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Material Models in SCC Mix Design

Claus Pade, SCC-seminar in Copenhagen, 19 June, 2006

Nytænkning gennem 100 år

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Role of Model in Mix Design

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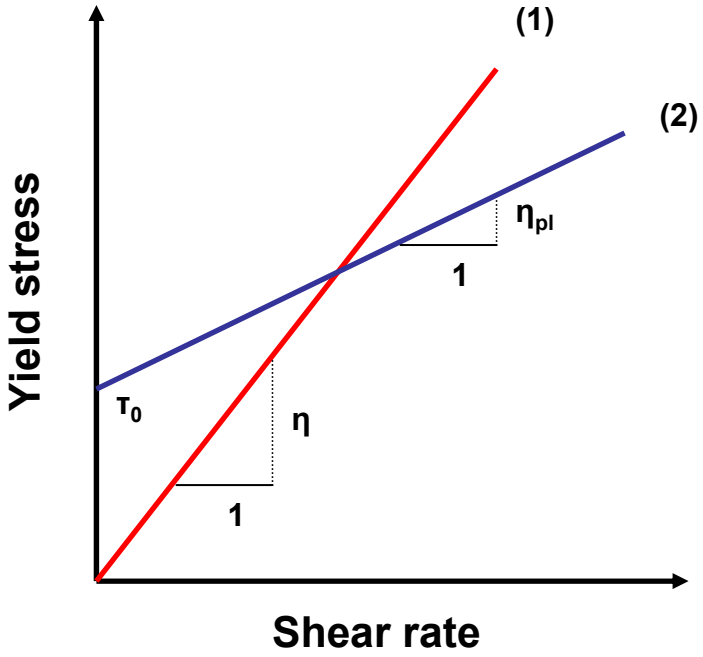
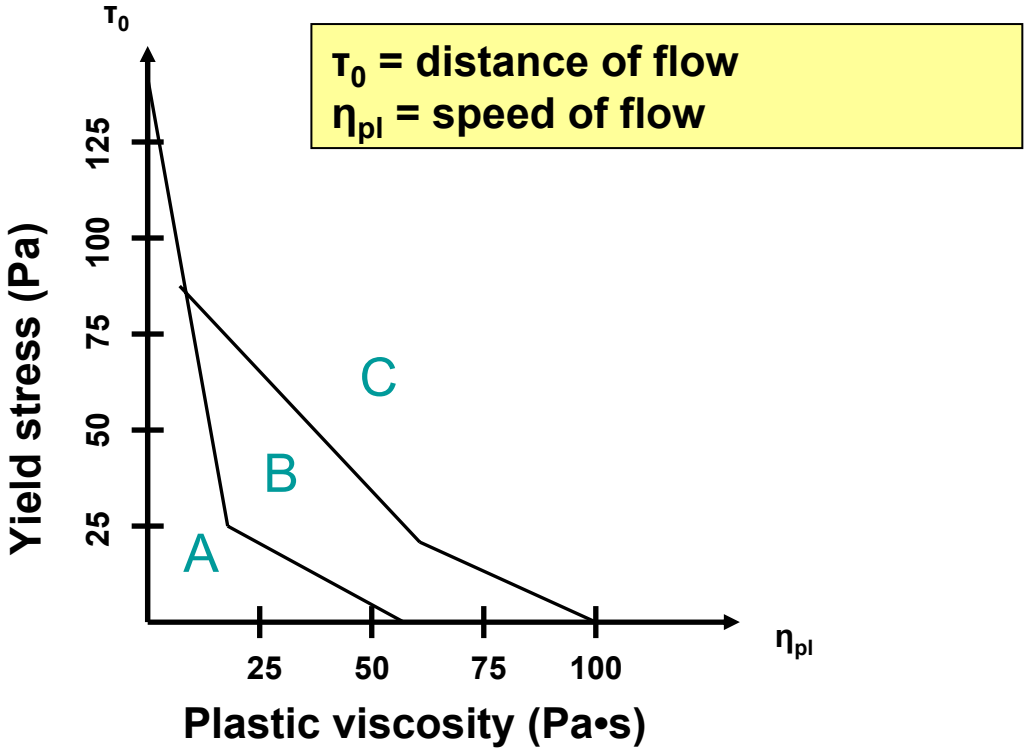
- **Estimate/predict the rheological behavior of concrete**





(1) Newtonian liquid (water)
(2) Bingham-material (concrete)

