Rheology of fresh concrete

Influence of superplasticizers

dr. Luka Zevnik, Vesna Jereb

Regensburg 2013

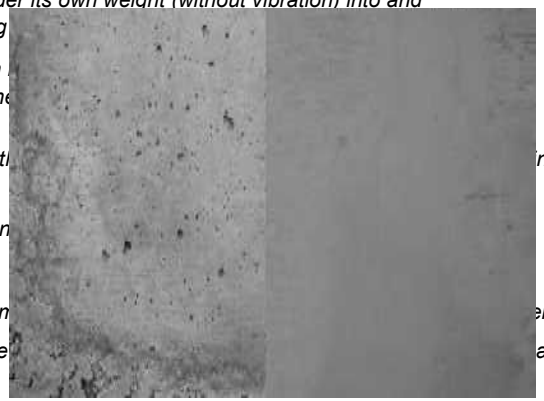
Introduction

Definitions and terms Relating to SCC

[http://www.na.graceconstruction.com/custom/concrete/downloads/tb_1501b.pdf]

Air-migration *The undesirable condition in which entrapped air in fresh SCC migrates to*

Filling ability *The ability of SCC to flow under its own weight (without vibration) into and*



nal max size aggregate

ement, finishing, curing.

and air voids once all

Stickiness *Adherance to finishing tools*

Viscosity

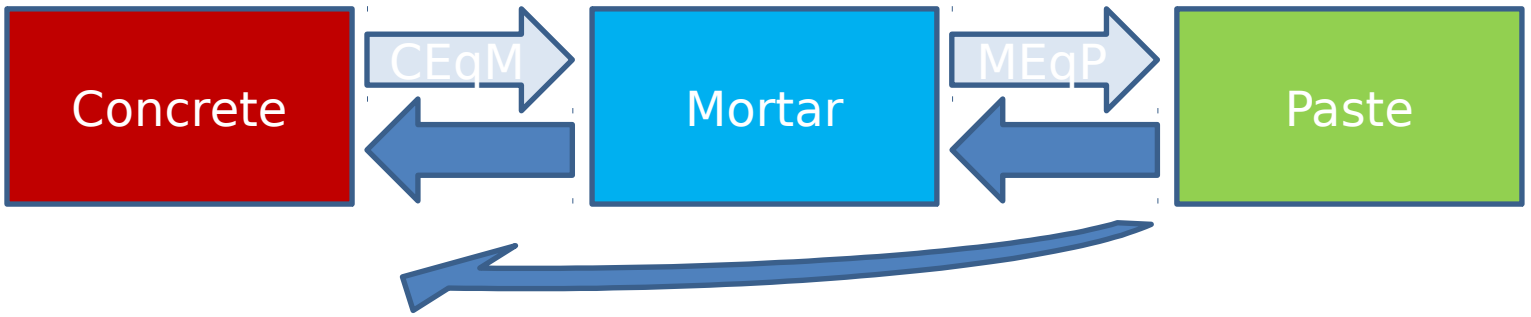
Water sensitivity *The amount of free water variation witin the mixture change the stability (and other SCC properties) of concrete from accaptable to unaccaptable range.*

Superplasticizer influence on concrete rheology

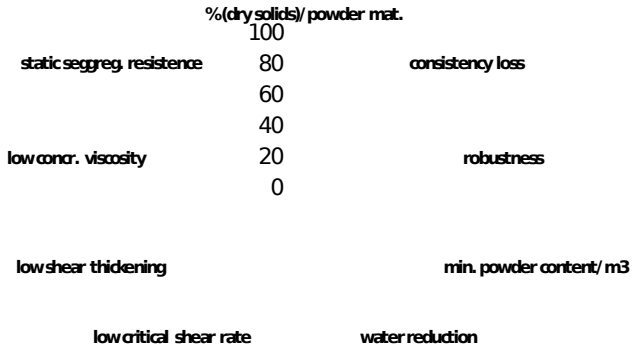
- **How could we evaulte superplasticizer influence on concrete rheology(robustness etc…)?**

  Numerous investigations on job sites, and long term use in practice

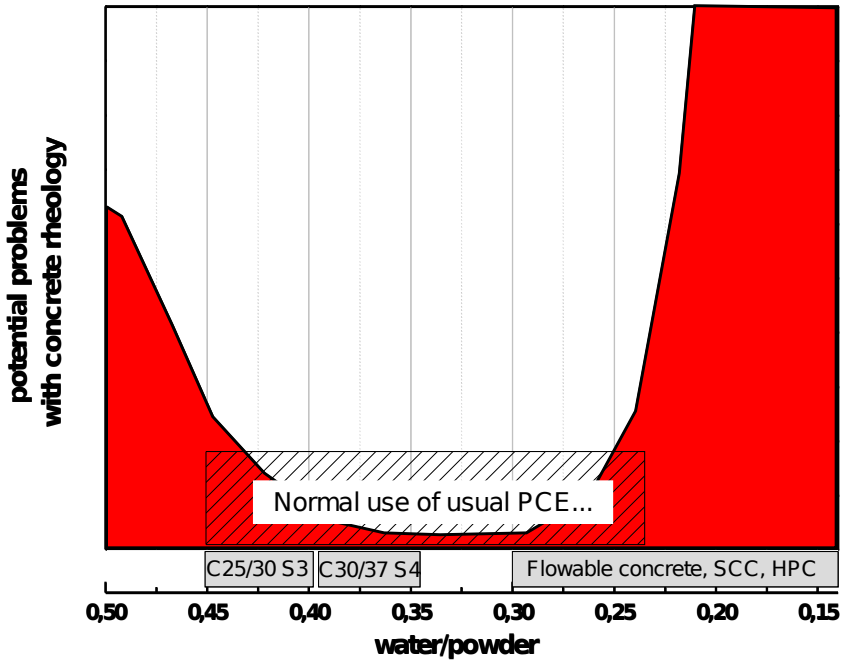
  - **Is there any other option?**
  - **Could we predict the concrete rheology with mortar or paste experiments?**



