

The injection process - effecting mechanical properties?

Ludwig Hertwig

Email: ludwig.hertwig@htwk-leipzig.de

HTWK Leipzig
Structural Concrete Institute



Prof. Dr.-Ing. Klaus Holschemacher

HTWK Leipzig
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Structure

1. Injection and high-performance concrete
2. Comparison manufacturing process
 1. set up
 2. properties
3. Rheology
 1. set up
 2. workability
4. Conclusion

motivation

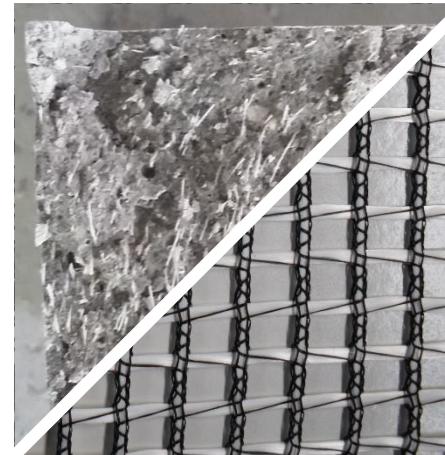
high-performance concrete
 $D_{\max} < 2 \text{ mm}$



textile reinforcement
fibres



high-quality products



manufacturing process?

effects on mechanical properties?

mix design

mix	water	cement	fly ash	micro silica	agg.	SP	w/b	ρ_{fr}
	[kg/m ³]						[−]	[kg/m ³]
SCM 1	239	540	56	56	1198	4.0	0.38	2130
LWSCM 1	252	550	96	41	210	6.3	0.41	1160
ECM 1 ^b	269	1923				14.1		2190
ECM 1a ^{a,b}	269	1923						2170
ECM 2	233	2000						2230
ECM 2a ^a	233	2000				5.0		2240
G 1 ^b	288	1923						2210
G 2 ^b	288	1923						2210

^a additional dosage of SP ^b $D_{max} = 1$ mm

^c no mix design available, sum of dry components

measured properties	process	no.	mix	dimensions ^a component [mm]	quantity member [-]	total specimen [-]
ρ_d, f_{cm}, E_Y	pouring	1	SCM 1	480 x 100	3	9
		2	ECM 1a ^b	480 x 100	3	9
		3	LWSCM 1	480 x 100	3	9
	injection	4	SCM 1	480 x 100	3	9
		5	ECM 1a ^b	480 x 100	3	9
		6	LWSCM 1	480 x 100	3	9
$p, u_{wp}, u_{cap}, u_{cap,K}$	pouring	7	SCM 1	500 x 150 x 150	2	6
		8	ECM 1a ^b	500 x 150 x 150	2	6
		9	LWSCM 1	500 x 150 x 150	2	6
	injection	10	SCM 1	500 x 150 x 150	2	6
		11	ECM 1a ^b	500 x 150 x 150	2	6
		12	LWSCM 1	500 x 150 x 150	2	6

^a cylinder ($h \times d$) or cuboid ($a \times b \times c$)

^b workability for pouring/injection expected at lower limit

ρ_d density

f_{cm} compressive strength

E_Y Young's modulus

p max. water penetration depth

u_{wp} water absorption (pressure)