A: Separation
B: SCC
C: Not sufficient flow

Types of Model

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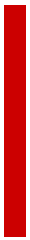
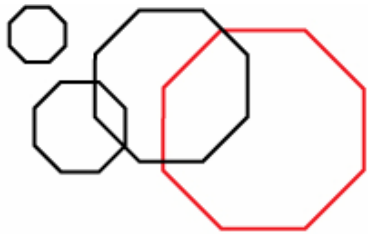
- **Emperic**
  - Too simplistic
  - It works but you don’t know why
- **Analytic**
  - Too complicated
  - It works and you know why





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Danish SCC-Consortium Model

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Originally proposed by Oh et al.:

$$\eta_{concrete} = \eta_{paste}\left(A_{\eta} \cdot \Gamma^{-B_{\eta}} + 1\right)$$

$$\tau_{0,concrete} = \tau_{0,paste}\left(A_{\tau} \cdot \Gamma^{-B_{\tau}} + 1\right)$$

$$\Gamma = \frac{1 - \varphi/\varphi^*}{f/k \cdot \varphi}$$

$\eta_{concrete}$, is the plastic viscosity of the concrete

η_{pasta}, is the plastic viscosity of the paste

$\tau_{0,concrete}$, is the yield stress of the concrete

$\tau_{0,pasta}$, is the yield stress of the paste

A_{η}, A_{τ}, B_{η}, B_{τ}, are constants

Γ, is the relative thickness of excess paste

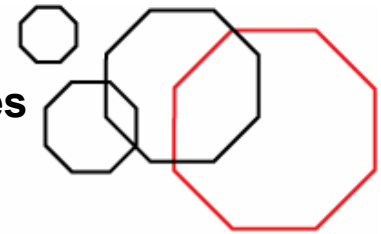
φ, is the volume fraction of the aggregate

φ^*, is the max volume fraction of the aggregate

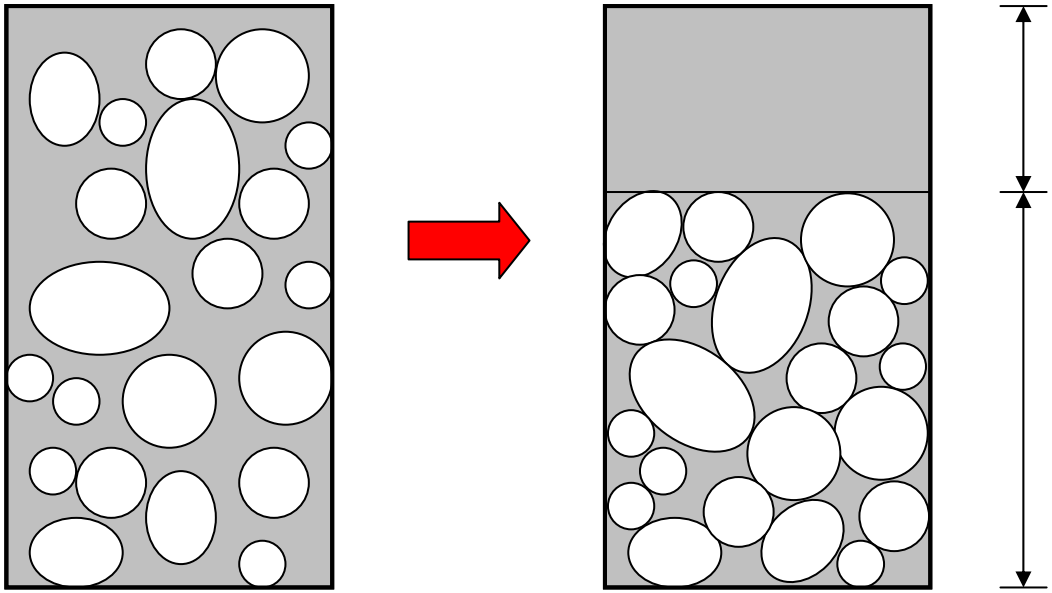
f/k, is a shape factor – related to the ratio between surface and volume of a particle with characteristic dimension 1

f/k (sphere) = 6

f/k > 6 for all other shapes

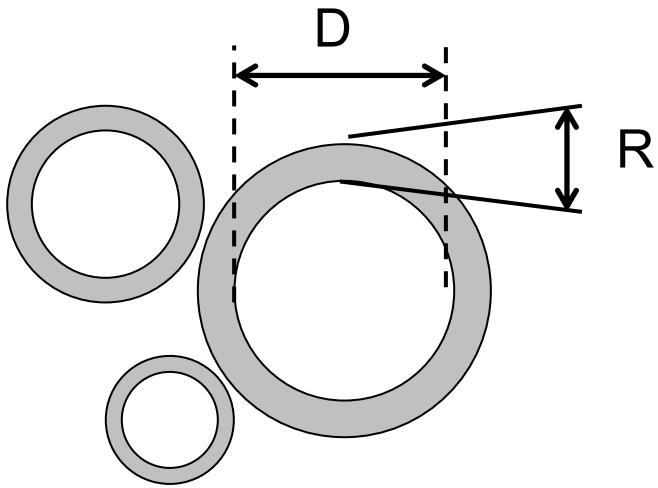


Elements of the Model



Excess paste

The excess of paste is found around each aggregate particle with Γ = R/D constant for all aggregate particles



