Thixotropy of SCC and Its Effects on Formwork Pressure

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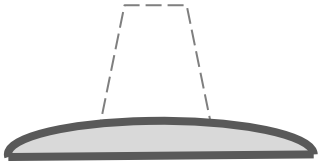
SCC would be impossible without thixotropy.

Due to thixotropy, concrete exhibits higher viscosity when at rest than when flowing.



Flows Under Its Own Mass

When SCC is flowing, a low viscosity means minimal resistance to flow.

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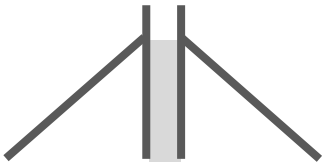

Formwork Pressure

When SCC is at rest, a high viscosity reduces formwork pressure…

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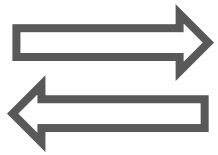
Segregation Resistance

…and prevents particles from settling.

Outline

What is Thixotropy?

Thixotropy is the reversible, isothermal, time-dependent decrease in viscosity when a fluid is subjected to increased shear stress or shear rate.

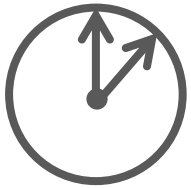


Reversible

Viscosity will increase to its original value when the shear stress or shear rate is decreased to its original value.

Isothermal

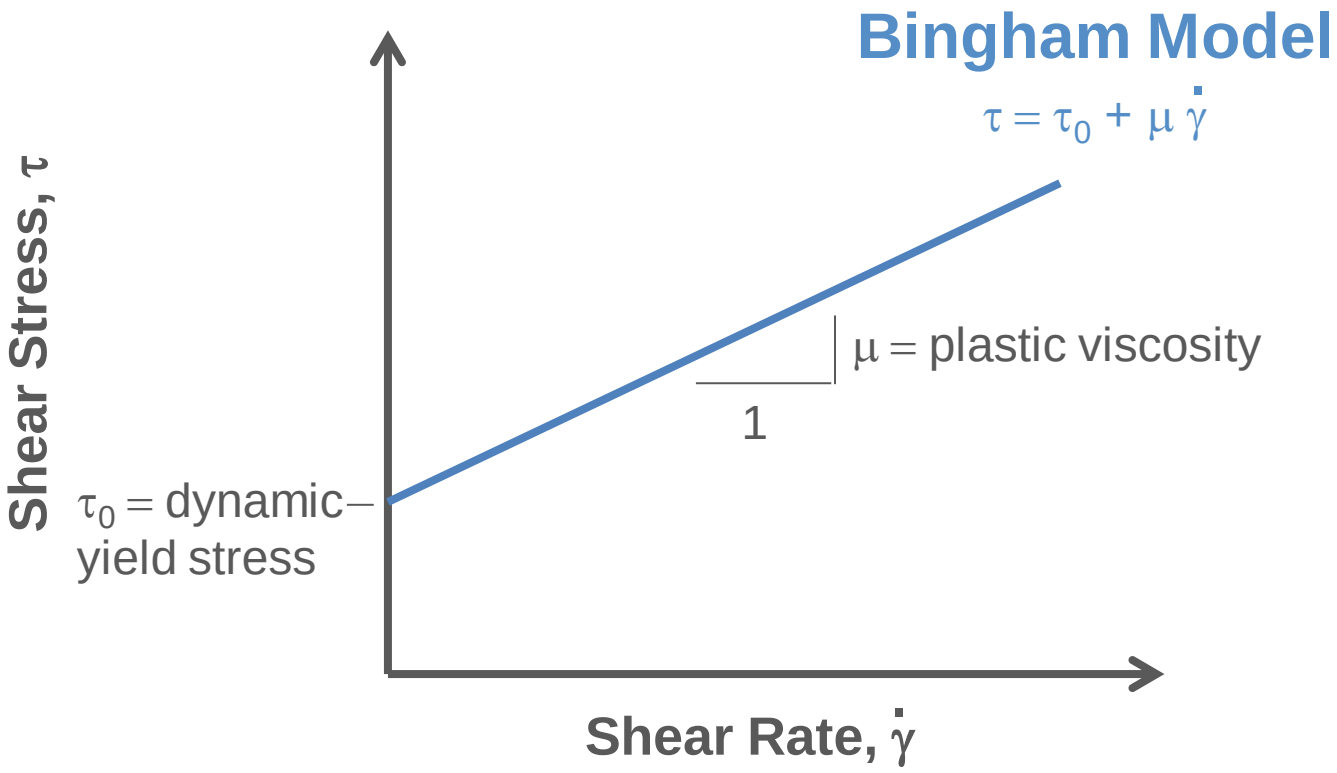
Independent from changes in viscosity due to changes in temperature.



Time-Dependent

Change in viscosity occurs over a period of time, rather than instantaneously.

What is Thixotropy?