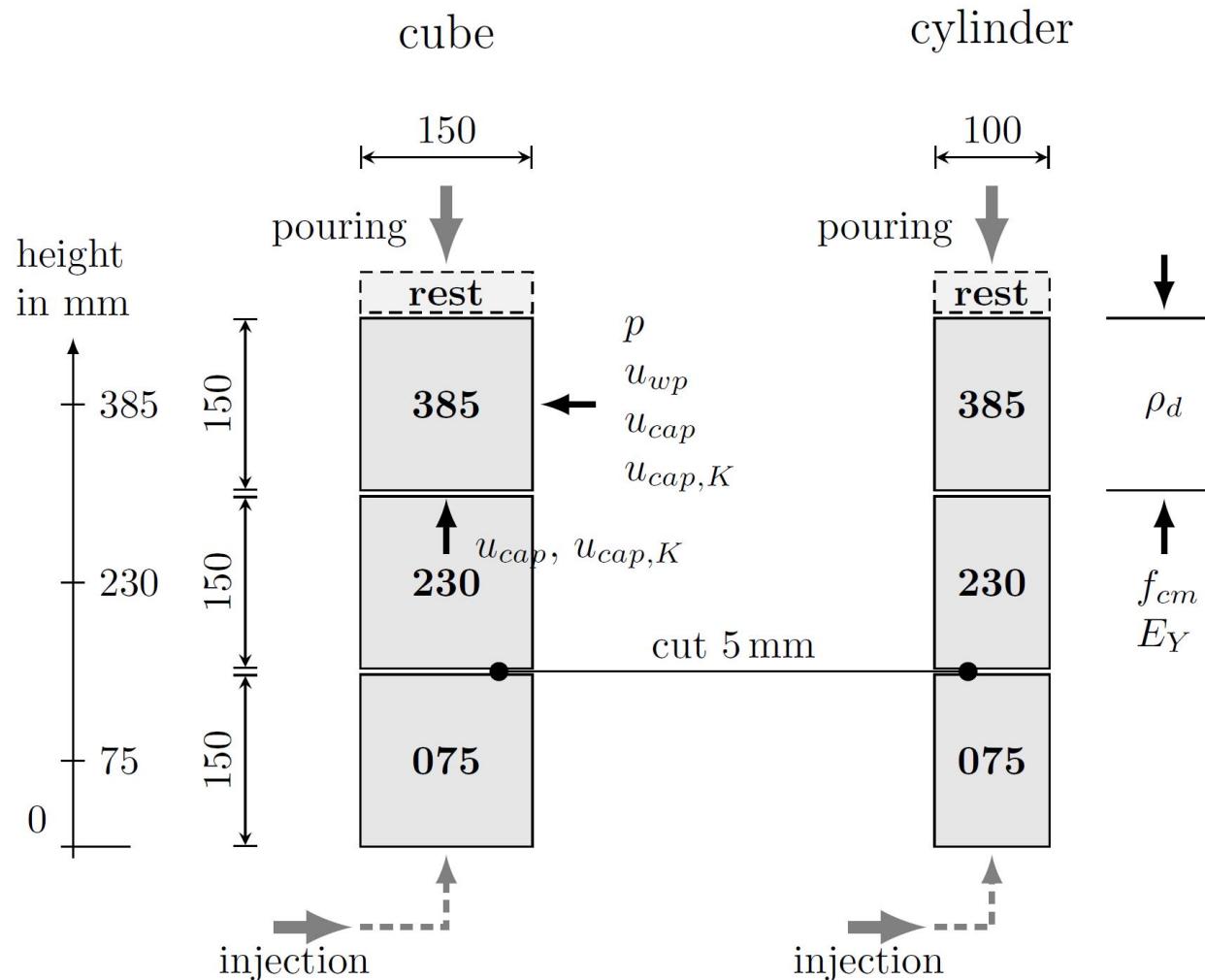
u_{cap} water absorption

$u_{cap,K}$ water absorption according to Karsten

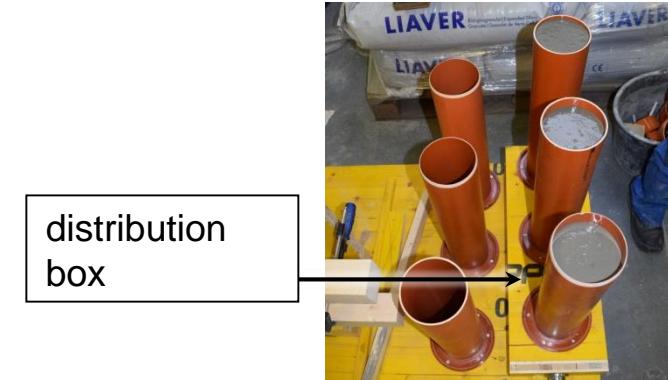
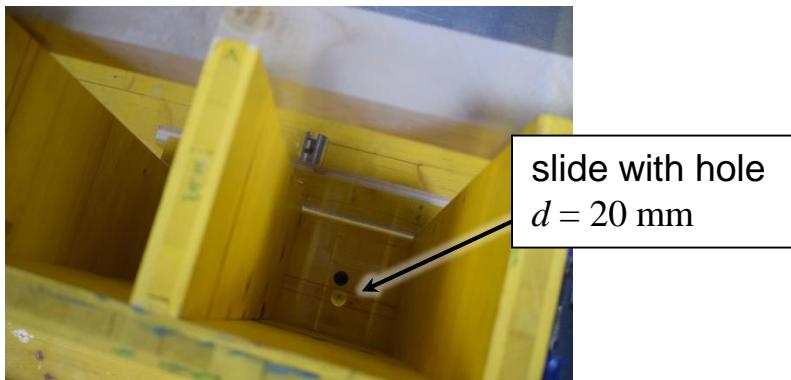
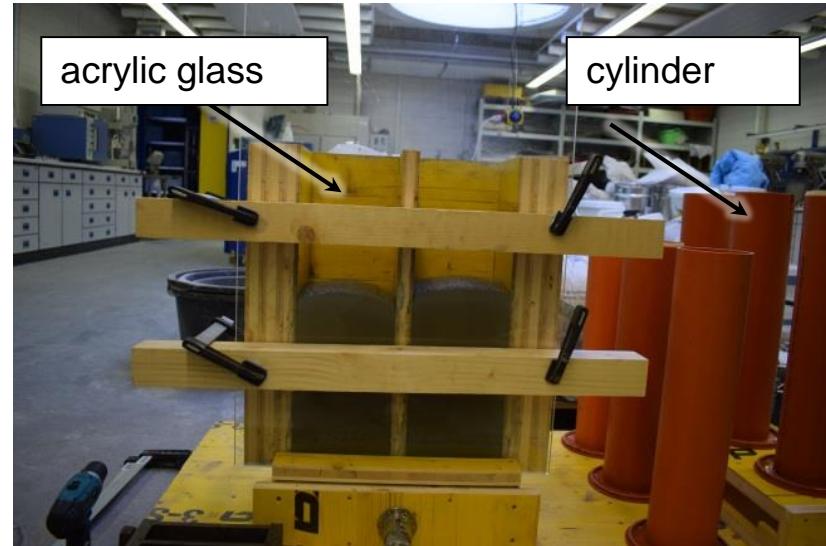
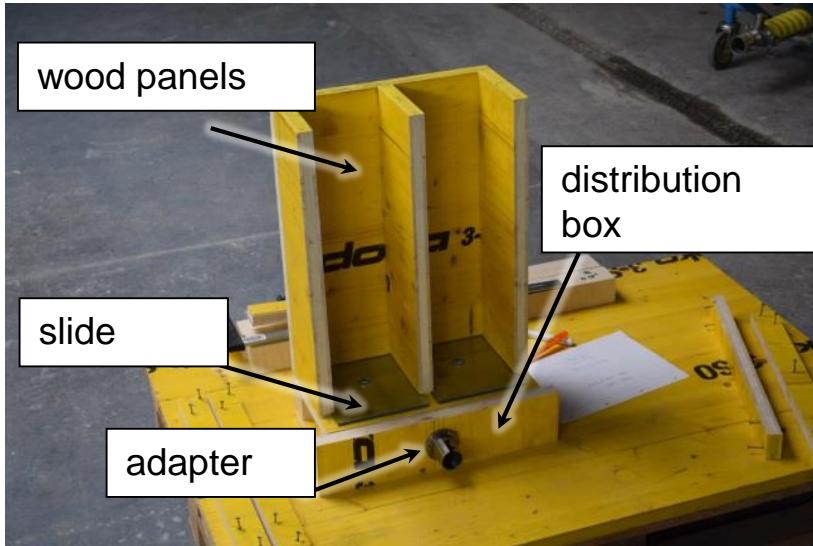
Specimen - testing

- dry density (ρ_d) in compliance with DIN EN 12390-7
- compressive strength (f_{cm}) according to DIN EN 12390-3
- secant modulus of elasticity (Young's modulus – E_Y) according to DIN EN 12390-13
- water resistance (maximum water penetration depth p in mm) in compliance with DIN EN 12390-08
- water absorption during measurement of water resistance (u_{wp}) by weighing specimens
- water absorption according DIN EN 772-11 ($u_{cap,K}$)

specimen



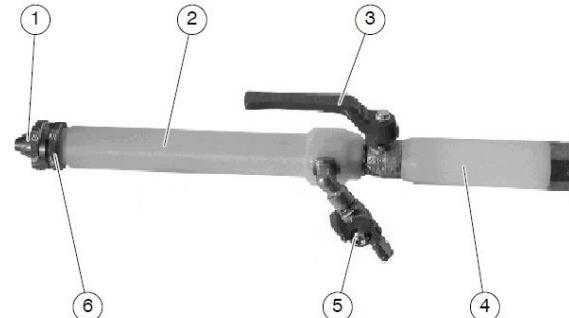
formwork



injection



+



+

adapter fixed
to formwork

source: Strobot



pressure

$$p = 3 \text{ to } 4 \text{ bar}$$

modulus of elasticity E_Y

estimated compr. strength



cuboids (a x b x c)

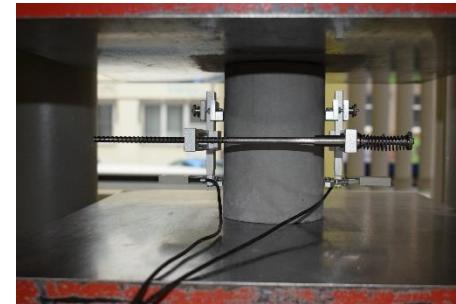
40 mm x 40 mm x 160 mm



overestimation!

