Politechnika Śląska

SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE

RHEOLOGY OF CONCRETE WITH LOW CARBON FOOTPRINT – CHALLENGES AND SOLUTIONS

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Rheology of Building Materials
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Low-carbon concrete LCC

Low carbon footprint concrete (LCC) – concrete that has a lower carbon footprint and consumes less energy than traditional concrete, while still achieving the required mechanical and durability properties.

DESIGNIG
Optimization of the properties and quantity of concrete in the structure in relation to its expected performance and durability.
Concrete composition enabling the achievement of the desired properties while minimizing its carbon footprint – low-clinker cements.

DEMOLITION
The possibility of reusing the material for concrete production.

SERVICE
Concrete durability – optimal w/c ratio.
Possibility of obtaining additional functionalities (smart concrete – self-diagnosis, self-repair, self-cleaning, energy storage, capture of CO_2, NOx and other substances).

PRODUCTION AND CASTING
The use of energy-efficient (and effective) concrete production technologies – workability of fresh LCC concrete.

Rheological properties, consistency and workability of fresh concrete

Rheological properties/consistency of fresh concrete – ability of fresh concrete to undergo deformation (flow) under load.

Workability of fresh concrete – ability of the mix to be processed using the technological method(s) applied in the concreting process.

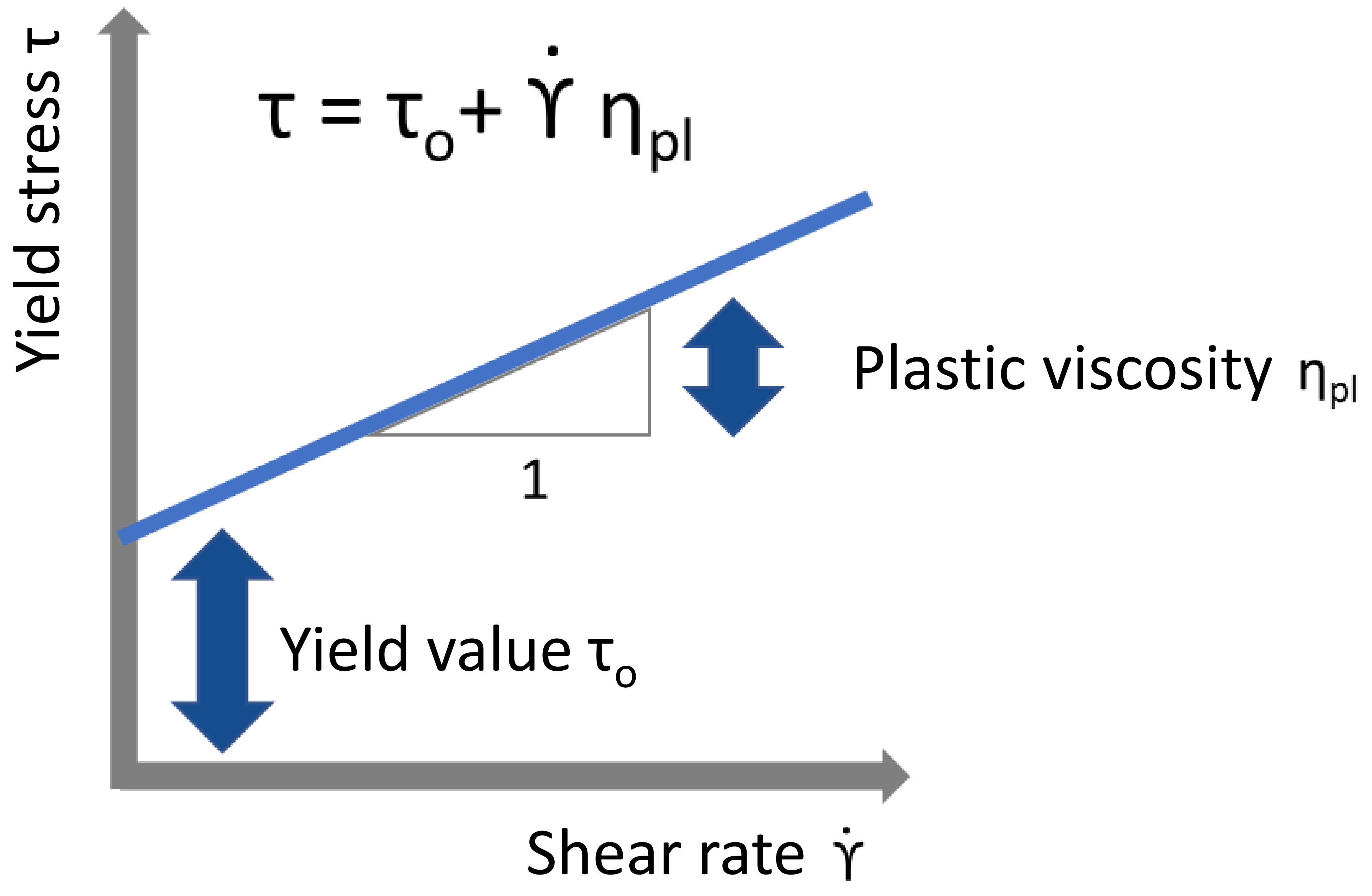
The consistency/rheological properties of the mix are designed in accordance with the technology used and the concreting conditions (e.g. formwork shape, reinforcement density).

The fresh concrete must have the required workability at the moment of concreting.

Rheological properties, consistency and workability of fresh concrete

Rheological properties of the fresh concrete - Bingham model

- yield value - load required for the mixture to flow
- plastic viscosity - resistance of the flowing mixture.



Rheological properties, consistency and workability of fresh concrete

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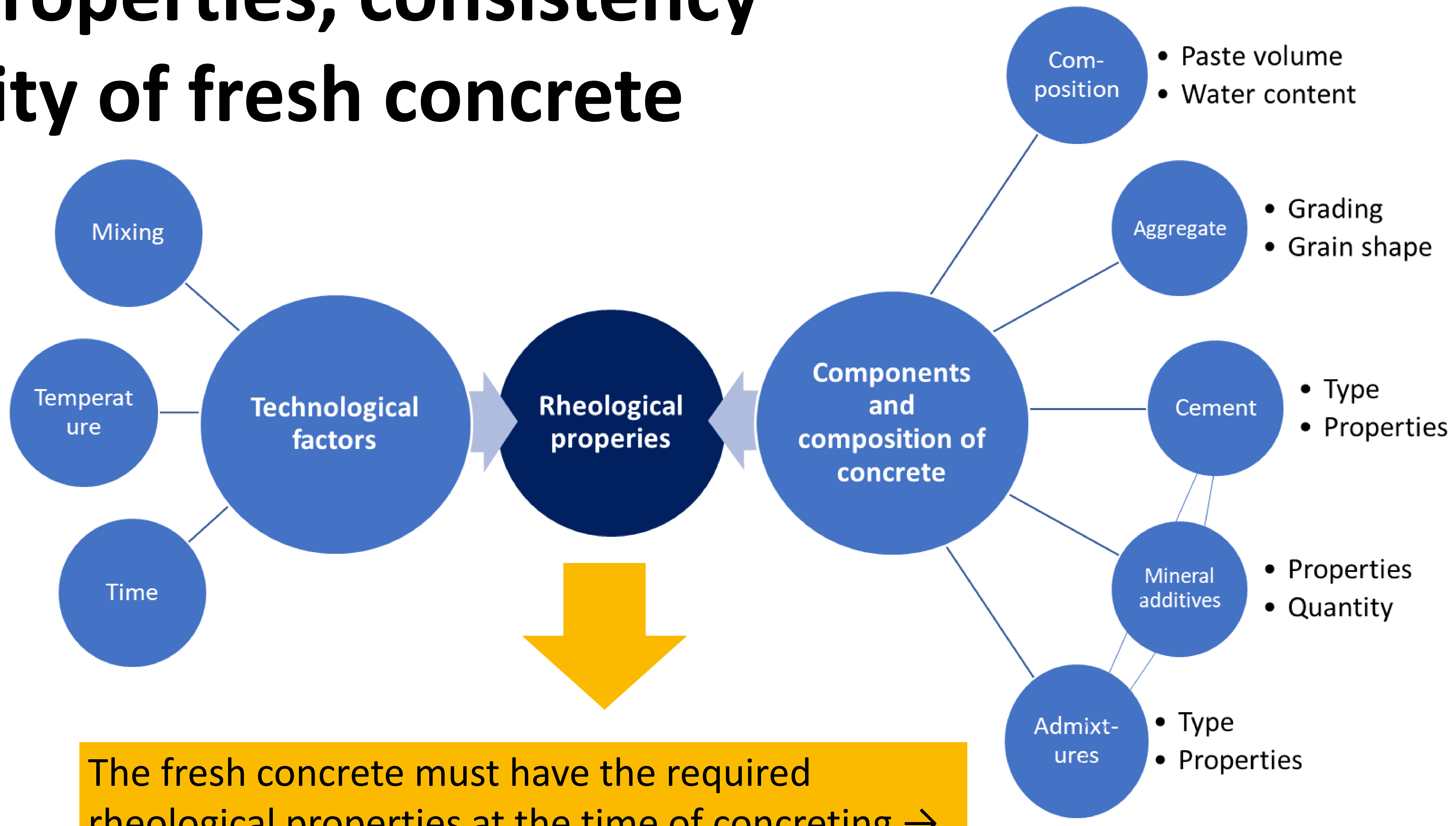
Consistency is determined using the methods specified in the standards. Certain methods enable determination of the rheological parameters of fresh concrete.

Test Standard	Measured characteristic, unit	Yield value	Plastic viscosity
Slump EN 12350-2	Slump, mm	+	-
Flow table EN 12350-5	Flow diameter, mm	+	-
Slump flow (SCC) EN 12350-8	Slump flow, mm	+	-
	Flow time, s	-	+
V-funnel (SCC) EN 12350-9	Time, s	-	+

Rheological properties, consistency and workability of fresh concrete



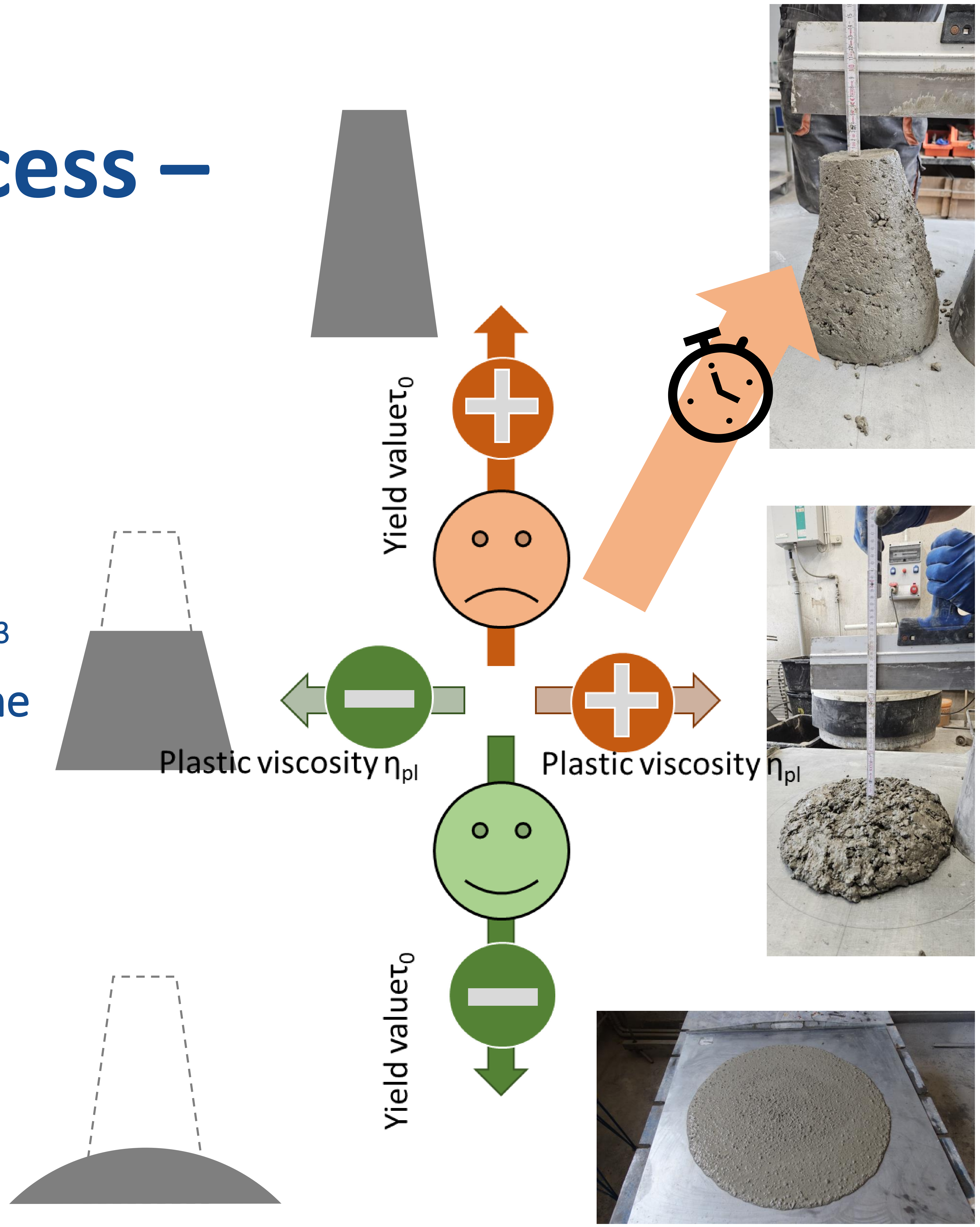
Factors affecting the rheological properties/consistency of fresh concrete

The fresh concrete must have the required rheological properties at the time of concreting → 90 minutes at 15 °C.