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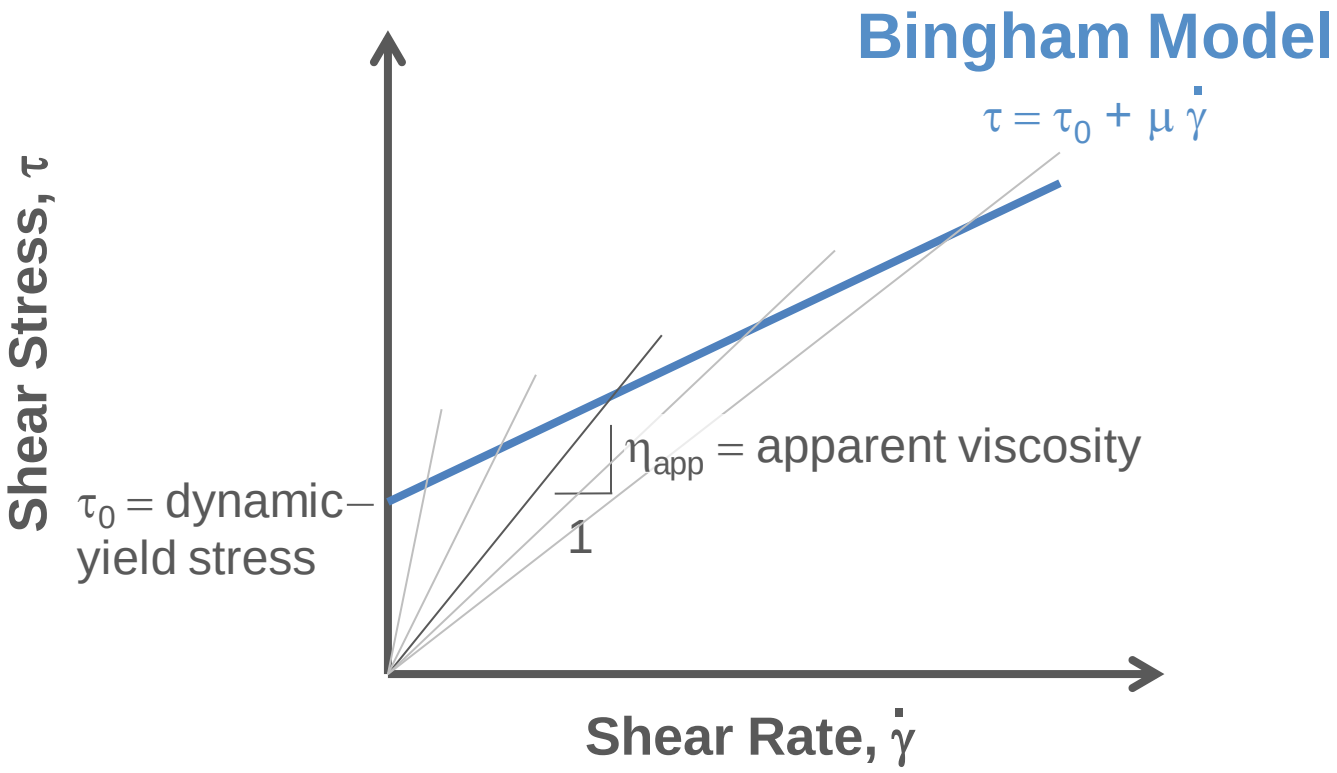
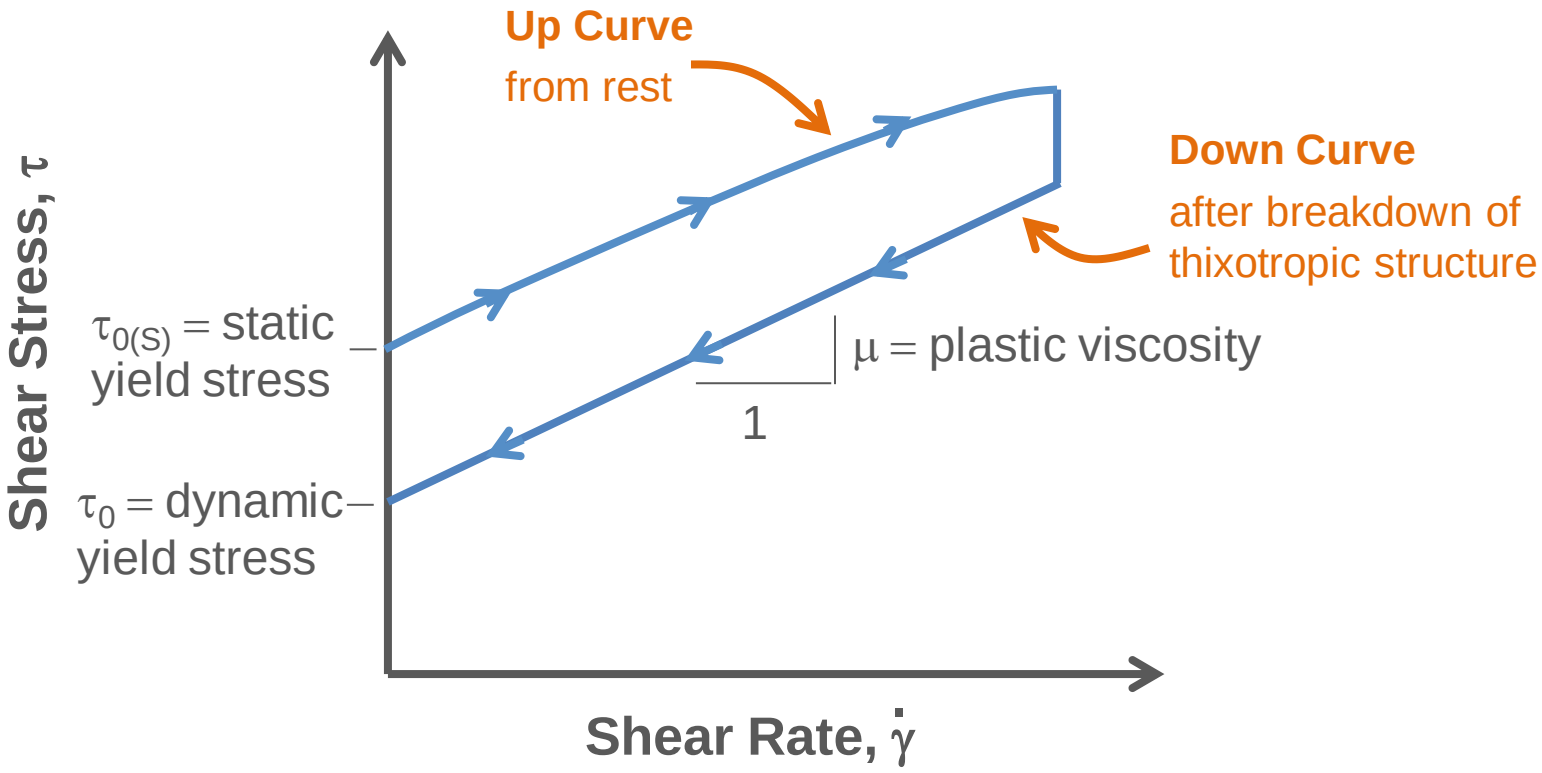


apparent viscosity is used in the definition of thixotropy

What is Thixotropy?



