

# *Development of a Fiber Reinforced Self-Compacting Heavyweight Concrete by Considering the Factory Conditions*

Entwicklung eines faserbewehrten  
selbstverdichtenden Schwerbetons unter  
Berücksichtigung der Werksbedingungen

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# Cooperation Project

## Kooperationsprojekt



**Tenwinkel**  
GmbH & Co.KG

Betongegengewichte

Wir sind DIE globale Alternative  
in Material und Design!

Über - 50 Jahre -  
Erfahrung!!



techn. Betonteile - Maschinenbau



Institut für Angewandte  
Bauforschung Weimar



**Zentrales  
Innovationsprogramm  
Mittelstand – ZIM**

Supported by:



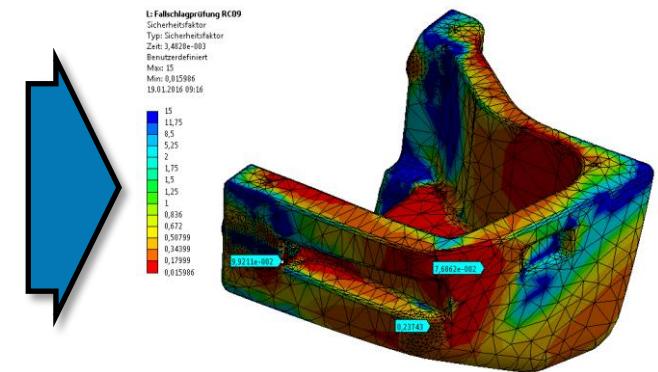
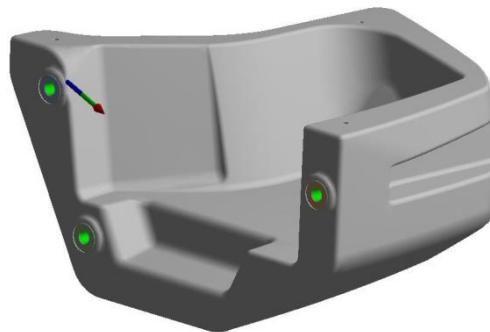
Federal Ministry  
for Economic Affairs  
and Energy

on the basis of a decision  
by the German Bundestag

# Objective Target of the Project

**“Development of a low-shrinkage, deformation-resistant, high-performance material with optimized dynamic load capacity for high-stressed ballast components of vehicles in aggressive environments”**

„Entwicklung eines schwindarmen, verformungsstabilen Hochleistungswerkstoffs mit optimierter dynamischer Belastbarkeit für hochbeanspruchte Ballastierungskomponenten im Fahrzeugbau in aggressiver Umgebung“



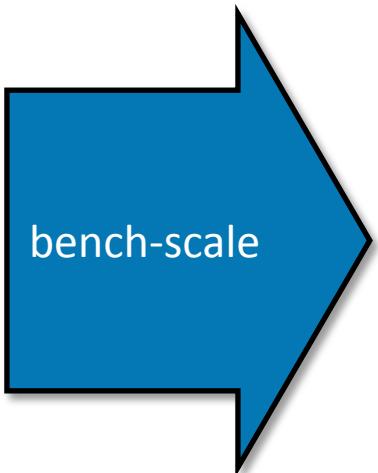
# Main Approach



- Deformation-resistance and dynamic load capacity
  - Fibers
  - Low dynamic E-Modulus
  - High tensile strength
- Aggressive environment
  - Coating
- Frame conditions:
  - Density:  $\geq 4000 \text{ kg/m}^3$
  - Acceptable early strength
  - Homogenous structure, no blowholes

*Now:  
Focus on rheology as part of  
the mix design development*

# Factory Conditions



# Factory Conditions

- Available and no change

- 1) Cement
  - 2) Water
  - 3) Fly ash
  - 4) Fine aggregate
  - 5) Coarse aggregate
  - 6) Superplasticizer
- Additional
- 7) Powder
  - 8) Admixture
  - 9) Fibers



## Why SCC?

- High surface quality
  - Less rework (bubbles/blowholes)
- Complete filling of:
  - Complex formworks
  - Reinforced formworks
- Fibers are more effective:
  - Better activation in mortar matrix
  - Orientation in flow direction
- No vibration:
  - Less noise pollution
  - Less man power needed
  - Less physiological stress



