Rheology of water reduced Eco-friendly concretes – Rheologie wasserreduzierter Ökobetone

Technische Universität Darmstadt, Institut für Massivbau
M. Rezvani, M.Sc. Dipl.-Ing. P. Ramge,
Dr.-Ing. T. Proske, Prof. Dr.-Ing. C.-A. Graubner

Outline

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- Motivation for sustainability in the concrete industry
- Mix approach for cement and water reduced eco-friendly concretes
- Experimental Program
- Results and discussion
- Conclusion

Motivation for sustainability in the concrete industry

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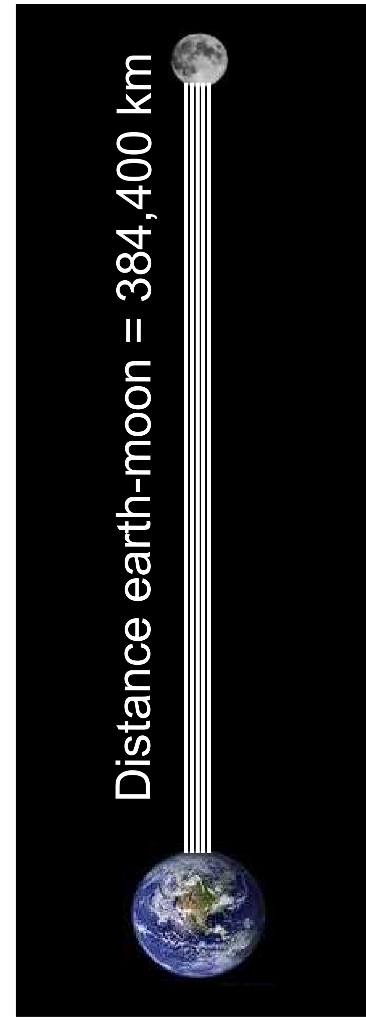
Concrete is the <u>mass</u> building material of our time.

Cement production (2009)
worldwide: ca. 2.8 Billion tonnes / year

Assumption:
for 1m³ mortar and concrete ≈ 300 kg cement
= 9.3 billion tonnes concrete
≈ 3.9 billion m³ concrete

Equivalent to a column (1 m x 1 m)
with a length of 3,900,000 km



10 columns Earth – Moon !

Motivation for sustainability in the concrete industry

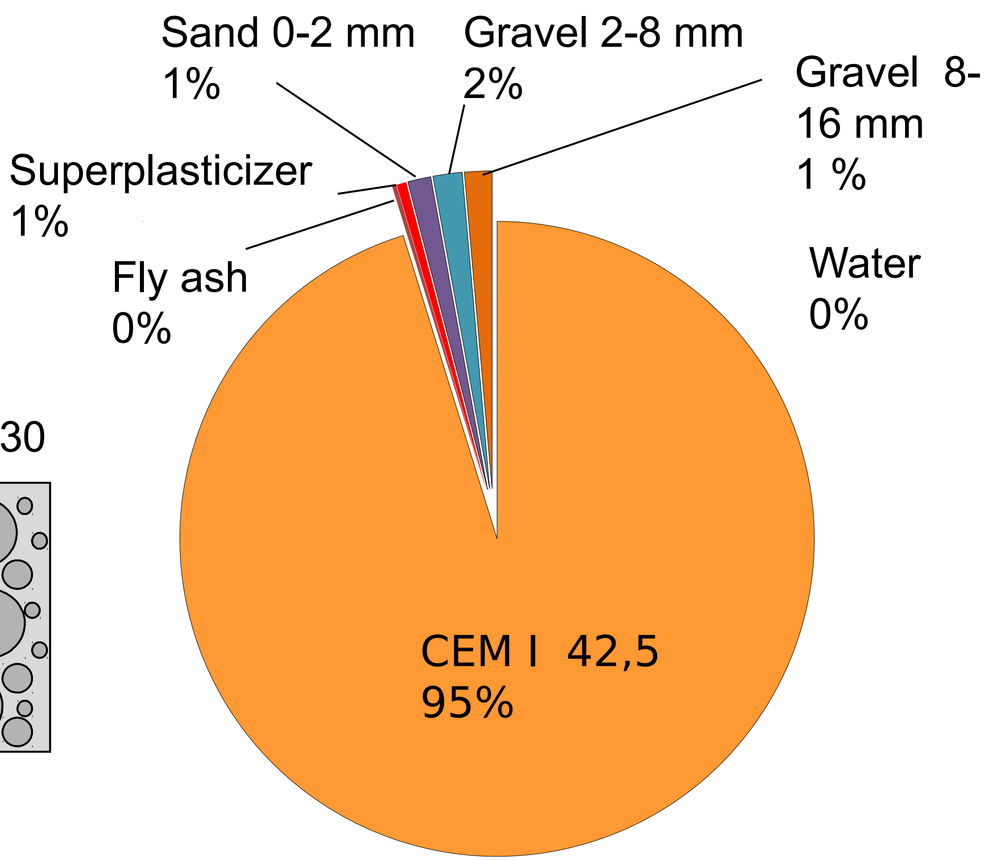
- Cement ~ 5% of worldwide CO_2-Emission*
- Cement ~ 3.8% annual of global energy use*

0.8 ~ 1.0 ton CO_2	→ 1 ton of Cement
1,700 kWh	
1.5 ton of raw material	← 1 ton of Cement

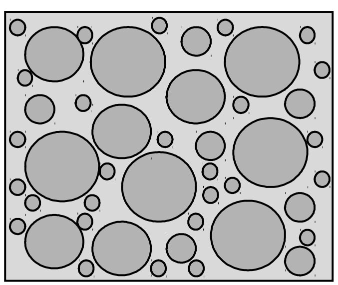
** Source: World Resources Institute*

Influence of concrete components on GWP

Contribution of component on Global Warming Potential (GWP) of concrete – Example concrete mix C25/30



Concrete C25/30



Most of the Global Warming Potential (ca. 95%) comes from the cement

Alternatives to reduce the demand of cement clinker

1 Currently no serious alternative to Portland cement clinker based cements (e. g. Alkali activated alumina silicates, Novacem, Celitement).

