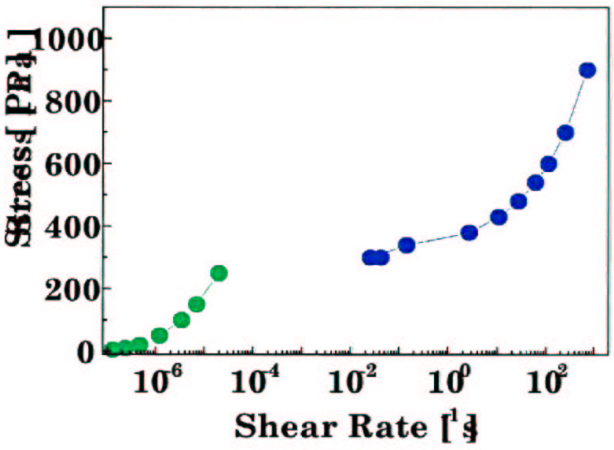




Creep test 100 Pa

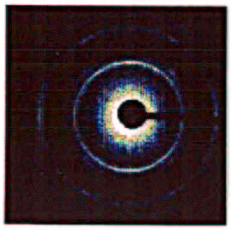
Elastic modulus 2 10^4 Pa

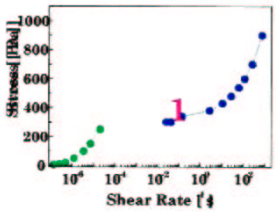
FCC crystal flow curve

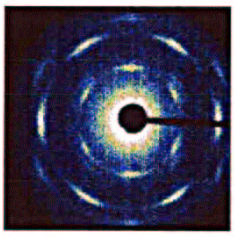


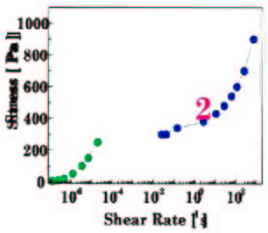
[*F108* $\phi = 33\%$ $T = 25°$]