Γ = R/D is the same for either particle

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Experimental Program

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$$\tau_{0,concrete} = \tau_{0,paste}\left(A_{\tau} \cdot \Gamma^{-B_{\tau}} + 1\right) \qquad \Gamma = \frac{1-\varphi/\varphi^*}{f/k \cdot \varphi}$$

$\tau_{0,paste}$
η_{paste}
} EMPA Zürich - Estimated from plate-plate rheological measurements

$\tau_{0,concrete}$
$\eta_{concrete}$
} DTI - Estimated using 4C Auto Slump Flow equipment

φ^*
φ/φ^*
} DTI - Estimated using the 4C Packing software

f/k
A
B
} Fit-parameters in regression analysis

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Materials and Composition

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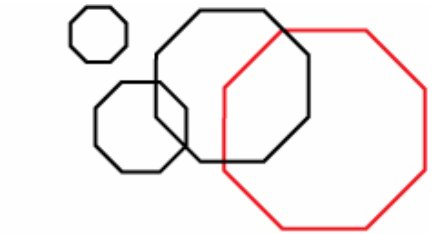
Mix 1		
0/2	4/8	8/16
Natural pit	Sea dredged	Sea dredged
Max packing	0.808	
w/c	0.35	
SP-konc	0.50	
Excess paste	110,120,130,140 L	

Mix 2		
0/2	4/8	8/16
Glass beads	Glass beads	Glass beads
Max packing	0.848	
w/c	0.35	
SP-konc	0.50	
Excess paste	100,110,120,130 L	

Mix 3		
0/4	4/8	8/16
Natural pit	Crushed granite	Crushed granite
Max packing	0.804	
w/c	0.35	
SP-konc	0.50	
Excess paste	160,170,180,190 L	

Identical pastes in all three mixtures



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4C Packing Diagrams

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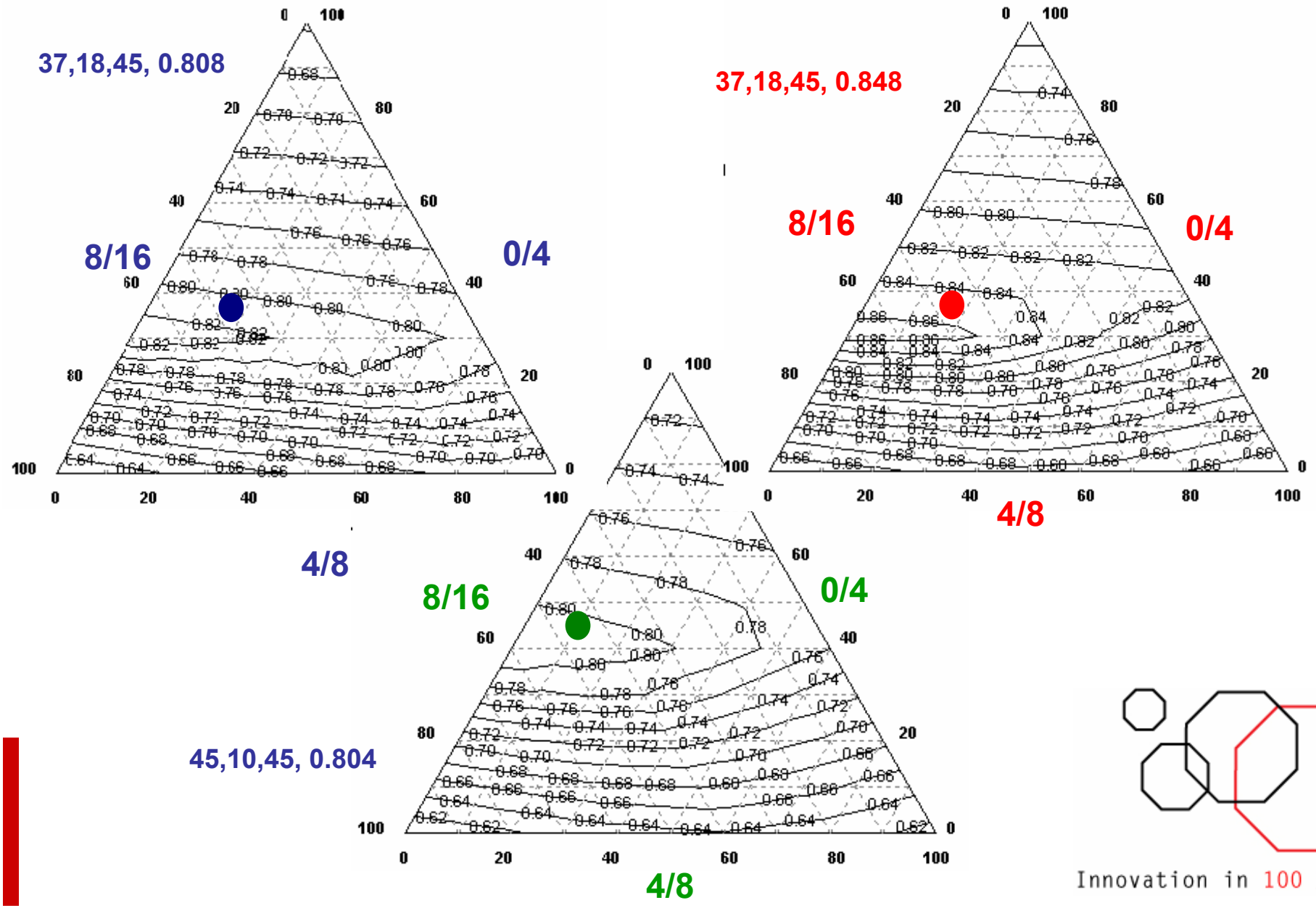