2 Minimization of the cement in the concrete.

Modification in conventional concrete technology

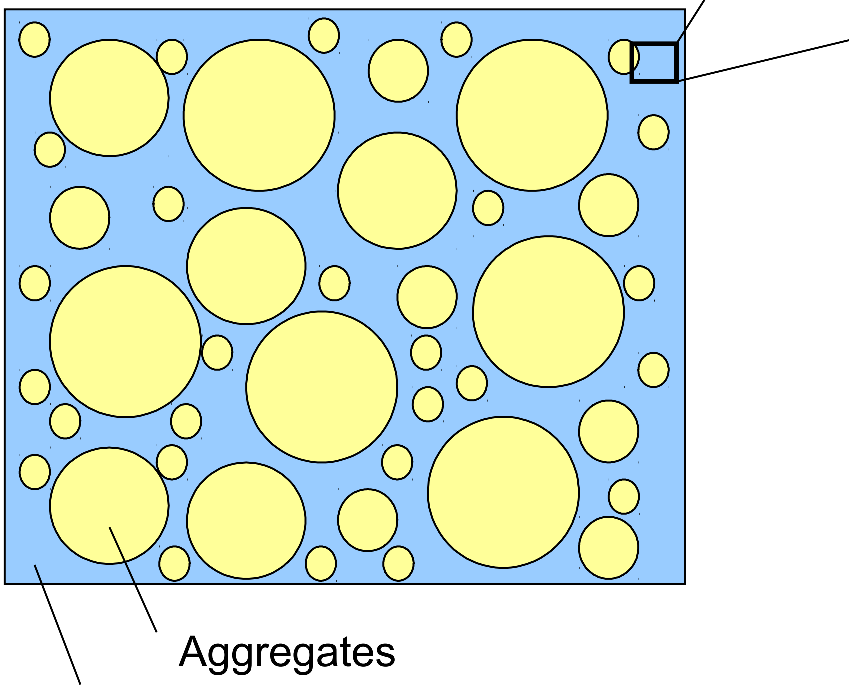
Stepwise design of eco-friendly concrete mixes

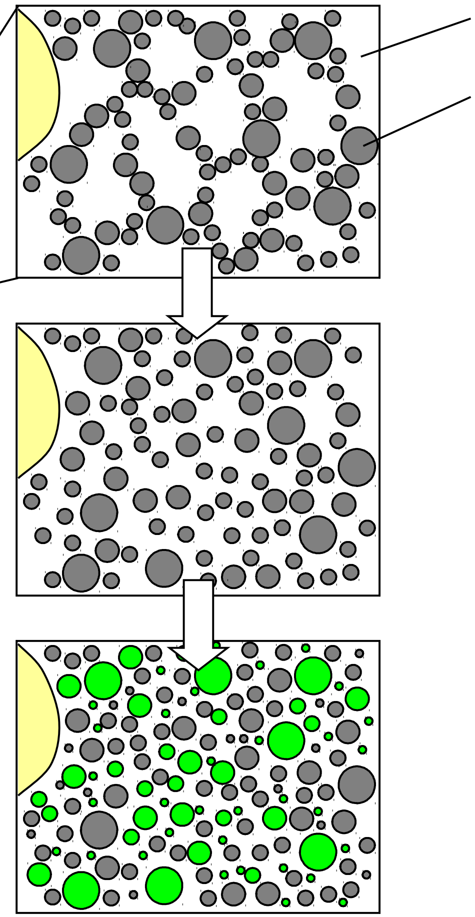
Reduction of Water and Cement

Objectives:

Low cement volume

Sufficient performance





\+ Superplasticizer (dispersing, packing density)

\- **Water**

\- **Cement**

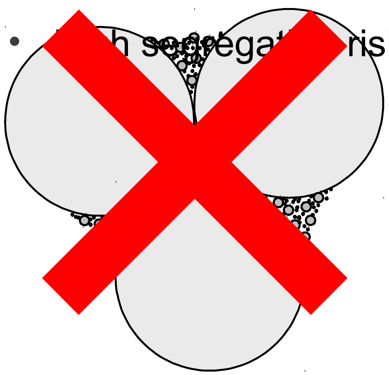
\+ Additives, filler (inert, reactive)

\+ Optimization of the packing

Options available for "Optimised" Packing Density

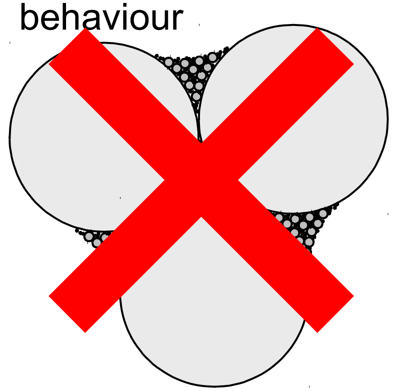
coarse particles dominant:

- to many voids, to much water needed
- no proper coherence without additional stabilizer
- high segregation risk



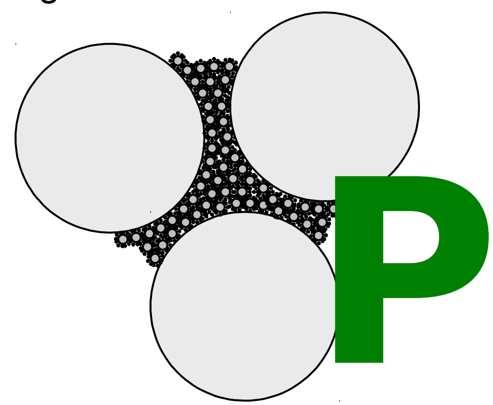
coarse and fine particles co-dominant:

- lowest possible voids content, lowest water demand
- but very high viscosity
- Distinct shear thickening behaviour



fine particles dominant:

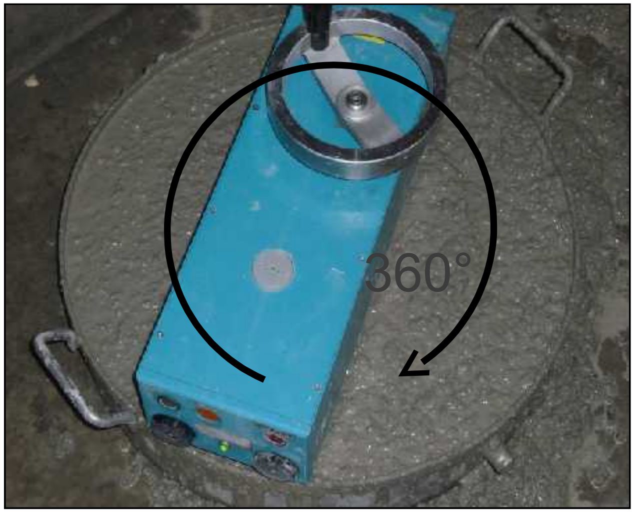
- a bit more water needed
- low viscosity possible despite high solid content
- good coherence