SCC typical vol.-%	Components factory	Density kg/m <sup>3</sup>	Composition			
10.3	Cement	3005	Paste $\rho \approx 1800 \text{ kg/m}^3$	Mortar $\rho \approx 3140 \text{ kg/m}^3$	$\Delta\rho \approx 1860 \text{ kg/m}^3$	
10.4	Fly ash	2400				
18.4	Water + SP	1000		Aggregate $\rho \approx 5050 \text{ kg/m}^3$		
2.4	Air void	0				
28.8	Fine aggregate 0/2	5100		Aggregate $\rho \approx 5000 \text{ kg/m}^3$		
28.9	Coarse aggregate 4/16	5000				

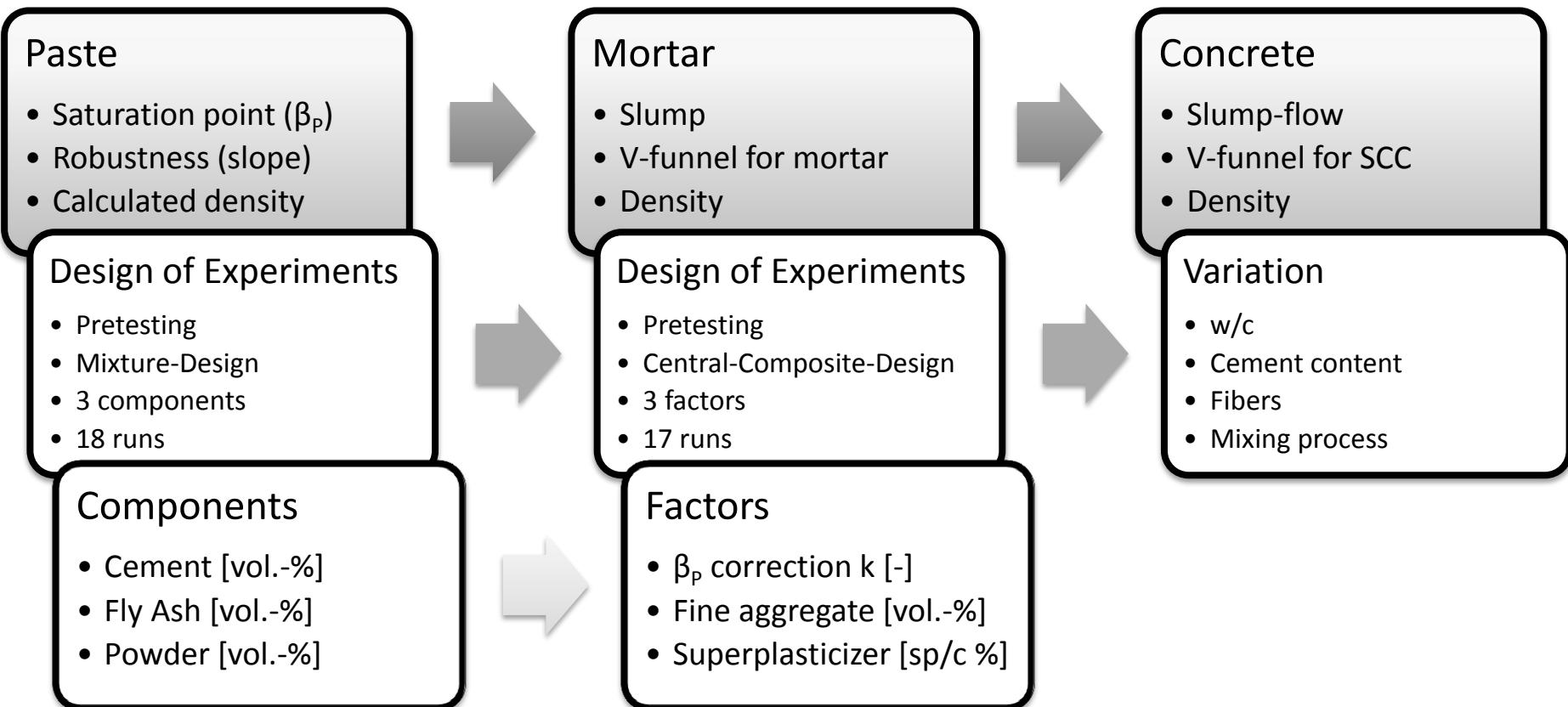
**Challenge:**  
Difference in density  
→ Segregation

