

# INVESTIGATION OF TERNARY MIXES MADE OF CLINKER, LIMESTONE AND SLAG OR METAKAOLIN IMPORTANCE OF REACTIVE ALUMINA & SILICA



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# Outline

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1. Introduction
2. Materials & Methods
3. Results
4. Discussion
5. Conclusions & Outlooks

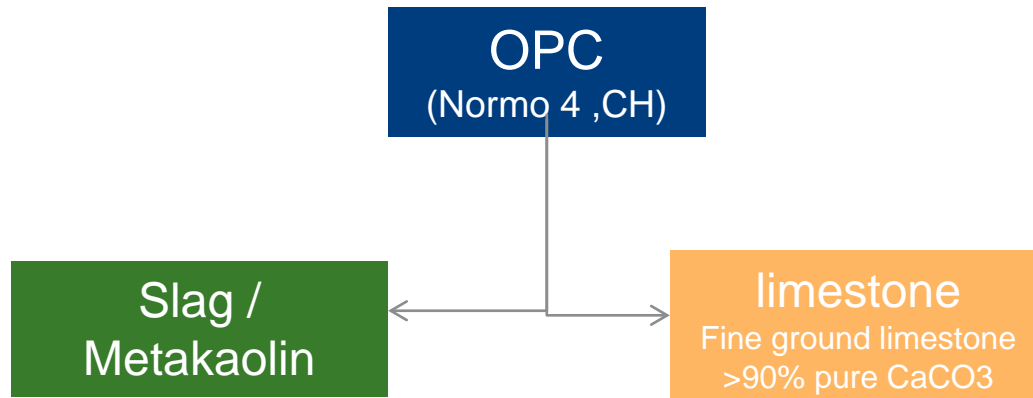
# Introduction

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- Calcined clays are very interesting SCM, especially in combination with limestone (LC3)
- Clays are often in competition with other SCMs
- How compare high quality metakaolin and good quality slag in models systems?
- Do synergistic effects play a role with other SCMs and how far can limestone content be optimized with each SCM?

# Systematic investigation of strength synergies OPC-limestone – SCM

- Tested binder compositions



	MK	Slag
Amorph. Content	>95%	>97%
BET [m <sup>2</sup> /g]	>13	<1
XRF	52% Al <sub>2</sub> O <sub>3</sub> ; 45% SiO <sub>2</sub>	10% Al <sub>2</sub> O <sub>3</sub> ; 38% SiO <sub>2</sub> ; 40% CaO

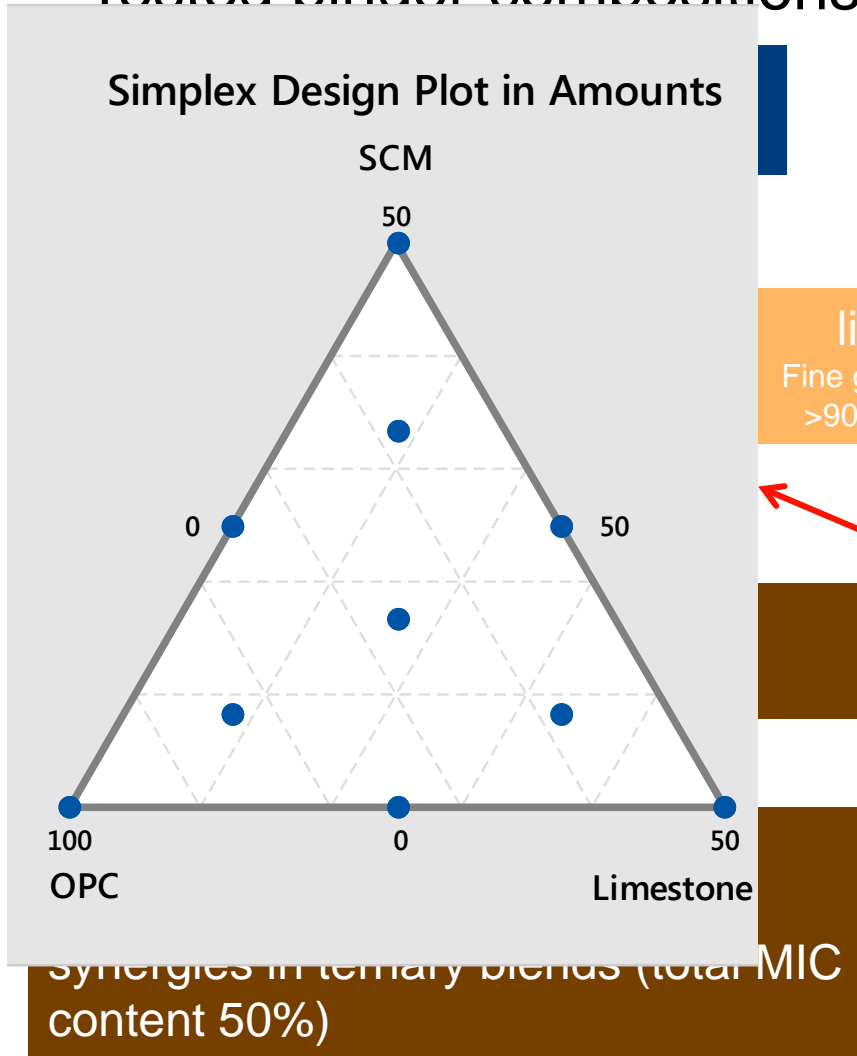
- Modified EN tests (w/c=0.5) strength of mortars