Energy-efficient concreting process – workability of fresh concrete

Rheological properties – high-flow concrete mix – self-compacting concrete (SCC) mix.
Maintaining the required workability during concreting – 90 minutes.

- Amount of cement paste – VCC 250 – 280 dm^3/m^3 – SCC 300 - 400 dm^3/m^3
- Amount of cement – minimum required, use mineral additives to obtain the necessary amount of cement paste.
- Amount of water – appropriate for requirements, not unnecessarily low (higher SP addition, higher viscosity, faster loss of workability).
- Rheological properties – SP addition.
- Additives other than SP also affect rheological properties.



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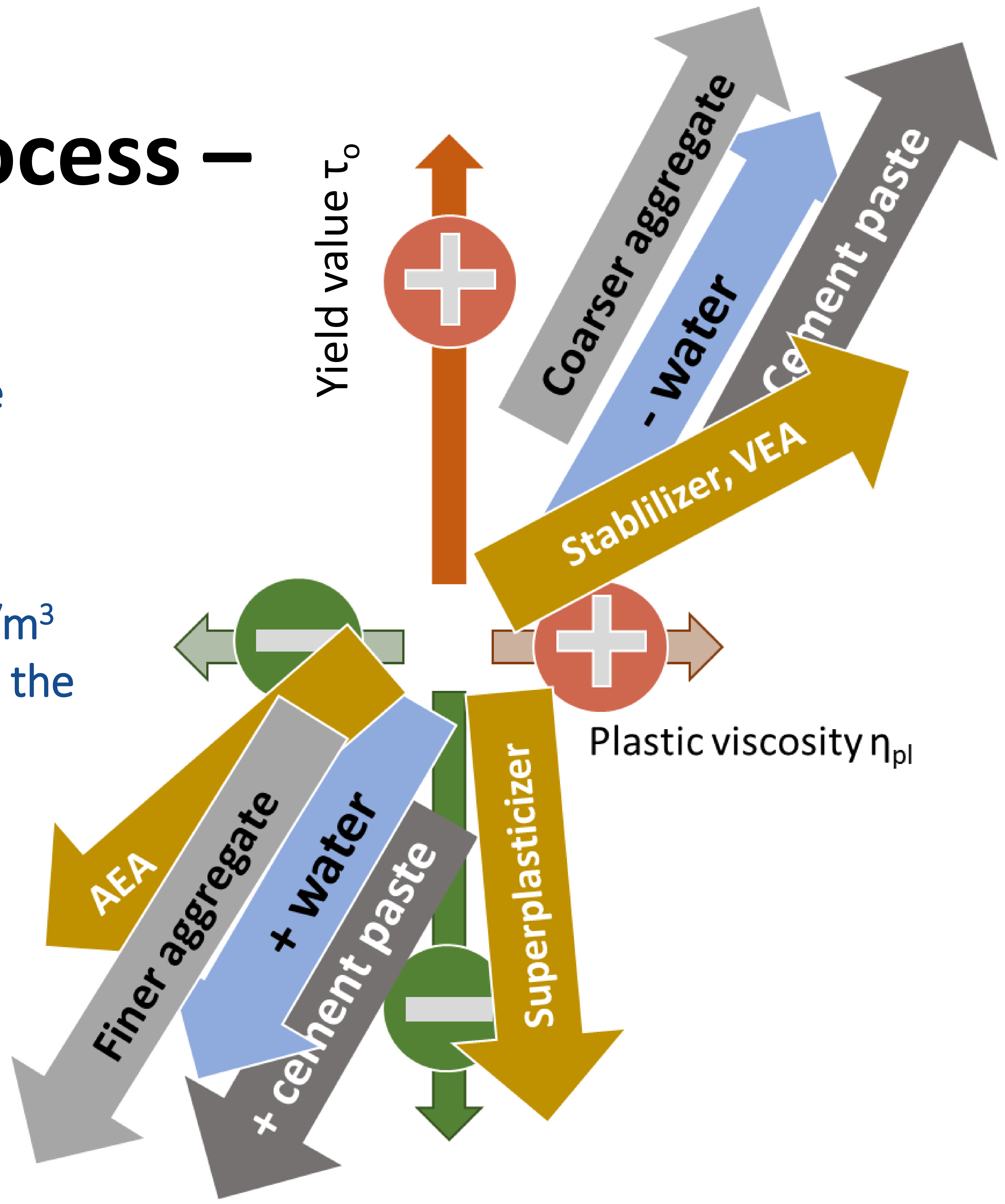
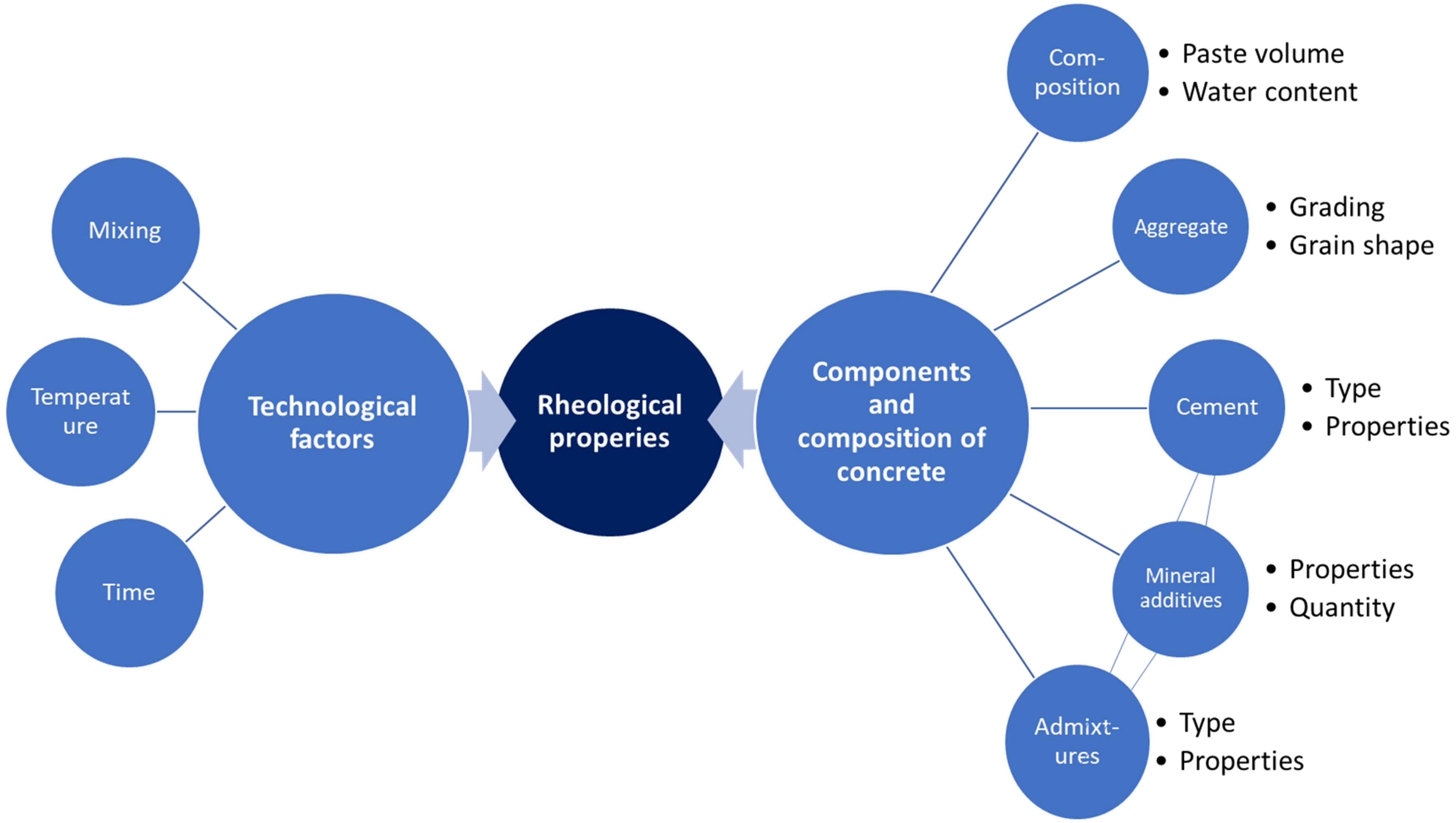


LCC – specifics of the mixture composition



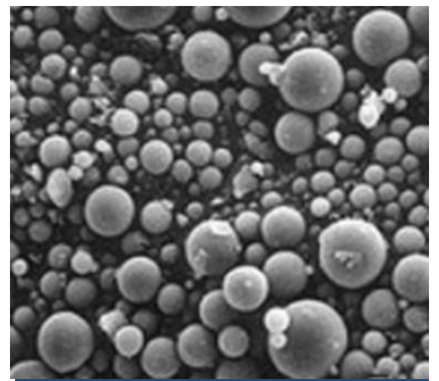
- low-carbon cement (with trduced clinker content → CEM II – up to 50%, CEM III – up to 5%, CEM IV – up to 45%, CEM V – up to 20% CEM VI – up to 35%)
- replacing part of the cement with mineral additives or alternative materials (waste or recycled)

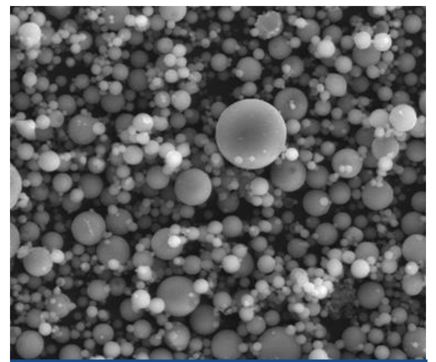
- optimisation of aggregate grain size to minimise the amount of cement paste
- the use of alternative materials as a substitute for aggregate in concrete

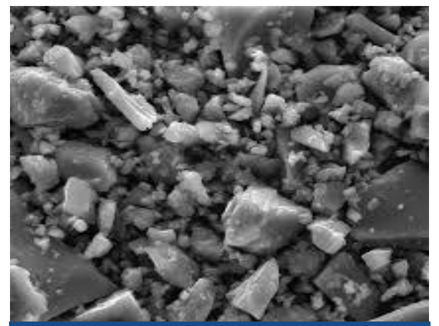
- reducing the amount of water in combination with the use of superplasticisers (offsetting the negative impact of less cement/lower quality ingredients on concrete properties)

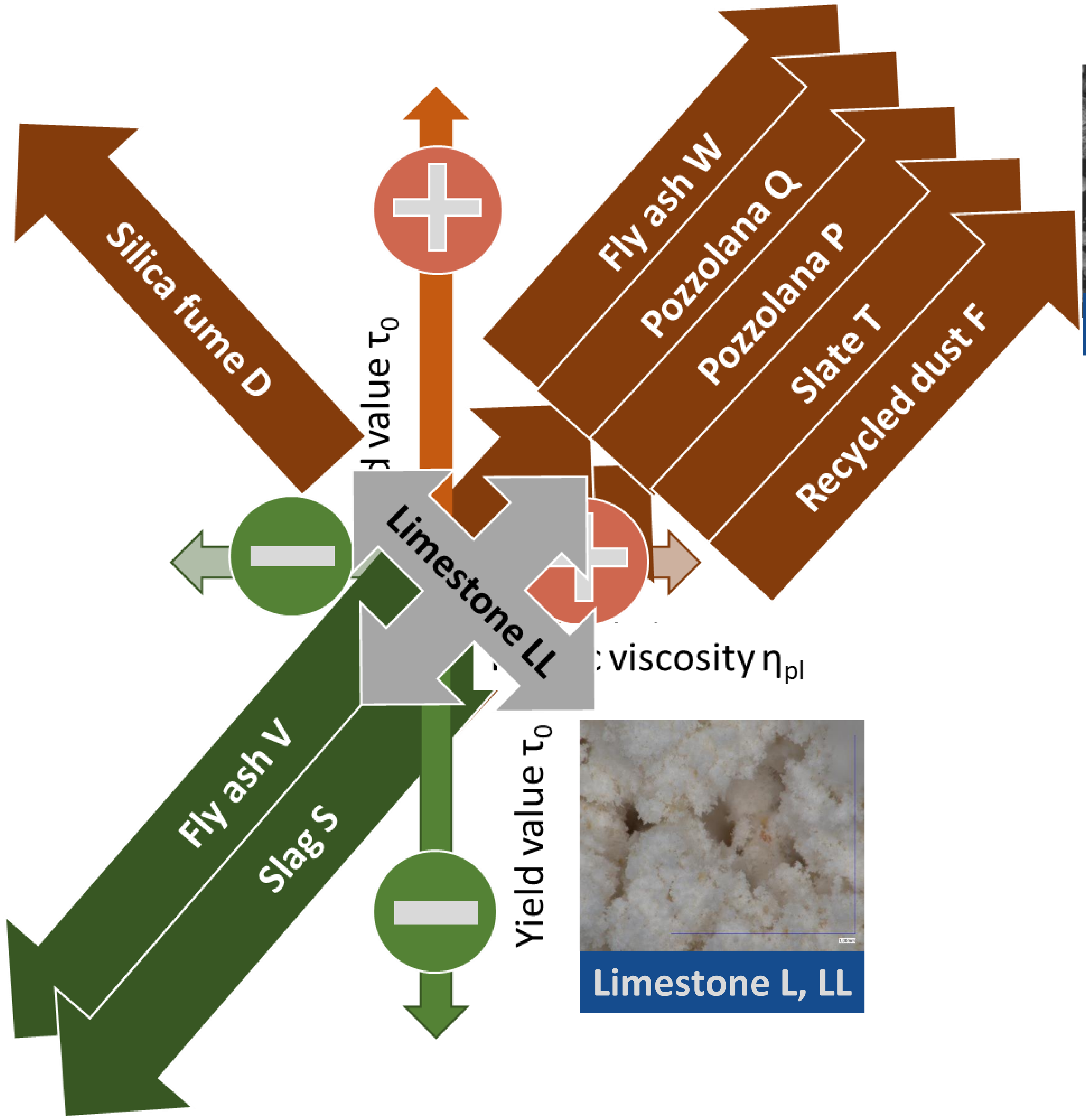
The effect of mineral additives on the rheological properties of fresh concrete