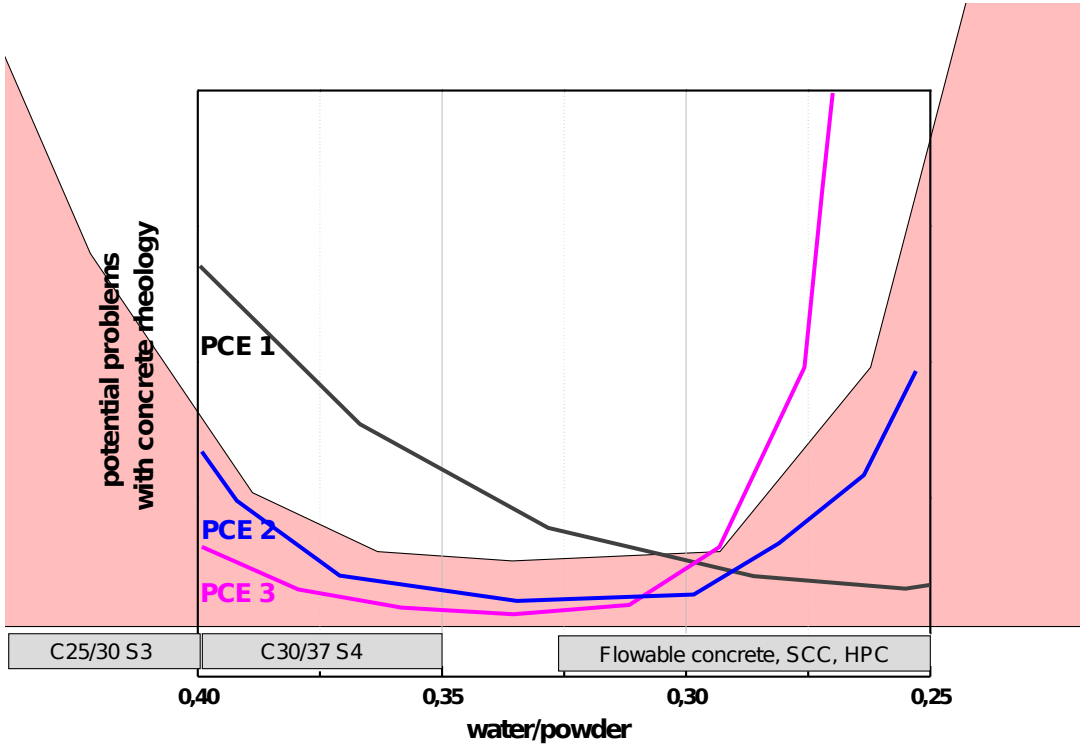
Superplasticizer influence on concrete rheology



Superplasticizer influence on concrete rheology



Superplasticizer influence on concrete rheology



Concrete rheology evaluation

Important rheological concrete parameters
Cohesivity
Bleeding
Seggregation at rest
Seggregation at pumping
Slump shape
Sound at mixing (air content)

Most advanced concrete rheometer

Concrete rheology evaluation – standard investigations

	Concrete PCE	Concrete Ph
CEM II A-M (LL-S) 42,5R	420 kg	420 kg
Limestone filler	90 kg	90 kg
Crushed aggregate 0/2, Soča	842 kg	842 kg
Natural aggregate 4/8, Soča	258 kg	258 kg
Natural aggregate 8/16, Soča	592 kg	592 kg
w/c	0,44	0,44
Air content	1,6 %	2 %
PCE (dry content)	0,21%	/
Ph (dry content)	/	0,63%

Cohesivity	Slumpflow, t500	V - funnel

Concrete rheology evaluation – standard investigations

	Concrete PCE	Concrete Ph
CEM II A-M (LL-S) 42,5R	420 kg	420 kg
Limestone filler	90 kg	90 kg
Crushed aggregate 0/2, Soča	842 kg	842 kg
Natural aggregate 4/8, Soča	258 kg	258 kg
Natural aggregate 8/16, Soča	592 kg	592 kg
w/c	0,44	0,44
Air content	1,6 %	2 %
PCE (dry content)	0,21%	/
Ph (dry content)	/	0,63%
flow	680 mm	670 mm
t500	4,0s	2,2s
V funnel	9,3 s	6,5 s
L box (H1/H2)	91%	89%
cohesivity	*****	*****
Overall filing	Quite good	Good

Mortar rheology – standard investigations

	Mortar PCE	Mortar Ph
CEM II A-M (LL-S) 42,5R	600 g	600 g
Limestone filler	177 g	177 g
Quartz sand 0-1	775 g	775 g
Quartz sand 0,5-1	87 g	87 g
w/c	0,475	0,480
Air content	2%	2%
PCE	0,24%	/
Ph	/	0,65%

Cohesivity- mortar

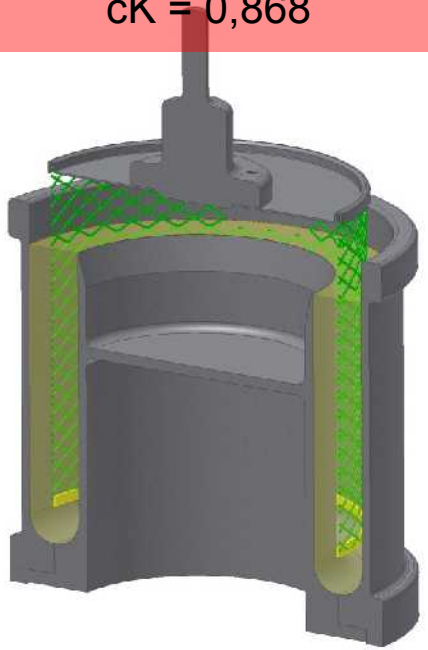
Slumpflow - mortar

Mortar rheology – standard investigations

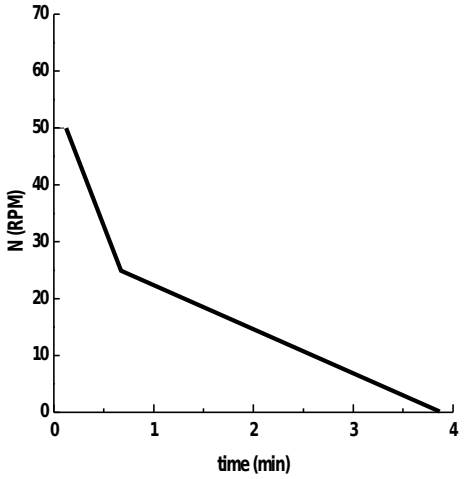
	Mortar PCE	Mortar Ph
CEM II A-M (LL-S) 42,5R	600 g	600 g
Limestone filler	177 g	177 g
Quartz sand 0-1	775 g	775 g
Quartz sand 0,5-1	87 g	87 g
w/c	0,475	0,480
Air content	2%	2%
PCE	0,24%	/
Ph	/	0,65%
flowminicone	39,5 cm	36,5 cm
t 250	4,7 s	2,6 s
t final	50 s	20,5 s
Cohesivity	*	****
Overall filing	Bad	Very good