- Paste XRD investigation (w/c=0.5) Fixed OPC 65%, with & without limestone

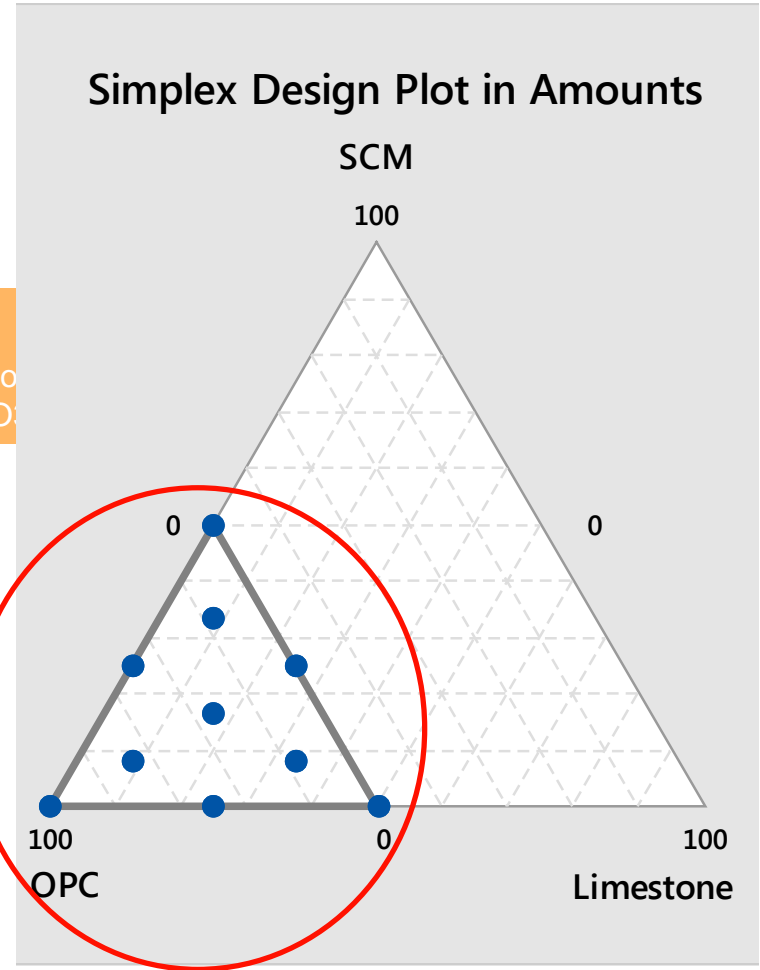
Use of Design of Experiment approach to describe strength synergies in ternary blends (total MIC content 50%)