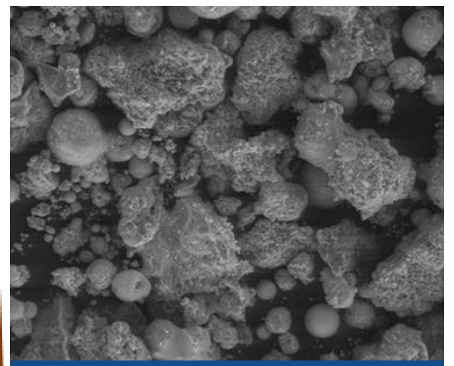
Slag S	up to 95%
Fly ash V	
Fly ash W	up to 55%
Natural pozzolana P	
Natural quarried pozzolana Q	
Quarried slate T	
Limestone L, LL	up to 35%
Recycled concreto dust F	
Silica fume D	up to 10%


Silika Fume D


Fly ash V


Slag S

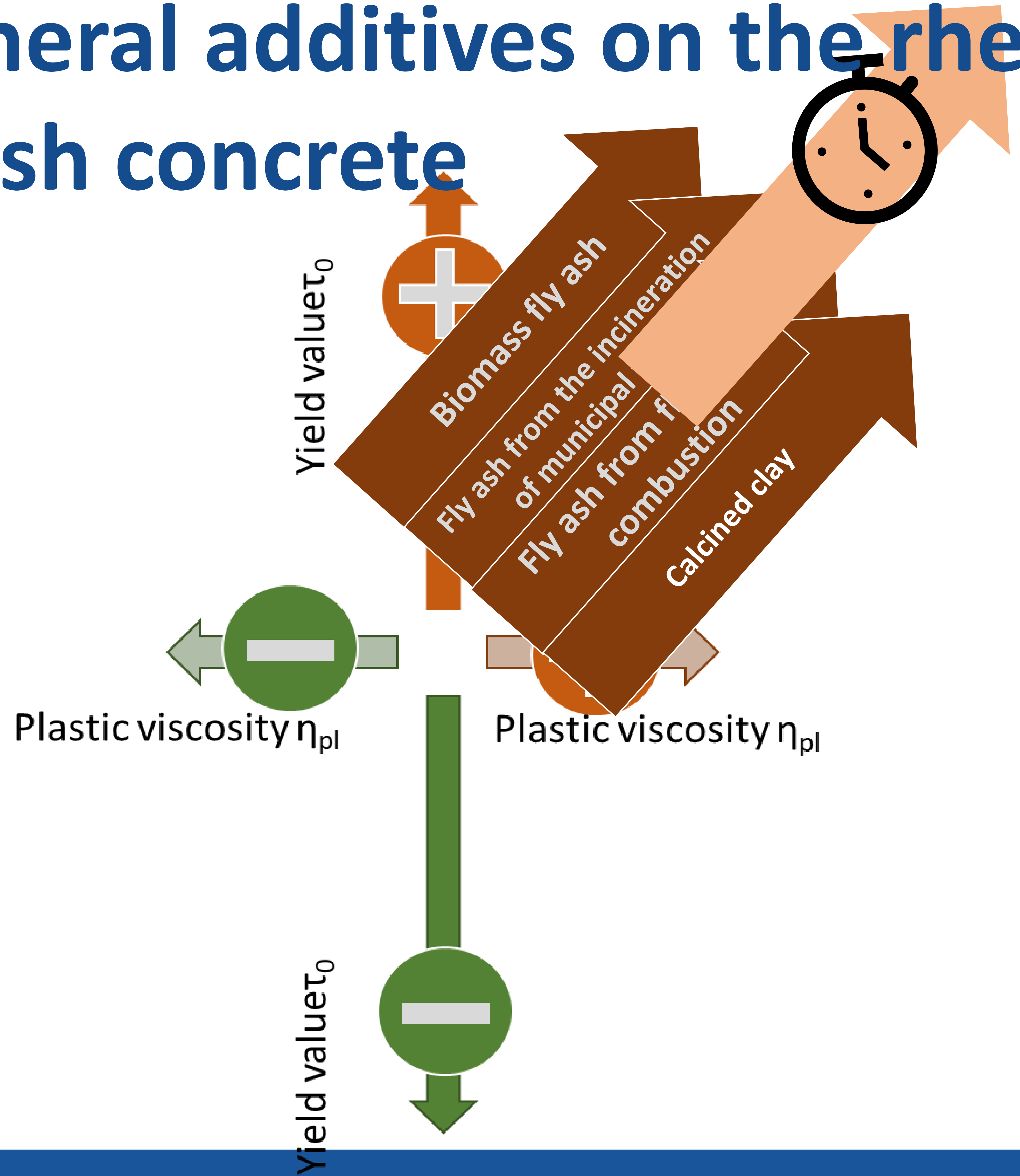


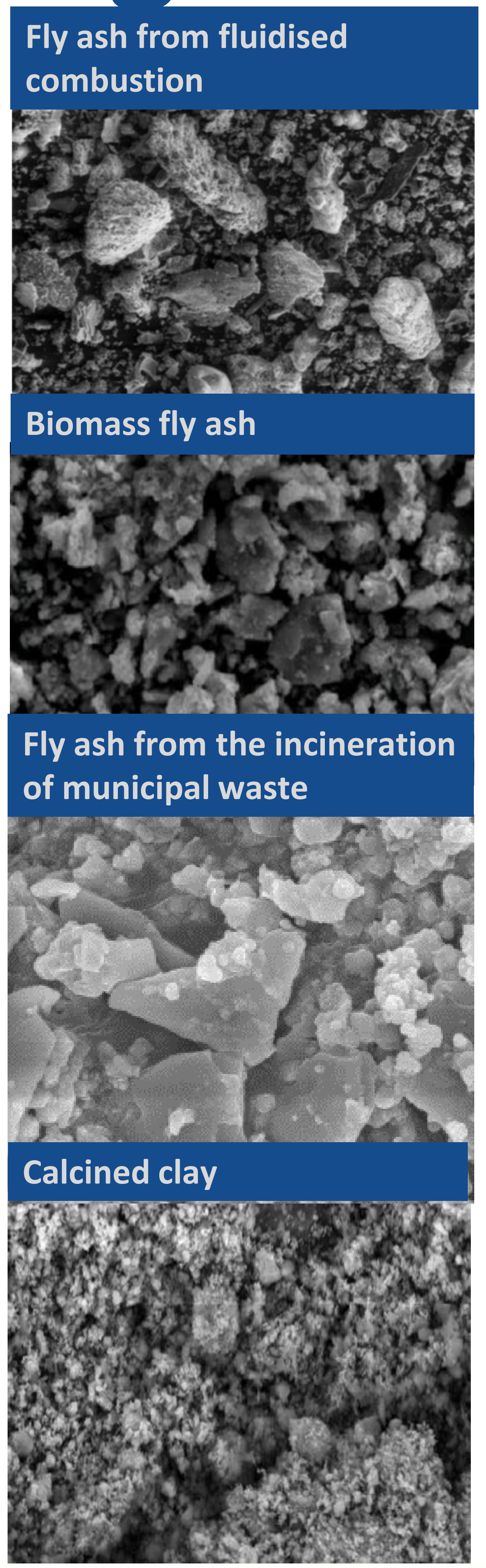

Fly ash W

Limestone L, LL

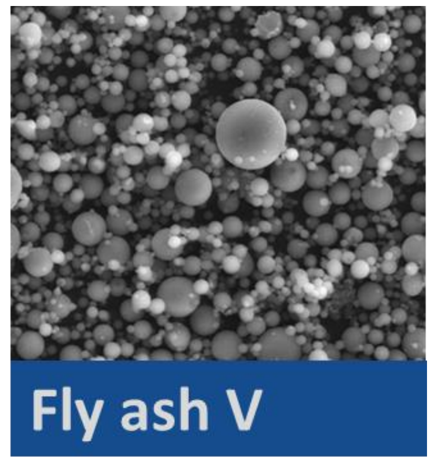
The effect of mineral additives on the rheological properties of fresh concrete

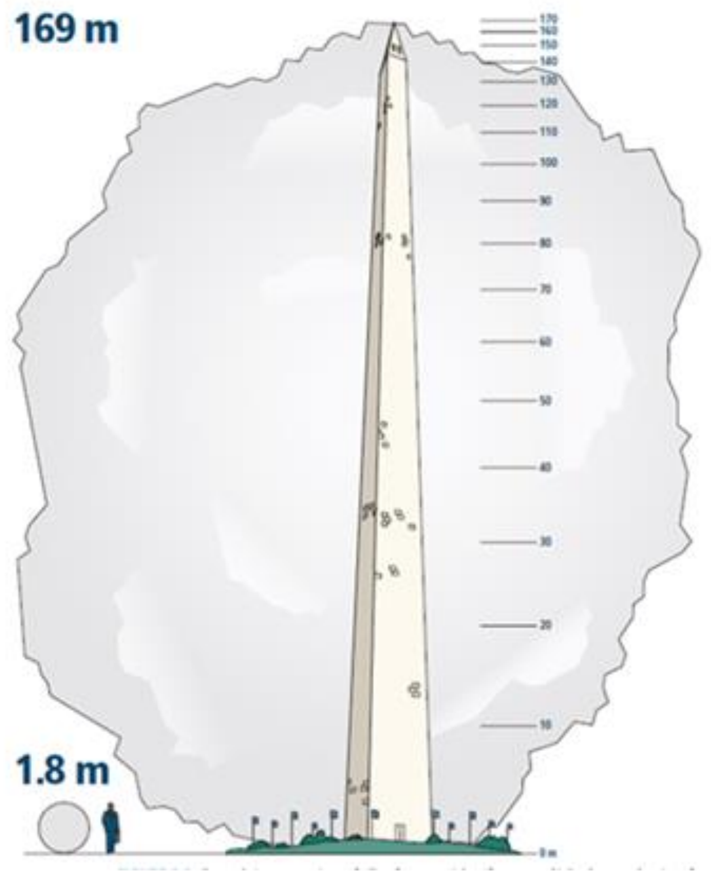
- Biomass fly ash
- Fly ash from the incineration of municipal waste
- Fly ash from fluidised combustion
- Clay and calcined clay
- Agricultural waste of plant and animal origin
- Industrial production waste