**Solution:**  
Increasing paste density

**Procedures:**  
Okamura et al. [1]  
DAfStb-Guideline [2]

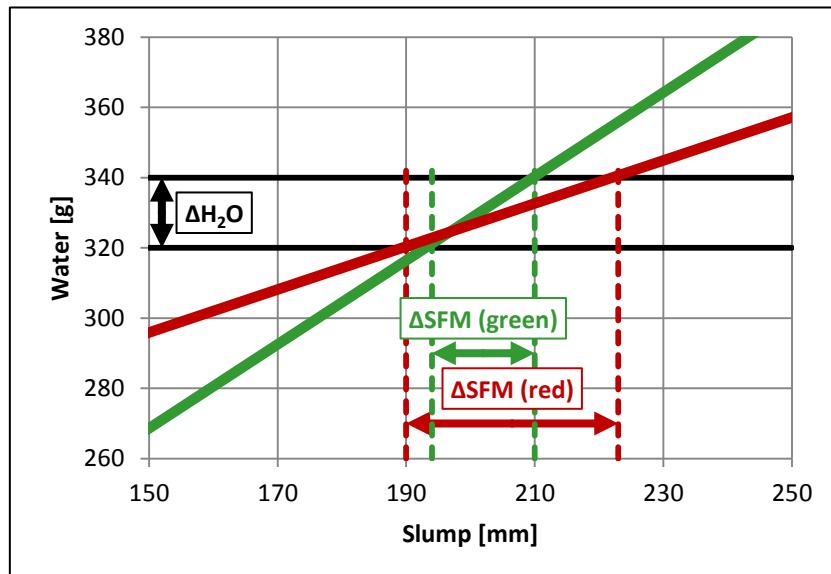
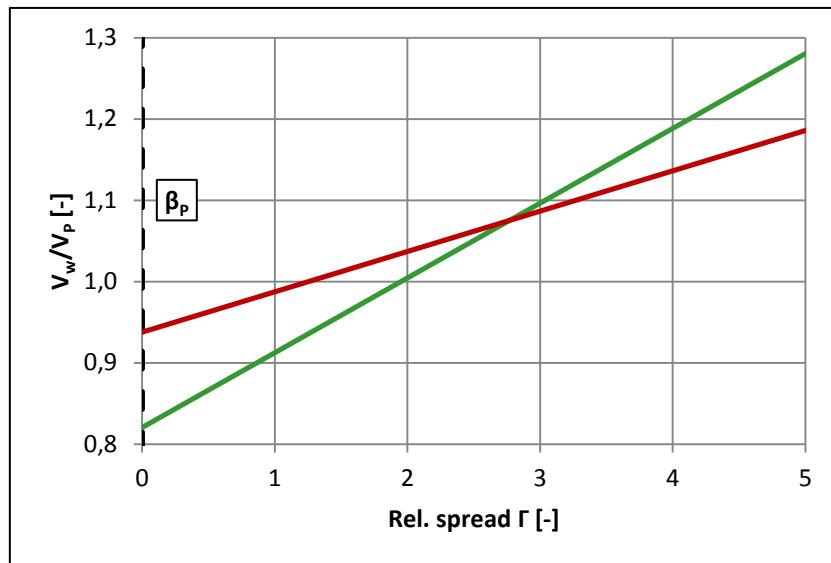
Iron oxide  
 $d_{50} \approx 35\mu\text{m}$   
 $\rho \approx 5400 \text{ kg/m}^3$

