Physical and chemical characteristics of natural limestone fillers: mix properties and packing density

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Outline

- Introduction
- Materials
- Physico-chemical characteristics
- Packing properties
- Conclusions

Introduction

Specific requirements for fresh SCC : high workability and good resistance to segregation.

Amount of coarse aggregate reduced and replaced by fine material.

In Belgium, local available materials = limestone fillers.

⇨ *Suitability of these fillers for use in SCC or conventional concrete ?*

Introduction

Production process of limestone fillers

Aggregate and lime production industry (quarrying operations)

Introduction

Production process of limestone fillers

Ornamental stones industry (sawing operations)

Materials

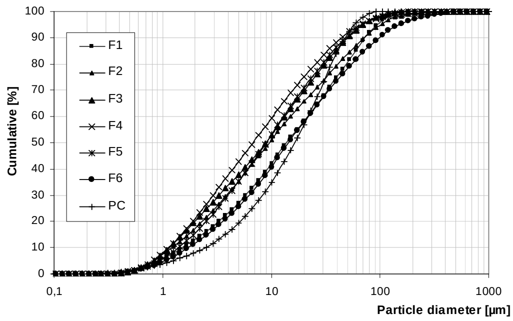
Ordinary Portland Cement (PC) CEM I 42,5 R HES

Six limestone fillers collected in Belgium (F1 to F6)

Limestone filler reference	Production process		Industrial sector
F1	Dry process	Crushing	Lime
F2			
F3		Drying / crushing	Aggregates
F4	Wet process	Sawing	Ornamental stones
F5		Washing	Aggregates
F6			

Physico-chemical characteristics

Physical characterization (Laser diffraction)



	F1	F2	F3	F4	F5	F6	PC
d_{50} (µm)	13.6	9.4	8.8	7.1	9.0	14.8	16.6
$S_{S,BET}$ [m^2/g]	1.3	1.2	5.5	4.0	5.7	3.7	–

Physico-chemical characteristics

Mineralogical and chemical characterization

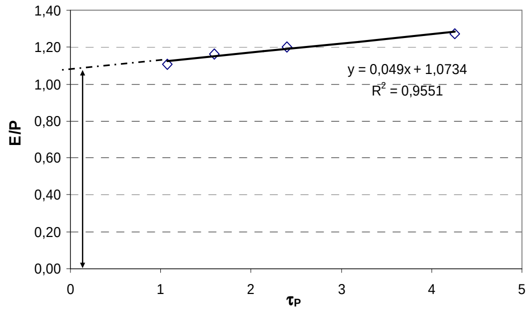
	F1	F2	F3	F4	F5	F6
Calcite $CaCO_3$ [%]	**99.5**	**99.5**	82.0	**94.5**	86.0	75.0
Quartz SiO_2 [%]	0.0	0.0	**15.5**	1.8	6.5	2.0
Dolomite $Ca(Mg,Fe)(CO_3)_2$ [%]	0.5	0.5	2.5	3.7	7.5	**23.0**
Methylene Blue Adsorption MBA [g/kg filler]	0.7	0.7	4.0	1.3	5.0	3.3

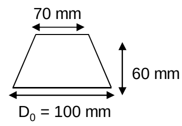
- Fillers coming from lime production (F1, F2) and ornamental stones sawing (F4) : high $CaCO_3$ content.
- Fillers produced in limestone quarries (F3, F6) : large amounts of impurities.

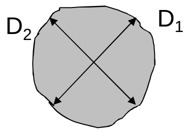
Physico-chemical characteristics

Bêta-P: spread measurement for different W/P

$$\tau_p = \left(\frac{D_{m1} + D_{m2}}{2D_0}\right)^2 - 1$$







$$D_{m1} = \frac{D_1 + D_2}{2} \quad \text{à t}$$

$$D_{m2} = \frac{D_1 + D_2}{2} \quad \text{à t + 5min}$$

Avec Dm [140 - 250 mm]

Physico-chemical characteristics

Smooth Paste test (Legrand, 1971)