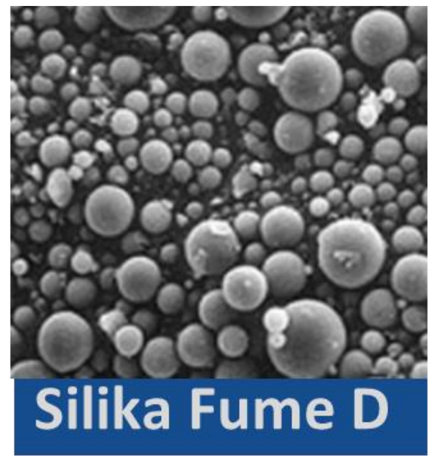




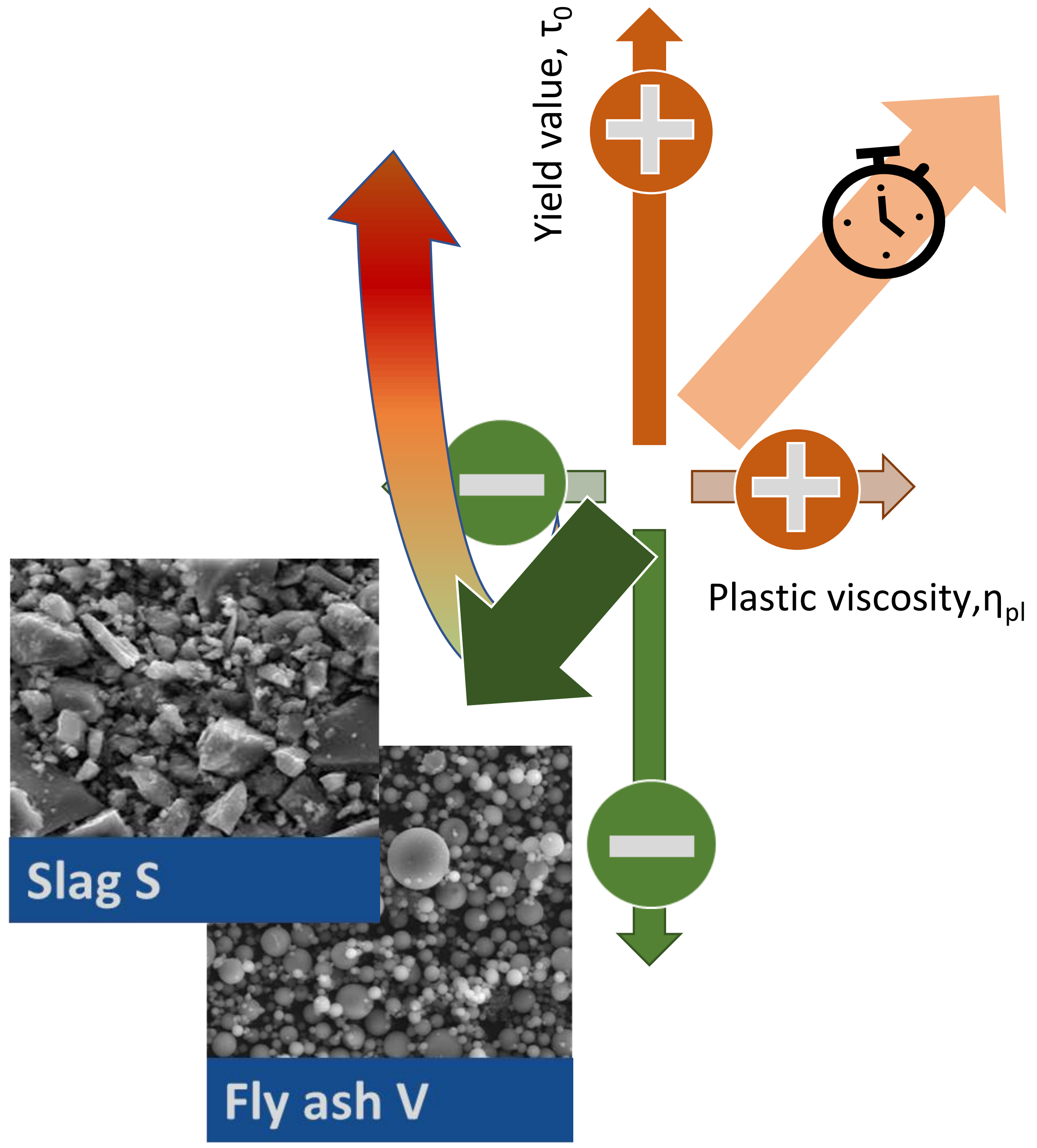
The effect of mineral additives on the rheological properties of fresh concrete







- Specific surface, fineness
- Shape of grains
- Porosity of grains
- Composition / chemical activity
- Composition / Presence of contaminants



Material	Density, g/cm³	Average grain size, µm	Specific surface, m²/kg
Cement	3,1	15	300 - 500
Fly ash	1,9 - 2,8	< 20	300 - 500
Slag	2,85 - 2,95	< 15	400 - 600
Silica fume	2,2 - 2,5	0,1	20 000
Limestone	2,65	< 10	400 - 900

Higher surface area - increased water absorption, faster binding

The effect of mineral additives on the rheological properties of fresh concrete

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- Porosity of grains
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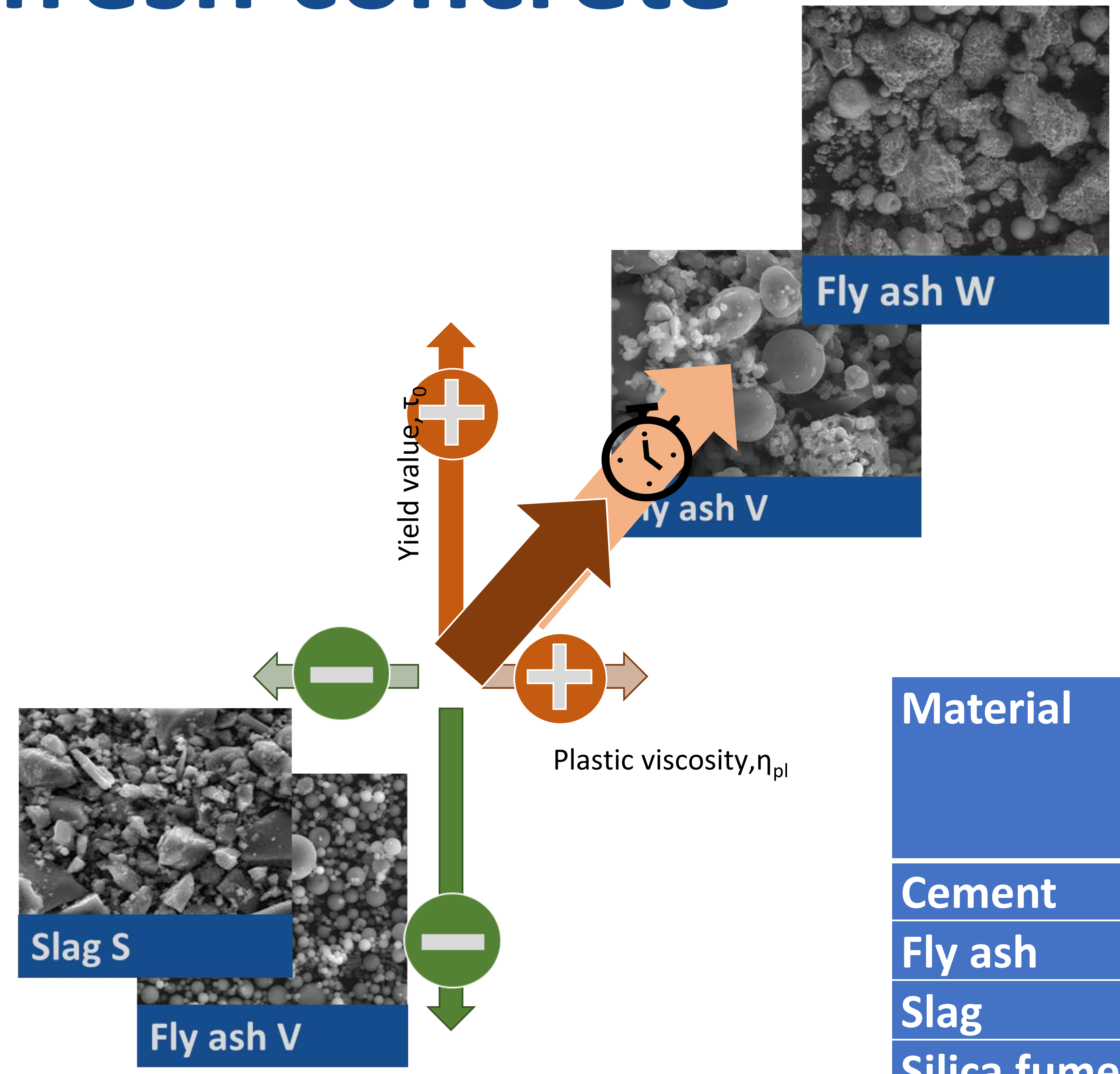
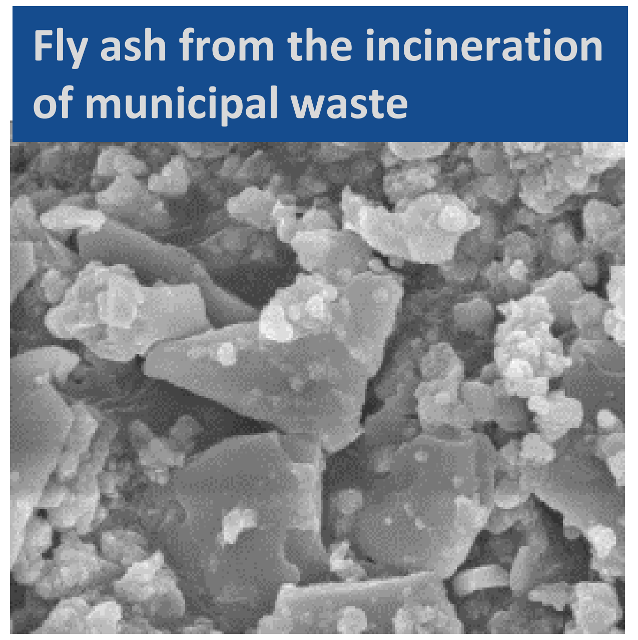
- Composition / Presence of contaminants





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Larger grains - higher flow resistance

Porous grains – absorption of water and admixtures

The effect of mineral additives on the rheological properties of fresh concrete

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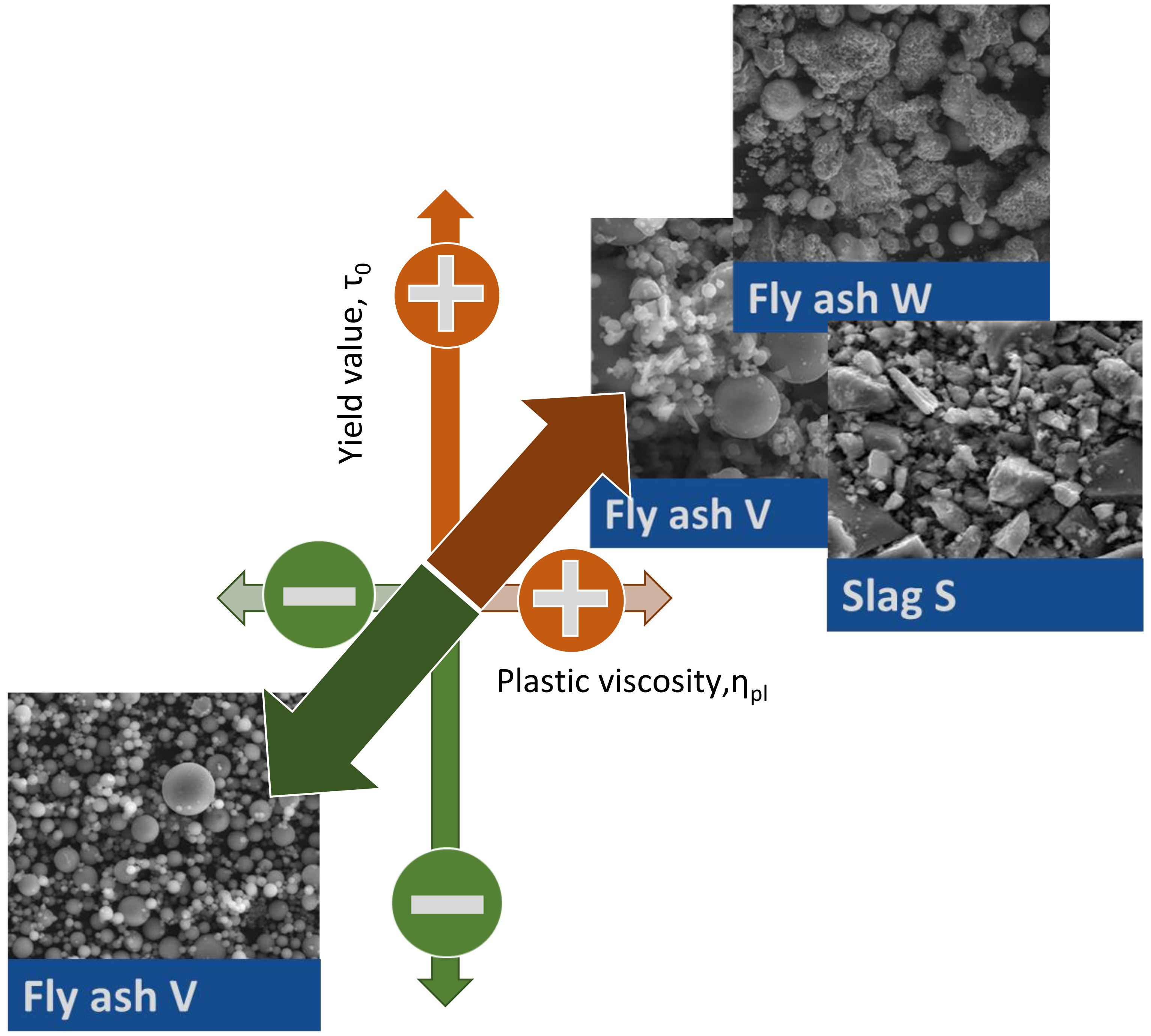
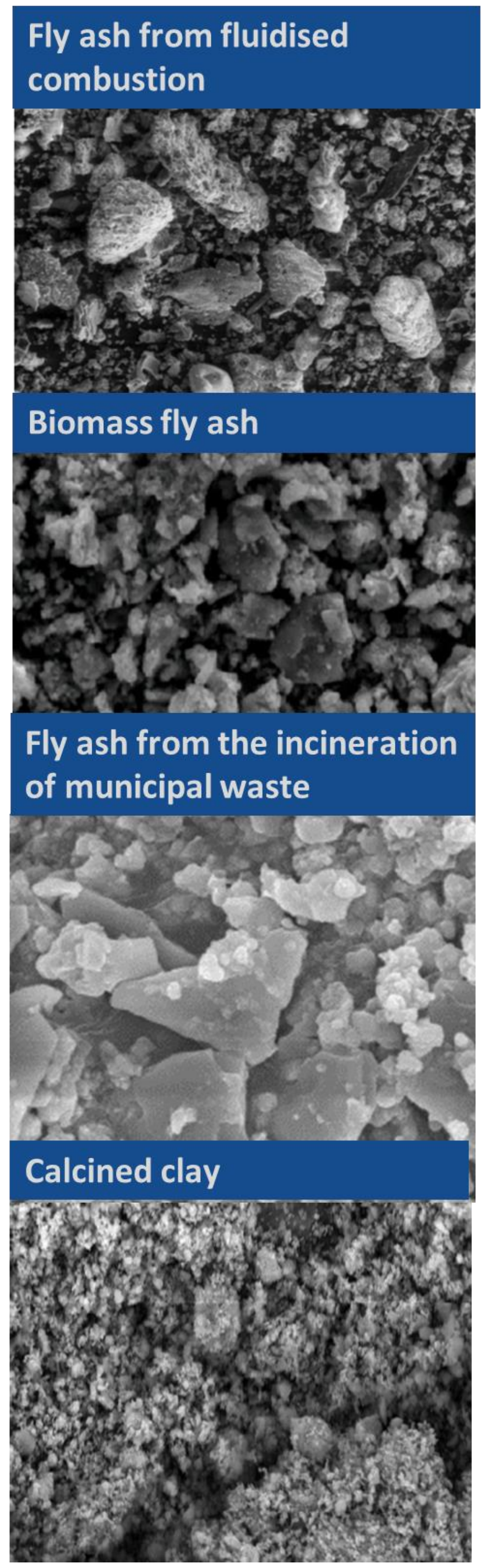
- Composition / Presence of contaminants