## Procedure

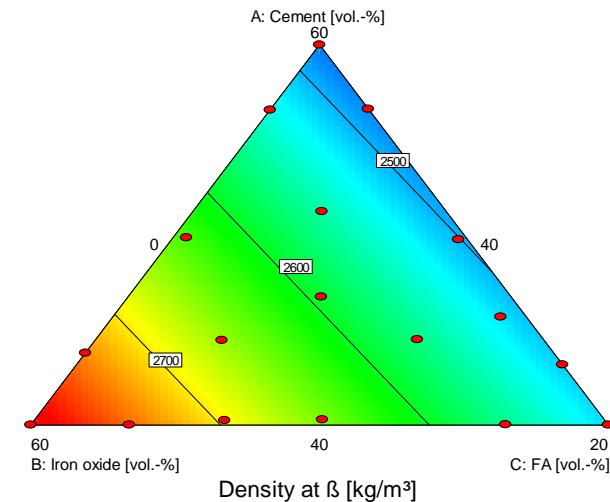
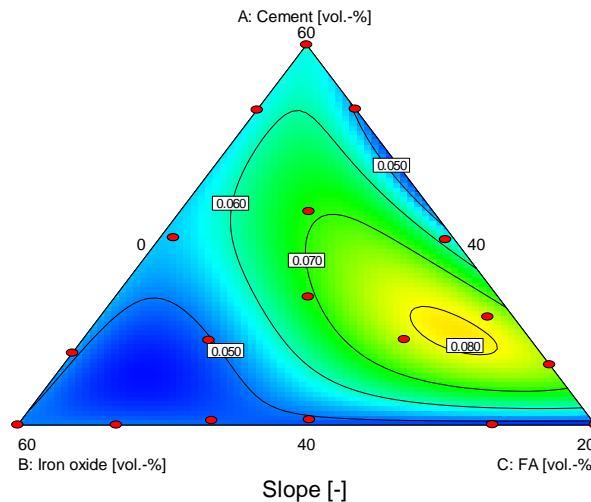
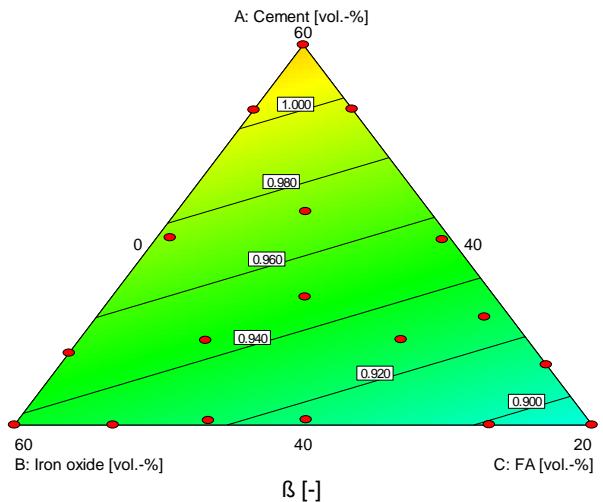


# Mix Design – Paste

- Methods
  - $V_w/V_p$  at saturation point ( $\beta_p$ )
  - Slope as measure for robustness
  - Calculated density with water at  $\beta_p$
  
- Experimental design based on pretesting
  - FA improves robustness, packing density, workability
  - Disadvantage: FA reduces density