# Systematic investigation of strength synergies OPC-limestone – SCM

- Tested binder compositions

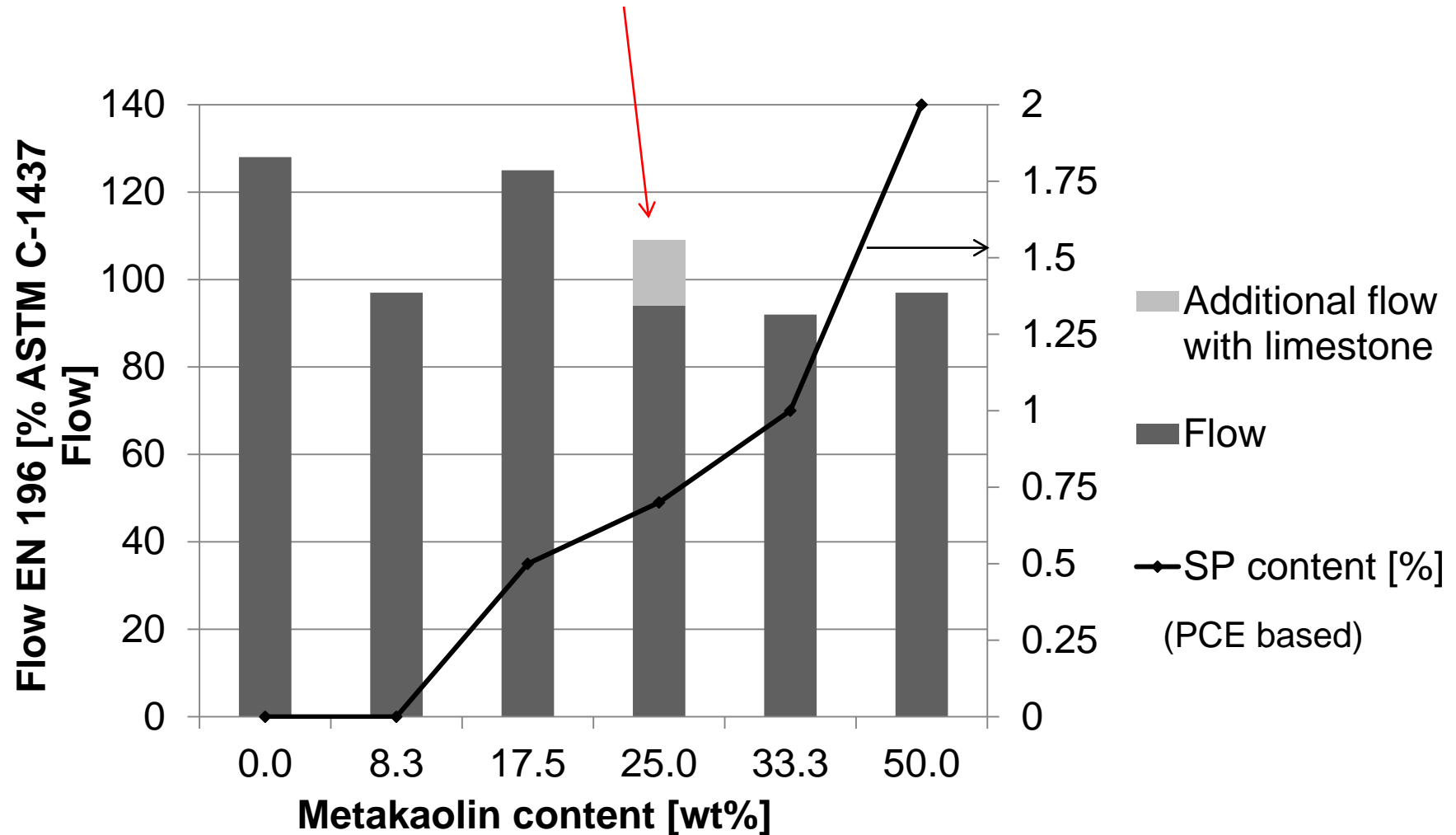


limestone  
Fine ground limestone  
>90% pure CaCO<sub>3</sub>



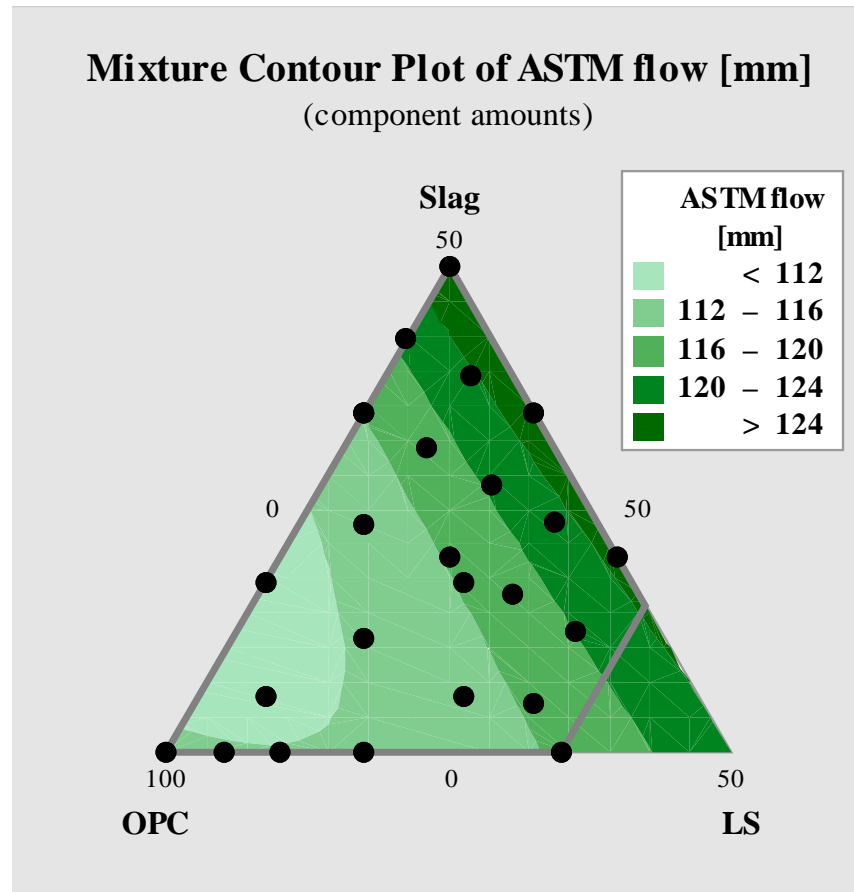
# Workability issue: maintaining slump requires high dosages of superplasticizer with the use of metakaolin