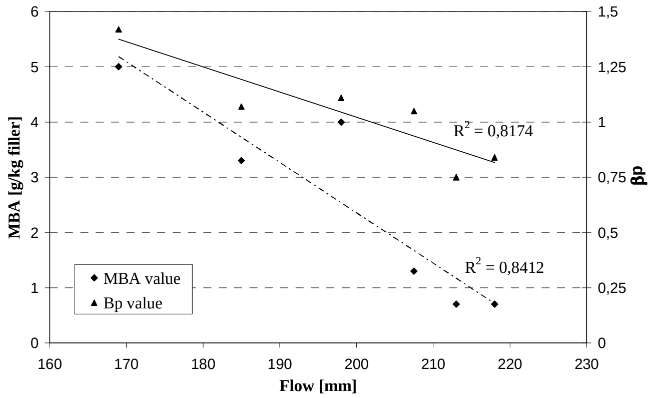
Modification of the paste appearance

$V_E \nearrow$

… correlated with threshold value of dilantancy (rheological behaviour)

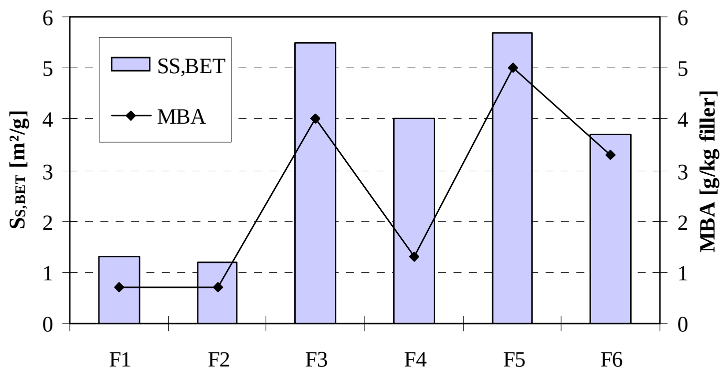
Physico-chemical characteristics

Relationship between mortar flowability and MBA or b_P of limestone fillers



Physico-chemical characteristics

Relationship between $S_{S,BET}$ and MBA



Physico-chemical characteristics

Materials

CEM I 42.5

CEM I 52.5

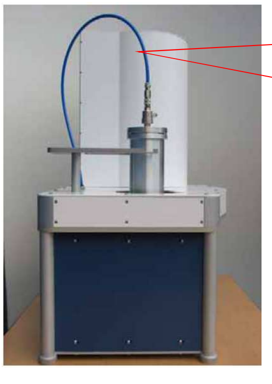
Limestone Filler

Standard sand EN196-1:2005 (0~2 mm)

Physico-chemical characteristics

Size and shape characterization

Equipments



OCCHIO 500Nano (0.5 µm~2 mm)

Vacuum dispersion

Image analysis

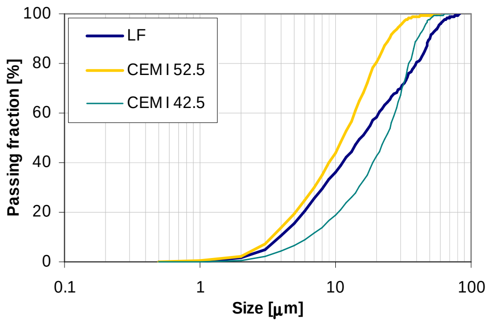
Physico-chemical characteristics

Particle size

Traditional equivalent volume (area) diameter

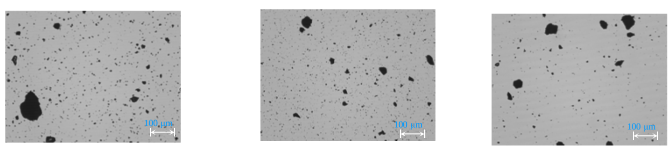
Maximum inscribed diameter

PSD:



Physico-chemical characteristics

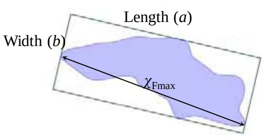
Particle shape



LF

CEM I 52.5

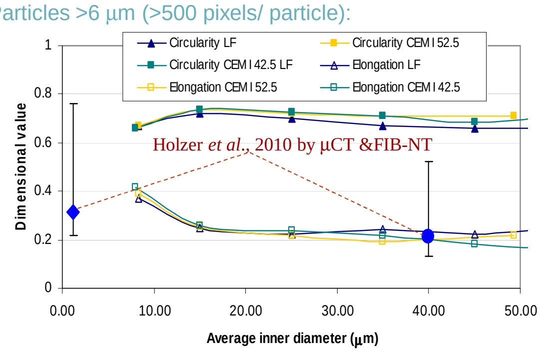
CEM I 42.5



$$Elongation = 1 - \frac{b}{a}$$

$$Circularity = \sqrt{\frac{4\pi A}{P^2}}$$

Particles >6 μm (>500 pixels/ particle):