## Results



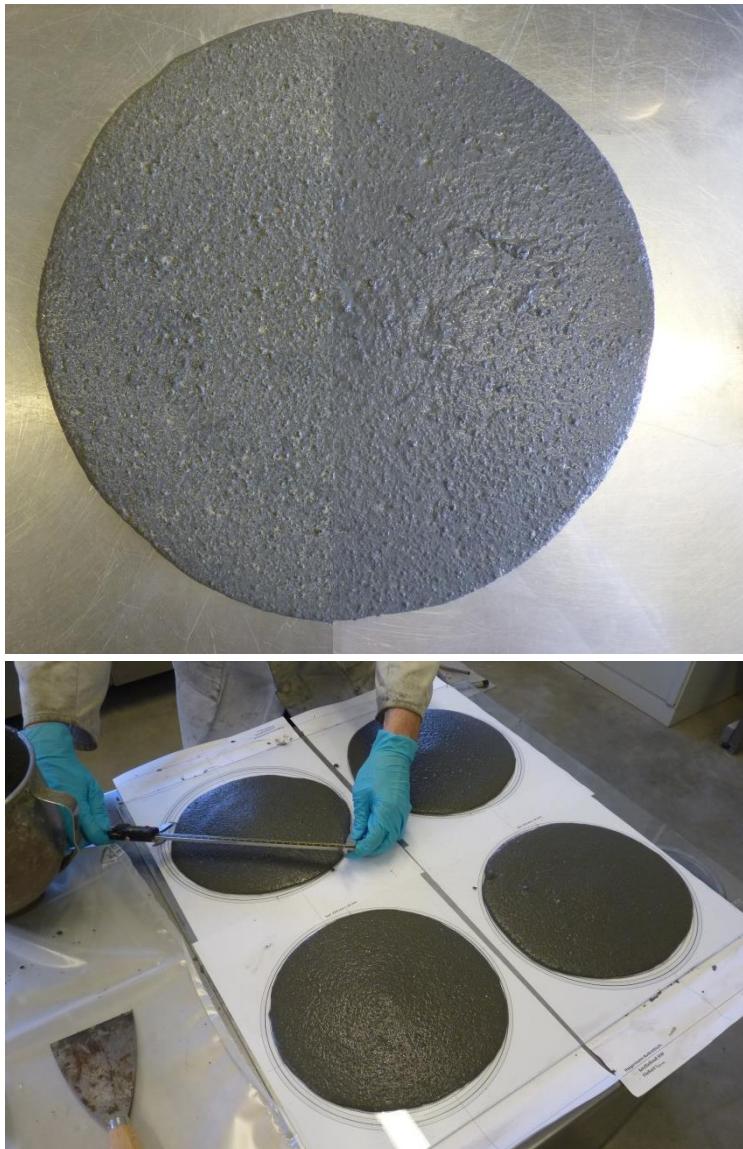
### Numeric optimization

Solution	$\beta_p$ [-]	Slope [-]	Calc. density [ $\text{kg}/\text{m}^3$ ]
with fly ash	0.933	0.077	2573
without fly ash	0.953	0.051	2733

# Mix Design – Mortar

- Pretesting
  - Constant amount stabilizer  
→ Extended mixing time
  - Efficiency SP and thixotropy
  - Time-dependent slump  
→ 4 points → Function

*Which yield point or slump is required for sedimentation-stable SCC?*



# Mix Design – Mortar

## Estimated max. slump of the SCC mortar

$$\tau_0 \geq K |\rho_G - \rho_{Fl}| d_G g$$

Stability criterion	Geometry	K
Theoretical	sphere	$\frac{1}{18}$
Jossic et al. [3]	sphere (rough)	$\frac{1}{17.2}$
Ansley et al. [4]	sphere	$\frac{4}{21\pi}$
Bethmont et al. [5]	sphere	$\frac{1}{18.4}$
Beris et al. [6]	sphere	$\frac{1}{21}$
Vogel [7]	sphere	$\frac{2}{3\pi}$
	aggregate	$\sim 0.3$



Roussel et al. [8]