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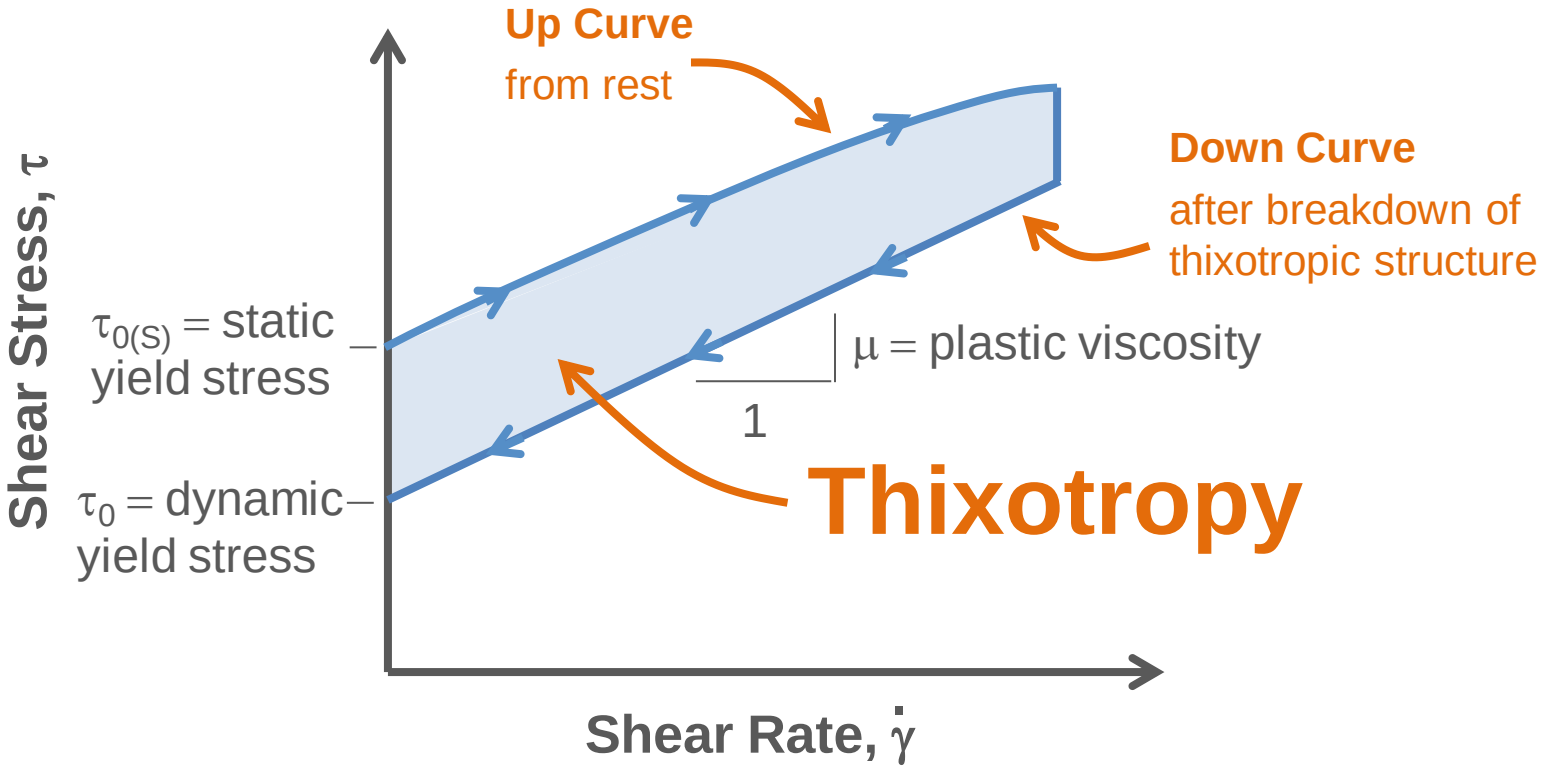
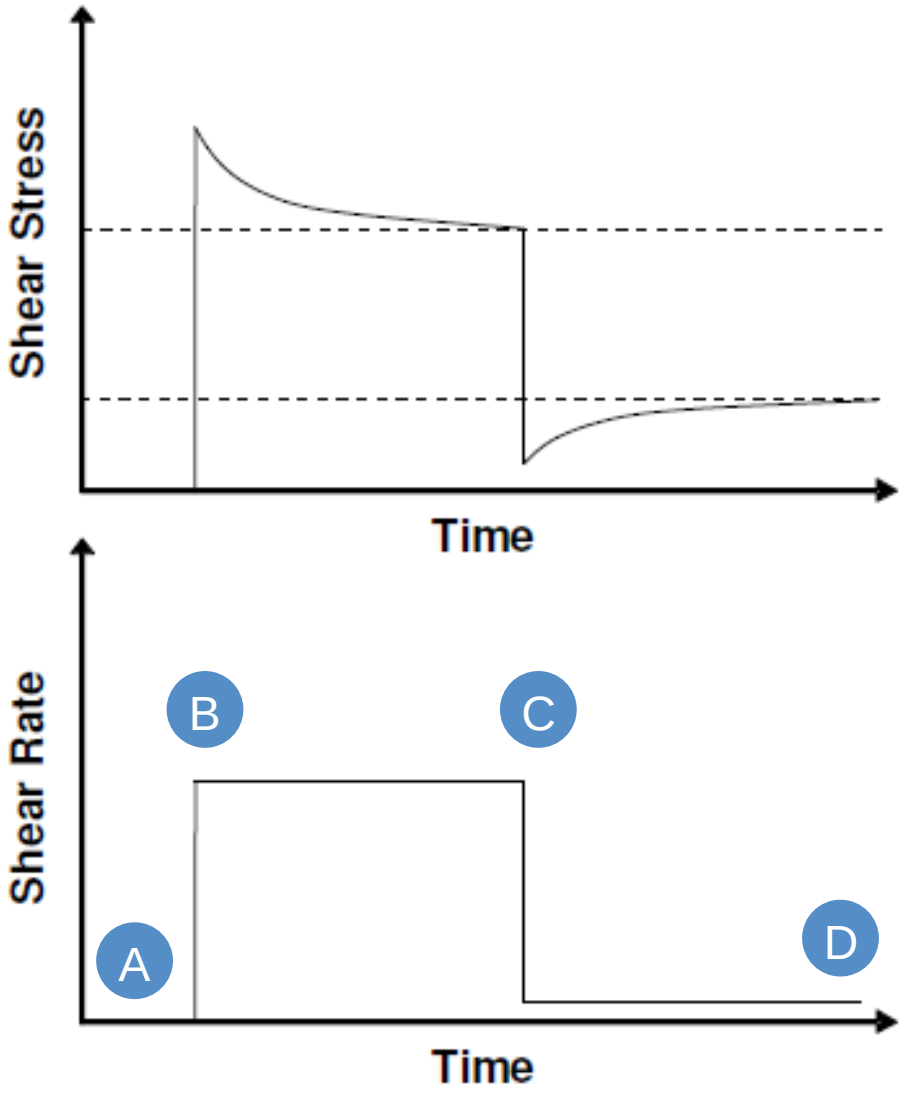