$f_{cm} + 15\%$ (first specimen)

Modulus of elasticity E_Y



cylinders (h x d)

150 mm x 100 mm



strength f_{cm}



cylinders (h x d)

150 mm x 100 mm

water penetration depth p

LWSCM 1
Injection



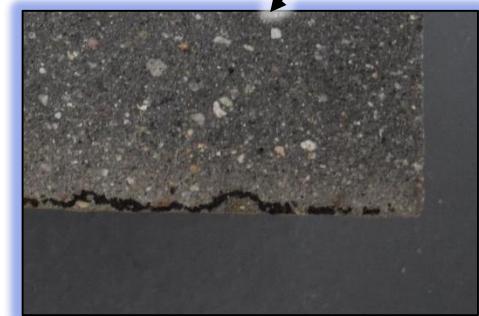
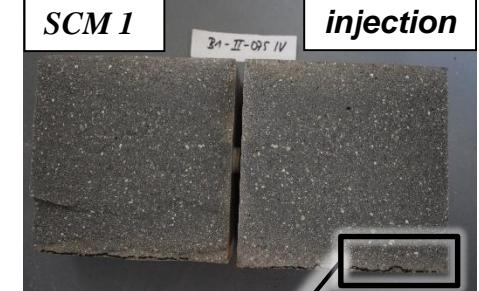
$t = 72 \text{ h}$

$p = 5 \text{ bar}$

adjust procedure?

SCM 1

injection



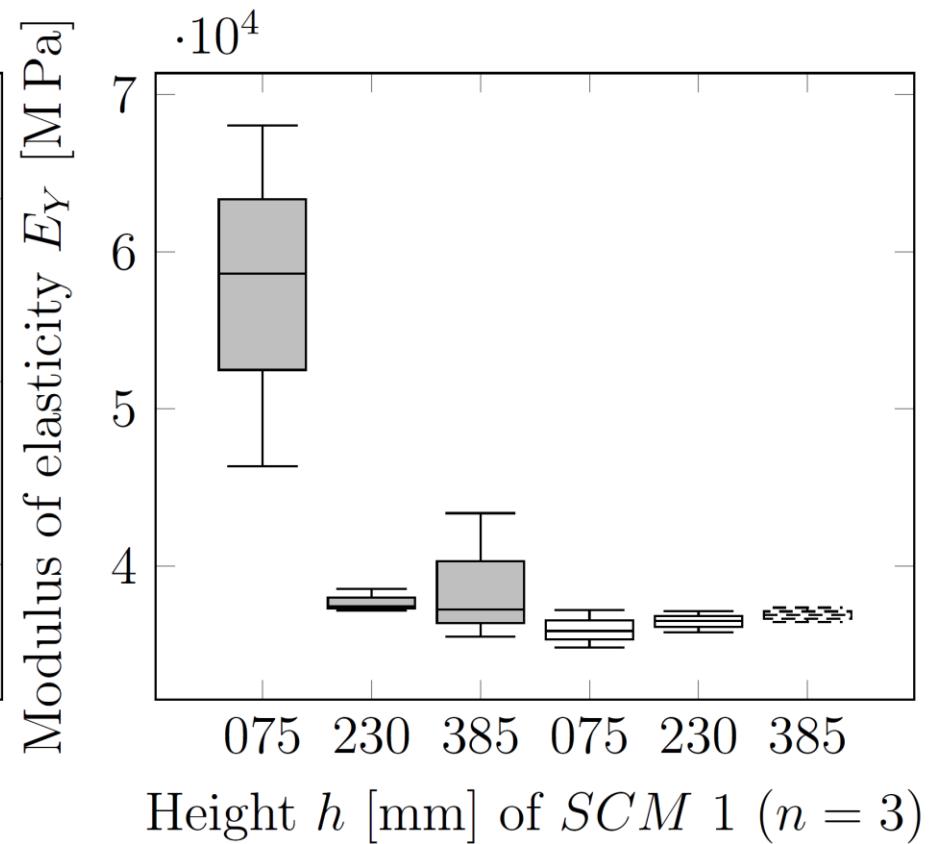
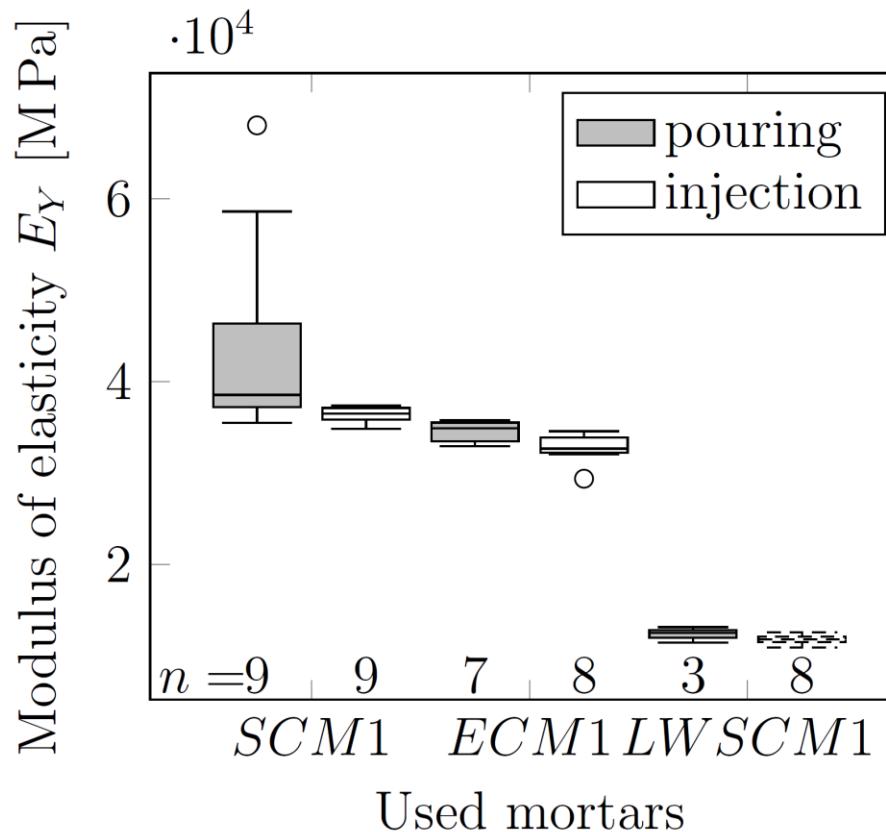
ECM 1a