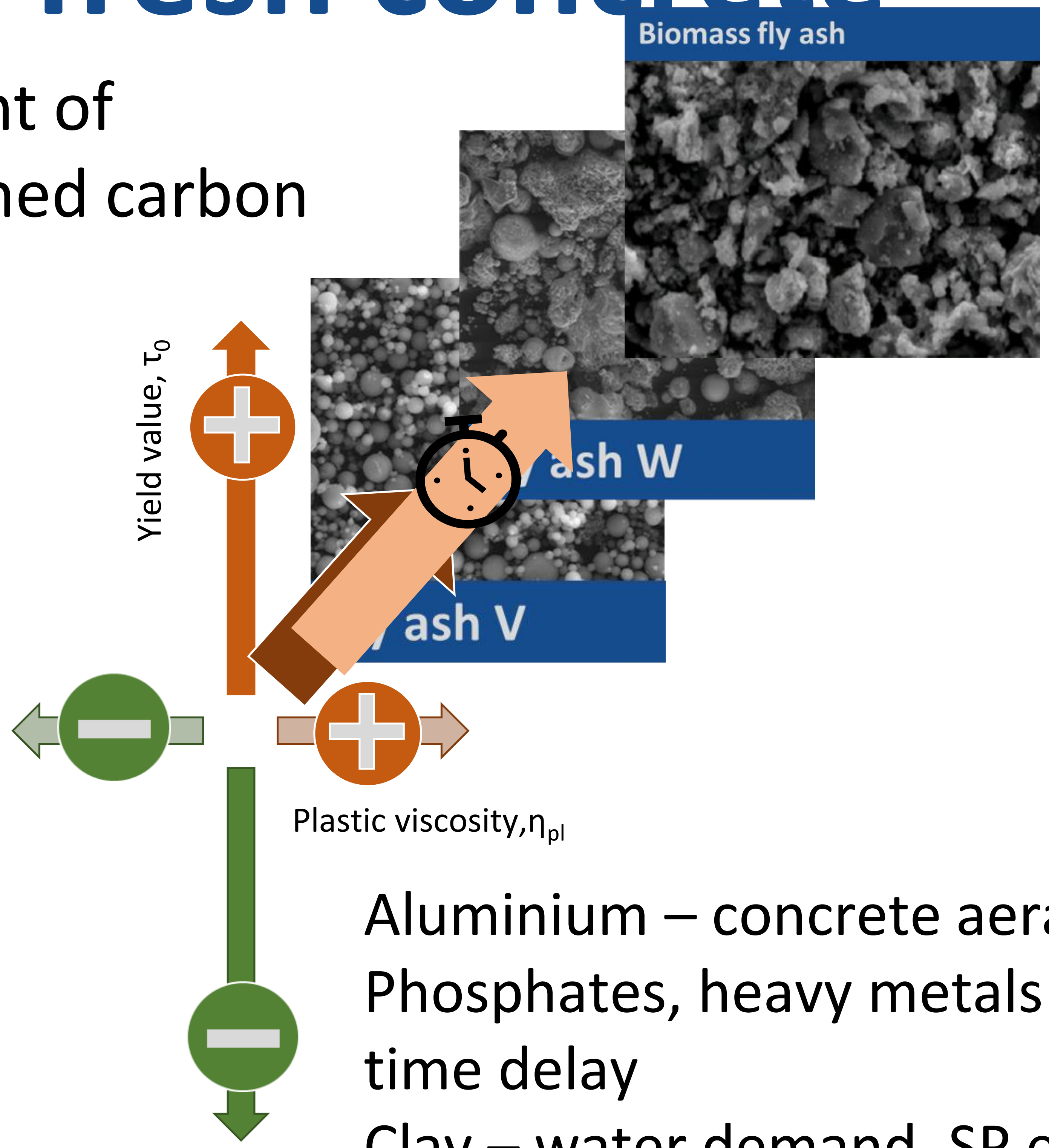


Irregular grains - increased flow resistance

The effect of mineral additives on the rheological properties of fresh concrete

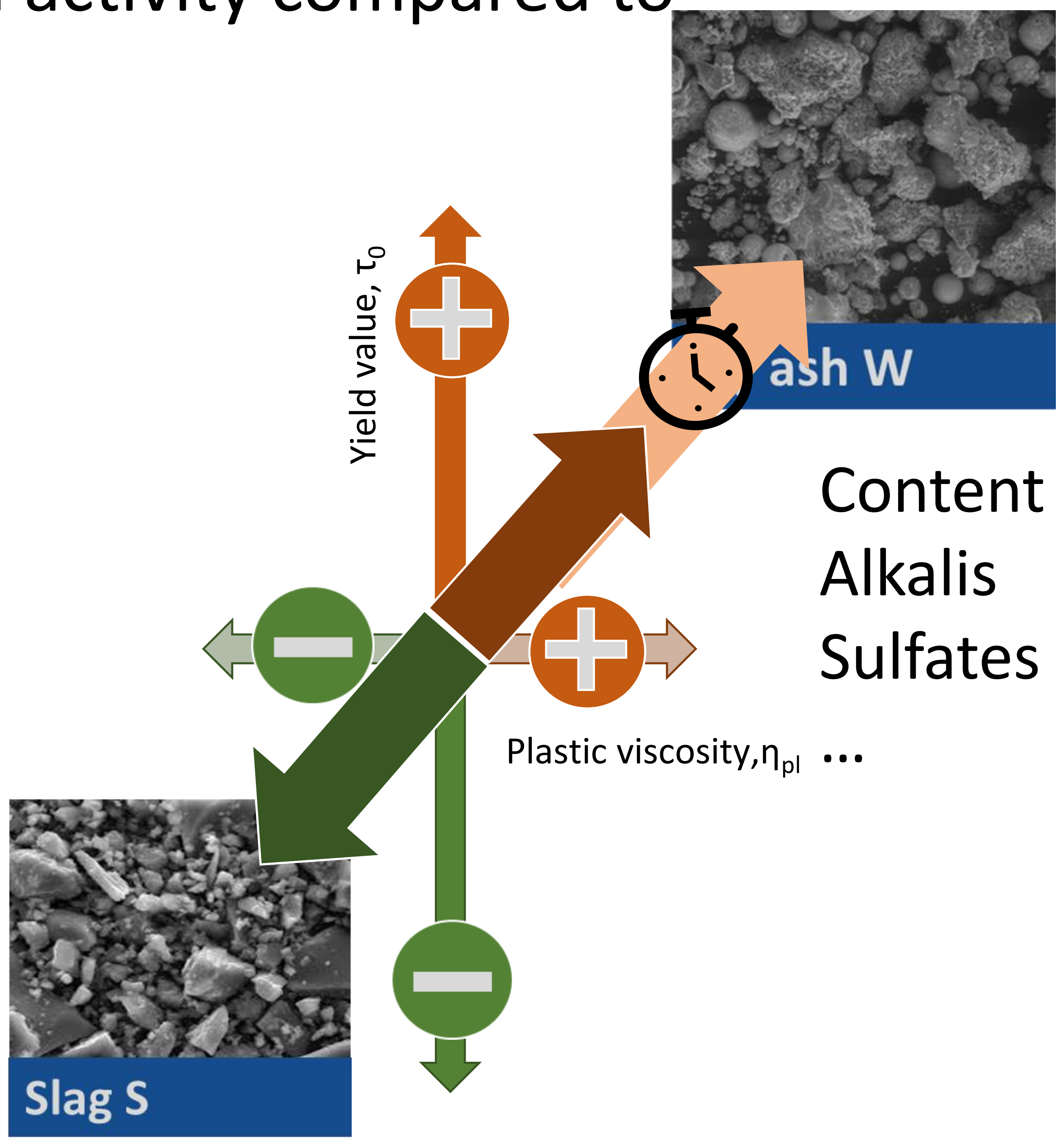
- Specific surface, fineness
- Shape of grains
- Porosity of grains
- Composition /chemical activity
- Composition /Presence of contaminants

Amount of unburned carbon



Aluminium – concrete aeration
Phosphates, heavy metals – setting time delay
Clay – water demand, SP effectiveness

Chemical activity compared to cement



Content of CaO_w
Alkalis
Sulfates
...

Alkalis – SP effectiveness

Variability in the properties of mineral additives

- Specific surface, fineness
- Shape of grains
- Porosity of grains
- Composition and chemical activity
- Presence of contaminants

The variability of properties applies to all components, to a lesser extent to cement and S slag, and to a large extent to fly ashes. Differences in properties occur both between different sources of a given material and within a single source. The research problem is poorly explored, and there is a lack of analysis of the impact of material variability on the properties of fresh and hardened concrete.

Component	Coefficient of variation, %		
	Fly ashV	Fly ash W	Biomass ash
LOI	21	33	45
SiO_2	10	13	43
Al_2O_3	19	8	7
Fe_2O_3	18	27	27
CaO	12	20	37
Na_2O	15	59	11
K_2O	15	63	29
SO_3	11	33	21