Mortar rheology – rheological experiments

Rheology of mortar =Viscomat NT + Vogel cell	
Calibration (TKK)	
γ/N = 0,447 [min]/[s]	γcrit-/(τo /ηpl) = 0,321
cK = 0,868	τ/T = 0,76 [Pa]/[mNm]



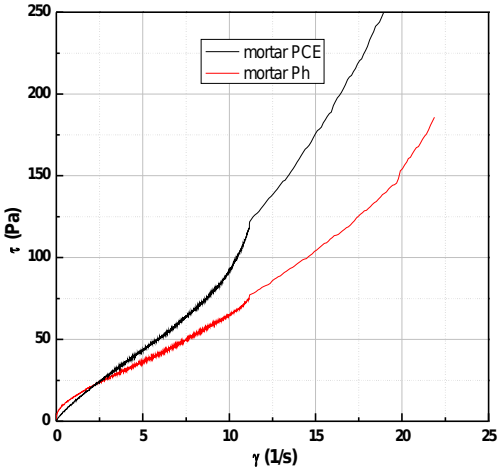
Vogel [*Ein Messezell fur Specialmortel, www.vogel-labor.de*] type measuring body. [*www.schleibinger.com*]

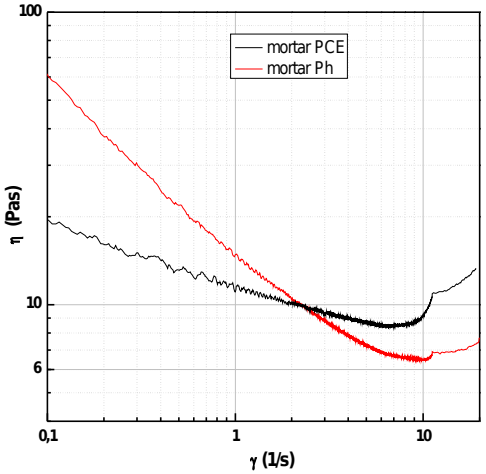


A typical speed profile.

Mortar rheology – rheological experiments

Mortar SCC and Mortar Ph

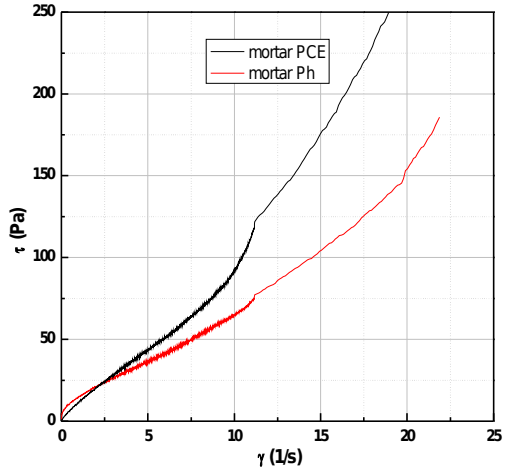


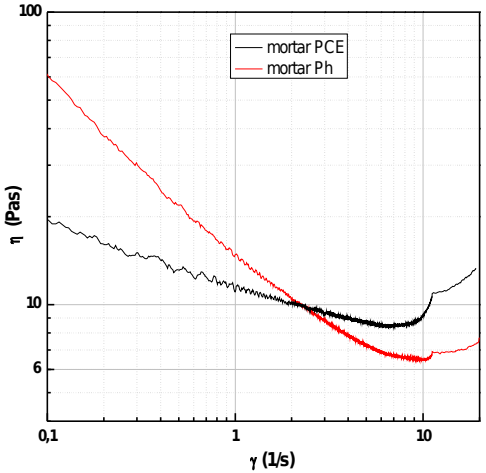


γ = 10 1/s	γ = 1 1/s	γ = 0,1 1/s

Mortar rheology – rheological experiments

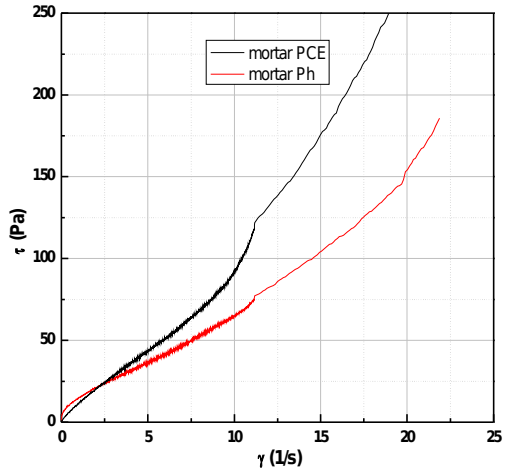
parameter	Mortar PCE	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

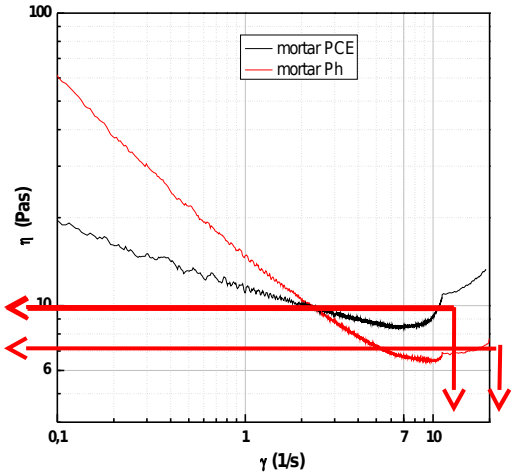




Mortar rheology – rheological experiments

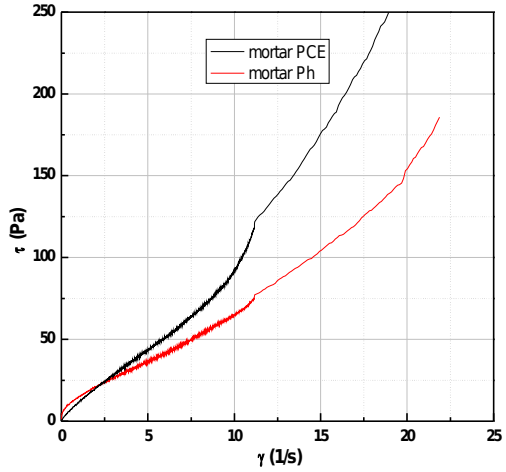
parameter	Mortar PCE	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