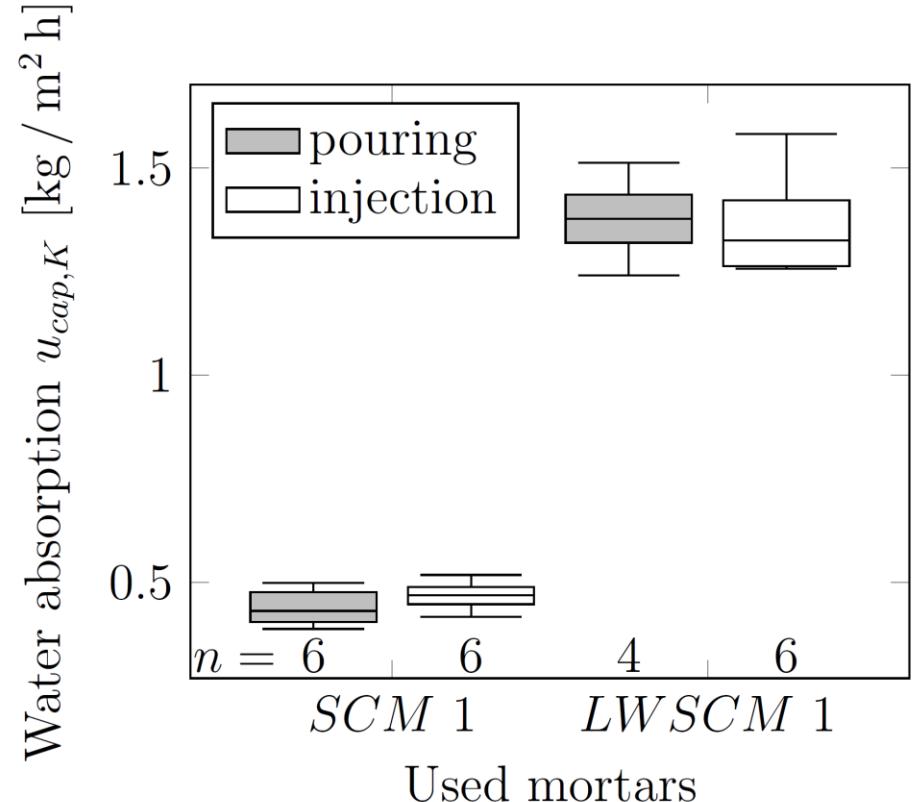
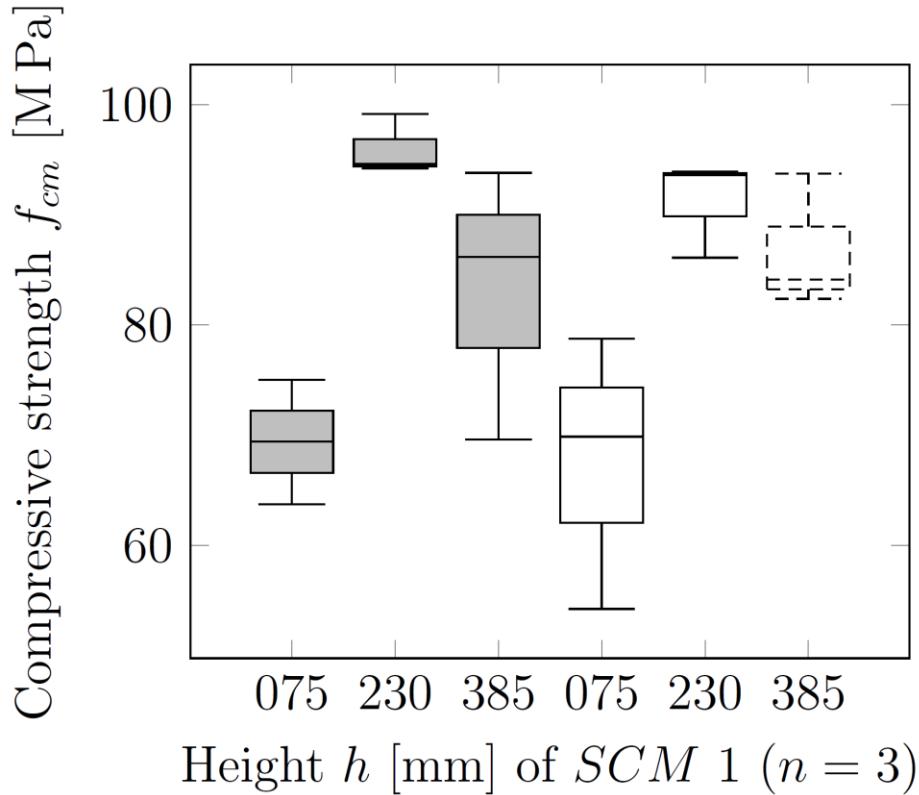
pouring