- Combined addition of limestone can improve flow by 20%



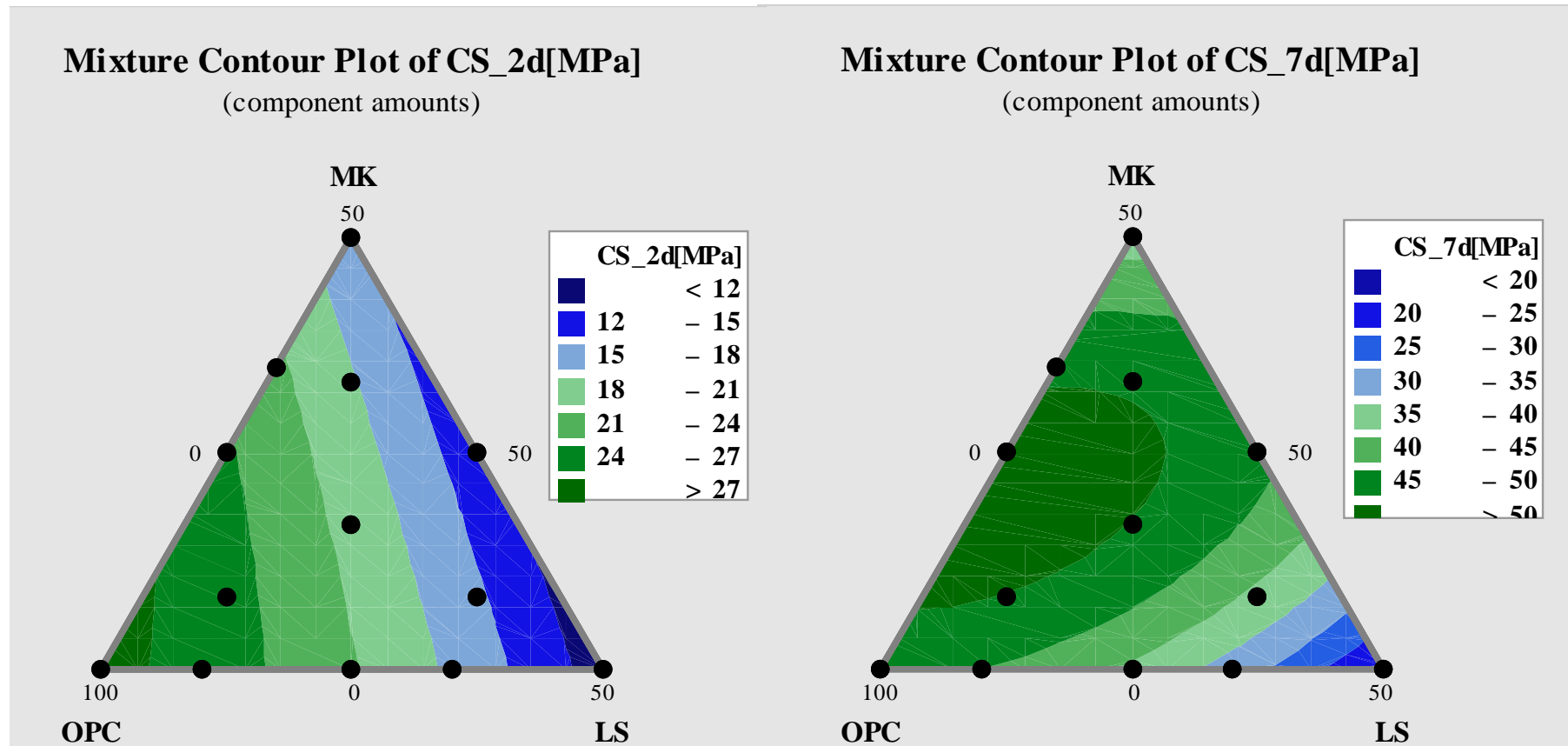
# For comparison, flow properties almost unaffected for replacement of slag by limestone

Both slag & limestone (besides higher Blaine) slightly improves flow when substituting for OPC.



# With metakaolin: Very strong synergies at 7days

- Metakaolin-limestone systems show very good synergy potential, very large at 7d
- At 2 days, strength mostly governed by clinker content