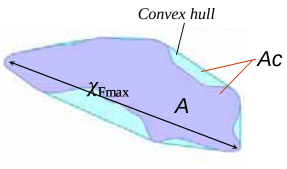


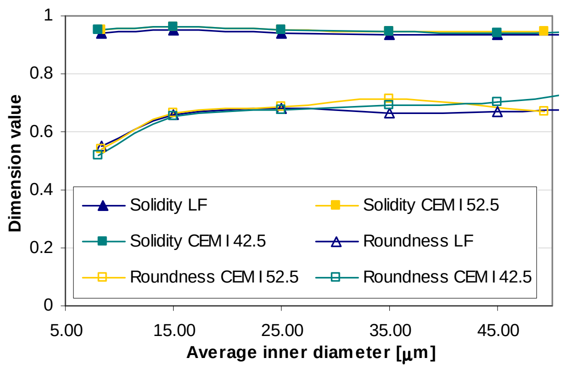
Physico-chemical characteristics

Particle shape

$$Roundness = \frac{4A}{\pi \chi_{F\max}^2}$$

Solidity $= A/Ac$





Physico-chemical characteristics

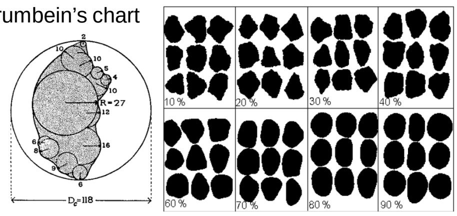
Bluntness describes the maturity of the particle in the abrasion process.

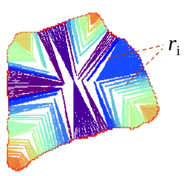
$$Bluntness = \frac{1}{\sqrt{\overline{V}} - 1}$$

In which:

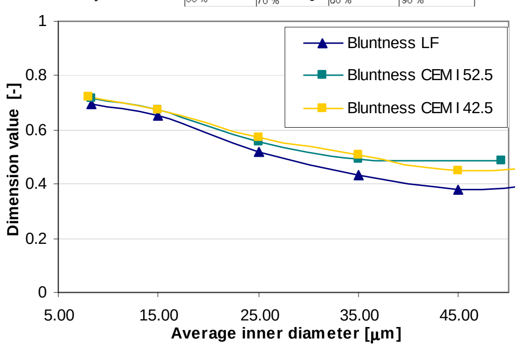
$$\overline{V} = \frac{1}{N}\sum_{i}^{N}\left(1 + \frac{r_{\max}}{r_i}\right)^2$$

Krumbein's chart





Calypter tools



Packing properties

Dry packing (direct) methods, e.g. BS 812:Part 2:1995

- For aggregate
- For fillers

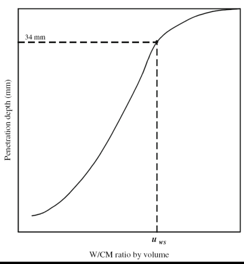
➢ Influences of inter-particle forces?

➢ Standard of compaction level?

Wet packing (indirect) methods:

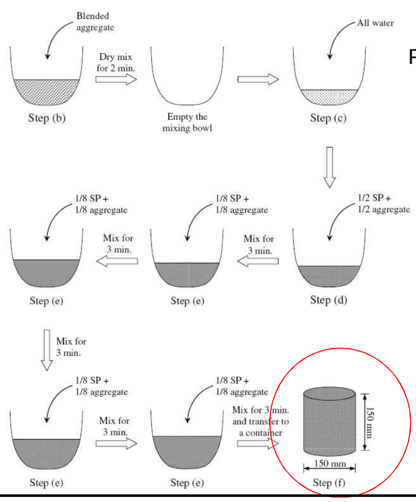
- Standard consistence test, BS EN 196:part 3, 1
- the wet packing method (Wong & Kwan, 2008)

Standard consistence test:



Packing properties

The wet packing method (Wong & Kwan, 2008)