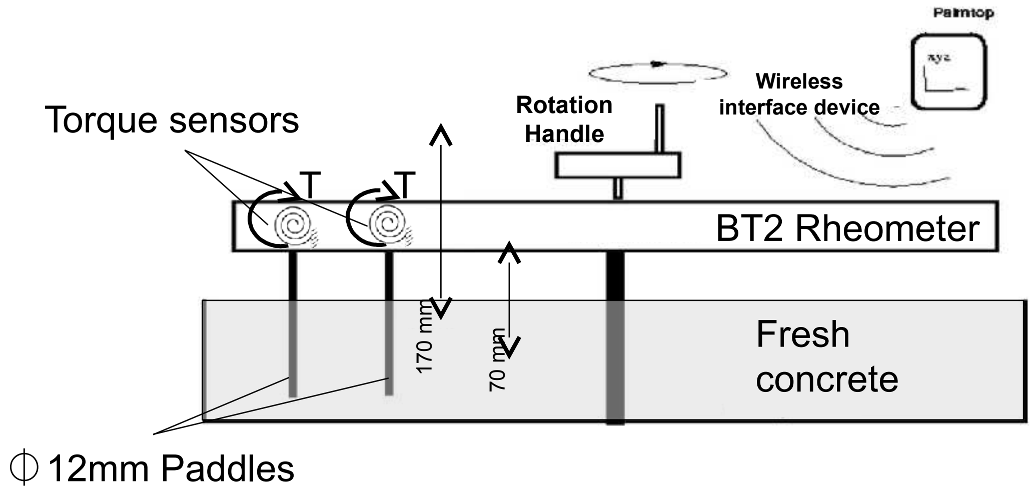


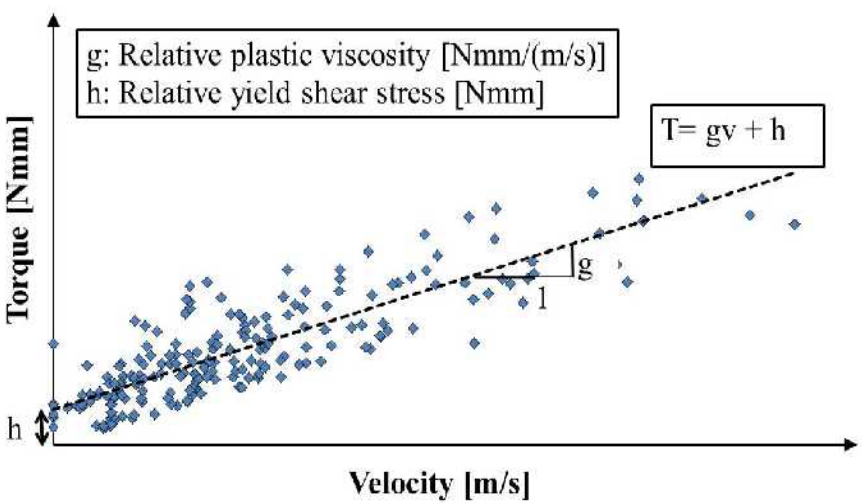
a) A relative surplus of paste volume is needed to ensure workability.

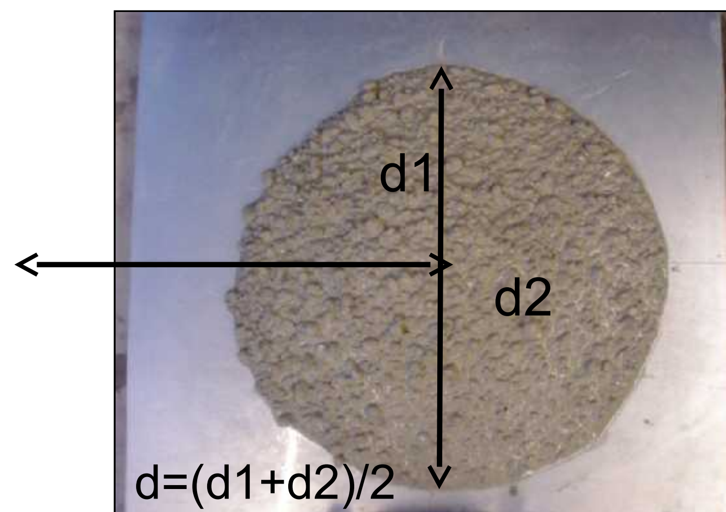
b) Even using **fine-particles** approach, Eco-friendly concretes sometimes exhibit a high sticky behavior → An improvement in rheology in required

Measurement of rheological properties









Experiments overview

Effect of cement substitutions

- **w/p=0.60** PC1) / N-LSP2)= 100 / 0
- **w/p=0.35** PC / N-LSP= 100 / 0

  PC / N-LSP= 70 / 30

  PC / N-LSP= 50 / 50

  PC / N-LSP= 30 / 70

  FA3) (25, 50, 75, 100%)
  SF4) (7, 14%)
  UF-LSP5) (10, 20, 30%)
- **w/p=0.30** PC / N-LSP= 50 / 50 UF-LSP (10, 20, 30%)

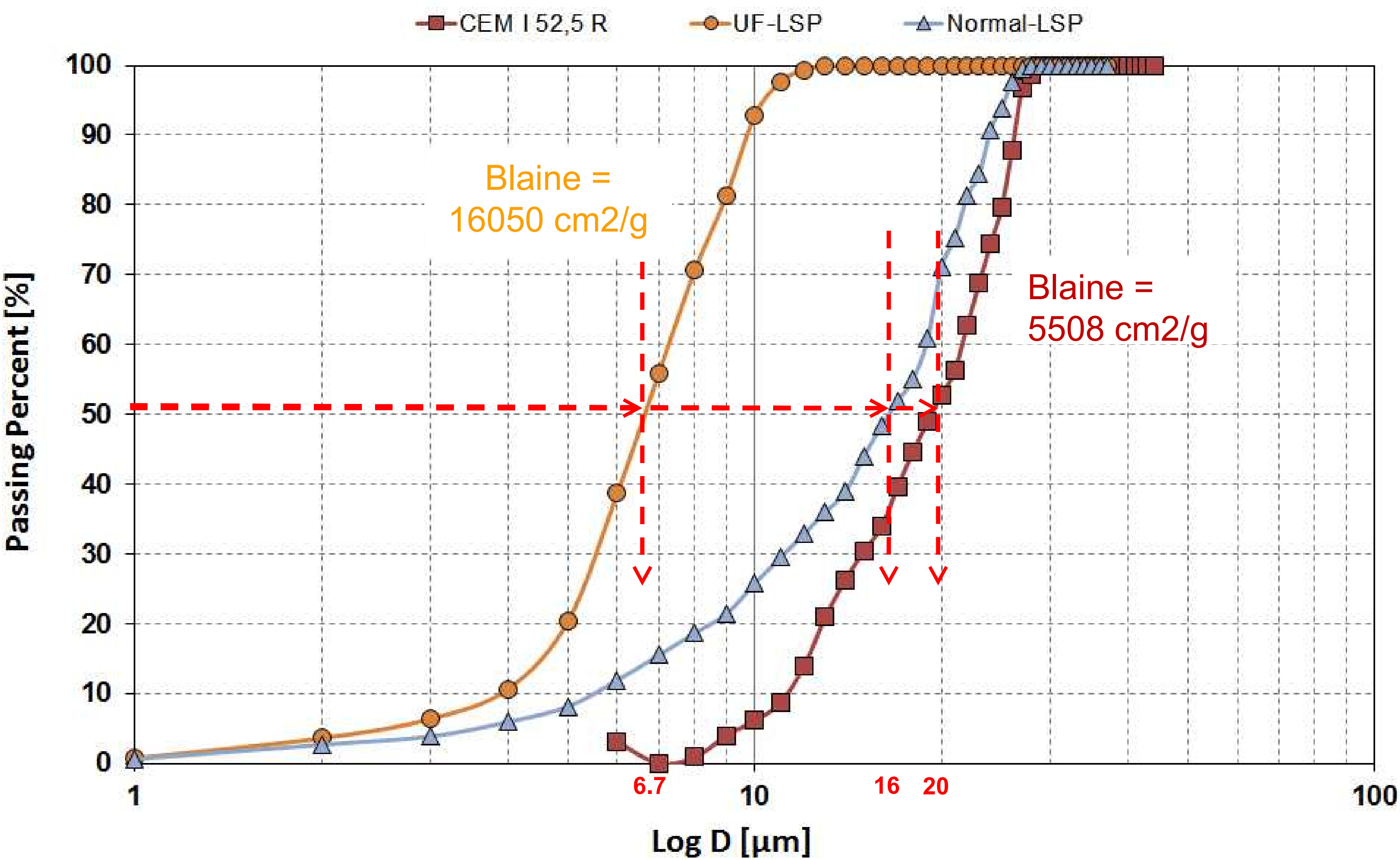
  PC / N-LSP= 70 / 30 UF-LSP (10, 20, 30%)