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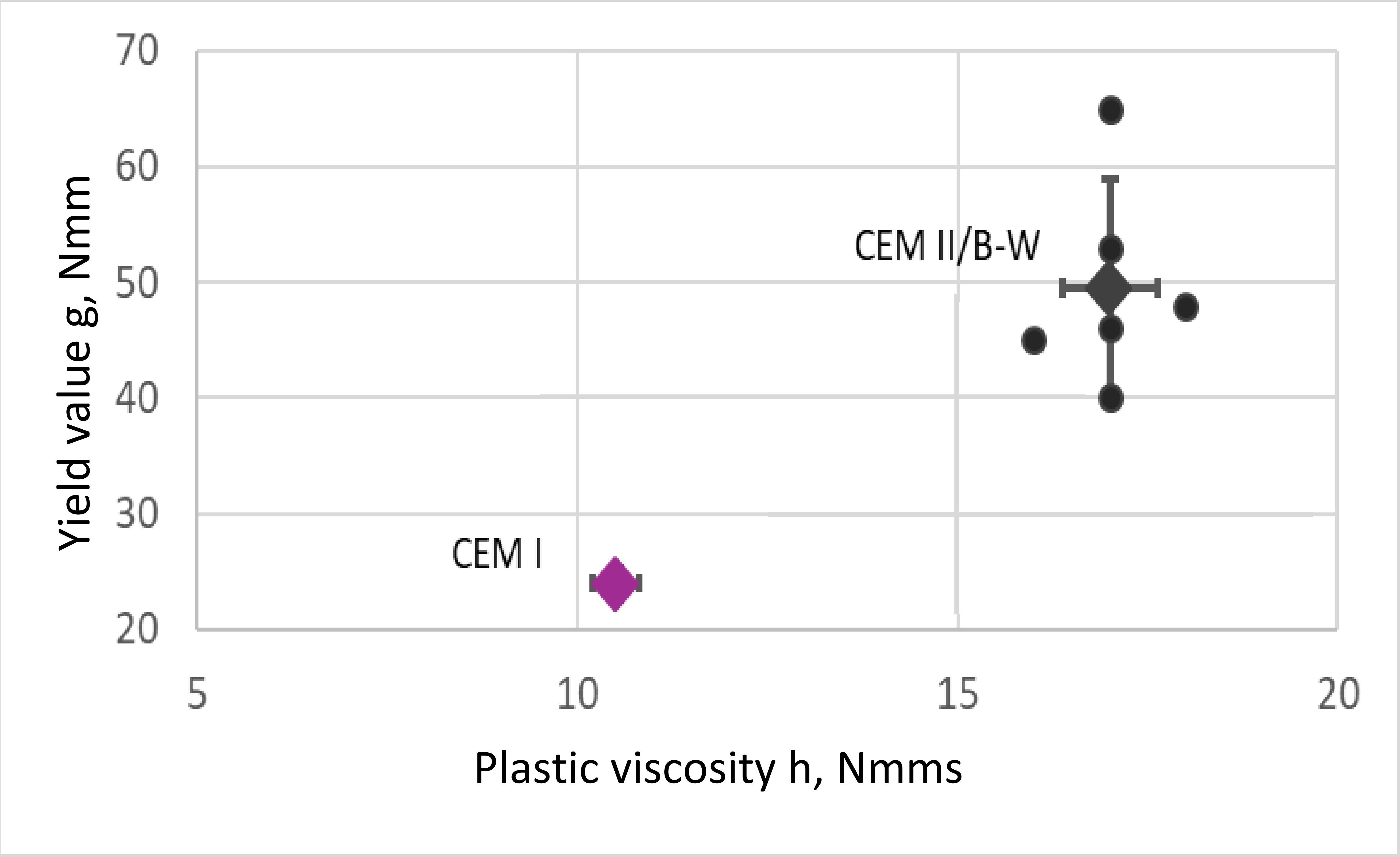
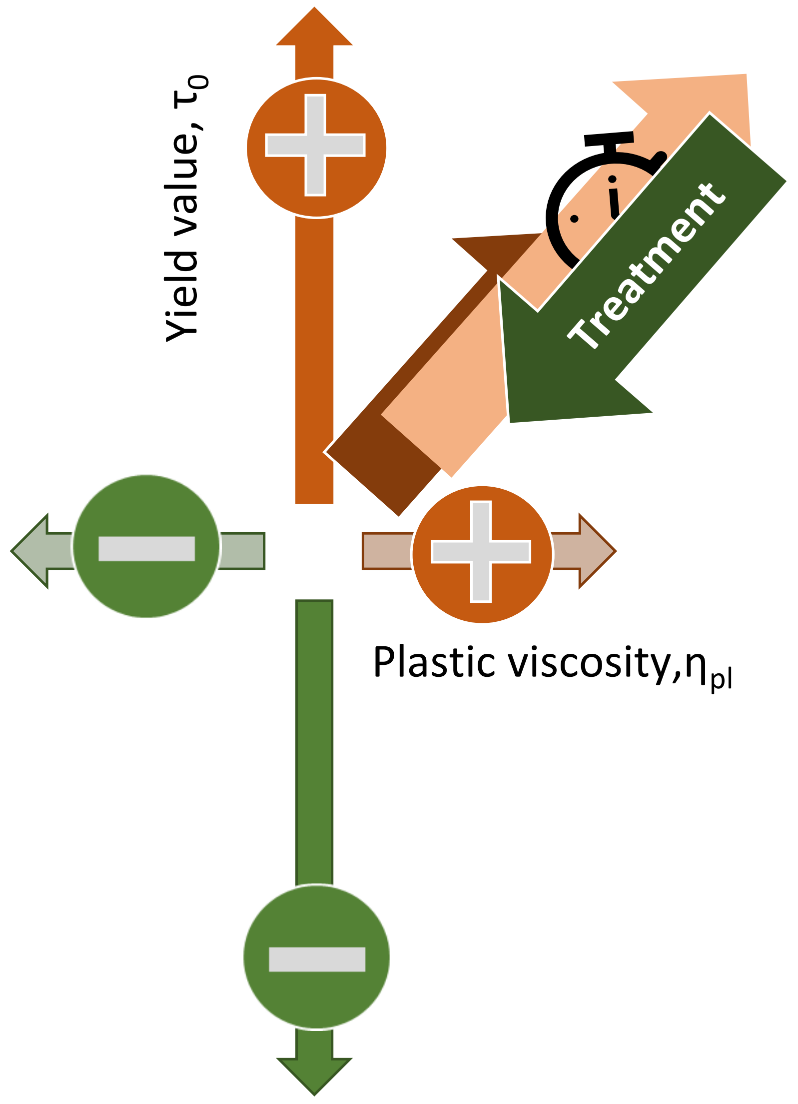


Reducing the negative impact of mineral additives

Use of additives with a negative impact on workability with additives improving workability – V, S, LL

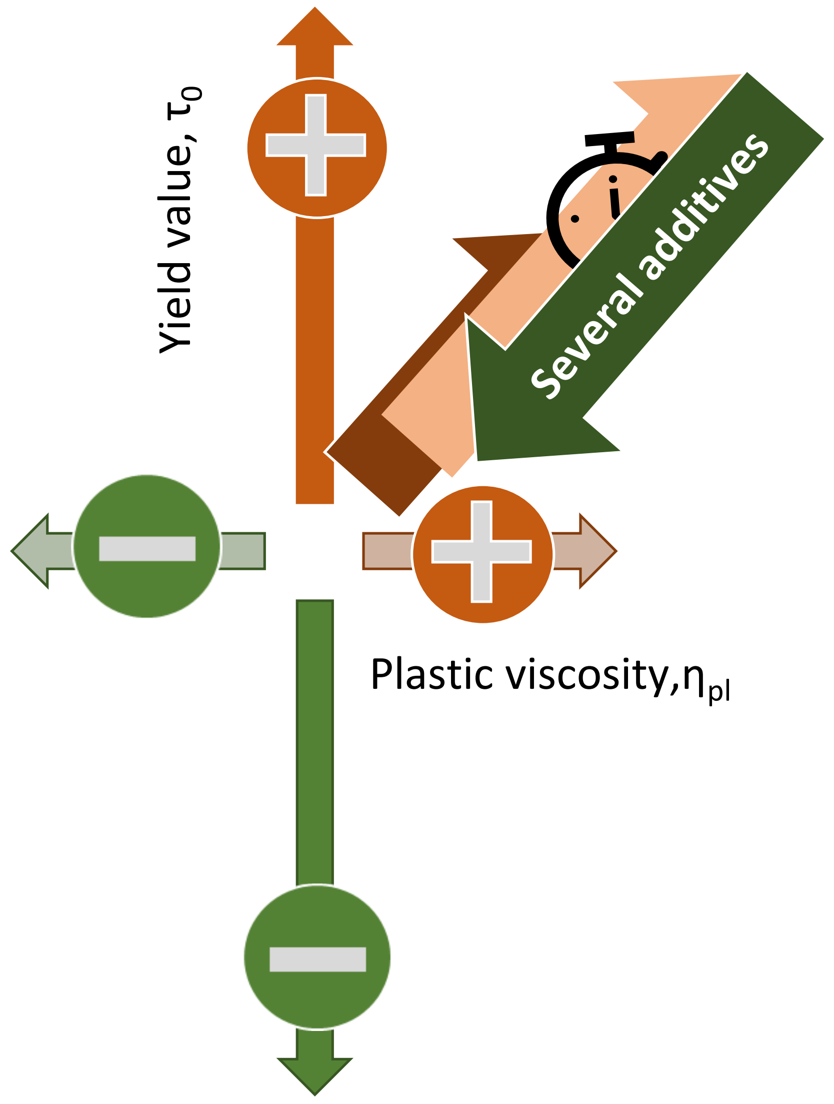
Optimisation of cement grain size – additives