Static Yield Stress
Minimum shear stress to initiate flow from rest

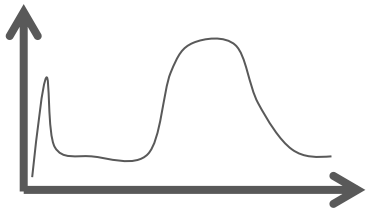
Dynamic Yield Stress
Minimum shear stress to maintain flow

Plastic Viscosity
Change in shear stress per change in shear rate, above dynamic yield stress

What is Thixotropy?

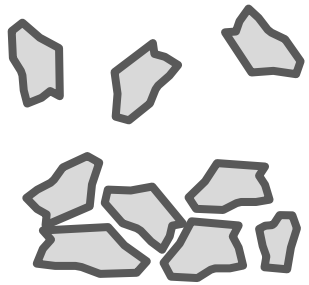


Thixotropy Should Not Be Confused With…



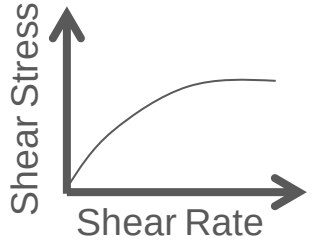
Hydration

An increase in viscosity due to hydration. **Not reversible.**



Segregation

An change in viscosity due to a denser or less dense concentration of aggregates.

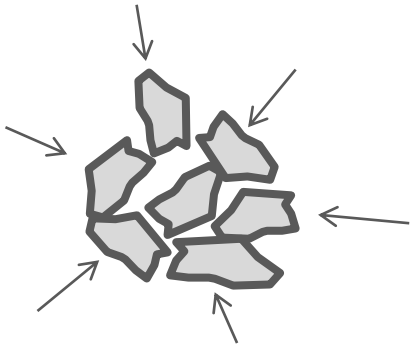


Shear Thinning

A decrease in viscosity with increased shear rate. **Not time-dependent.**

Why is Concrete Thixotropic?

At Rest

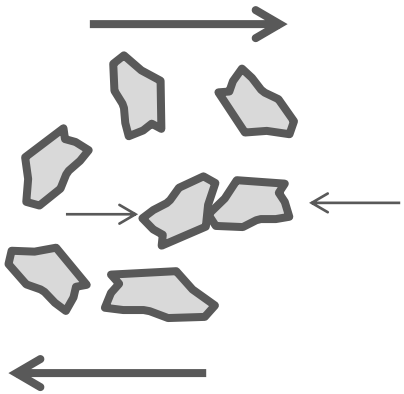


Cement particles flocculate to form a three-dimensional, networked structure

- ✓ van der Waals attraction
- ✓ Brownian motion

↑ Viscosity

Flowing



An equilibrium is achieved between:

- ✓ Shear breaking apart flocs
- ✓ Flocculation between contacting cement particles