water absorption $u_{cap,K}$

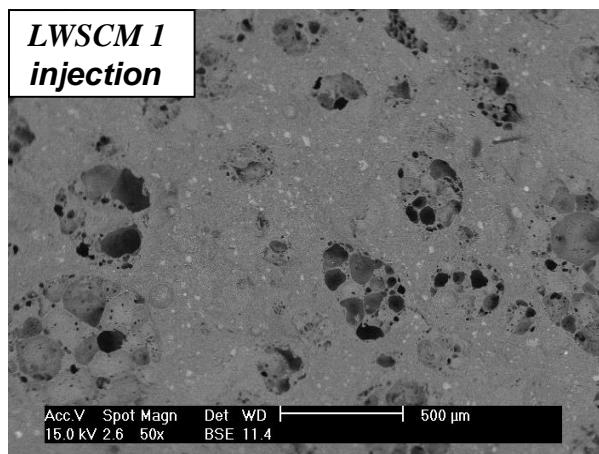
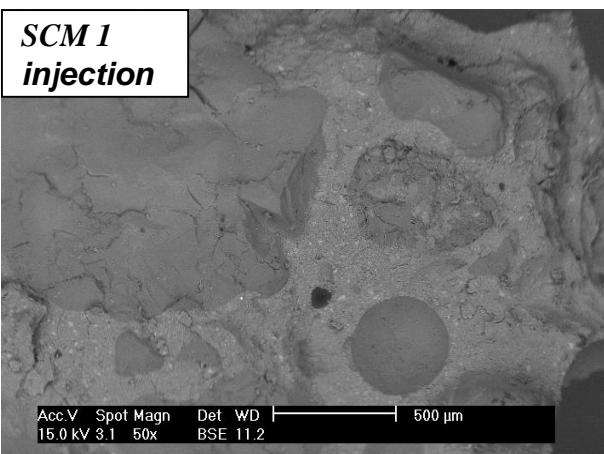
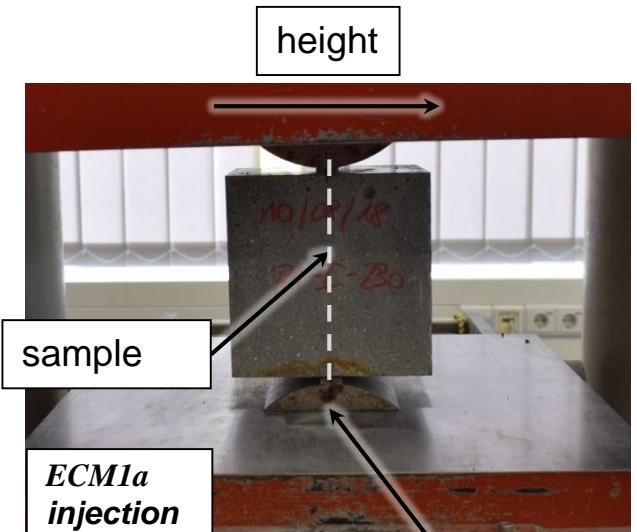
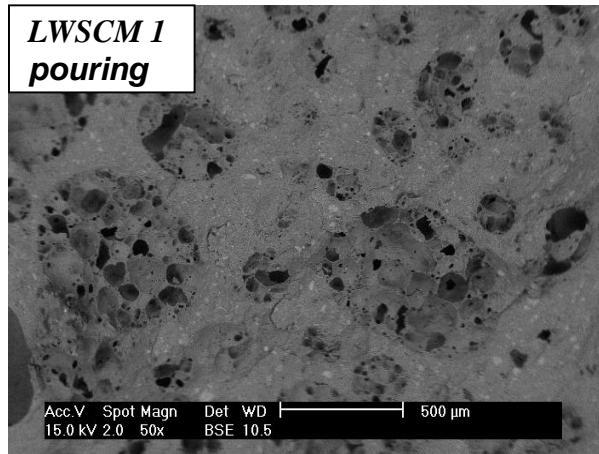
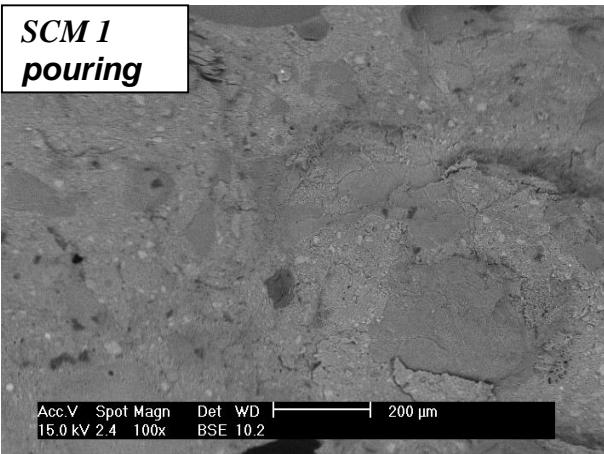


$t = 24 \text{ h}$
no sealing of sides!

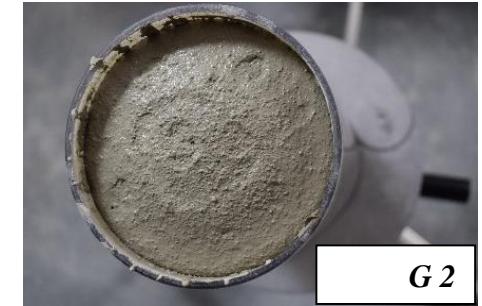
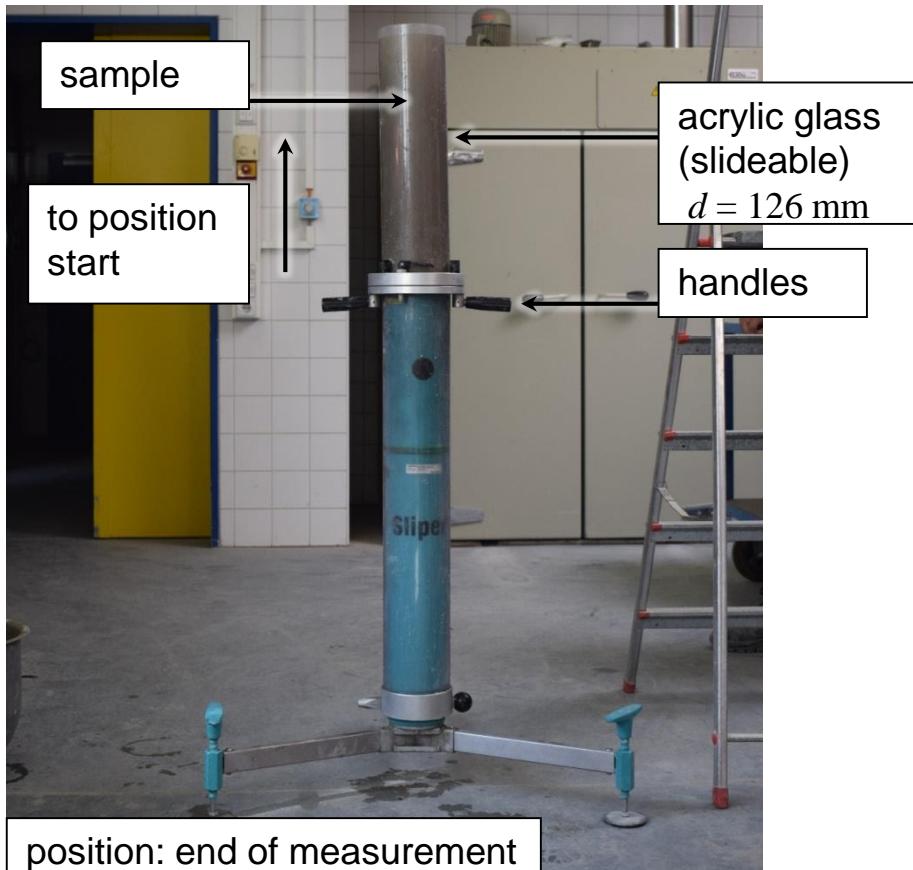
box plots – E_Y 