Effect of paste volume

- **Different paste volume 270~390 l/m3**

1) PC= Portland cement clinker 2) N-LSP= Normal-limestone powder 3) FA= Pulverized fly ash
4) SF= Silica fume 5) UF-LSP= Ultra-fine limestone powder

Raw material properties – Particle size distribution



Mix Proportion – w/p= 0.60 and 0.35

Mix design	Mass per m³ concrete	(w/p=0.60)		(w/powder=0.35)									
		C280-CEM I 52.5 R-w170	C280-CEM II/A-LL 32.5 R-w170	C385-CEM I 52.5 R-w135	C270-CEM I 52.5 R-LSP115-w135	C190-CEM I 52.5 R-LSP190-w135	C115-CEM I 52.5 R-LSP270-w135	C190-CEM I 52.5 R-LSP175-SF 15-w130	C190-CEM I 52.5 R-LSP165-SF 25-w130	C190-CEM I 52.5 R-LSP140-FA 45-w130	C185-CEM I 52.5 R-LSP95-FA 95-w130	C185-CEM I 52.5 R-LSP45-FA 140-w130	C185-CEM I 52.5 R-FA 180-w130
CEM I 52.5 R	[kg]	282	-	384	270	190	116	190	191	188	186	184	182
CEM II/A-LL 32.5 R	[kg]	-	277	-	-	-	-	-	-	-	-	-	-
Fly Ash (EN 450)	[kg]	-	-	-	-	-	-	-	-	47	93	138	182
Limestone powder (N)	[kg]	-	-	-	116	190	270	176	165	141	93	46	-
Silica Fume	[kg]	-	-	-	-	-	-	13	25	-	-	-	-
Water	[kg]	169	166	134	135	133	135	133	132	131	134	132	131
Superplasticizer	[kg]	0.0	0.0	5.6	5.6	2.6	2.0	2.5	2.8	3.4	2.8	2.7	2.4
River sand 0-2 mm	[kg]	522	522	504	504	504	493	504	504	504	504	504	504
River gravel 2-8 mm	[kg]	477	477	477	477	477	477	477	477	477	477	477	477
River gravel 8-16 mm	[kg]	826	826	826	826	826	826	826	826	826	826	826	826
Portland cement/powder	[%]	100	80	100	70	50	30	50	50	50	50	50	50
Paste volume	[l/m³]	258	257	261	267	264	271	263	263	266	270	271	272
Slump flow [1]	[mm]	445	485	600	510	620	610	530	490	605	570	560	520
Relative plastic viscosity	[$\times 10^{-3}$ Nmm/(m/s)]	9.8	6.7	59.0	19.6	24.9	53.3	24.5	28.8	55.4	39.5	31.5	31.3
Relative flow yield stress	[Nmm]	6505	5264	1191	2006	540	542	1579	1758	303	790	1553	1458
1d Compressive strength	[Mpa]	21.2	7.0	63.8	33.3	18.6	8.4	23.8	25.8	21.9	17.5	17.5	14.8
28d Compressive strength	[Mpa]	51.5	38.5	106.7	88.5	63.0	30.6	68.3	79.0	68.1	71.5	72.3	70.1

[1] Table flow test according to DIN 1045: 2008-08

- Superplasticizer was adjusted for a certain table flow value ~ 550 mm
- The mixtures had constant paste volume of about 270 l/m3

Mix Proportion – w/p= 0.30

Mix design	Mass per m³ concrete	w/powder=0.30							
		C210-CEM I 52.5 R-LSP210-w125	C210-CEM I 52.5 R-LSP (N/F) 185/20-w125	C210-CEM I 52.5 R-LSP (N/F) 165/40-w125	C210-CEM I 52.5 R-LSP (N/F) 145/60-w125	C125-CEM I 52.5 R-LSP (N/F) 285-w125	C125-CEM I 52.5 R-LSP (N/F) 255/30-w125	C125-CEM I 52.5 R-LSP (N/F) 230/55-w125	C125-CEM I 52.5 R-LSP (N/F) 200/85-w125
CEM I 52.5 R	kg	208	208	208	208	123	123	123	123
Limestone powder (N)	kg	208	187	166	146	286	257	229	200
Limestone powder (F)	kg	0	21	42	62	0	29	57	86
Water	kg	125	125	125	125	125	125	125	125
Superplasticizer	kg	3.4	3.3	3.3	3.5	3.2	2.5	2.9	2.6
River sand 0-2 mm	kg	493	493	493	493	493	493	493	493
River gravel 2-8 mm	kg	477	477	477	477	477	477	477	477
River gravel 8-16 mm	kg	826	826	826	826	826	826	826	826
Portland cement/powder	[%]	50	50	50	50	30	30	30	30
Paste volume	[l/m³]	271	271	271	271	272	272	272	272
Slump flow [1)]	[mm]	530	490	580	595	495	570	620	550
Relative plastic viscosity	[$\times 10^{-3}$ Nmm/(m/s)]	24.5	28.8	67.6	50.1	44.8	38.9	120.2	56.9
Relative flow yield stress	[Nmm]	1579	1758	797	1045	1314	782	333	1045
1d Compressive strength	MPa	23.8	25.8	27.7	28.2	28.2	32.7	12.6	14.4
28d Compressive strength	MPa	68.3	79.0	73.5	73.1	72.7	77.6	41.9	43.8