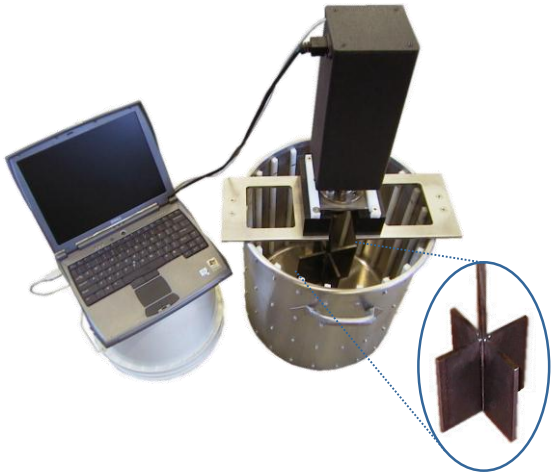
↓ Viscosity

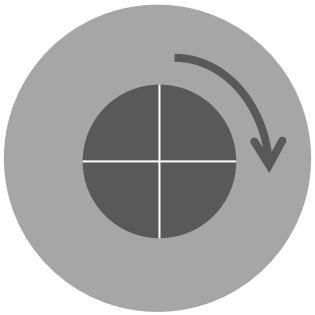
Outline

Measurement of Thixotropy

1. Hysteresis Loop Test
2. Constant Shear Rate Test
3. Stress Growth Test

These tests make use of a rotational rheometer for concrete





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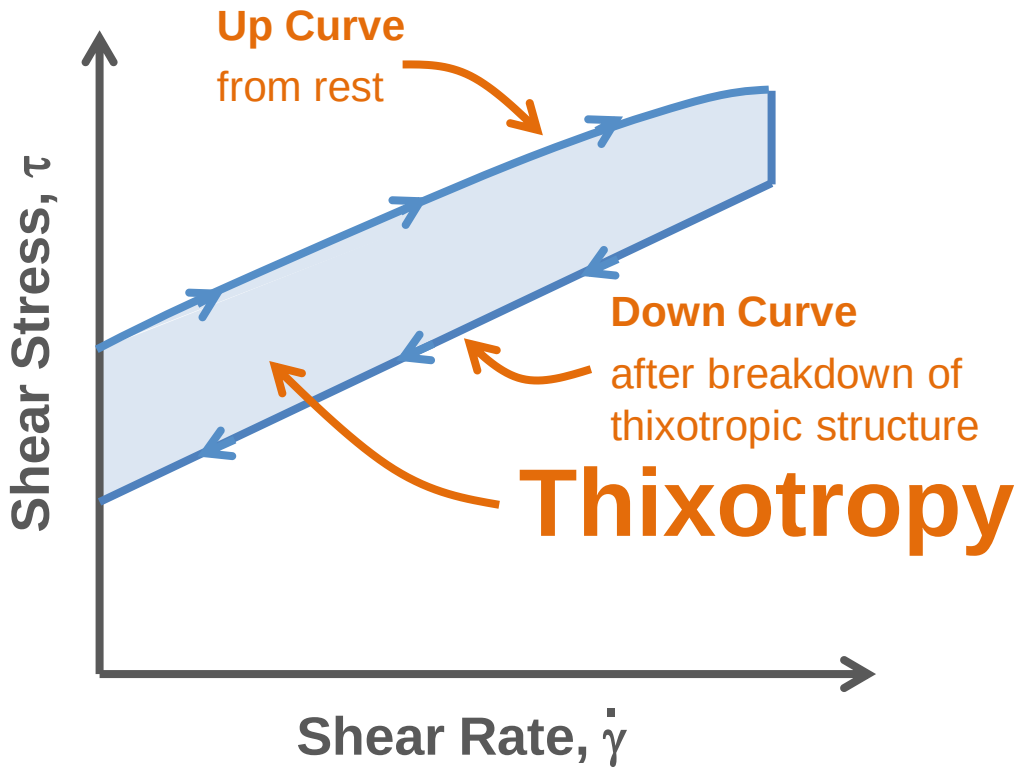
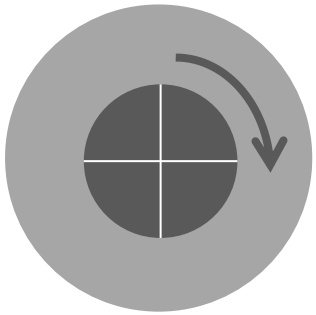
❶ Hysteresis Loop Test