box plots – f_{cm} and $u_{cap,K}$ 

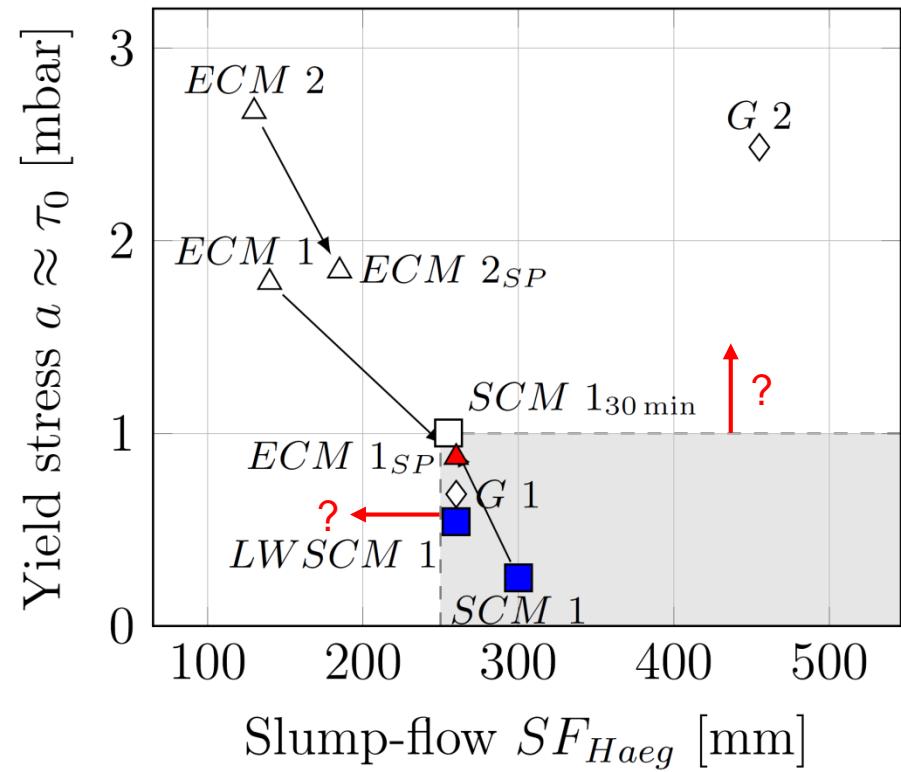
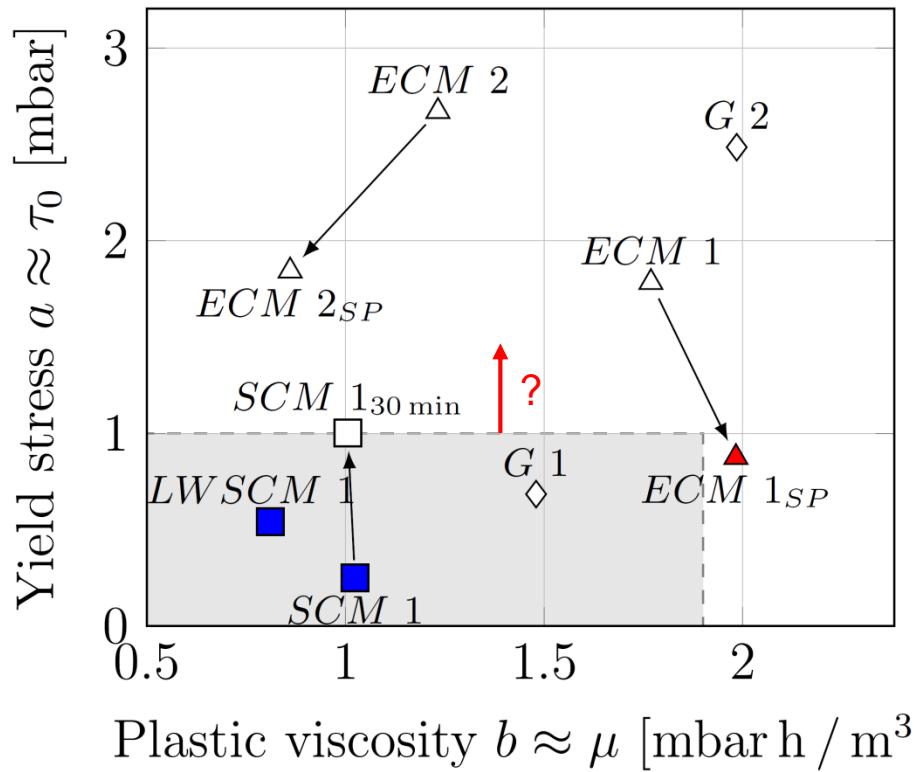
REM-microscope



no difference!