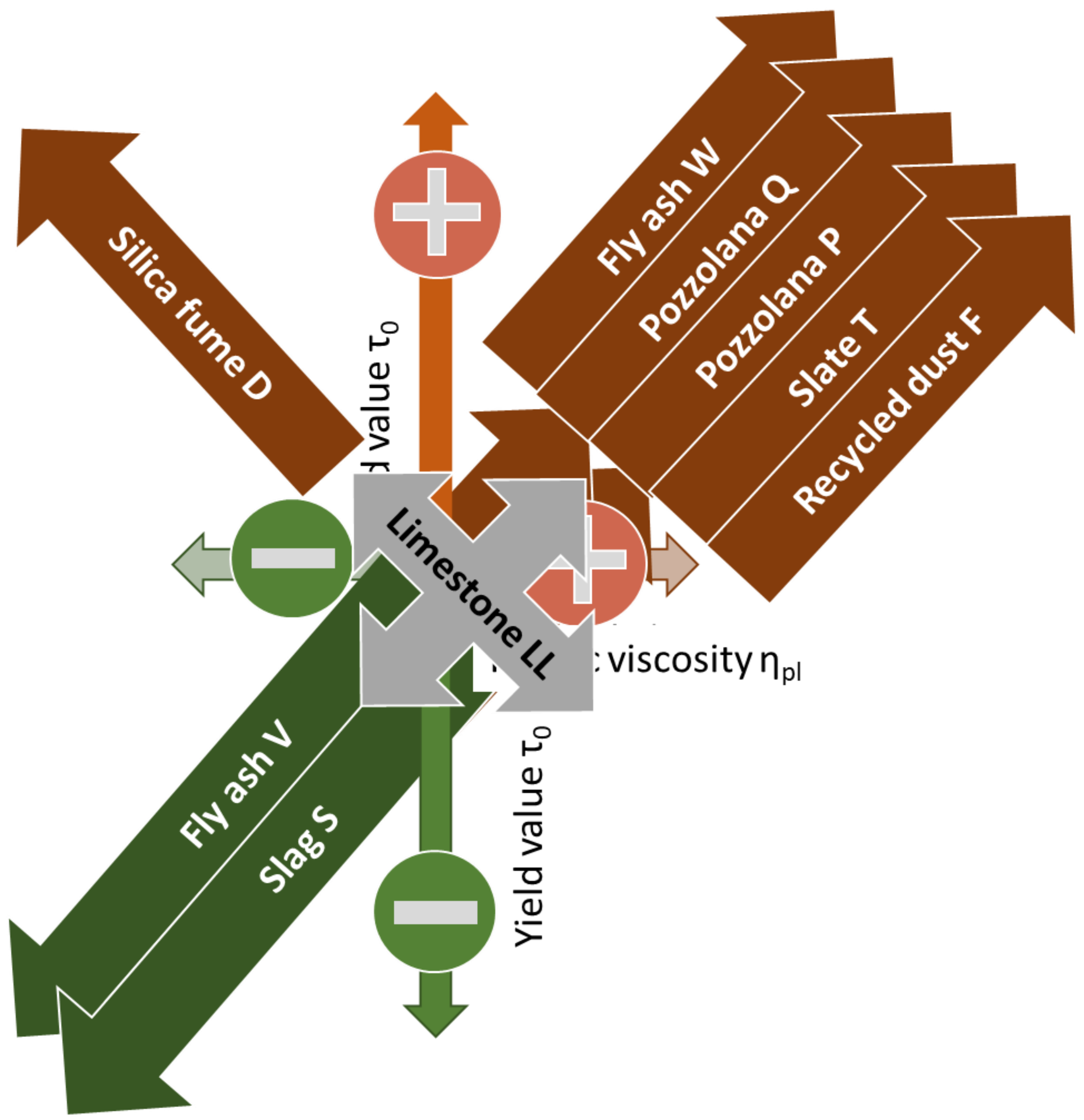


Fly Ashes
Dust from recycling
Pucolans, calcined clays

Treatment

Grinding
Separation
Selective collection
Thermal processing
Washing

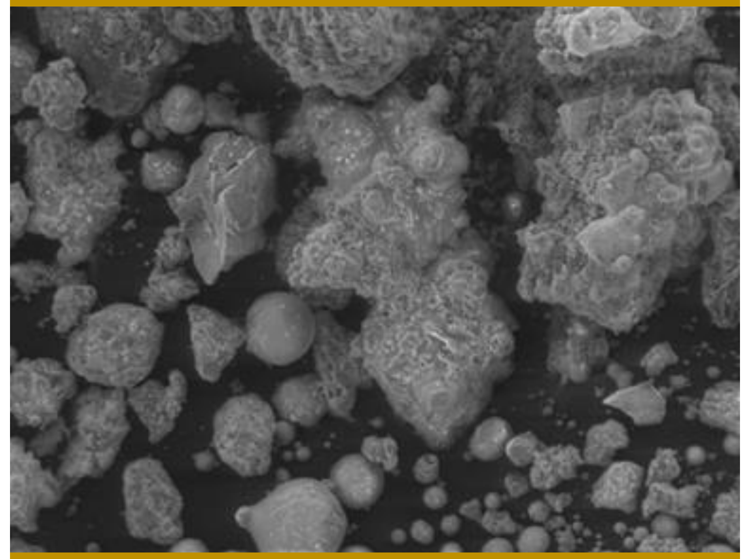




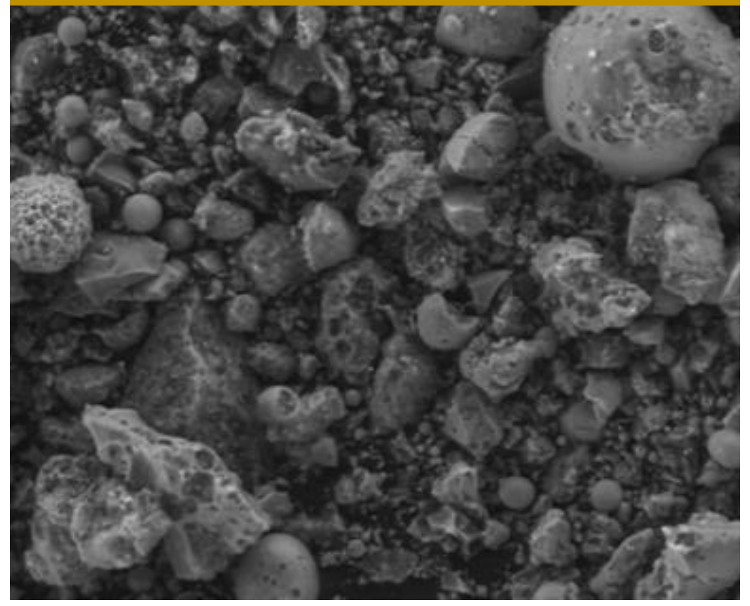
Using several additives

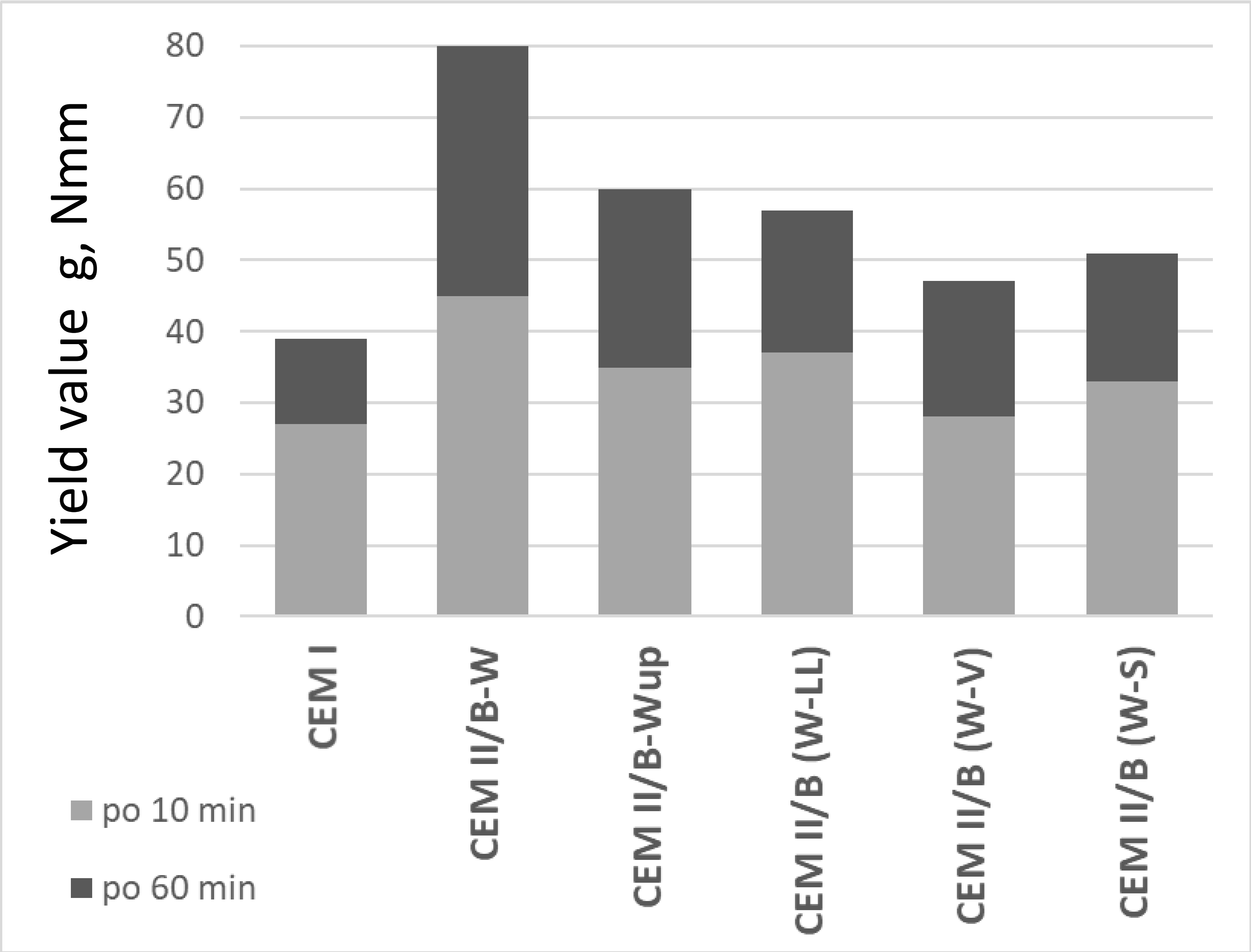
Reducing the negative impact of mineral additives

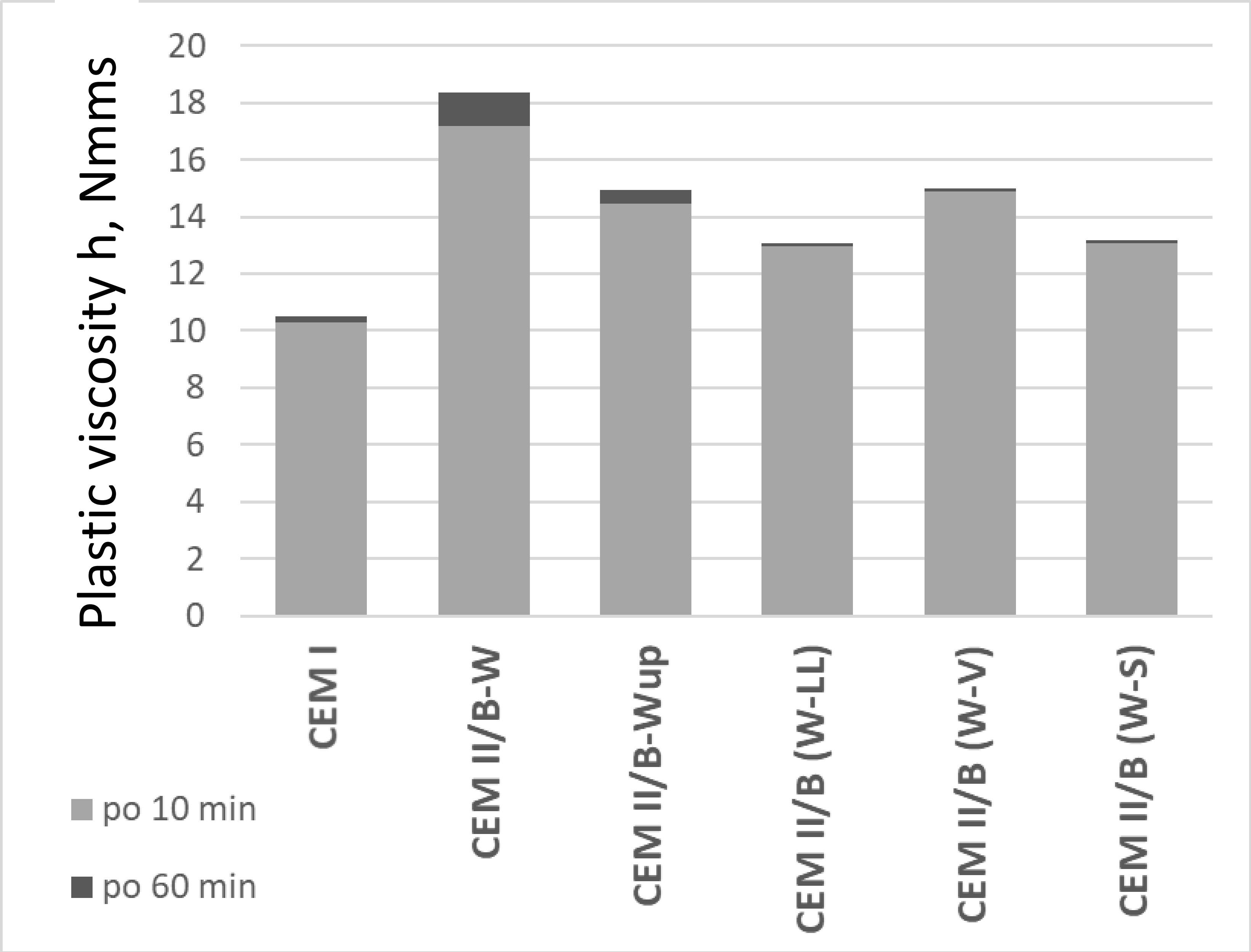
Fly ash W



Fly ash W ground

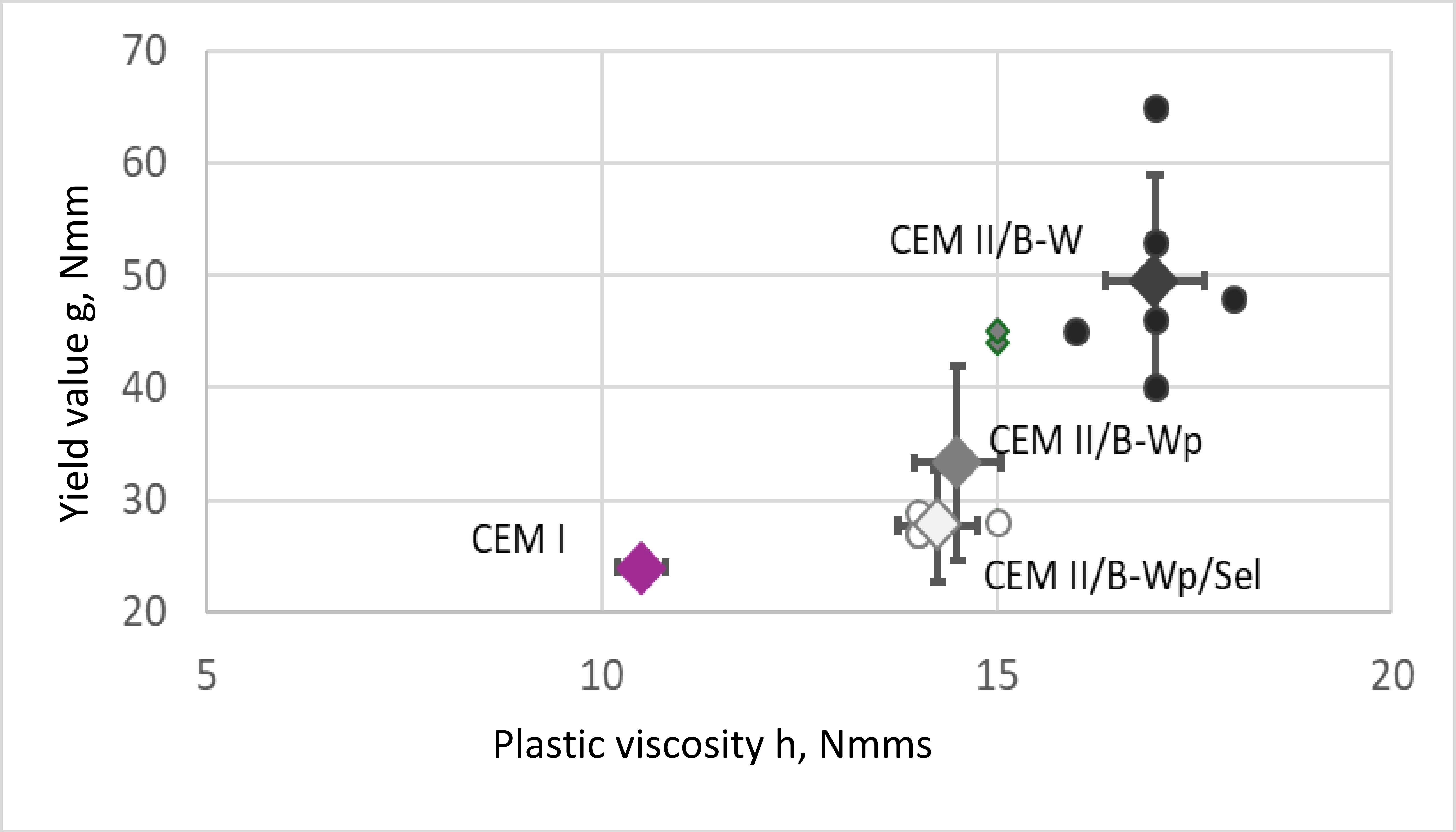






Reducing the negative impact of mineral additives

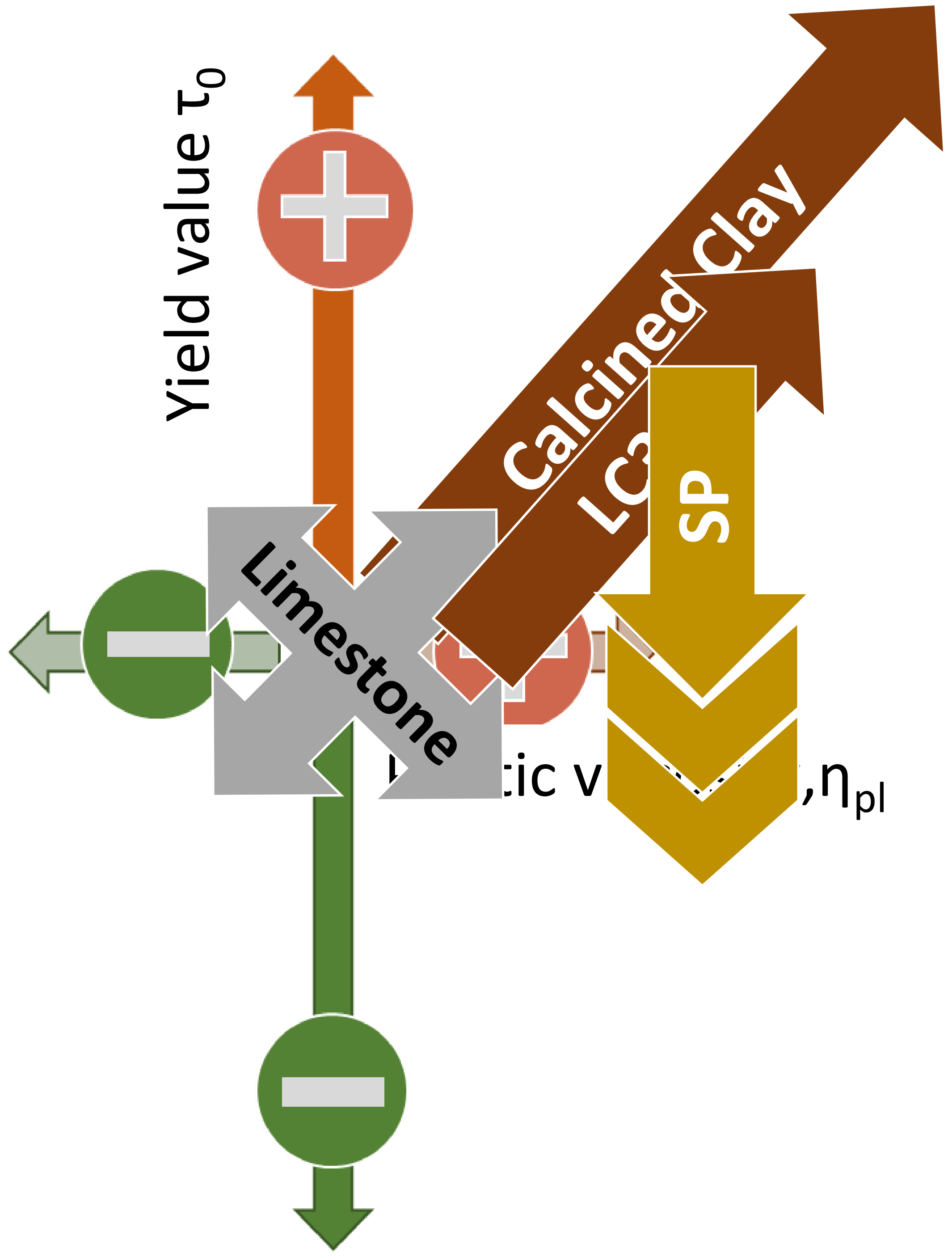
Variability in the composition and properties of mineral additives



The effect of LC3 cement on the rheological properties of fresh concrete

LC3 cement consists of clinker, calcined clay and limestone.