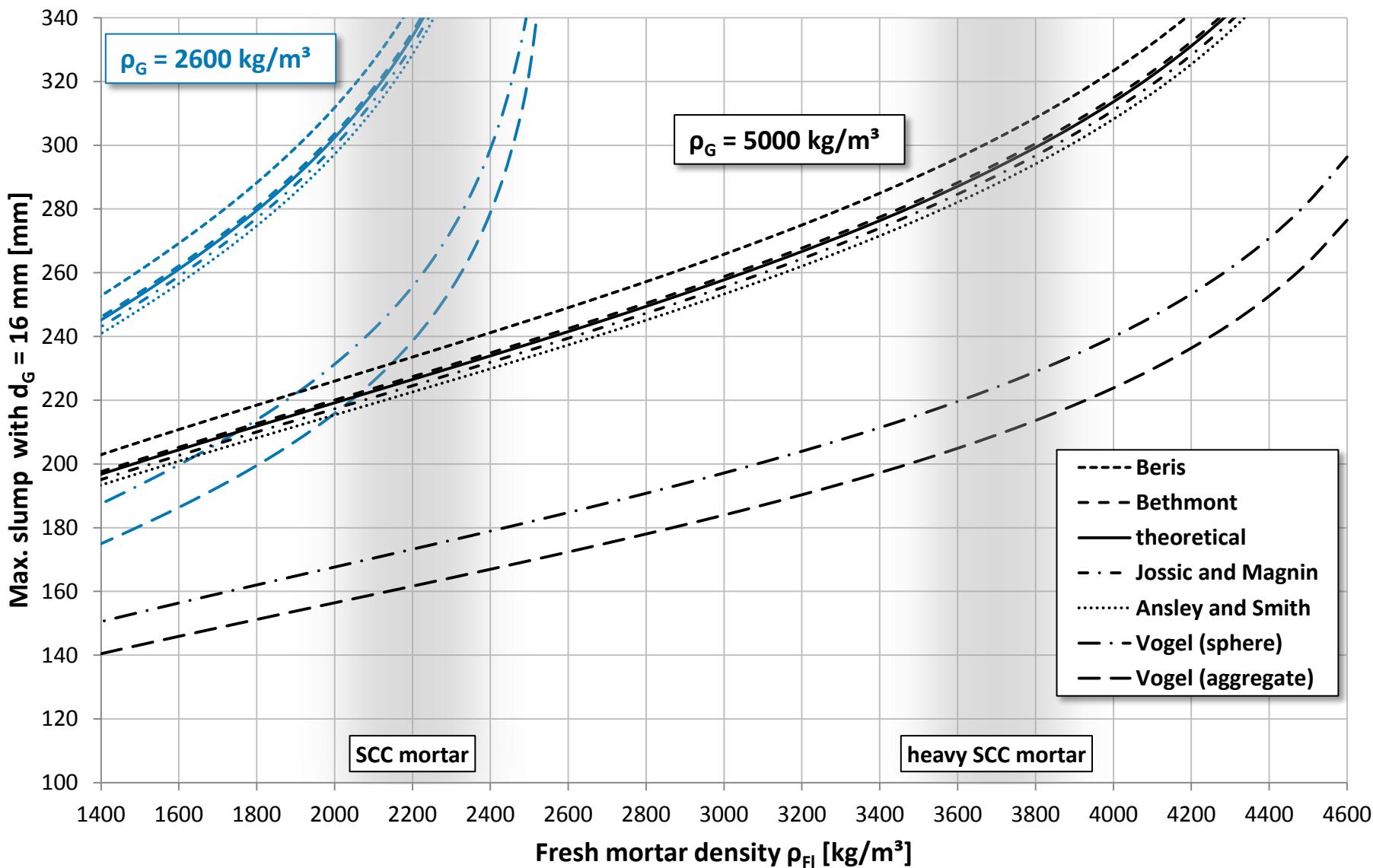
$$\tau_0 = \frac{225 \rho_{Fl} g \Omega^2}{128 \pi^2 R^5}$$