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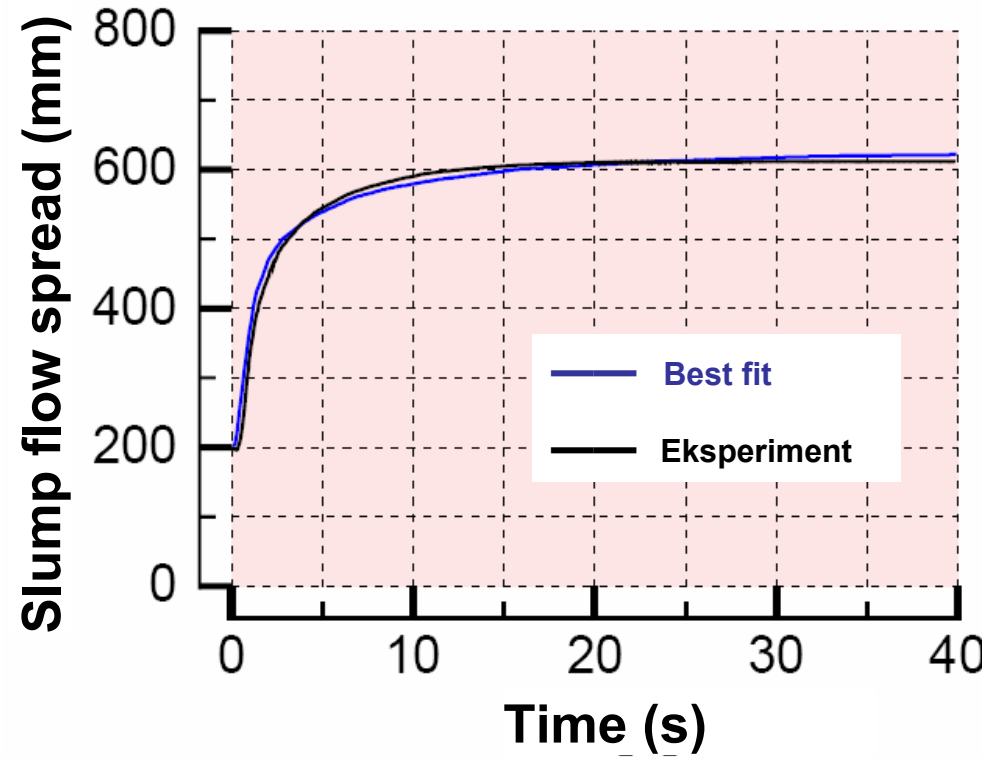
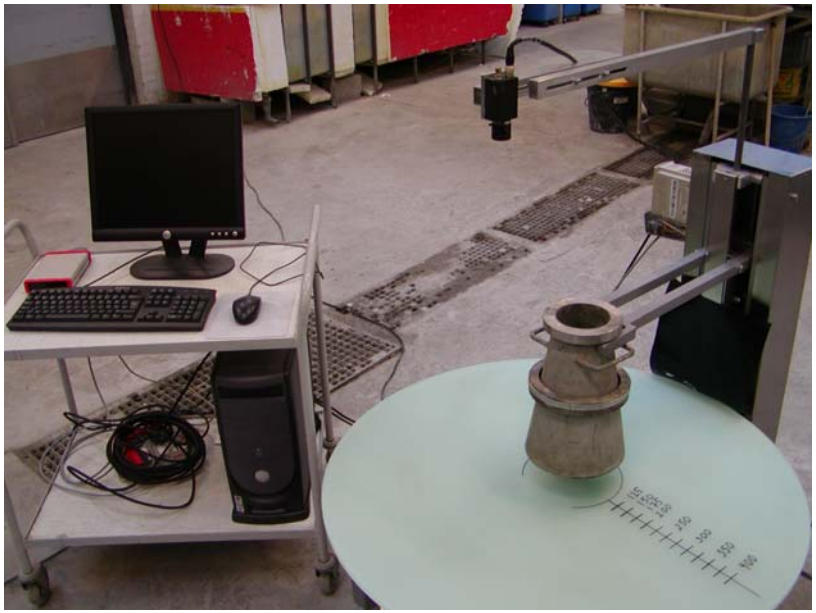
4C Auto Slump Flow