Packing density:

$$\phi = \frac{V_b}{V} = \frac{M_b}{V\rho_b} = \frac{M}{V(u_w\rho_w + \rho_b)}$$

The voids ratio (u):

$$u = \frac{V - V_b}{V_b} = \frac{1}{\phi} - 1$$

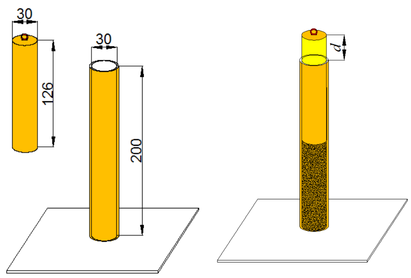
Packing properties

Experiments

The wet packing method (Wong & Kwan, 2008)

The dry packing method

- Influences of inter-particle forces?
- Standard of compaction level?



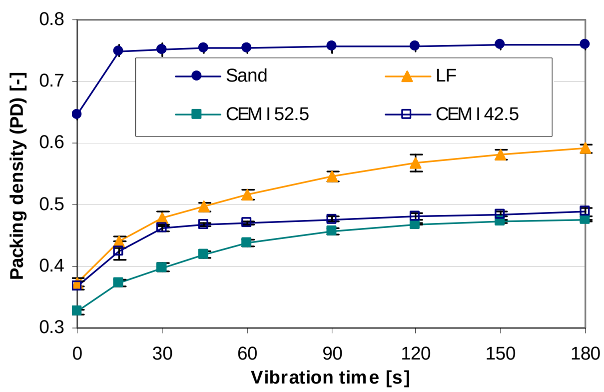
Compaction cylinder

Concrete vibration table

Packing properties

Packing tests

The dry packing method



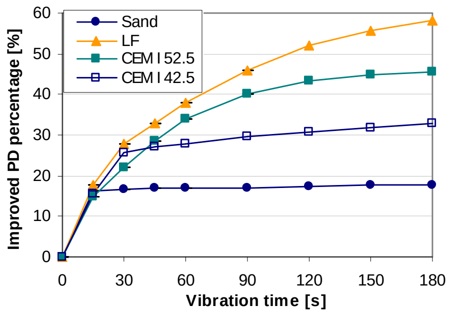
PSD?

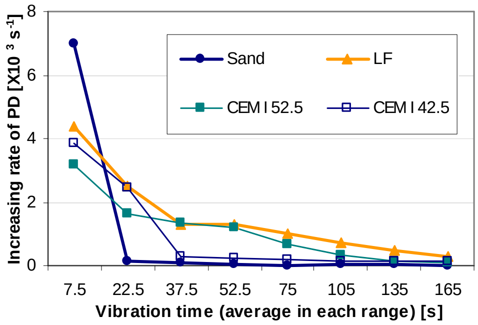
Shape?

Inter-particle forces?