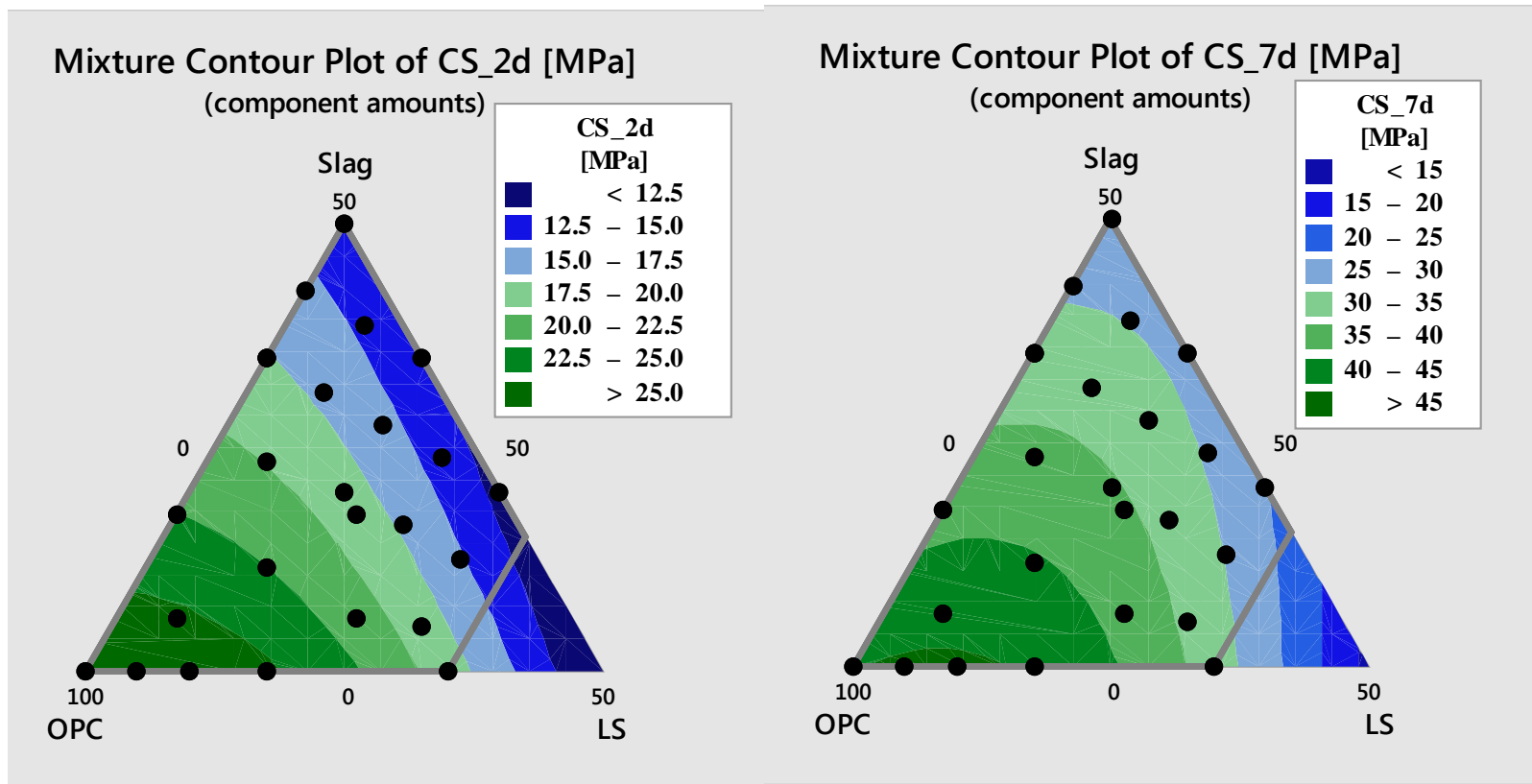




# With slags

## Compressive strength, 2 & 7d

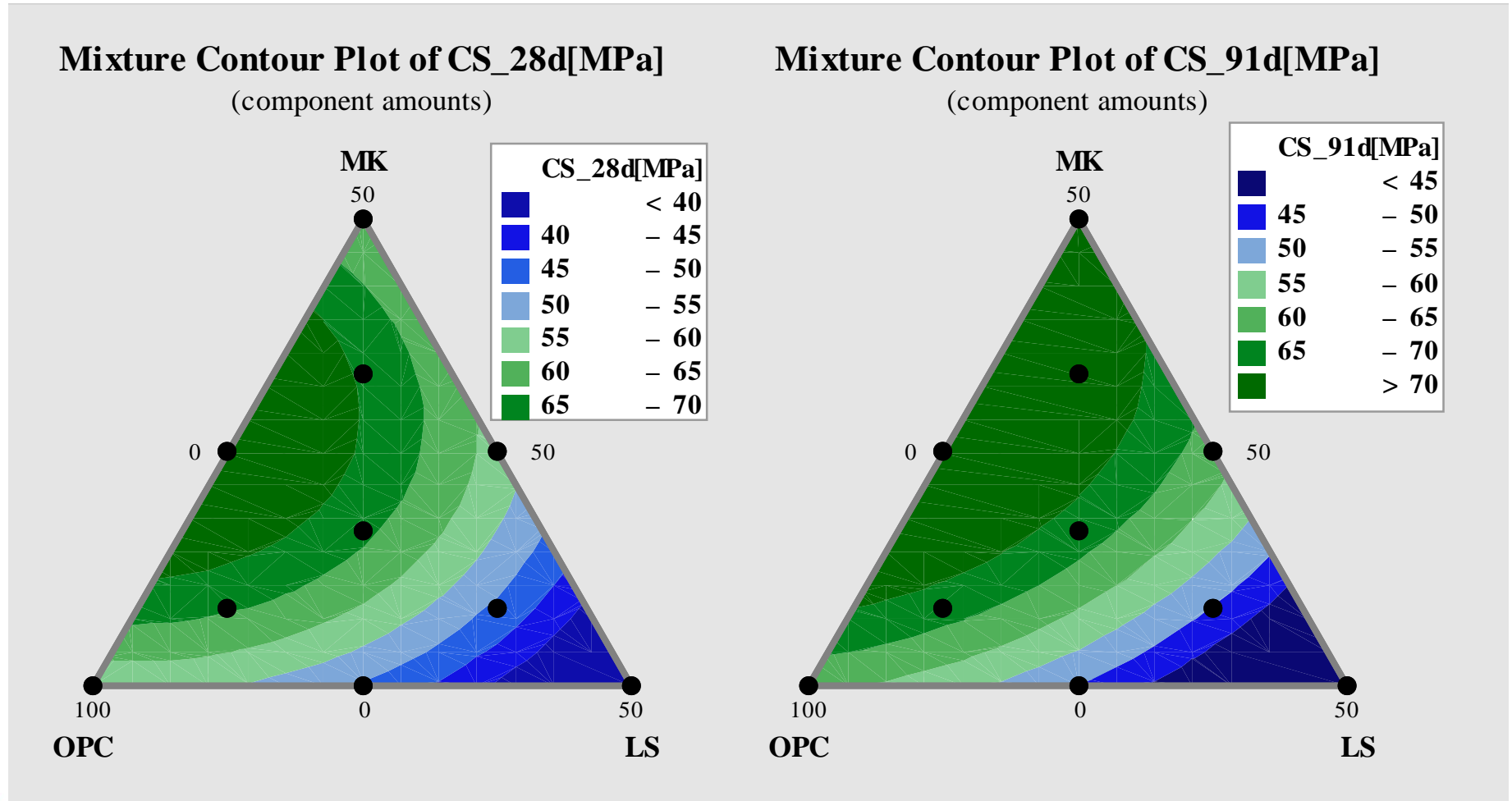
- At 2d: minor effect of limestone, decrease only for limestone content above 20%
- At 7d, for 50% OPC, strength improved for low limestone substitution and can be maintained up to 26% limestone