$$R = 0.708 \sqrt[5]{\frac{\rho_{Fl} g \Omega^2}{\tau_0}}$$



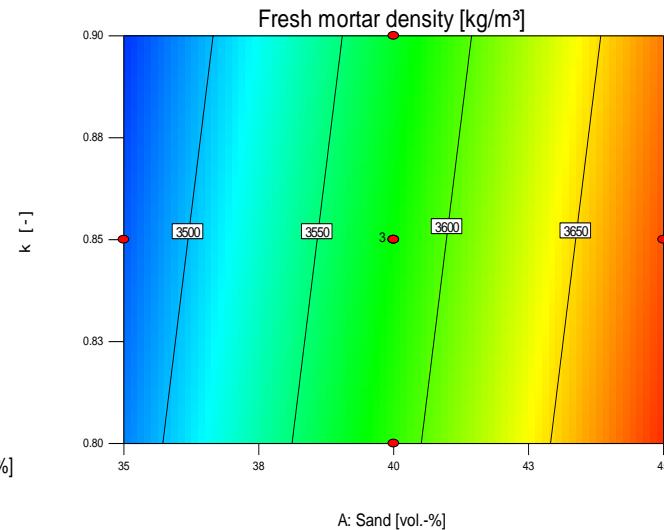
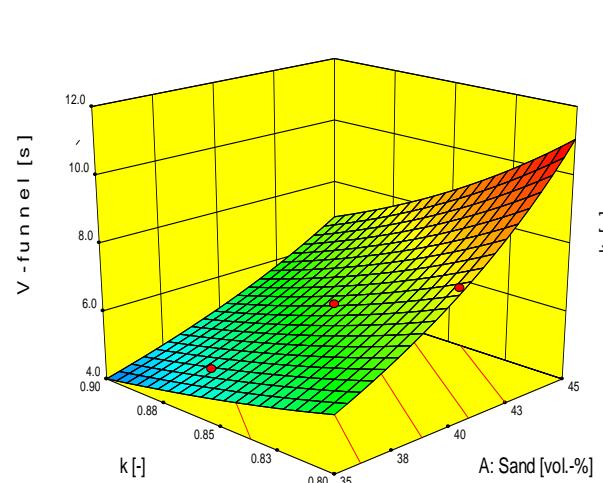
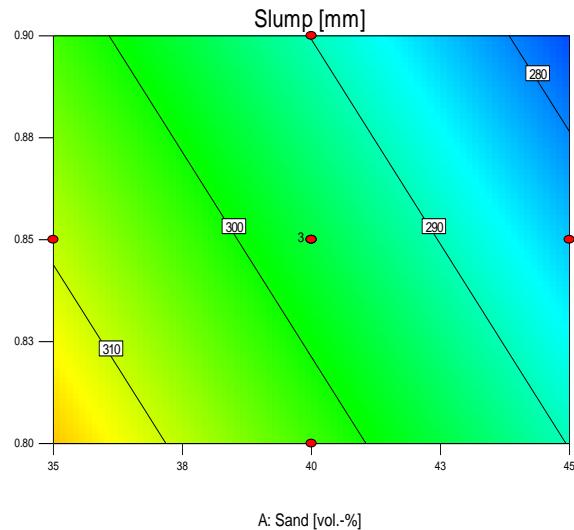
	Unit	Ordinary	Heavy
$\rho_G$	kg/m <sup>3</sup>	2600 – 2750	5000
$\rho_{Fl}$	kg/m <sup>3</sup>	2000 – 2400	3200 - 3900
$ \rho_G - \rho_{Fl} $	kg/m <sup>3</sup>	200 – 650	1100 - 1800
$d_G$	mm	16	16