Packing properties

The dry packing method

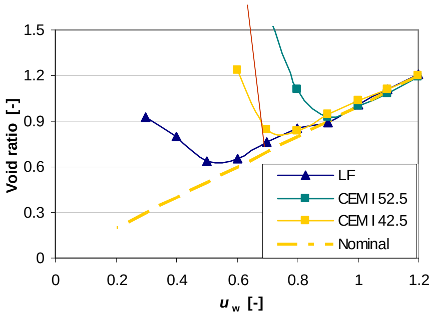


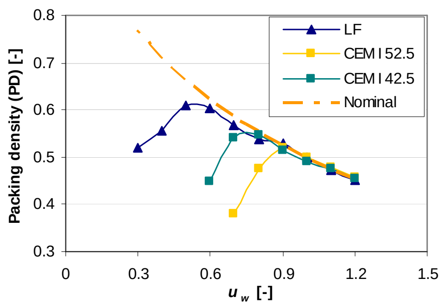


Packing properties

The wet packing method

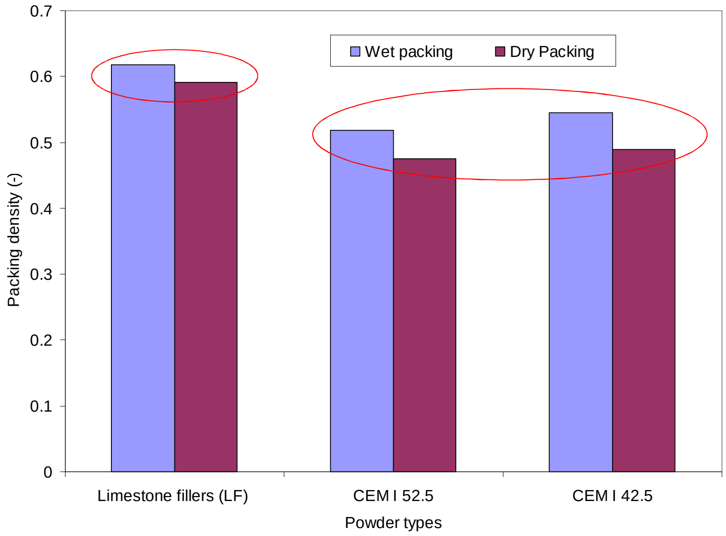
Influence of entrapped air





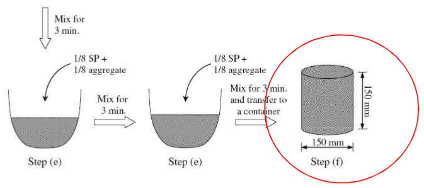
Packing properties

Comparisons of the dry method and the wet packing method



Packing properties

Discussion on the wet packing method

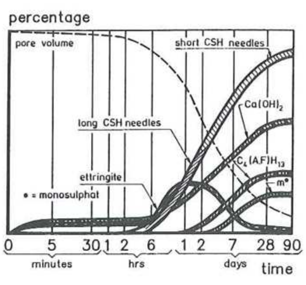


Limitations in the wet packing method

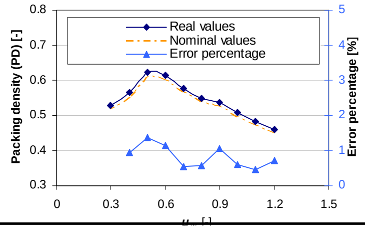
- manual effects on M-V evaluation
- Superplasticizer

- Cement hydration

$$\phi = \frac{V_b}{V} = \frac{M_b}{V\rho_b} = \frac{M}{V(u_w\rho_w + \rho_b)} \Rightarrow \phi = \frac{V_b}{V} = \frac{M}{V(u_w\rho_w + \rho_b + u_{SP}\rho_{SP})}$$

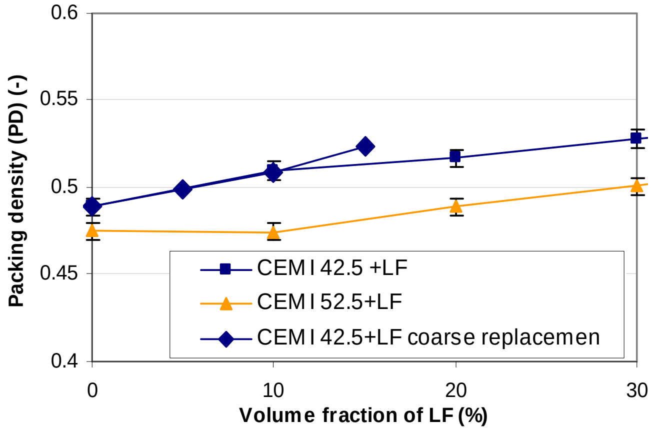


- Mixing efficiency (e.g. LF)



Packing properties

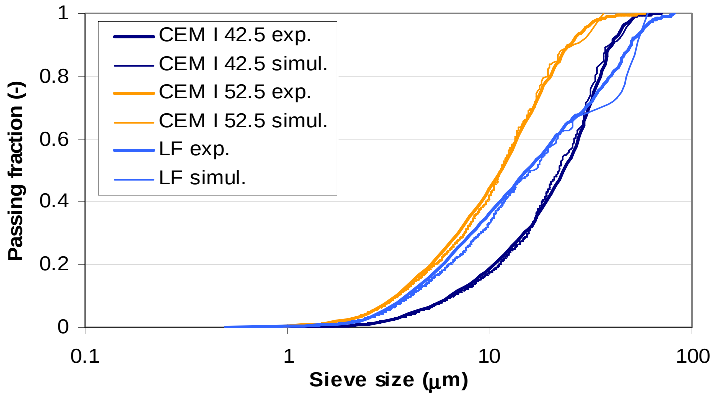
Results on blended cement (total replacement and coarse replacement)