# With metakaolin

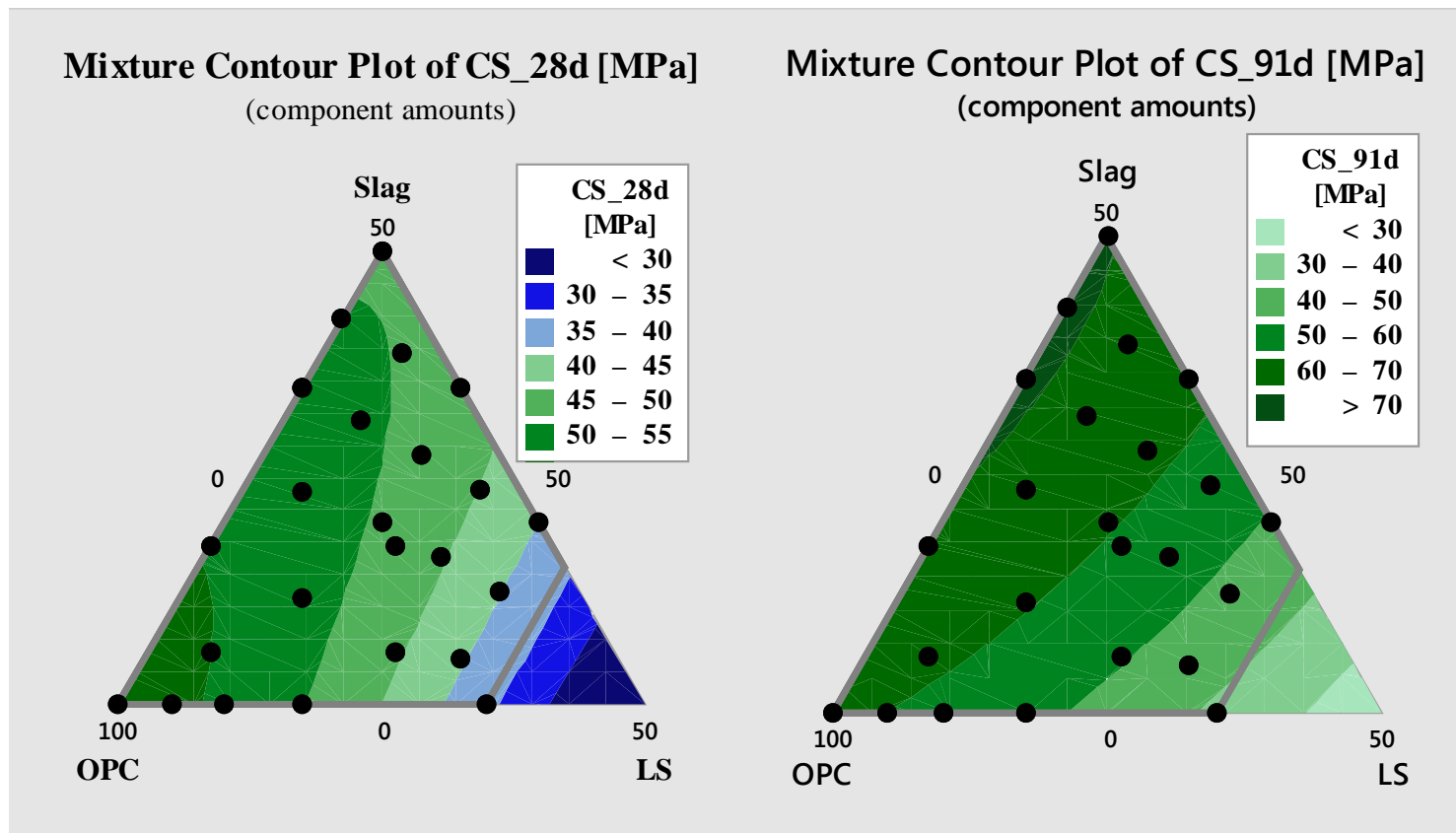
## Strength synergies very slowly decrease at later ages