# Mix Design – Mortar



# Mix Design – Mortar

## Results



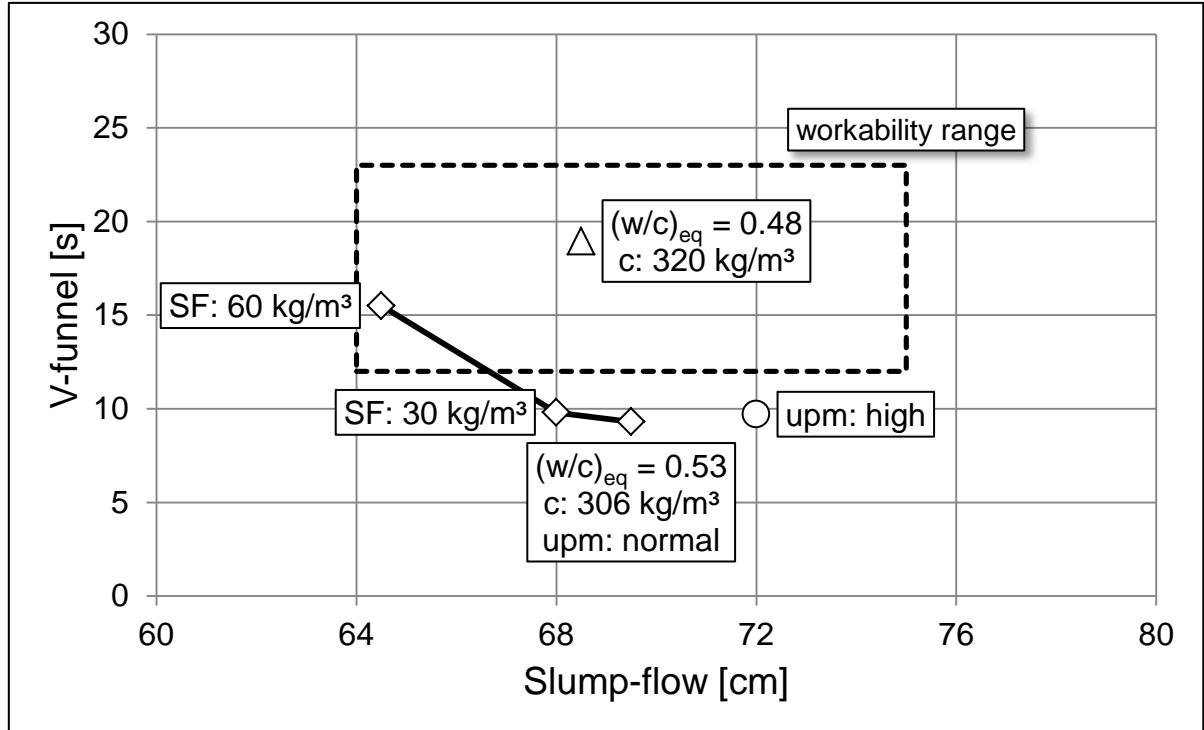
Numeric optimization

Solution	Slump [mm]	V-funnel [s]	Density [ $\text{kg}/\text{m}^3$ ]
with fly ash	295	6.3	3571

- ✓ Paste composition is known
- ✓ Mortar composition is known
- ✓ Last remaining unknown: proportion coarse aggregate
  - Controlled by paste proportion - rest follows automatically
    - 1<sup>st</sup> basic SCC mix design
  - With constant paste and coarse aggregate proportions:
    - Variation mix process
    - Variation w/c-ratio
    - Adding steel fibers

# Mix Design – Concrete

## Results: Workability



Overall	Slump-flow [cm]	V-funnel [s]	Density [kg/m <sup>3</sup> ]	Compressive Strength	
				1d [MPa]	28d [MPa]
Min	64.5	9.3	3936	10.8	61.5
Max	72.0	19.0	4083	13.5	76.1

# Mix Design – Concrete

## Results: Segregation



- ✓ Basic mix design for further investigations with three additional components: Powder, stabilizer, fibers
- ✓ Frame conditions
  - ✓ Density
  - ✓ Workability
  - ✓ Segregation
  - ✓ Surface
  - ✓ Strength
- ✓ Standard SCC procedures for mix design development
  - ✓ Handy, additional tool: Design of Experiments

- [1] Okamura, H.; Ozawa, K.: Mix Design for Self-Compacting-Concrete, Concrete Library of JSCE 25, 1995
- [2] Deutscher Ausschuss für Stahlbeton (DAfStb): Selbstverdichtender Beton (SVB-Richtlinie), Beuth Verlag GmbH, 2003
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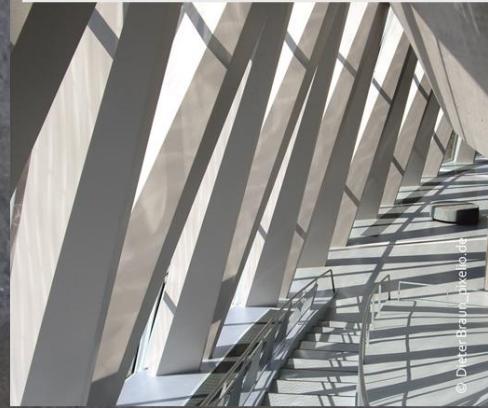
# Acknowledgment



Beton(t) UNSCHLAGBAR

Zukunft LEITUNGSBAU

IAB-Wissenschaftstage 16./17.11.2016



23. Internationale IFF-FACHTAGUNG

21. ROHRBAU-KONGRESS

Baustoffliche  
Entwicklungs-  
tendenzen

Verfahren  
und Aus-  
rüstungen

Betonwaren  
und Beton-  
fertigteile

Materialien/  
Baurecht/  
Grabenloses  
Bauen

Leitungs-  
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Nah- und  
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Wärme-  
speicher

## Thank you for your attention!