Packing properties

Numerical simulations

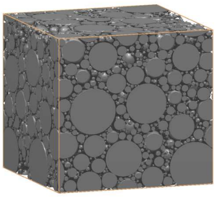
- PSD simulations



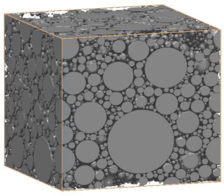
Packing properties

- Visualized models

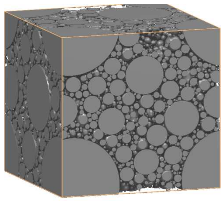
Periodical boundaries:



CEM I 42.5
0.72

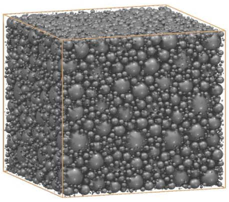


CEM I 52.5
0.68

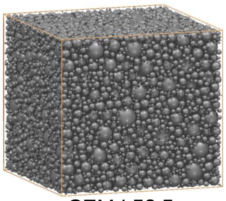


LF
0.716

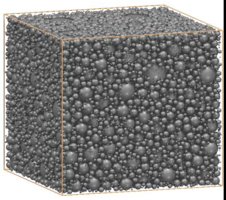
Rigid boundaries:



CEM I 42.5
0.674



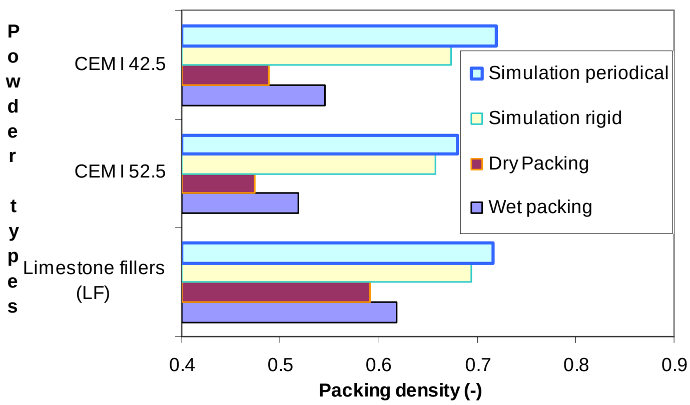
CEM I 52.5
0.658



LF
0.695

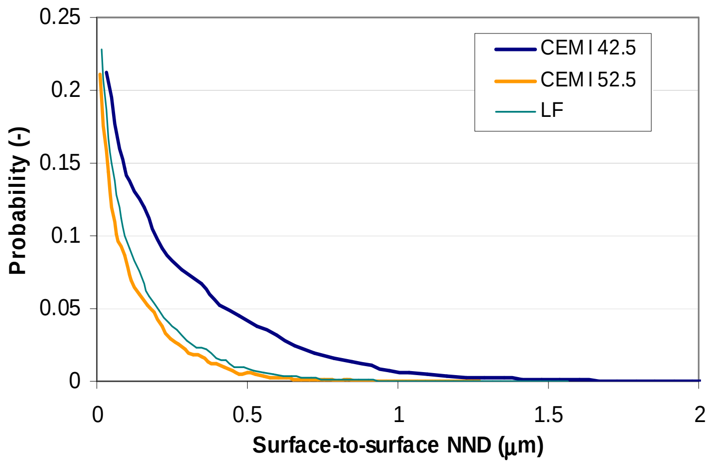
Packing properties

- Maximum packing density



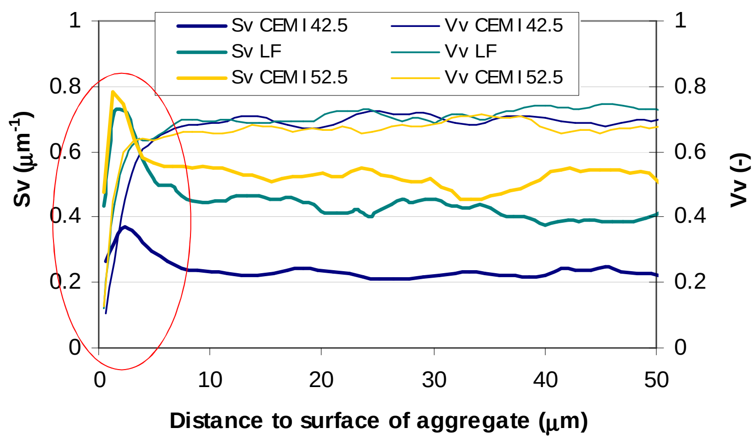
Packing properties

- Surface to surface nearest neighboring distance (NND)