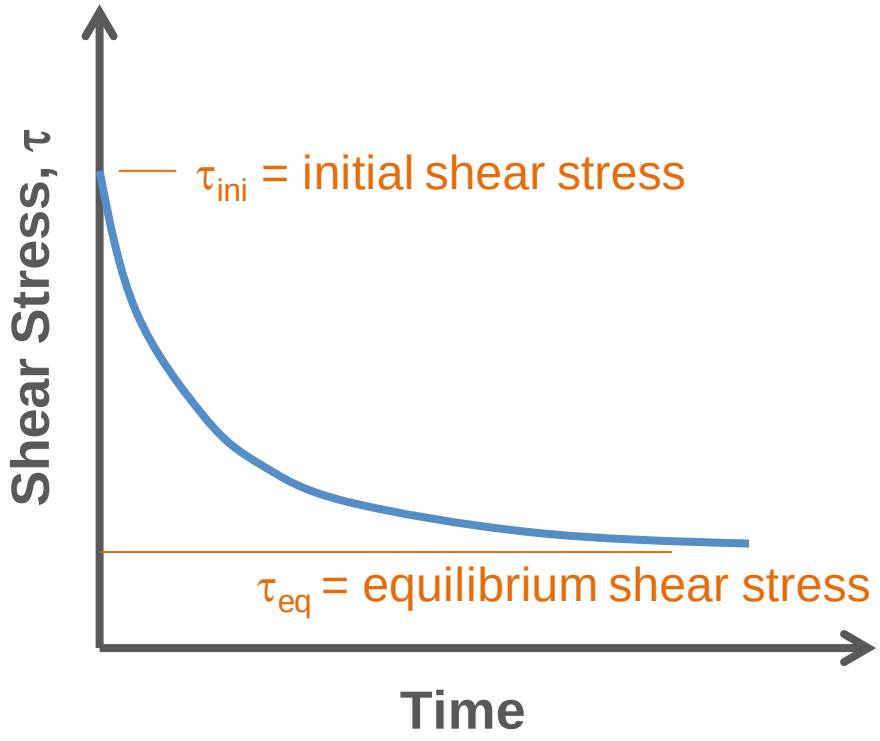
↑ Area = ↑ Thixotropy

In a rheometer…

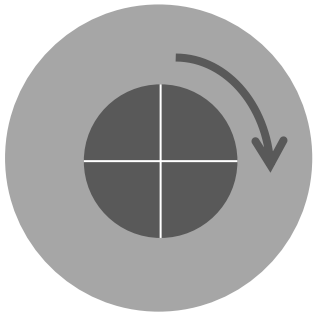


1) Maintain concrete initially at rest.
2) Increase shear rate from zero to maximum.
3) Hold shear rate at maximum to fully break down thixotropic structure.
4) Decrease shear rate from maximum to zero.
5) Calculate area between up and down curves.

❷ Constant Shear Rate Test



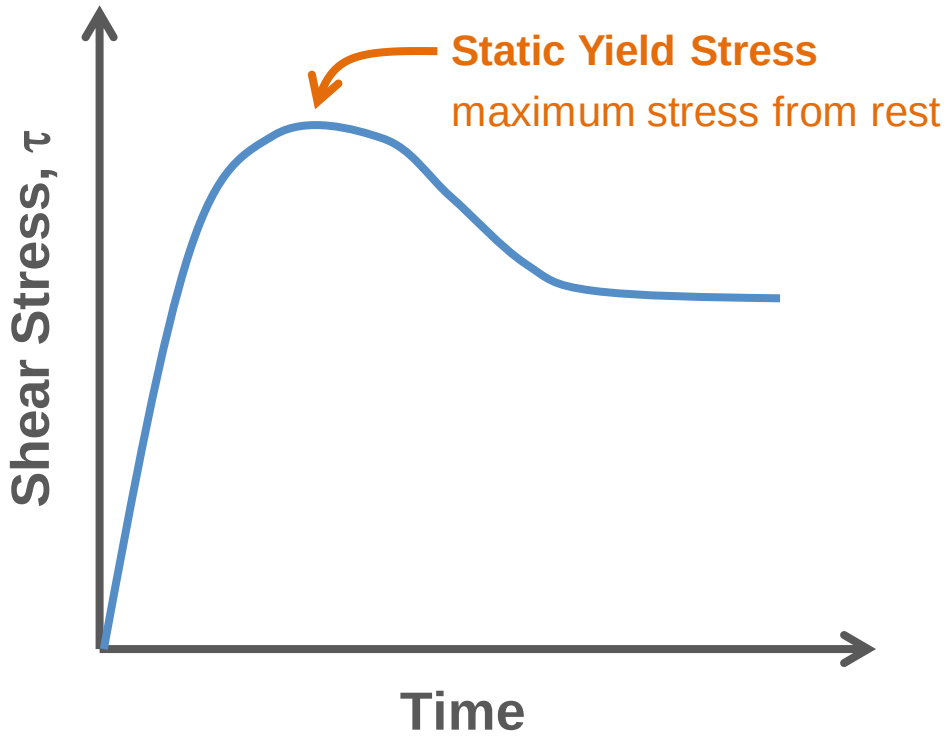
In a rheometer…



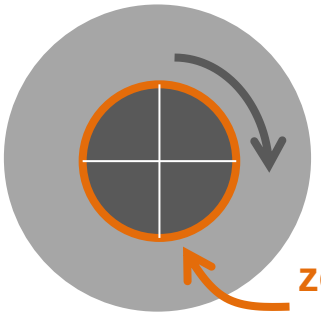
1) Maintain concrete initially at rest.
2) Apply a constant shear rate.
3) Measure the change in shear stress over time.
4) Compare the difference in shear stress (or apparent viscosity) initially and at equilibrium.

↑ Difference in shear stress = ↑ Thixotropy

❸ Stress Growth Test



In a rheometer…



1) Maintain concrete initially at rest.
2) Apply shear at a low, constant rate.
3) Measure increase in torque.
4) Record maximum torque.
5) Convert torque to shear stress to calculate static yield stress.