Strength synergy are maintained at later ages with calcined clays



# Slags-limestone diagram at later ages: synergetic effect of combined addition faster decrease

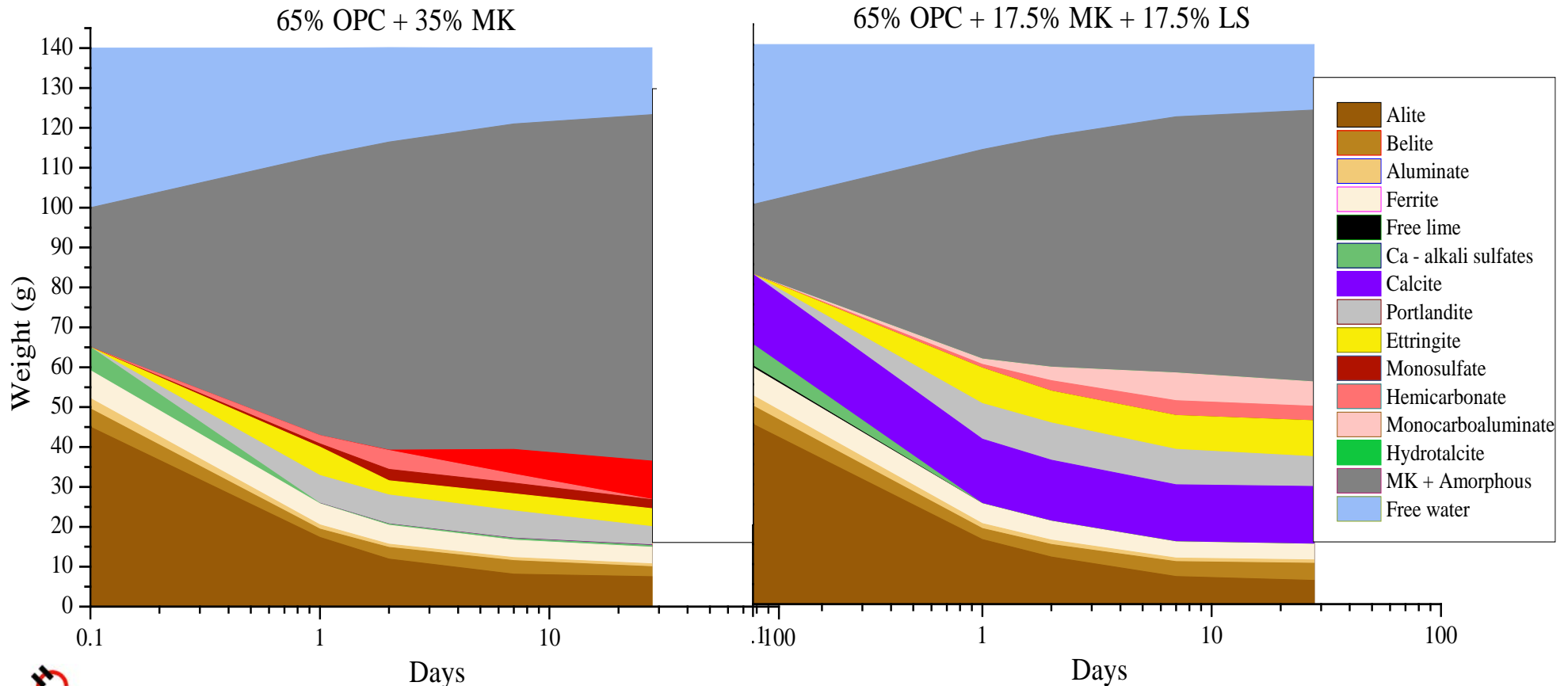
- At 28d, strength almost maintained for 20% replacement of slag by limestone at CF 50%
- At 91d, limestone purely acts as a filler and dilutes strength