Packing properties

- Surface area density (S_V) and volume density (V_V) in ITZ



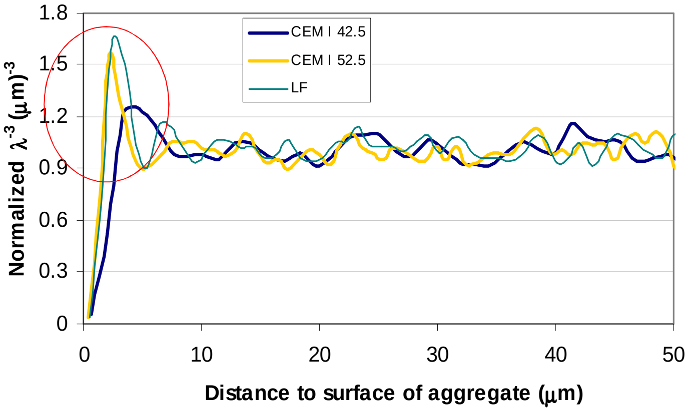
Packing properties

- Mechanical bounding capacities

Meaning free spacing: $\lambda = 4\frac{1-V_V}{S_V}$

A parameter proportional to global bonding capacity : λ^{-3}

Stroeven & Stroeven 2001
Hu, 2004

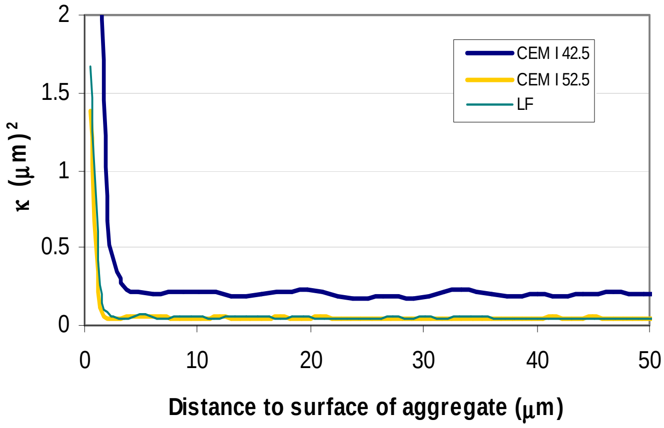


Packing properties

- Permeability

$$\kappa = \frac{(1-V_V)\lambda^2}{32+16V_V}$$

Carman 1939
Hu, 2004



Conclusions

- The limestone fillers collected in Belgium differ from each other through their physico-chemical characteristics (impurities such as clay, quartz and dolomite).
- The water requirement of limestone fillers is mainly influenced by their clay content (indicated by high MBA and $S_{S,BET}$ values).
- Size and shape characteristics of LF and OPC can be identified by an advanced image analysis system.
- With a proper replacement of cement by LF, packing density of the mixture can be improved. Filler effect is significant as also illustrated by the numerical simulation.

Conclusions

- Influence of clay in limestone fillers for self-compacting cement based composites. L. Courard, F. Michel and J. Piérard. Construction Building Materials **25** (2011) 1356–1361.
- Influence of physico-chemical characteristics of limestone fillers on fresh and hardened mortar performances. F. Michel, J. Piérard, L. Courard and V. Pollet. In: 5th International RILEM Symposium on Self-Compacting Concrete, Proceedings PRO 54 (Eds. G. De Schutter and V. Boel, Rilem Publications), Gent, Belgium (September 3-5, 2007), pp. 205-210.
- Characterization of fine aggregate in concrete by different experimental approaches (2011) He, H., Courard, L., Pirard, E. and Michel F. *ICS-13, the 13th International Congress of Stereology,* Oct. 19-23, 2011, Beijing, China.
- Particle packing density and limestone fillers for more sustainable cement (2011) He, H., Courard, L. and Pirard, E., *13th International Conference on Non-conventional Materials and Technologies (13 NOCMAT 2011),* Sep. 22-24, 2011, Changsha, China.


Hvala
Merci
Dziękuję
Thank you
Dank u
Grazie
Danke
Gratias
Arigato
Efkaristos
Thank you for your attention