- Superplasticizer was adjusted for a certain table flow value ~ 550 mm
- The mixtures had constant paste volume of about 270 l/m3

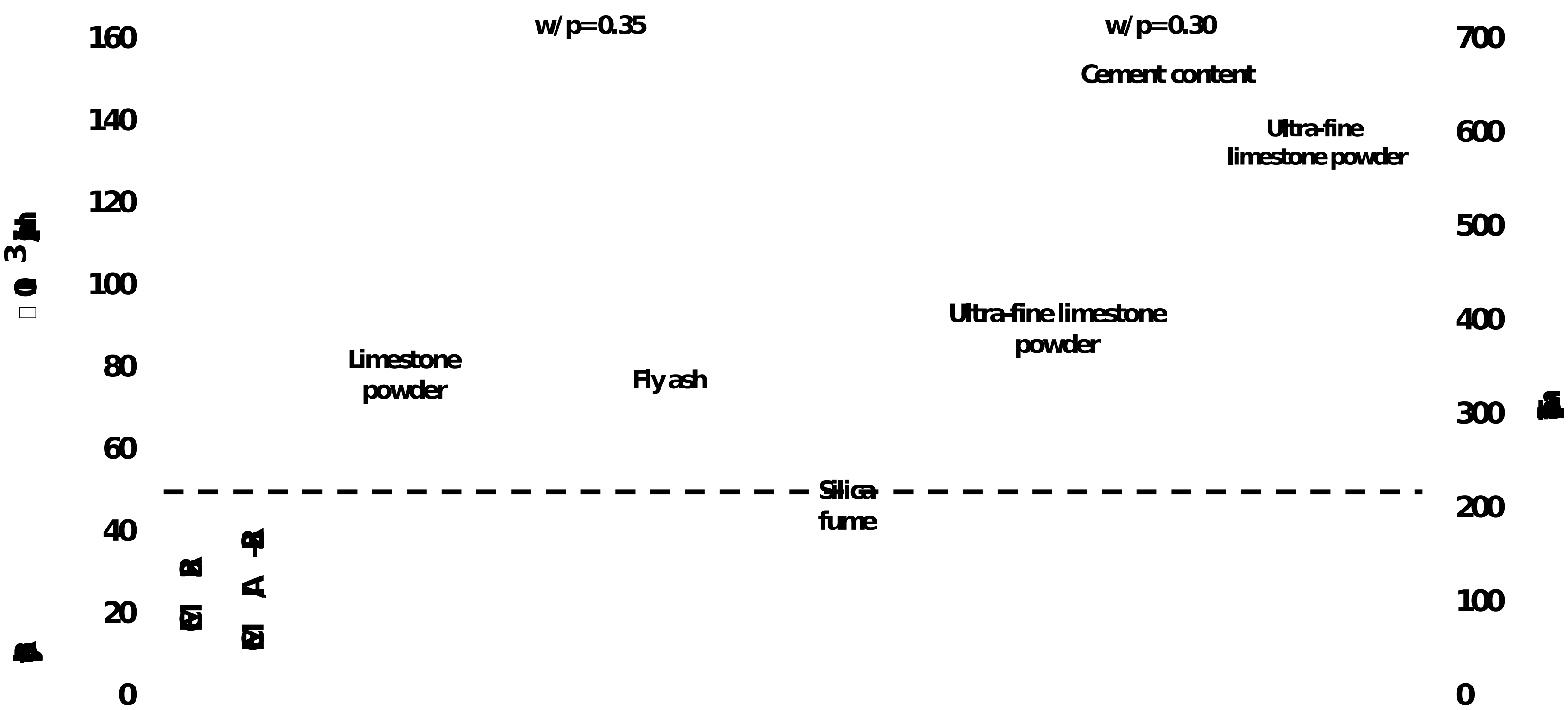
Mix Proportion – Different paste volume

Mix design (Series 2)	Mass per m^3 concrete	w/p=0.43		w/p=0.35						w/p=0.30				
		C280-CEM I 52.5 R-LSP 185-w205	C305-CEM I 52.5 R-LSP 205-w220	C215-CEM I 52.5 R-LSP 215-w155	C240-CEM I 52.5 R-LSP 240-w170	C260-CEM I 52.5 R-LSP 260-w185	C135-CEM I 52.5 R-LSP 320-w160	C155-CEM I 52.5 R-LSP 355-w180	C165-CEM I 52.5 R-LSP 385-w195	C135-CEM I 52.5 R-LSP 320-w140	C145-CEM I 52.5 R-LSP 340-w145	C165-CEM I 52.5 R-LSP 385-w165	C180-CEM I 52.5 R-LSP 415-w180	C165-CEM I 52.5 R-LSP(N/F) 270/115-w170
CEM I 52.5 R	[kg]	280	305	215	240	260	135	155	165	135	145	165	180	165
Limestone powder (N)	[kg]	185	205	215	240	260	320	355	385	320	340	385	415	270
Limestone powder (F)	[kg]	-	-	-	-	-	-	-	-	-	-	-	-	115
Water	[kg]	205	220	155	170	185	160	180	195	140	145	165	180	170
Superplasticizer	[kg]	1.8	4.5	2.4	2.5	2.9	1.9	4.5	2.5	5.5	4.1	4.1	3.6	3.8
River sand 0-2 mm	[kg]	663	717	575	632	690	572	663	717	553	590	663	717	690
River gravel 2-8 mm	[kg]	319	268	413	361	308	394	319	268	422	387	319	268	308
River gravel 8-16 mm	[kg]	552	465	715	625	534	682	552	465	730	671	552	465	534
Clinker/powder	[%]	60	60	50	50	50	30	30	30	30	30	30	30	30
Paste volume	[l/m^3]	360	390	300	330	360	320	360	390	300	320	360	390	360
Water/clinker	[-]	0.73	0.72	0.72	0.71	0.71	1.19	1.16	1.18	1.04	1.00	1.00	1.00	1.03
Slump flow[1)]	[mm]	660	698	560[2)]	615[2)]	670	680	710	690	740	745	760	710	700
Relative plastic viscosity	[$\times 10^{-3}$ Nmm/(m/s)]	1.5	1.5	23.8	13.6	2.0	7.1	4.2	3.2	61.8	30.3	9.4	6.2	2.7
Relative flow yield stress	[Nmm]	51	43	401	312	46	96	14	34	195	320[3)]	257	50[3)]	1
1d Compressive strength	[MPa]	20.4	19.4	NA	NA	26.0	9.0	11.8	12.3	17.2	13.0	14.3	18.6	20.5
28d Compressive strength	[MPa]	48.7	46.3	60.3	56.2	58.5	33.8	40.9	40.4	57.8	42.9	42.6	53.3	52.2

[1)] Slump flow for Self-compacting concrete according to [11] [2)]: Table flow test according to DIN EN 12350-5 [3)]: The minimum torque obtained from flow curve