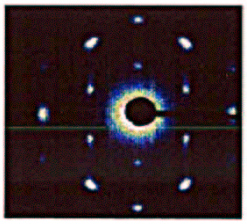
FCC : Structure /Rheology

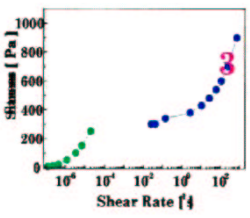




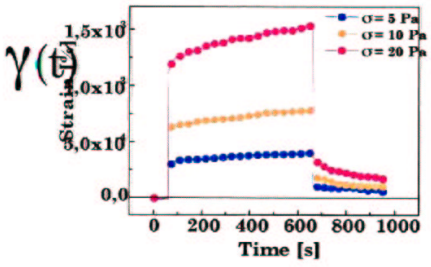




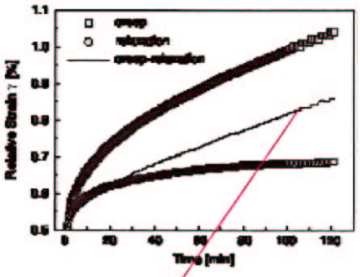


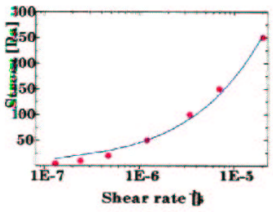


FCC : creep and dislocations

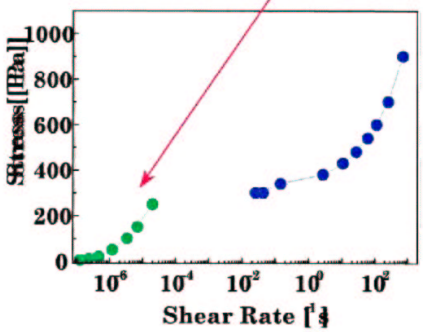


$\gamma(t)$





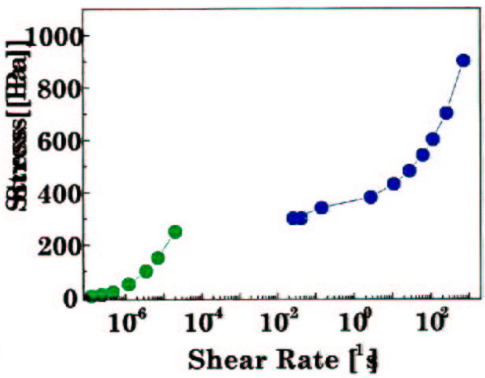
$\sigma \sim \gamma^{1/2}$

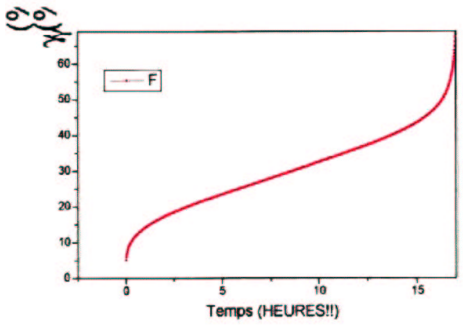


[*F108* $\phi = 33\%$ $T = 25°$]

FCC : creep and flow I

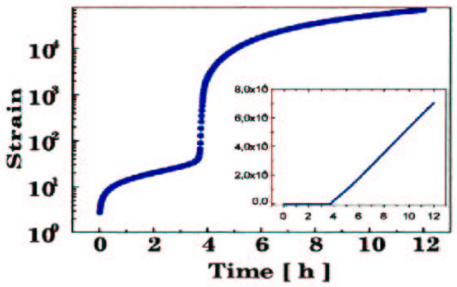
$\sigma_{'yield'}$: 300 Pa

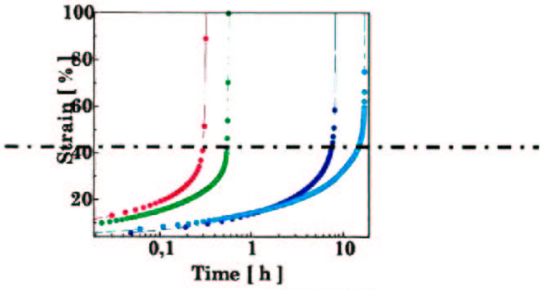


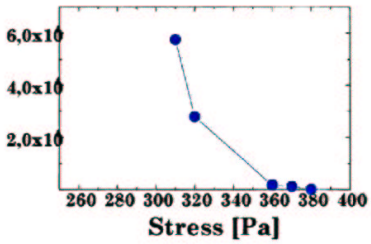


σ=310 Pa

FCC : creep and flow II

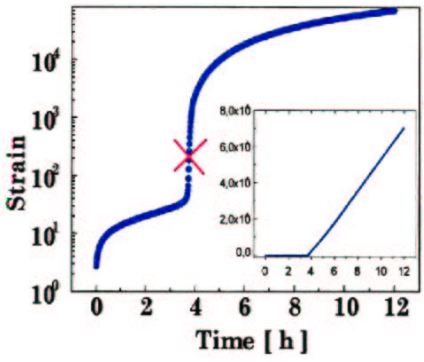


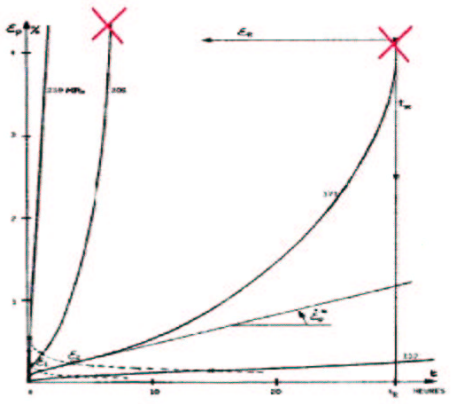




$\gamma_{flow} \sim 37\%$

Creep/flow transtion : fracture





Creep of *fcc* phase
Transition to flow

Creep of a metal
Transition to fracture

Nucleation of shear-banding is analogous to fracture in metals