Yield stress = 26 Pa

Plastic viscosity = 44 Pa x s

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Results – Yield Stress

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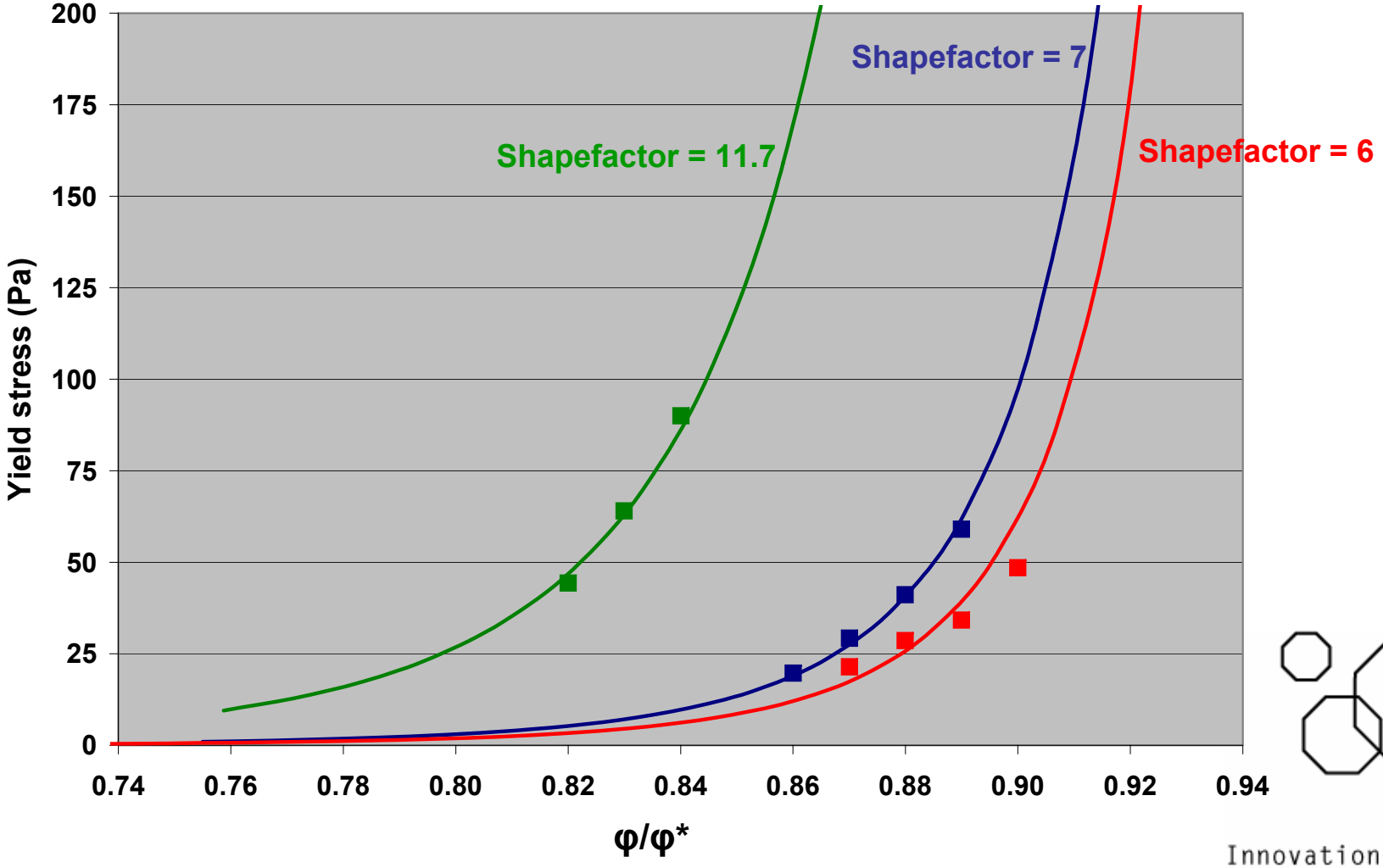
$$\tau_{0,concrete} = 4.5 \times 10^{-6} \times \Gamma^{-4.3} \qquad \Gamma = \frac{1 - \varphi/\varphi^*}{shapefactor \cdot \varphi}$$