SLIPER

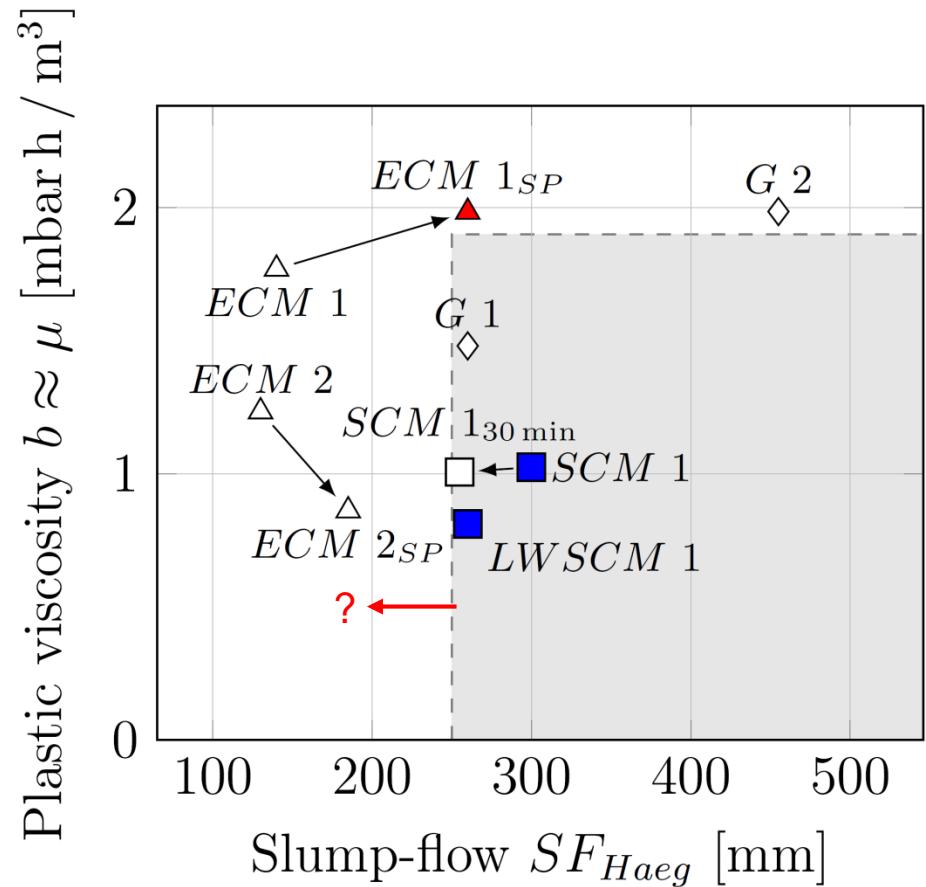
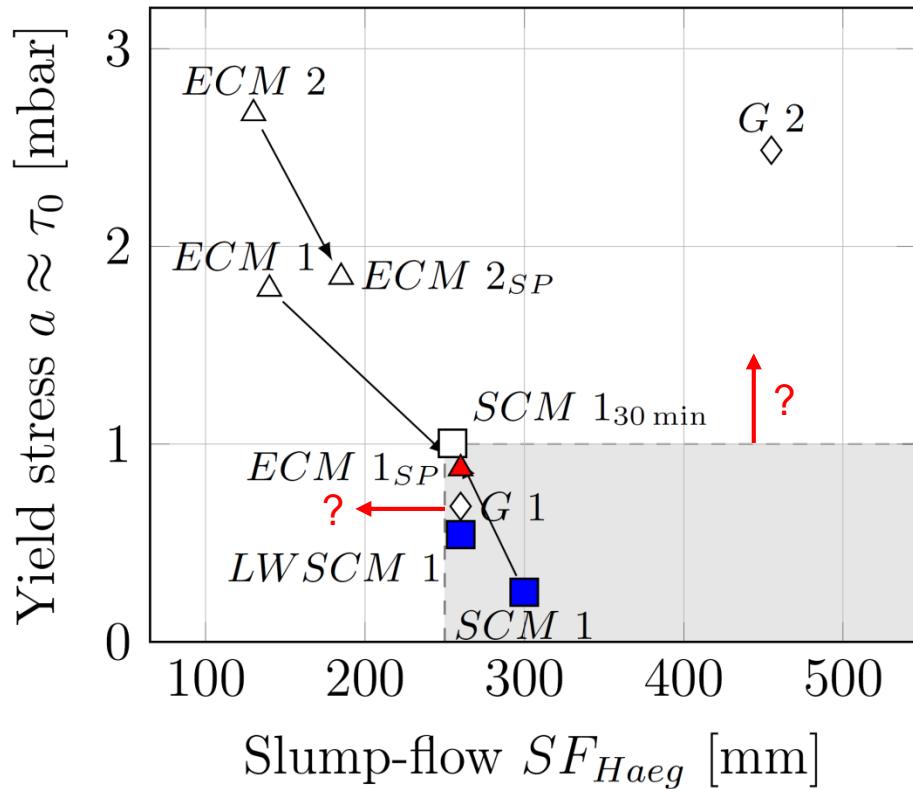
SLIPER – rheology



- ██████████ injectable area due to experiments
- ██████ successful injection
- █████ limit injection