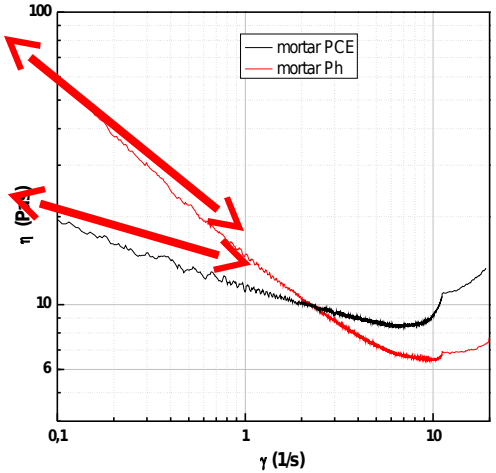




Mortar rheology – rheological experiments

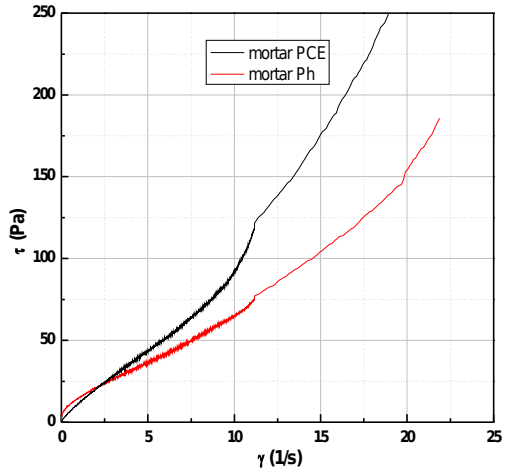
parameter	Mortar SCC	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

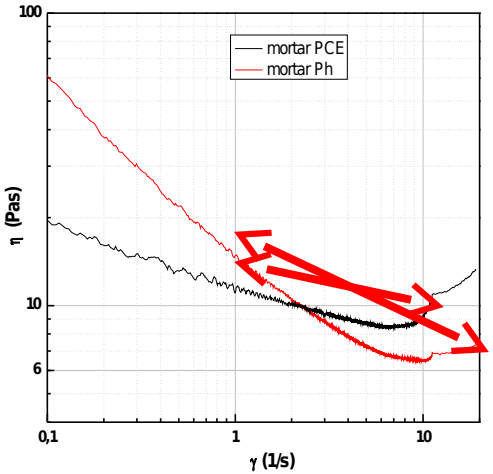




Mortar rheology – rheological experiments

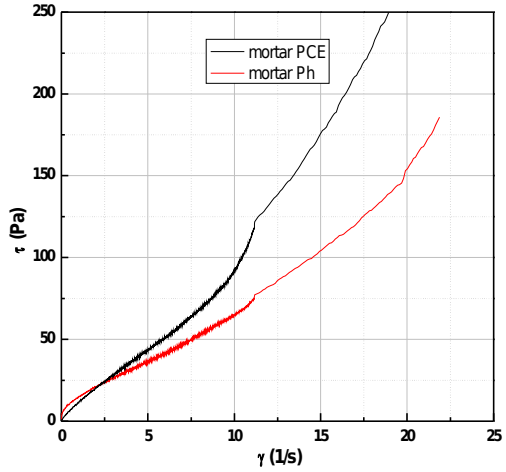
parameter	Mortar SCC	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

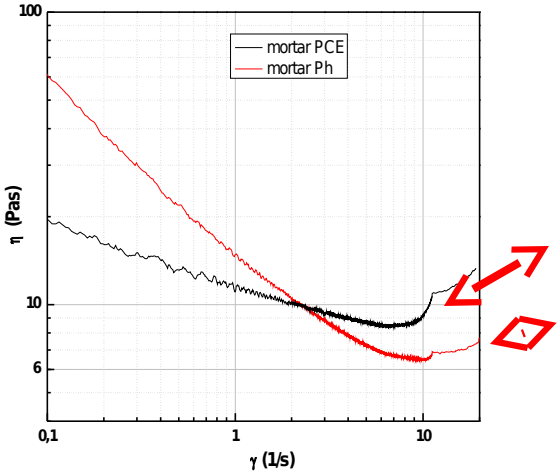




Mortar rheology – rheological experiments

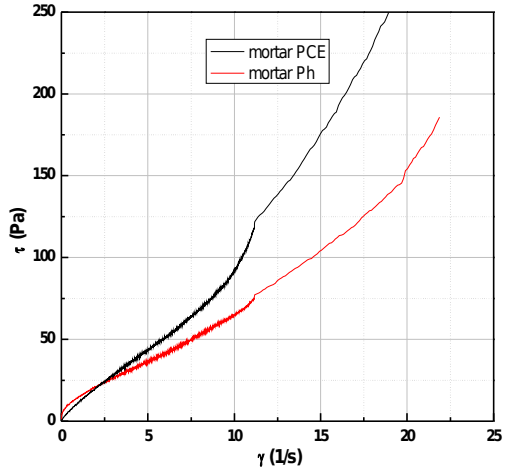
parameter	Mortar SCC	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

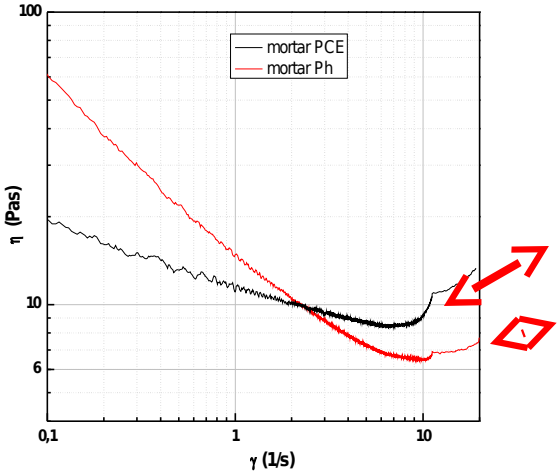




Mortar rheology – rheological experiments

parameter	Mortar SCC	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/[η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87





Mortar rheology – standard vs. Vogel rheology

	Mortar PCE	Mortar Ph
flowminicone	39,5 cm	36,5 cm
t 250	4,7 s	2,6 s
t final	50 s	20,5 s
Cohesivity	*****	*****
Overall filing	Bad	Very good
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/ [η@1]	1,7	4,2
Shear thinning [η@1]/ [η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/[η@20]	0,625	0,87

Stand. exp.