# Phase assemblage by XRD, metakaolin system

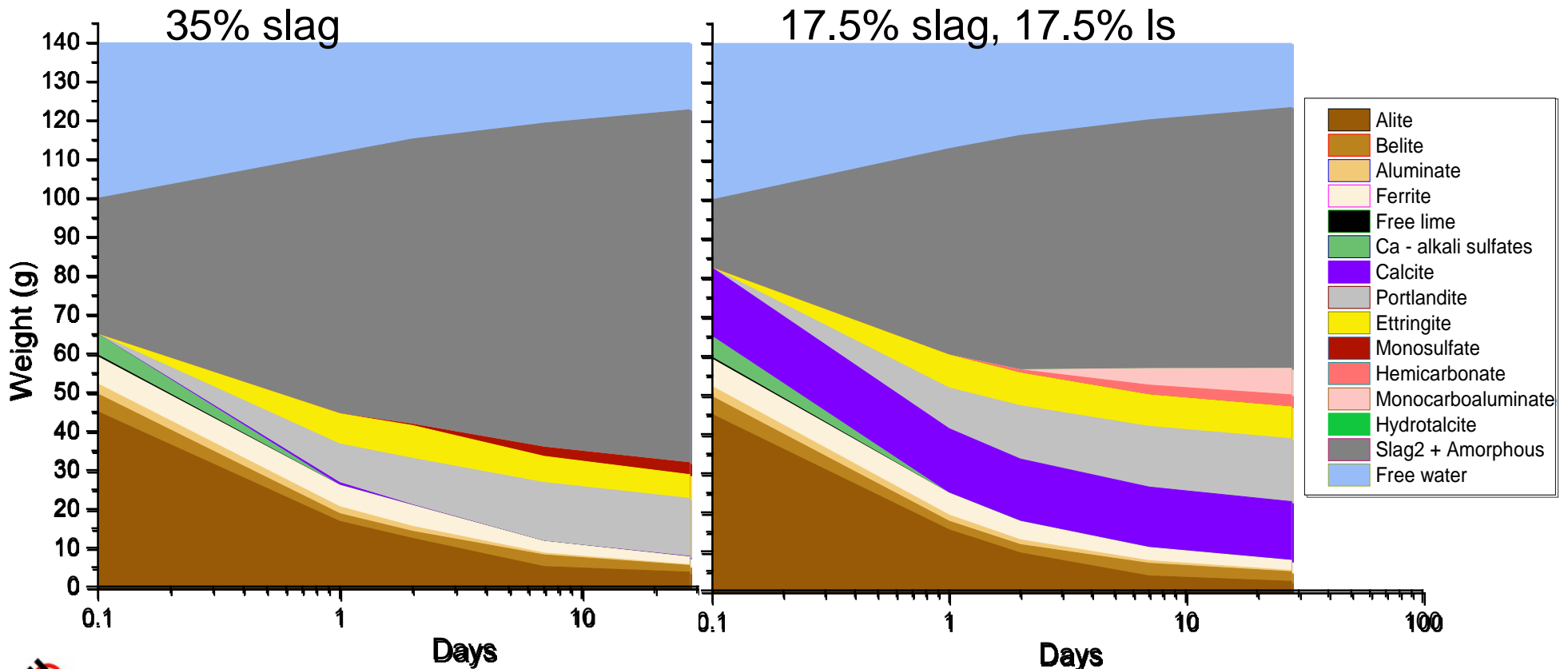
## OPC constant at 65%

- With only MK, monosulfate and strätlingite formation
- With LS, ettringite & hemicarbonate forming at considerable amounts, especially at 7 days. Amorphous reduced



# Phase assemblage by XRD, slag system

- With only slag, monosulfate observed
- With LS, formation of ettringite & monocarbonate. amorphous reduced



# Conclusions

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- Metakaolin strongly affects workability and require SP, but limestone combined addition improves the picture.
- Until 2 days, strength mostly relates to fineness, metakaolin > slag.  
Physical / nucleation contribution dominate
- At 7 days, important strength synergies observed for both slag & mk, stronger for metakaolin (high fineness, high dissolution rate).  
Strength synergies correlate well with appearance of carboaluminates & ettringite.  
At 7d, Aluminates contribution dominates

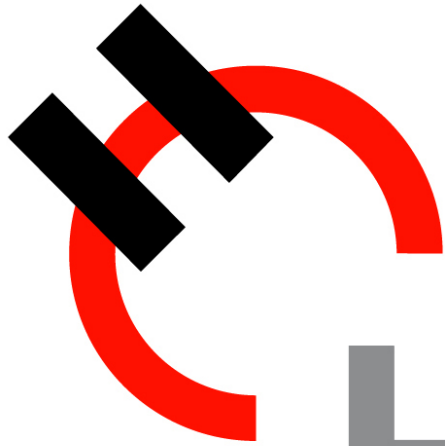
# Conclusions

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- At 28 days & later

Strength of slags systems tend to catch up. Consequence of (slower) slag dissolution

- ▶ Slag  $\text{Al}_2\text{O}_3$  content lower but  $\text{SiO}_2$  &  $\text{CaO}$  higher.
  - ⇒ Limestone synergy less important, total AFm+AFt content lower than with metakaolin, but amorphous & C-A-S-H higher
  - ▶ At 28d, the global SCM composition to be taken into account & silicate contribution increasingly important.
- For those both SCM, combined limestone addition is an option
    - ▶ Metakaolin allow higher limestone content than slag while maintaining strength
    - ▶ Durability the limitation parameter?



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