- Superplasticizer was adjusted for a slump flow value between 670 – 750 mm

Plastic viscosity – Influence of constitutions



Plastic viscosity – Effect of UF-LSP and fly ash

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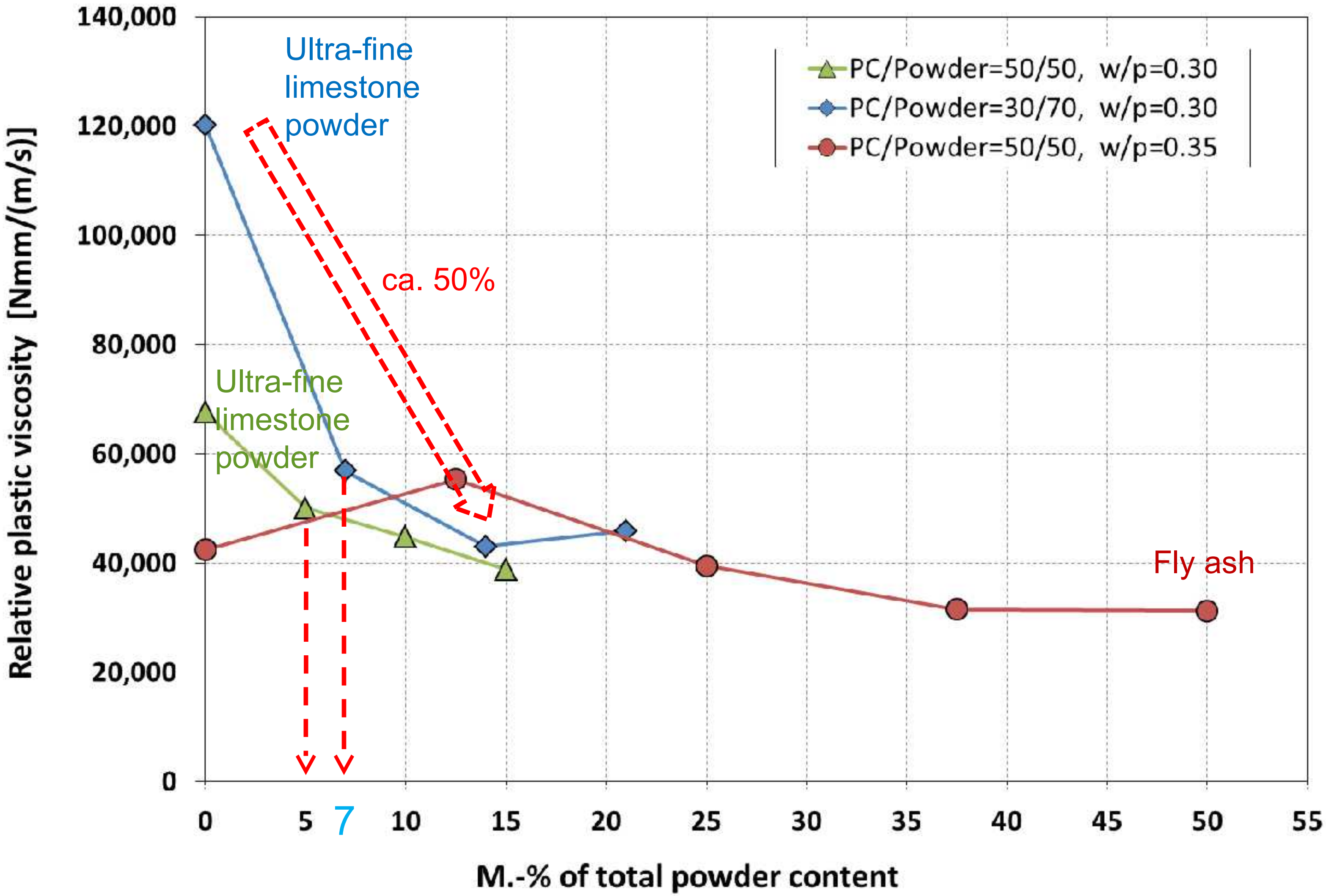
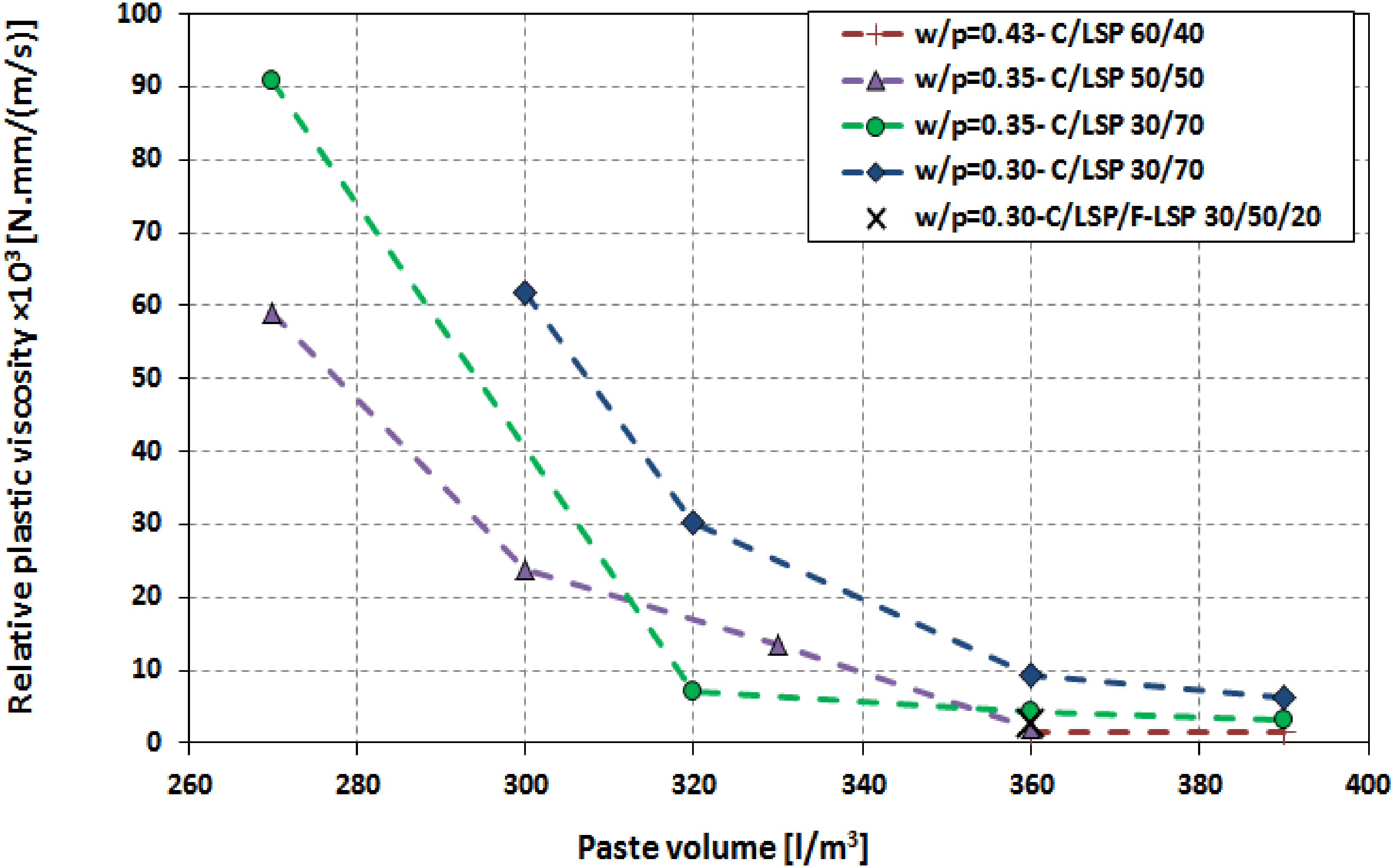