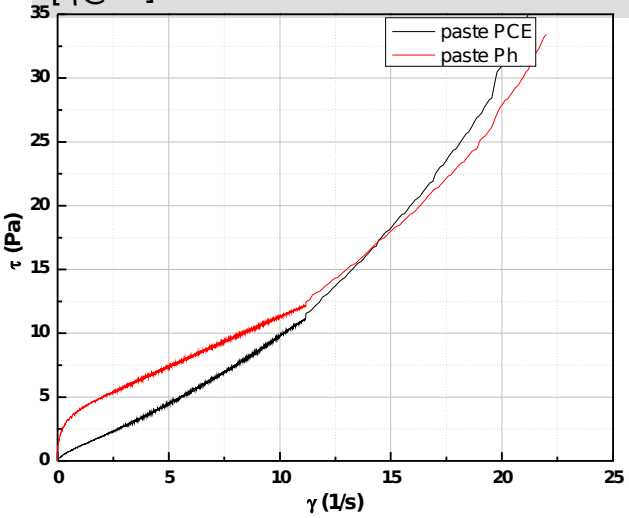
Vogel rheology

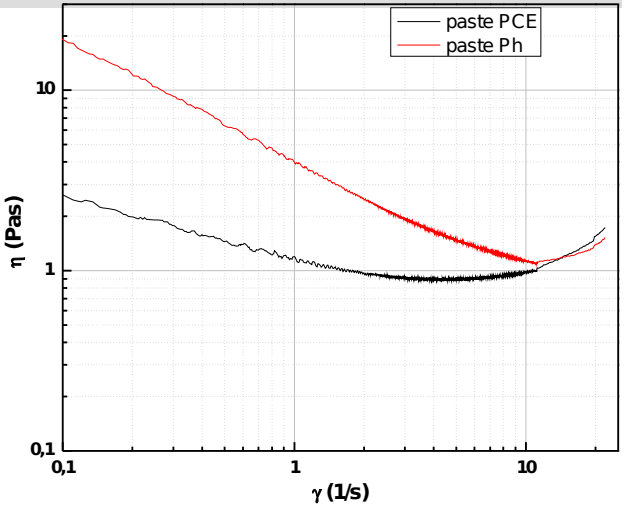
Paste rheology – standard experiments

	Paste PCE	Paste Ph
CEM II A-M (LL-S) 42,5R	600 g	600 g
Limestone filler	177 g	177 g
w/c	0,45	0,45
PCE	0,24%	/
Ph	/	0,65%
flowminicone	29,5 cm	26,5 cm
Cohesivity	**?**	**?**
Overall filing	??	??

Paste rheology – rheological experiments

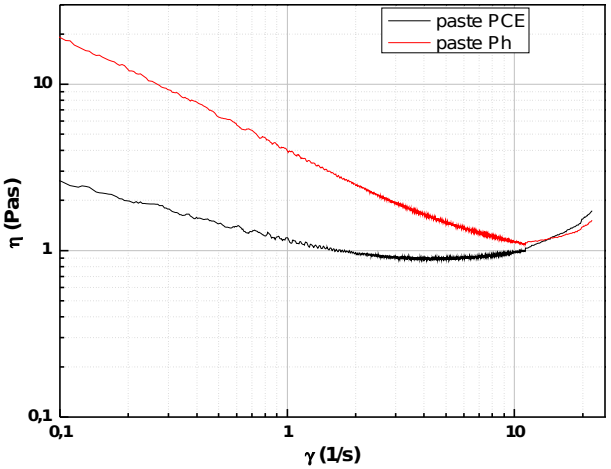
parameter	Paste PCE	Paste Ph
γcrit	4,3 s-1	12 s-1
η@γcrit = (min. η)	0,89 Pas	1,09 Pas
Shear thinning [η@0,1]/[η@1]	2,26	4,85
Shear thinning [η@1]/[η@γcrit]	1,29	3,7
Shear thickening [η@γcrit]/ [η@20]	0,58	0,77



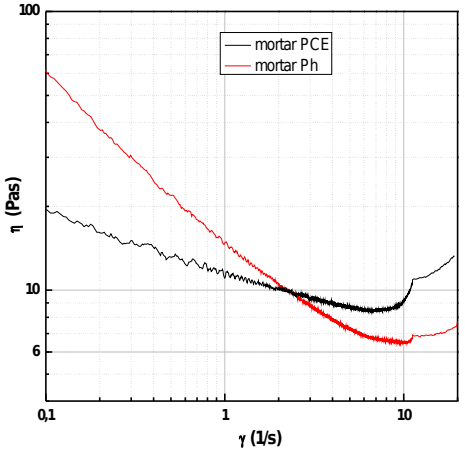


Paste rheology vs. Mortar rheology

parameter	Paste PCE	Paste Ph
γcrit	4,3 s-1	12 s-1
η@γcrit = (min. η)	0,89 Pas	1,09 Pas
Shear thinning [η@0,1]/[η@1]	2,26	4,85
Shear thinning [η@1]/[η@γcrit]	1,29	3,7
Shear thickening [η@γcrit]/ [η@20]	0,58	0,77



parameter	Mortar SCC	Mortar Ph
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/ [η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/ [η@20]	0,625	0,87