↑ Difference between static and dynamic yield stress = ↑ Thixotropy

Measuring Thixotropy

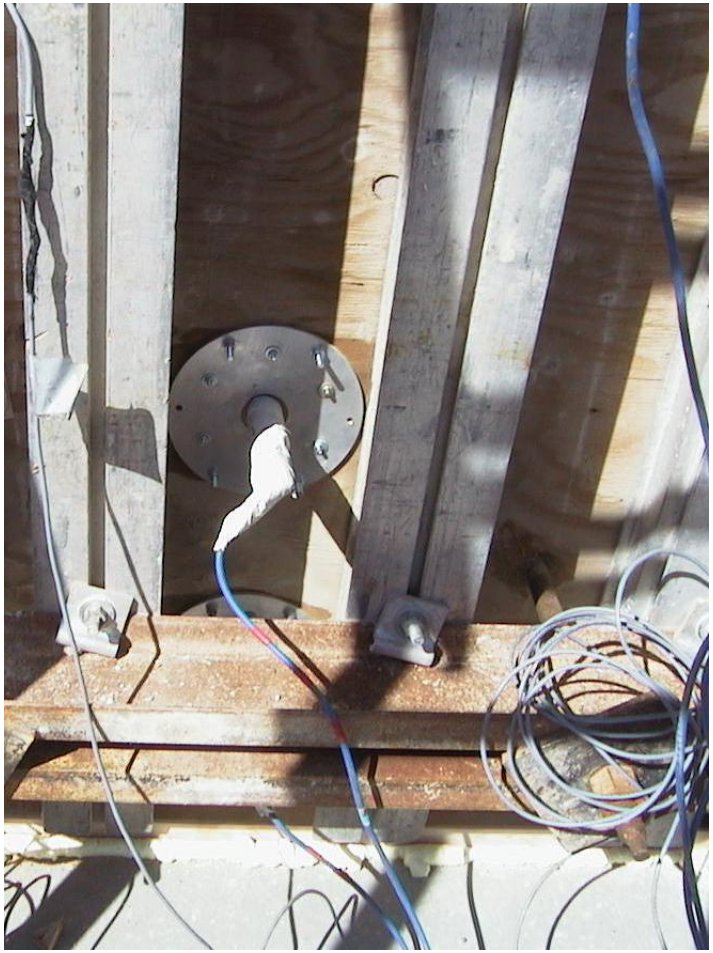
CAUTION

Results are highly dependent on the test protocol.

- ✓Consistent sample preparation
- ✓Consistent rest period before test
- ✓Consistent shearing regime

Outline

Role of Thixotropy in Formwork Pressure



Formwork pressure is related to concrete rheology

Pressure increases with slump (or slump flow)

Concrete is at rest in forms; therefore, static yield stress is relevant

Static yield stress is affected by dynamic yield stress and thixotropy

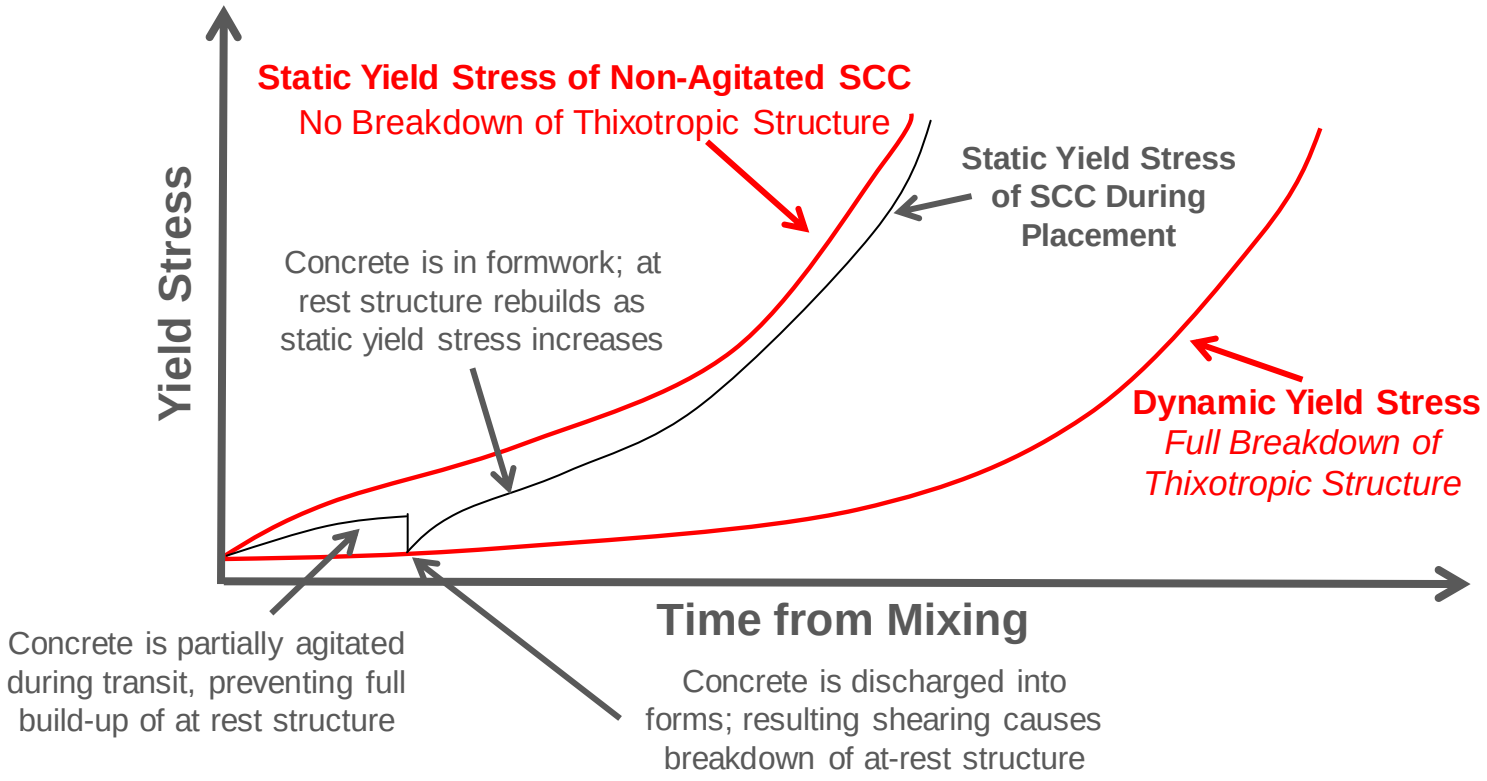
SCC must be designed to flow under its own mass and exert low formwork pressure

Low dynamic yield stress (self flow)

Fast increase in static yield stress due to thixotropy (reduced formwork pressure)