Plastic viscosity – Effect of paste volume



Flow yield stress – Influence of constitutions

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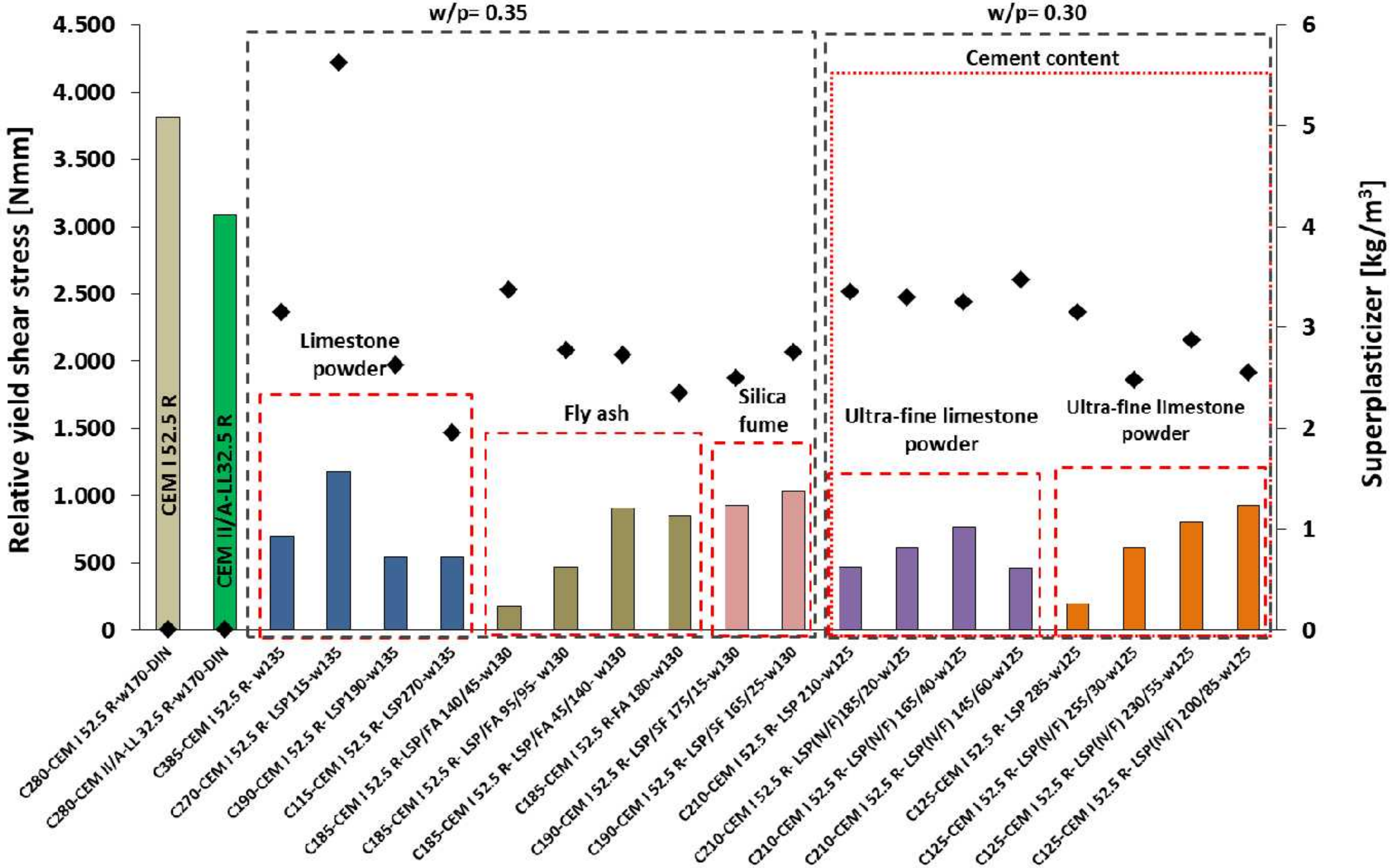
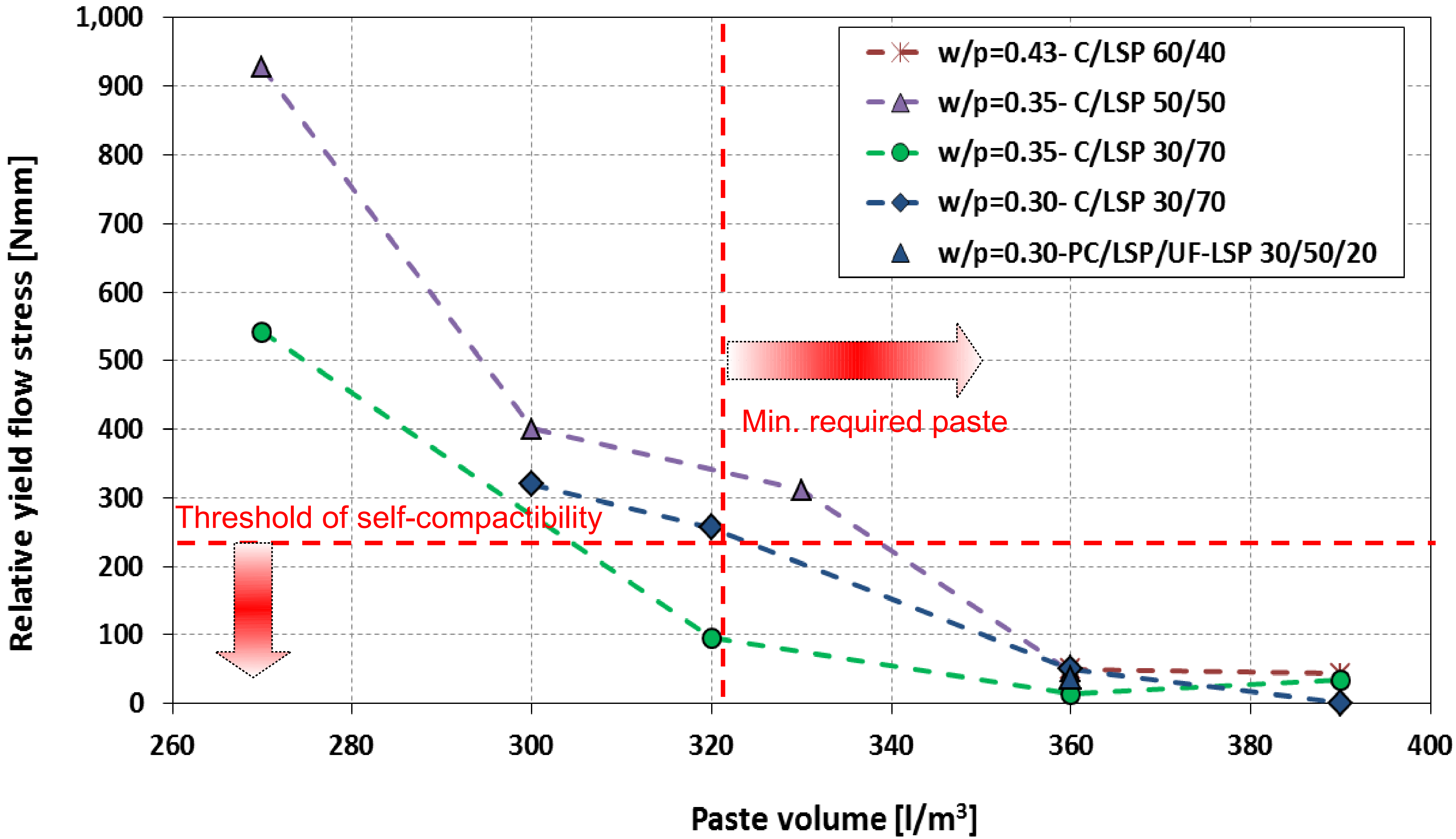
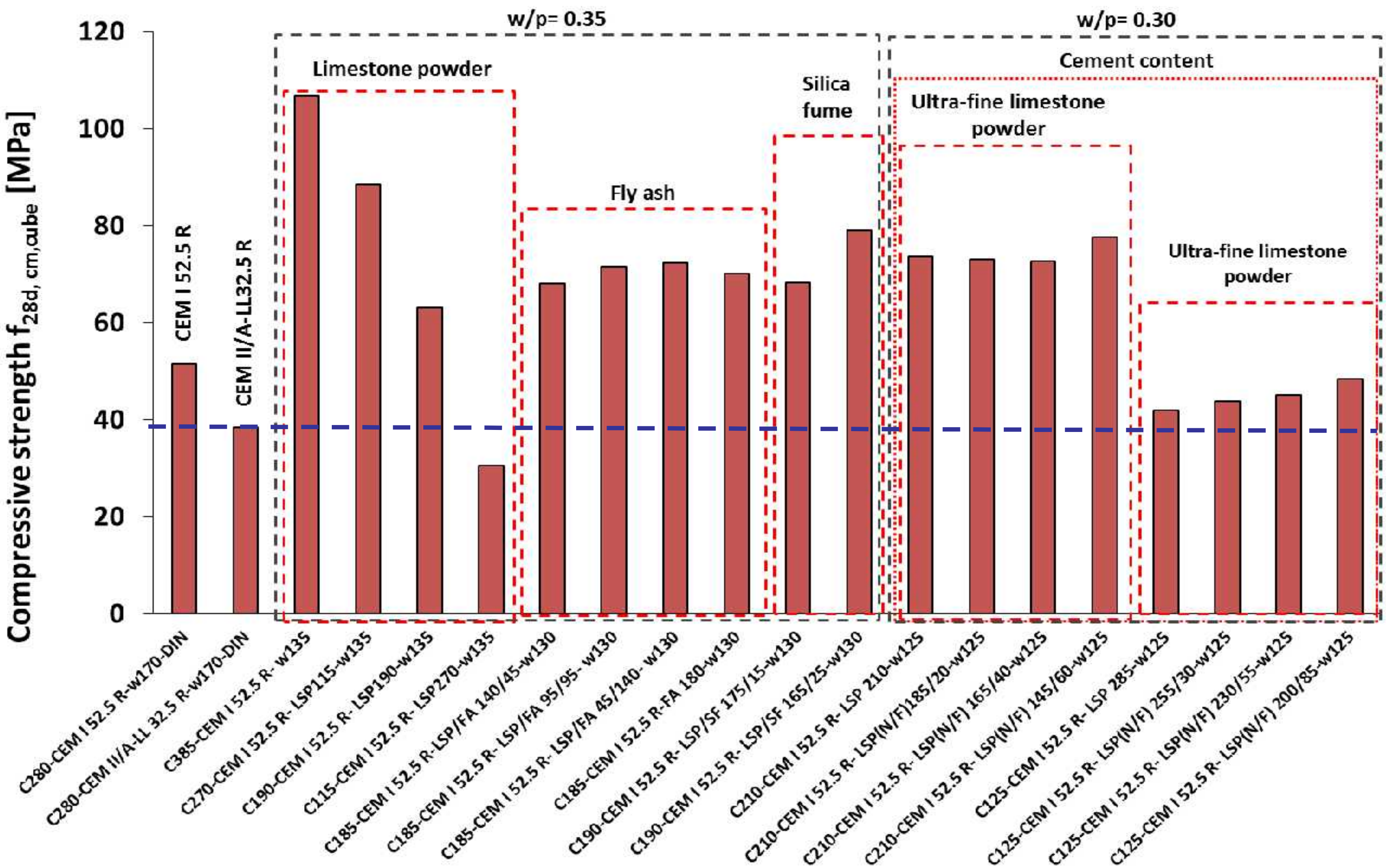


Flow yield stress – Effect of paste volume



Mechanical properties – Compressive strength



Conclusion and outlook

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- In comparison with the conventional concretes, Eco-friendly concretes with a reduced cement content exhibit a higher plastic viscosity but a lower yield flow stress.
- Even a small replacement of normal limestone powder with the finer one (up to 7%), results in a significant reduction of plastic viscosity (up to 55%).
- UF-LSP seems more efficient when a lower amount of cement clinker is used.
- Higher addition of both UF-LSP and fly ash results in an increase of yield stress.
- Addition of silica fume could not change the rheological properties significantly
- Depending on the w/p-ratio and cement content, a paste volume of about 330 up to 360 l/m3 seems to be required to achieve a self-compactable mixture. While an excessive paste volume (beyond 360 l/m3) was not beneficial.

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Thank you for your attention

Question?

www.oekobeton.de

rezvani@massivbau.tu-darmstadt.de