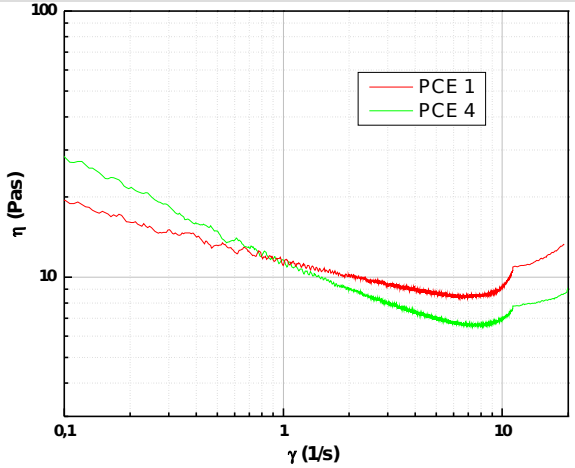


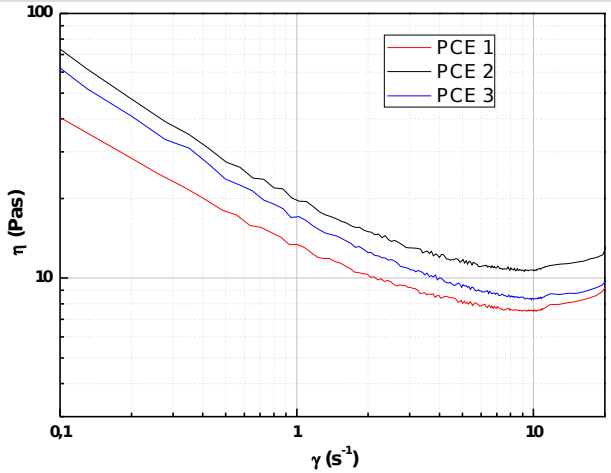
Concrete rheology vs. Mortar rheology

	Concrete PCE	Concrete Ph
flow	680 mm	670 mm
t500	4,0s	2,2s
V funnel	9,3 s	6,5 s
cohesivity	*****	*****
	Mortar PCE	**Mortar Ph**
flow	395 mm	365 mm
t250	4,7s	2,6s
t final	50 s	20,5 s
cohesivity	*****	*****
γcrit	7 s-1	11 s-1
η@γcrit = (min. η)	8,5 Pas	6,2 Pas
Shear thinning [η@0,1]/[η@1]	1,7	4,2
Shear thinning [η@1]/ [η@γcrit]	1,35	2,3
Shear thickening [η@γcrit]/[η@20]	0,625	0,87

PCE (pure) superplasticizers: Mortar rheology

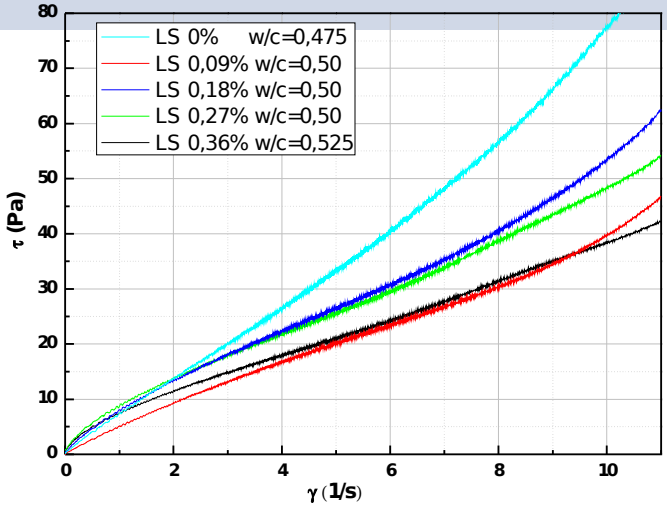
parameter	PCE 1	PCE 4	PCE 1	PCE 2	PCE 3
Mortar 1: agg. Size 0-1mm, w/c=0,475			**Mortar 0: agg. Size 0-2mm, w/c=0,50**		
Flow	39,5 cm	37 cm	37 cm	33,5 cm	35 cm
Dosage (dry solids)	0,24 %	0,35 %	0,24 %	0,32 %	0,36 %
γcrit	7 s-1	7,5 s-1	10,2 s-1	10 s-1	10,6 s-1
η@γcrit = (min. η)	8,5 Pas	6,6 Pas	7,6 Pas	10,7 Pas	8,5 Pas
Shear thinning [η@0,1]/[η@1]	1,7	2,5	3,0	3,50	3,53
Shear thinning [η@1]/[η@γcrit]	1,34	1,72	1,76	1,87	2,04
Shear thickening [η@γcrit]/[η@20]	0,63	0,75	0,85	0,87	0,87

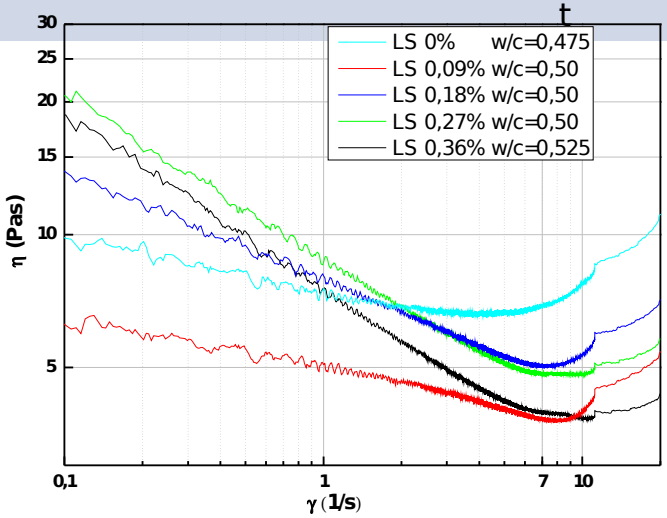




Superplasticizer formulations: mortar rheology

Mortar No	PCE 1	LSb	w/c	Flow	Cohesivity	Bleeding	Seggreg	Overall filling
1	0,24%	0,00%	0,475	43 cm	*	**	**	very bad
2	0,24%	0,09%	0,50	44,5 cm	**	*	**	bad
3	0,24%	0,18%	0,50	42,5 cm	***	***	*	ok
4	0,24%	0,27%	0,50	39 cm	****	***	***	good
5	0,24%	0,36%	0,53	40,5 cm	*****	***	***	excelent