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Results – Yield Stress

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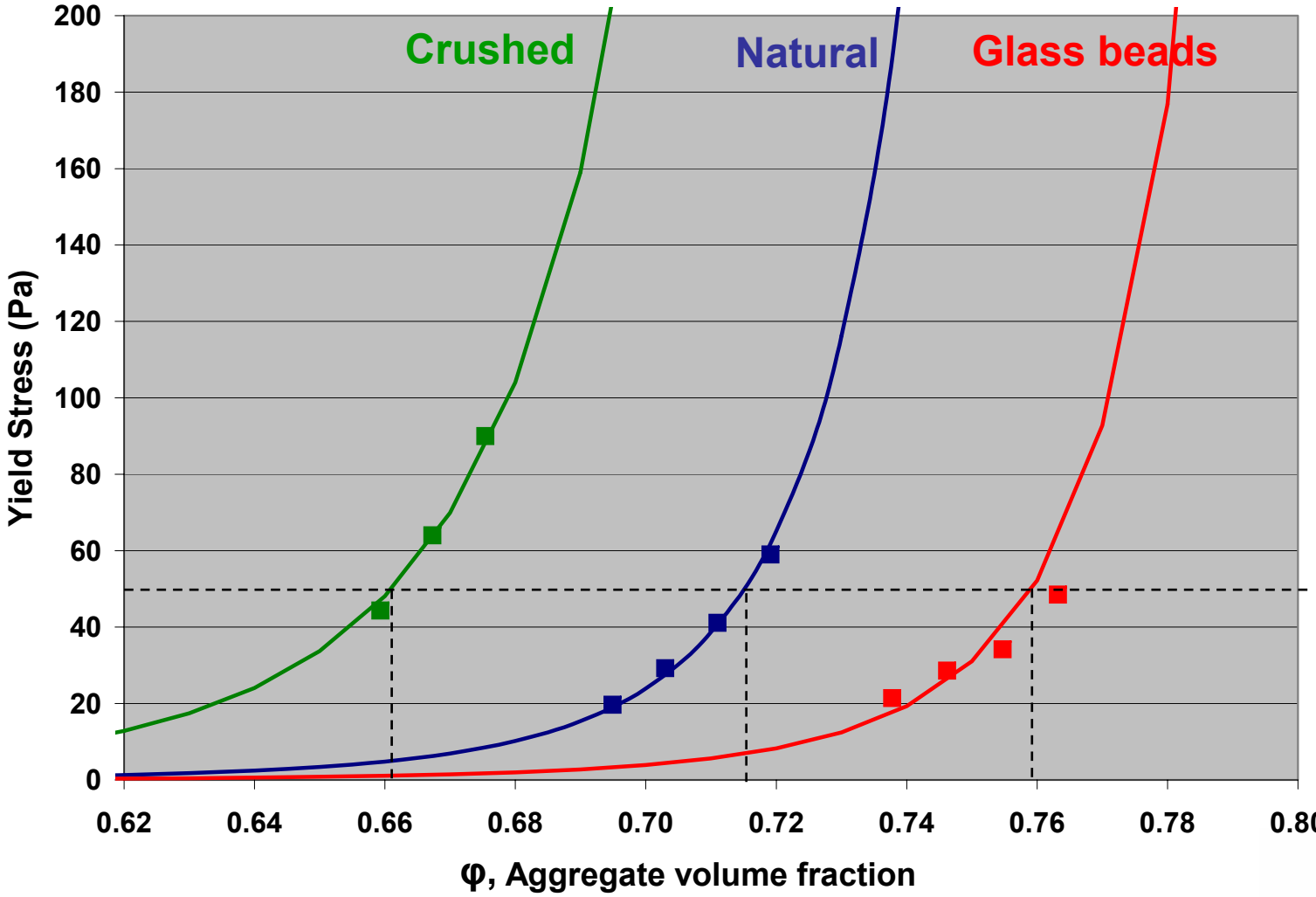