Thixotropy in a Concrete Delivery and Placement

Change in yield stress from mixing through delivery and placement



Effects of Rheology on SCC Formwork Pressure

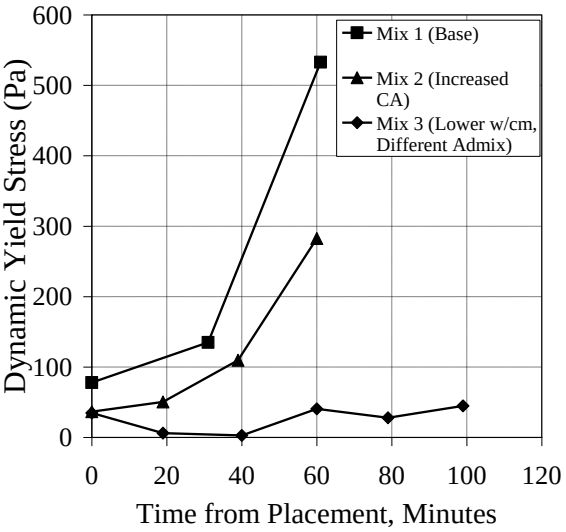
CAUTION

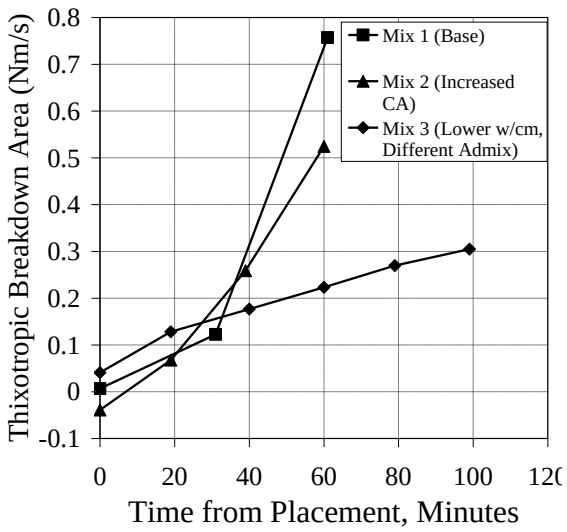
Thixotropy is needed, but should not be too high.

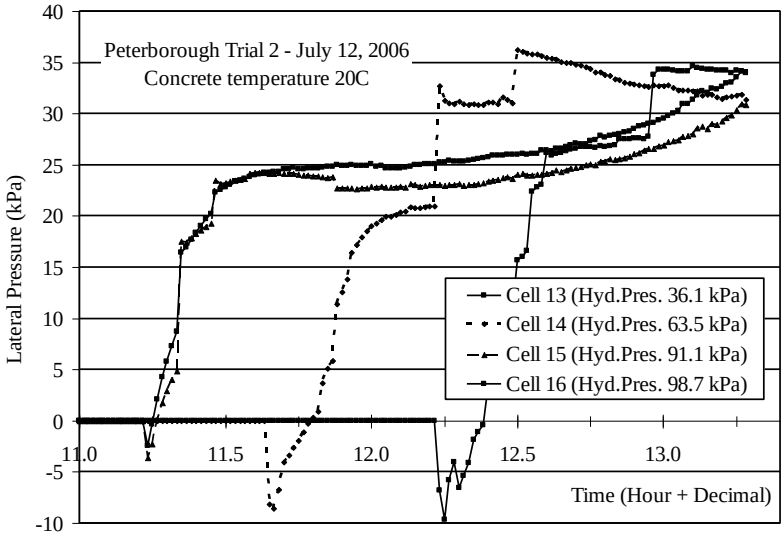
- x Cold joints
- x Poor pumpability
- x Restarting placement after rest (for example, bucket placement)

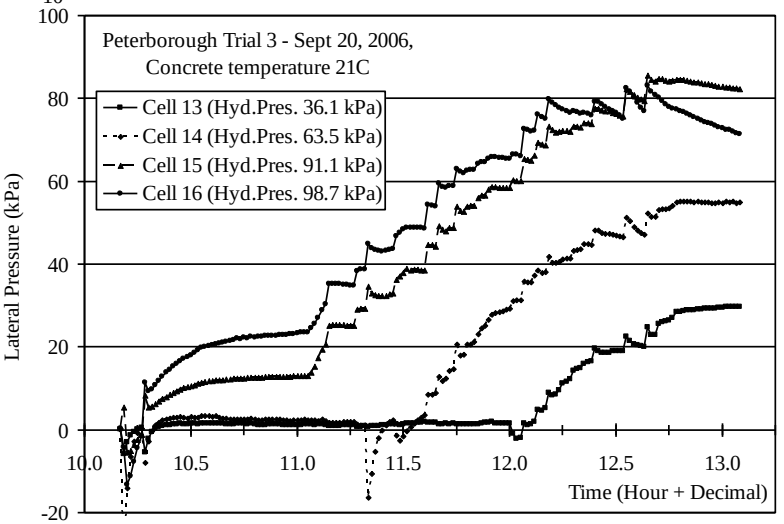
Outline

Effects of Rheology on SCC Formwork Pressure









Mix 1 and 2: Fast increase in yield stress and thixotropy – low formwork pressure

Mix 3: Slow increase in yield stress and thixotropy – high formwork pressure

Results confirm that thixotropy reduces formwork pressure.

Reference: Koehler, E.P., Keller, L., and Gardner, N.J. (2007). "Field Measurements of SCC Rheology and Formwork Pressure" Proceedings of SCC 2007, Ghent, Belgium

Outline

01	What is Thixotropy?
02	Measurement of Thixotropy
03	Role of Thixotropy in Formwork Pressure
04	Field Data
05	Conclusions

Conclusions

SCC is not possible without thixotropy.

Thixotropy is the reversible, isothermal, time-dependent decrease in viscosity when a fluid is subjected to increased shear stress or shear rate.

SCC should have:

- **Low dynamic yield stress (self-flow)**
- **Fast increase in static yield stress due to thixotropy (reduced formwork pressure)**

Thank You.