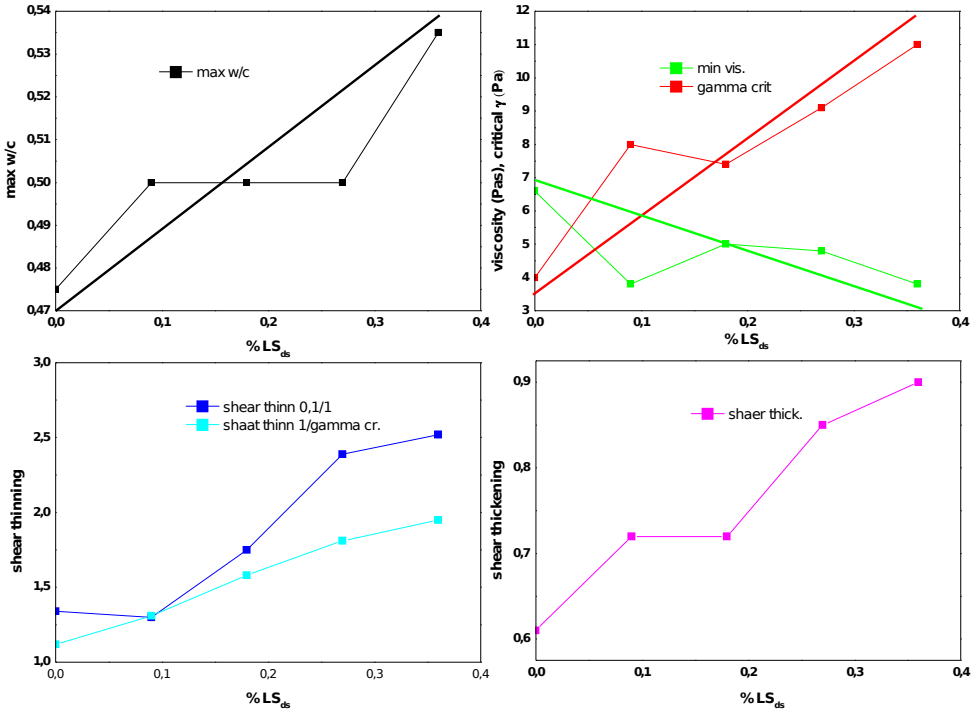


Superplasticizer formulations: mortar rheology

parameter	Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5
w/c	0,475	0,50	0,50	0,50	0,53
PCE (dry solids)	0,24%	0,24%	0,24%	0,24%	0,24%
LS (dry solids)	0,00%	0,09%	0,18%	0,27%	0,36%
Flow (minicone)	43 cm	44,5 cm	42,5 cm	39 cm	40,5 cm
Cohesivity	*	**	****	****	*****
Bleeding	**	*	***	***	***
Segregation	**	**	*	***	***
Overall filling	very bad	bad	ok	good	excellent
γcrit	4 s-1	8 s-1	7,4 s-1	9,1 s-1	11 s-1
η@γcrit = (min. η)	6,6 Pas	3,8 Pas	5 Pas	4,8 Pas	3,8 Pas
Shear thinning [η@0,1]/[η@1]	1,34	1,30	1,75	2,39	2,52
Shear thinning [η@1]/[η@γcrit]	1,12	1,31	1,58	1,81	1,95
Shear thickening [η@γcrit]/[η@20]	0,61	0,72	0,72	0,85	0,90

Superplasticizer formulations: mortar rheology

parameter	Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5
w/c	0,475	0,50	0,50	0,50	0,53
PCE (dry solids)	0,24%	0,24%	0,24%	0,24%	0,24%
LS (dry solids)	0,00%	0,09%	0,18%	0,27%	0,36%
Flow (minicone)	43 cm	44,5 cm	42,5 cm	39 cm	40,5 cm
Cohesivity	*	**	****	****	*****
Bleeding	**	*	***	***	***
Segregation	**	**	*	***	***
Overall filling	very bad	bad	ok	good	excellent

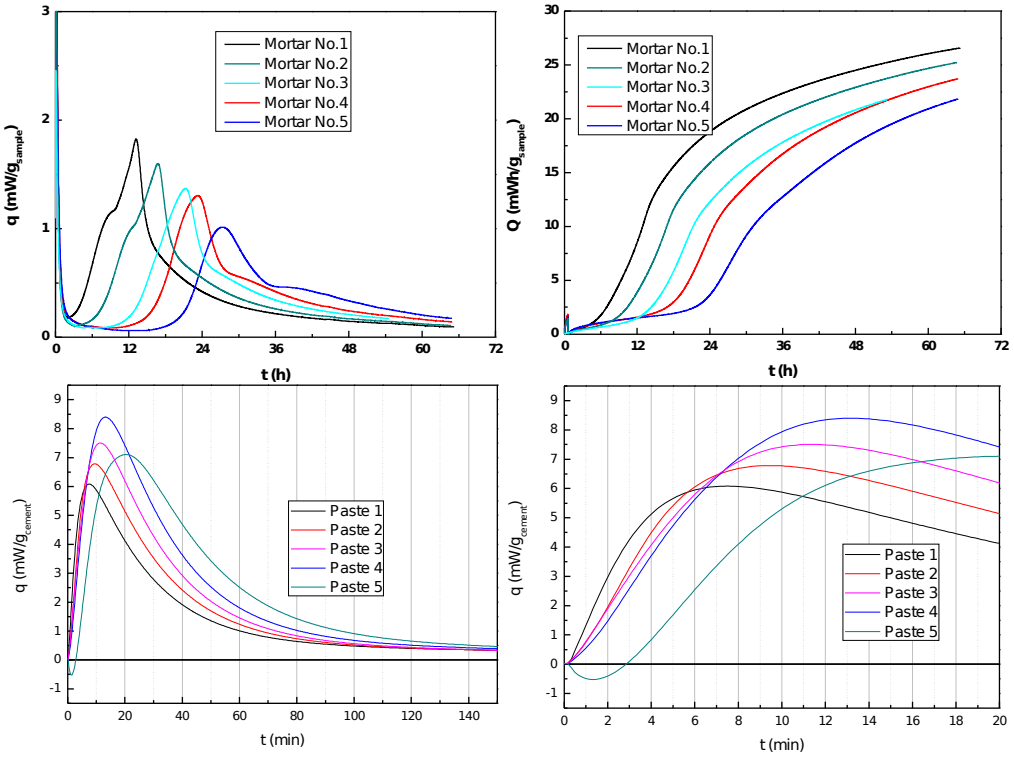


Superplasticizer formulations: workability vs. time

parameter		Mortar 1b	Mortar 4b
w/c		0,50	0,525
PCE (dry solids)		0,24%	0,24%
LS (dry solids)		0,00%	0,27%
Flow 10 min	10 min	40 cm	35 cm
Cohesivity	10 min	*☆☆☆☆	****☆
Bleeding	10 min	*☆☆	☆☆☆
Segregation	10 min	*☆☆	☆☆☆
Flow 60 min	60 min	38 cm	41 cm
Cohesivity	60 min	☆☆☆☆☆	*****
Bleeding	60 min	*☆☆	☆☆☆
Segregation	60 min	*☆☆	*☆☆