Crushed +100L excess paste
Natural +45L excess paste

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Shapefactor – Image Analysis

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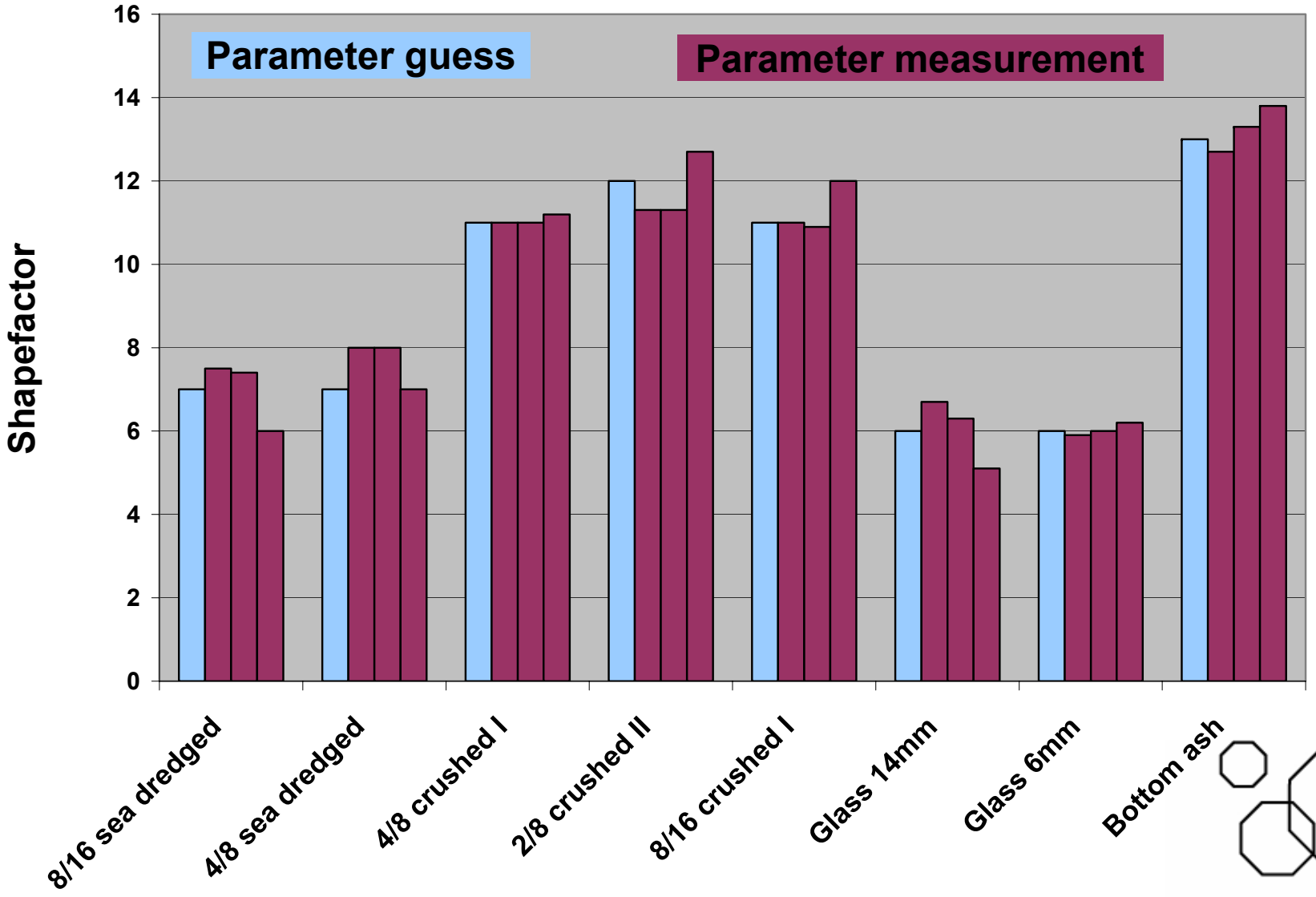

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Shapefactor – Image Analysis