- self-compacting mortars
- △ easy-compacting mortars
- ◊ grouts

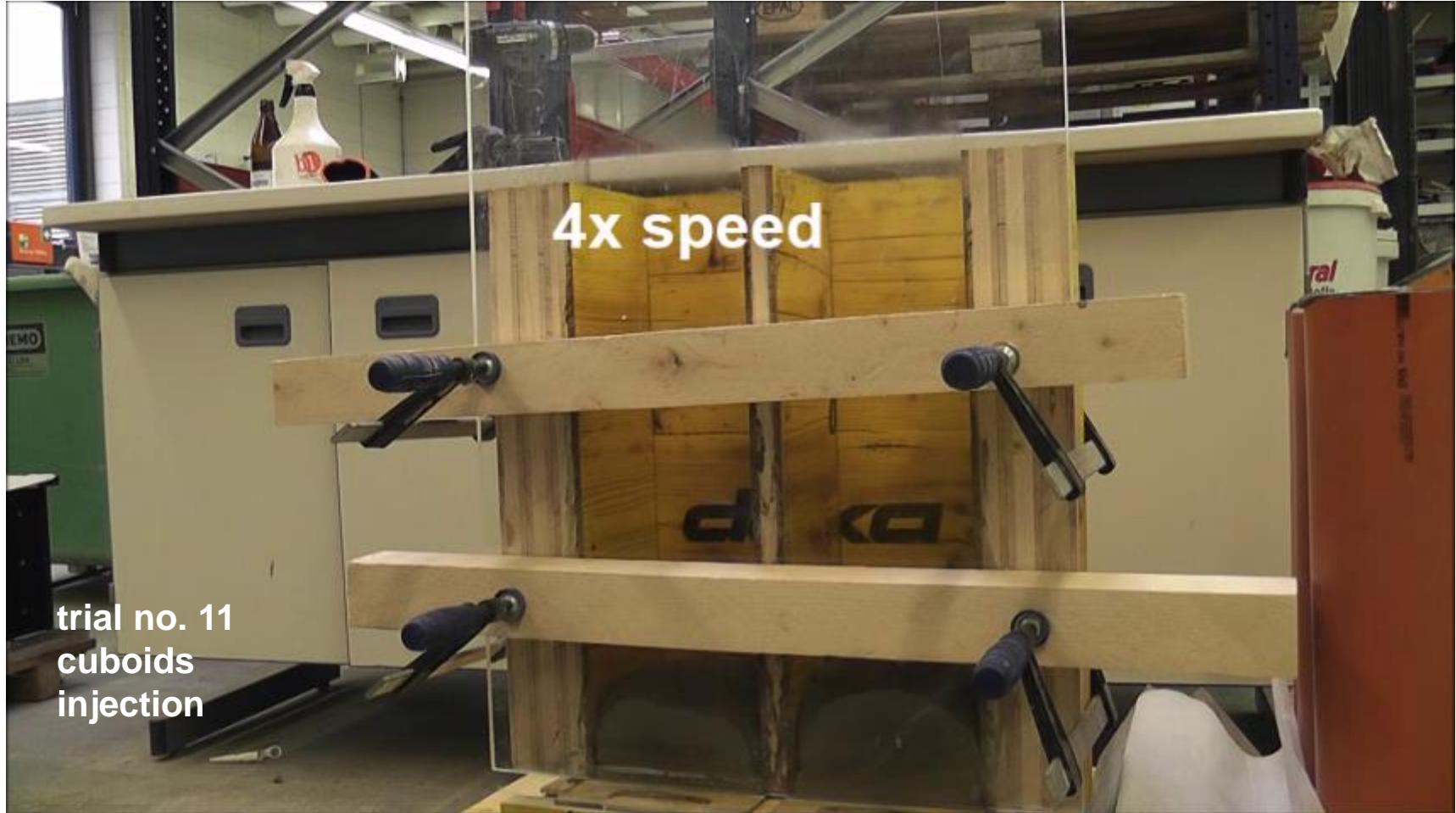
SLIPER – rheology



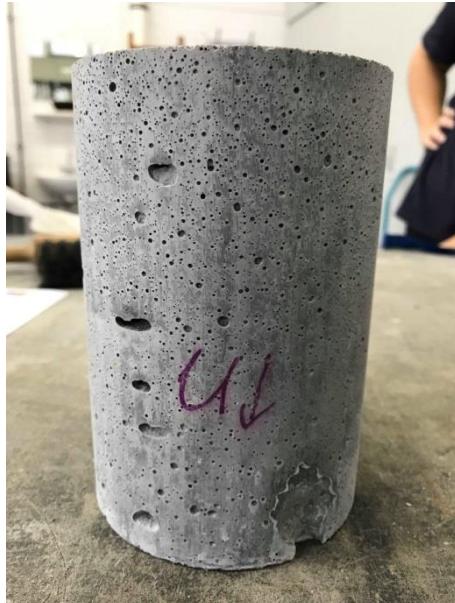
- ██████████ injectable area due to experiments
- ██████ successful injection
- █████ limit injection

- self-compacting mortars
- △ easy-compacting mortars
- ◇ grouts

experimental – limit of workability



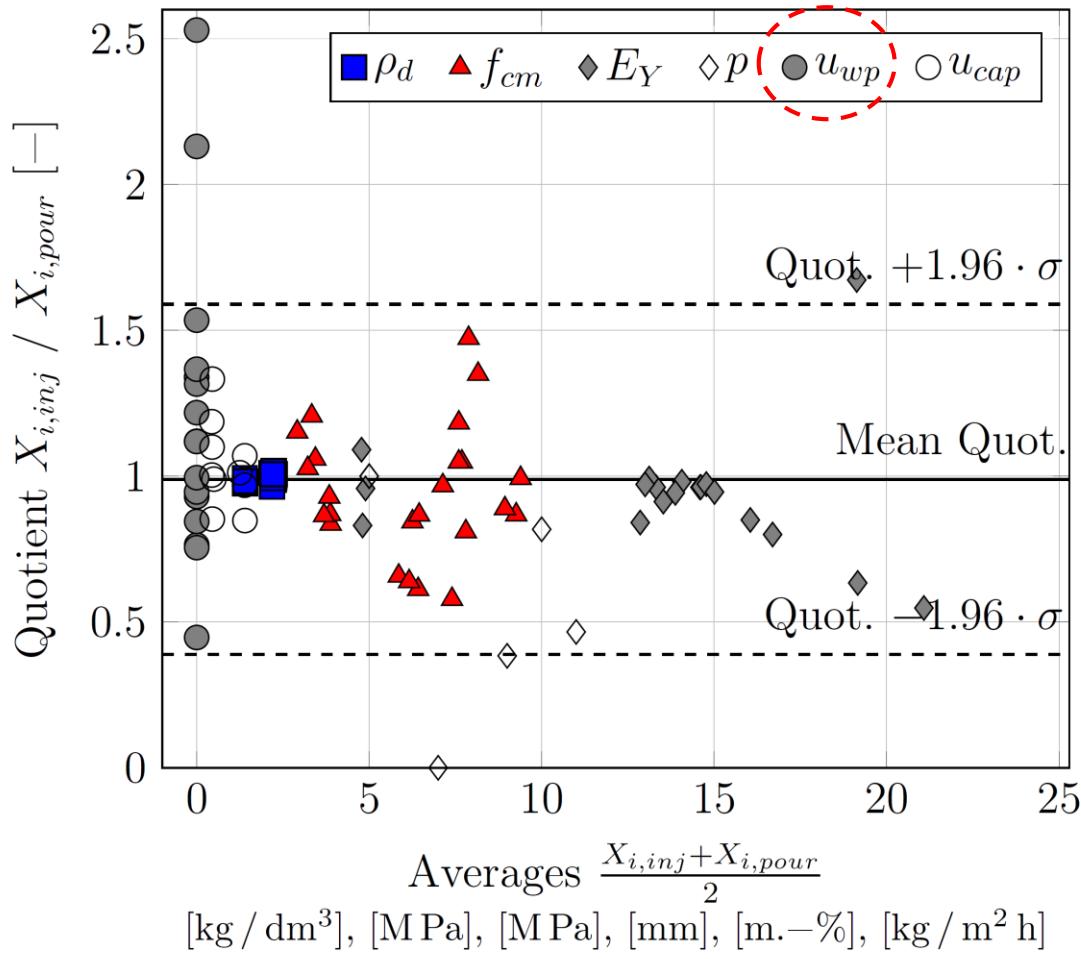
experimental – limit of workability: *ECM 1a*



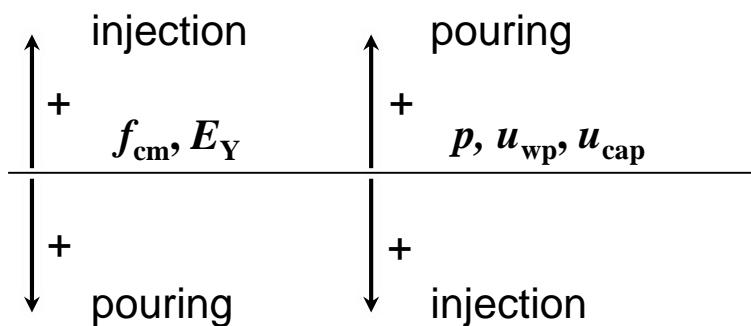
**trial no. 11
cylinders
injection**

Bland-Altman – mean values

not
representative!



interpretation:



$n = 124$ data pairs

scaling factors: $f_{cm} = 10$
 $E_Y = 2,500$

mechanical properties

- testing methods (esp. p) for high-performance concrete need adjustments
- no clear tendency for all properties, however **lower scattering**
- pressure does not effect the lightweight material

rheology

- one-point measurements misleading
- plastic viscosity has a greater influence than yield stress



The art challenges the technology, and the technology inspires the art.

- *John Lasseter*

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