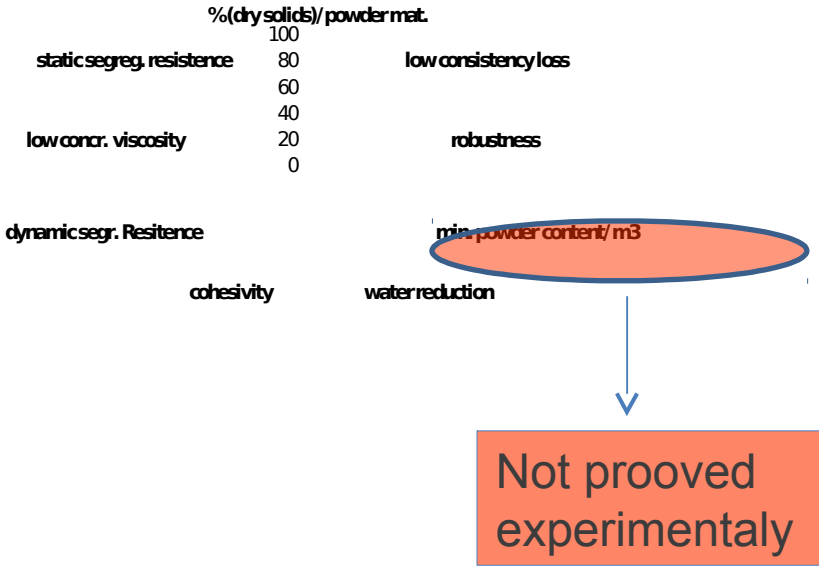
Superplasticizer formulations: hydration reaction

parameter	Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5
w/c	0,475	0,50	0,50	0,50	0,53
PCE (dry solids)	0,24%	0,24%	0,24%	0,24%	0,24%
LS (dry solids)	0,00%	0,09%	0,18%	0,27%	0,36%
Flow (minicone)	43 cm	44,5 cm	42,5 cm	39 cm	40,5 cm
Cohesivity	*	**	****	****	*****
Bleeding	**	*	***	***	***
Segregation	**	**	*	***	***
Overall filling	very bad	bad	ok	good	excellent



Superplasticizer formulations: overall aspect on concrete rheology

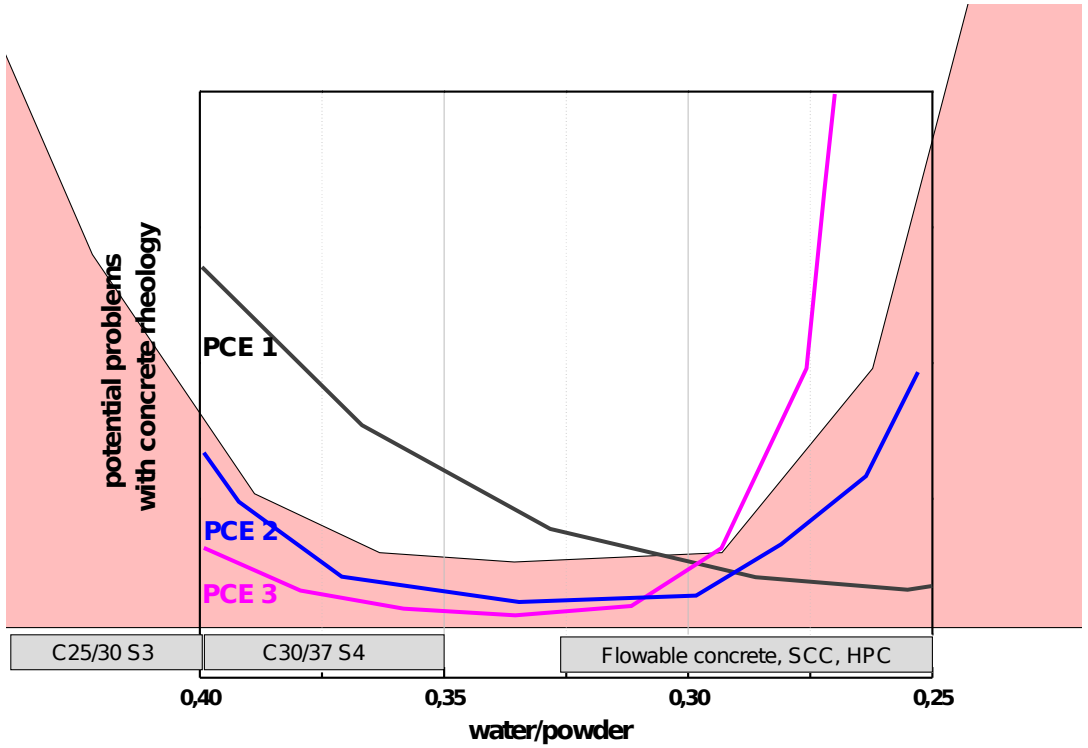
parameter	Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5
PCE (dry solids)	0,24%	0,24%	0,24%	0,24%	0,24%
LS (dry solids)	0,00%	0,09%	0,18%	0,27%	0,36%



Valid for flowable concrte (SCC)

Superplasticizer formulations: overall aspect on concrete rheology

parameter	Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5
PCE (dry solids)	0,24%	0,24%	0,24%	0,24%	0,24%
LS (dry solids)	0,00%	0,09%	0,18%	0,27%	0,36%



Our presentation at Schleibinger 2014