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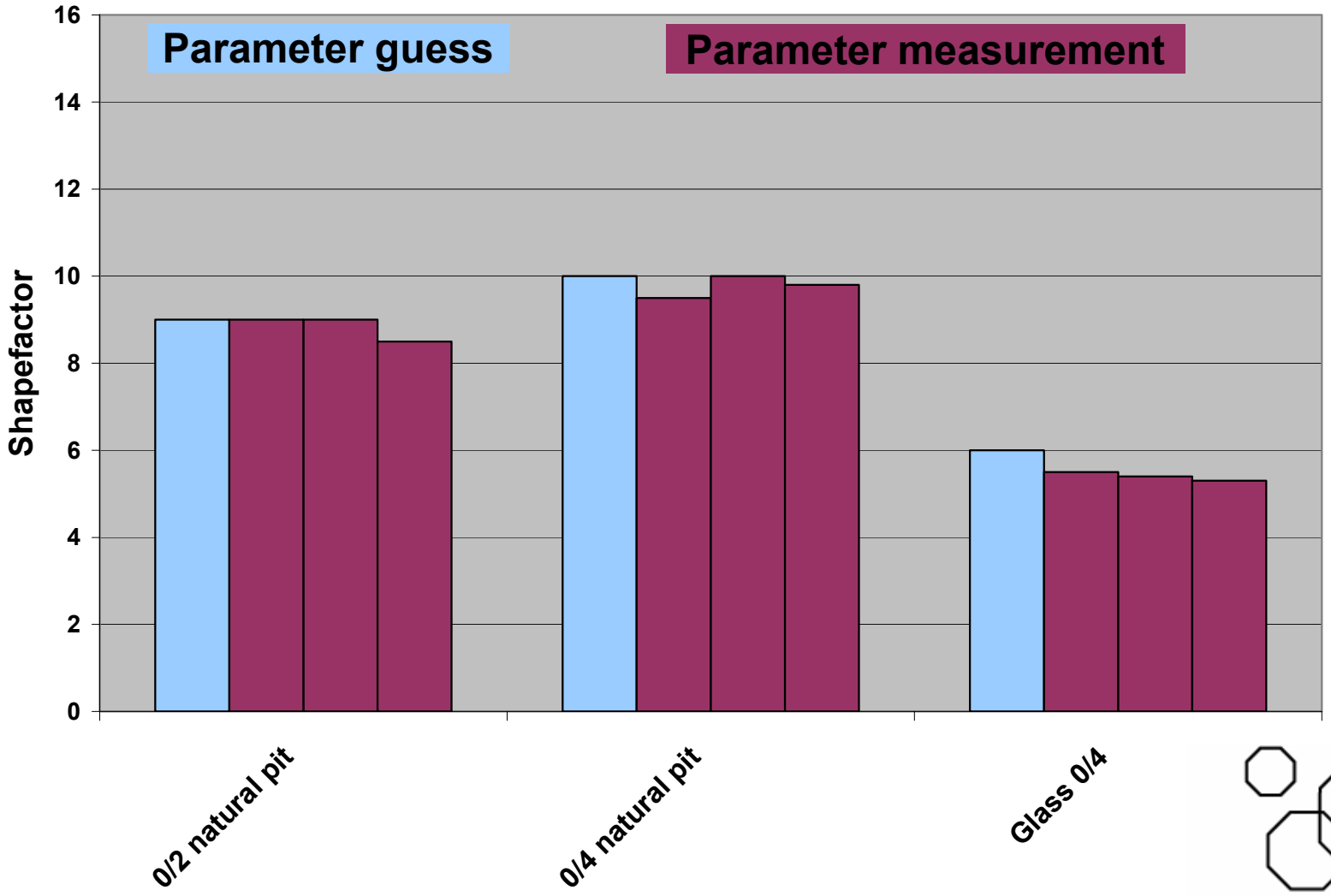

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Status

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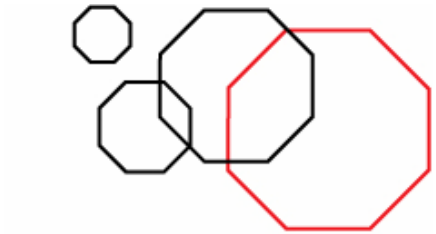
$$\tau_{0,concrete} = \tau_{0,paste}\left(A_{\tau} \cdot \Gamma^{-B_{\tau}} + 1\right) \qquad \Gamma = \frac{1-\varphi/\varphi^*}{f/k \cdot \varphi}$$

For practical purpose:

$$\tau_{0,concrete} = A \times \Gamma^{B} \qquad \Gamma = \frac{1-\varphi/\varphi^*}{shapefactor \cdot \varphi}$$

- **Estimate particle packing parameter - φ*** **OK!**
- **Select aggregate proportions – φ** **OK!**
- **Estimate shapefactor** **?**
- **Estimate the constants A and B** **?**



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