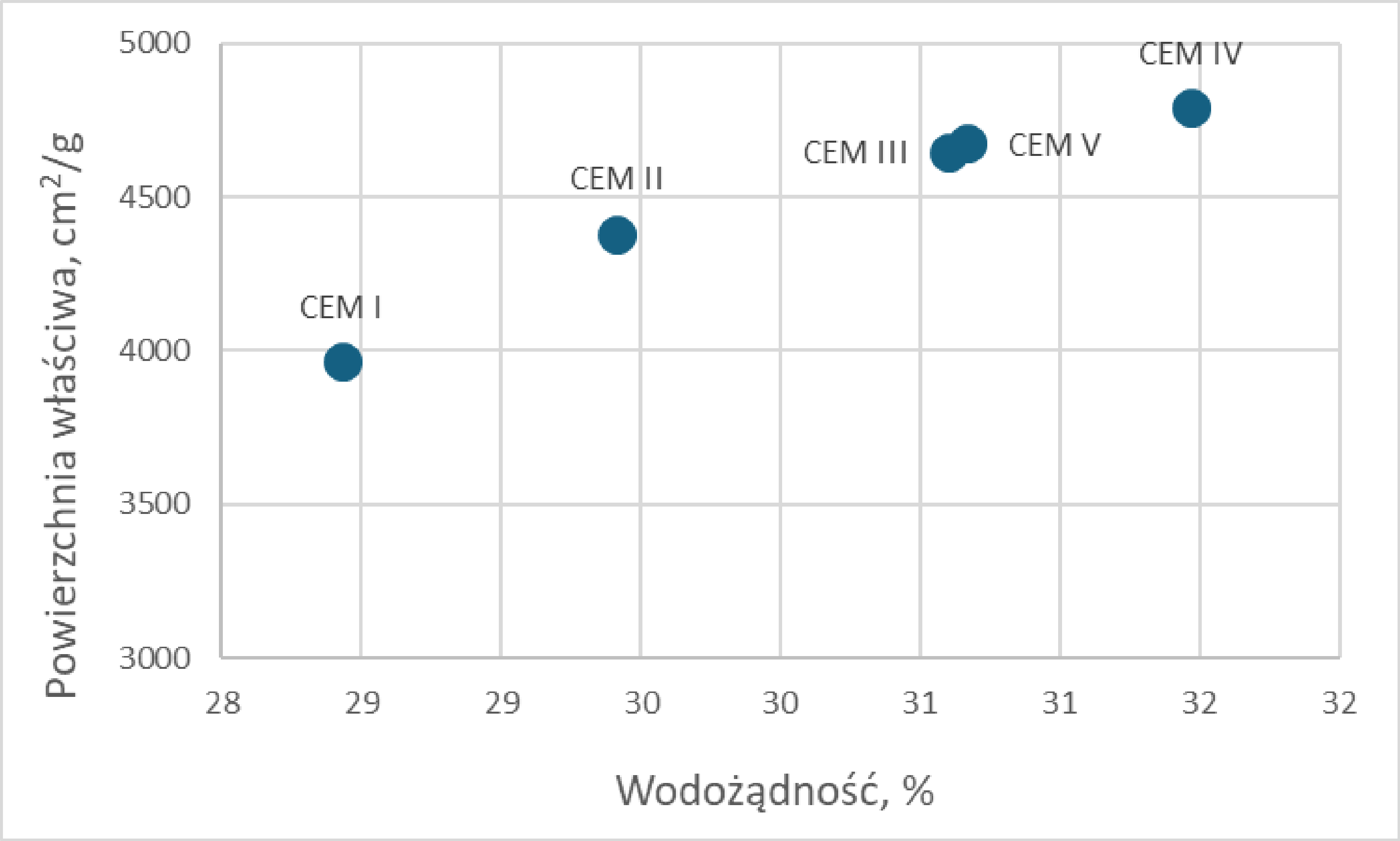
The idea of LC3 cement is based on two assumptions:
(1) the widespread availability of LL and CC materials and (2) their expected beneficial chemical and physical interaction.



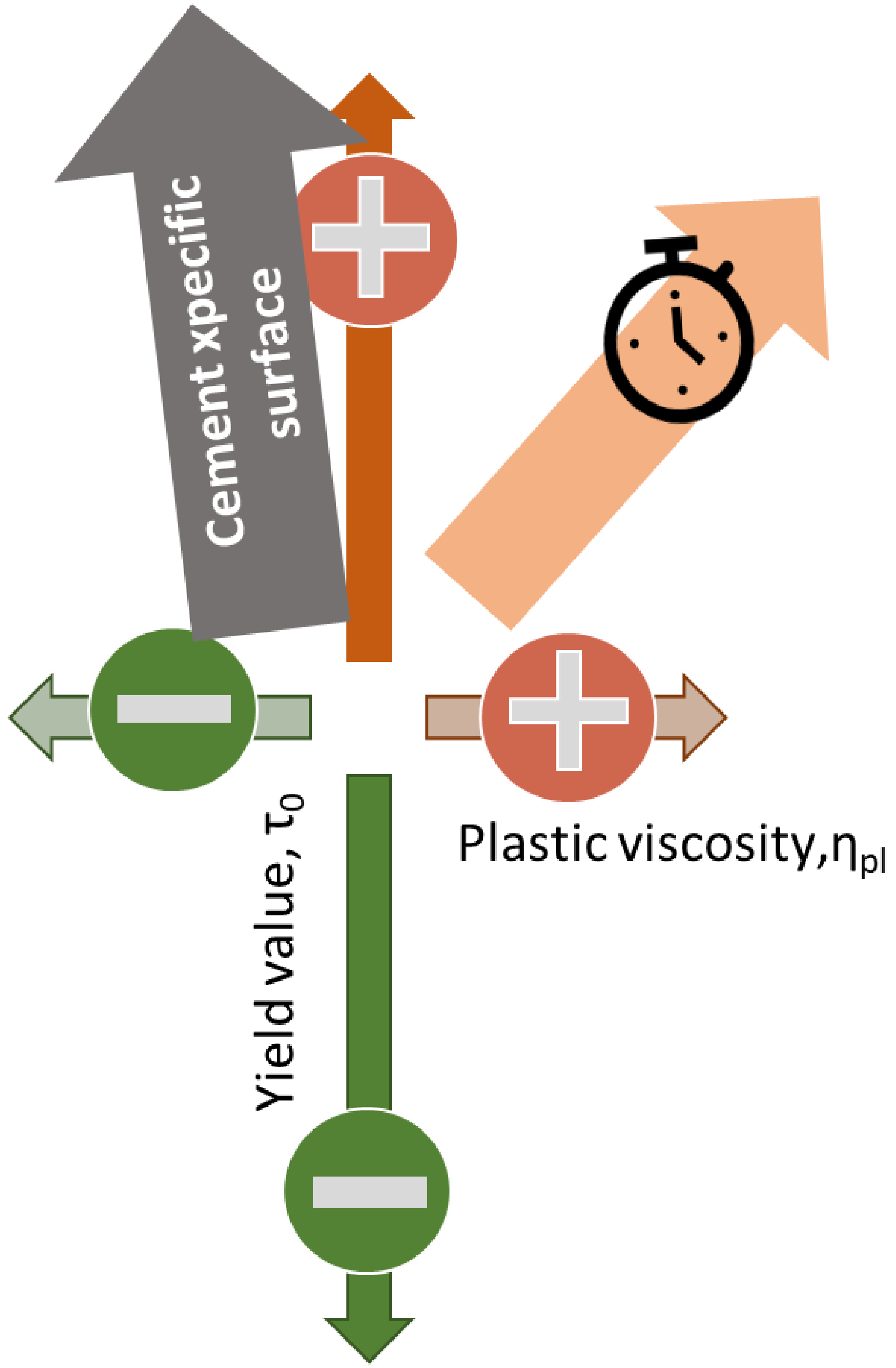
Fresh LC3 concretes are characterized by increased plastic viscosity, yield value and fast workability loss.

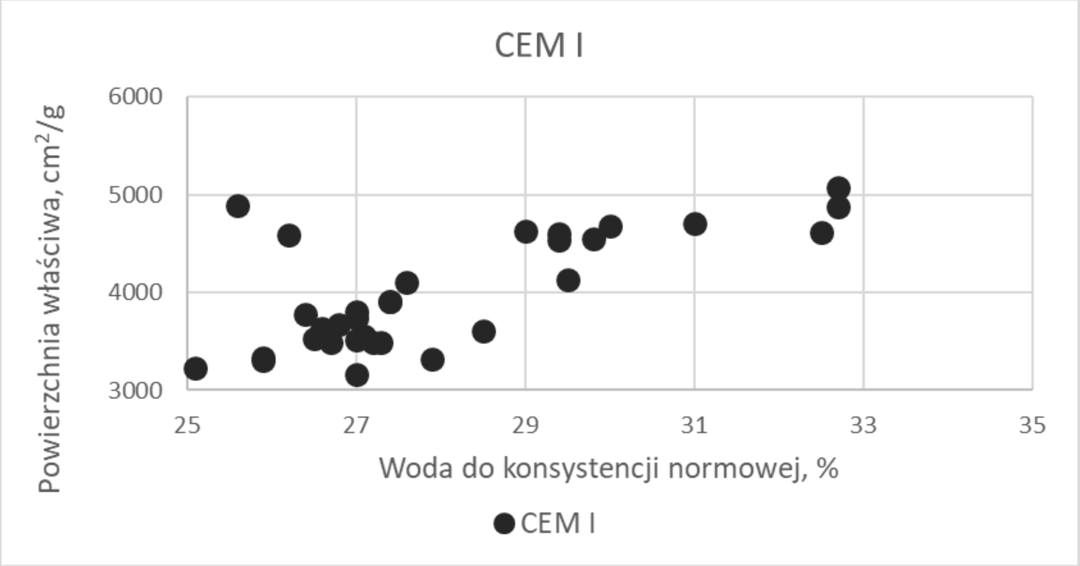
The high specific surface area of CC and its microstructure cause LC3 to require more water. Possible negative impact of some CC on SP efficiency and the need to use specially selected or specially designed SP.

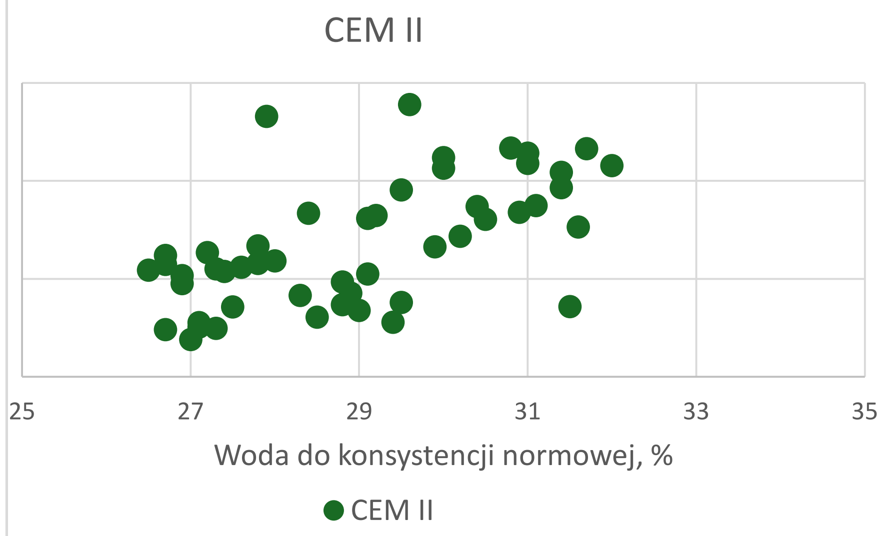
The influence of cement specific surface area on the rheological properties of fresh concrete

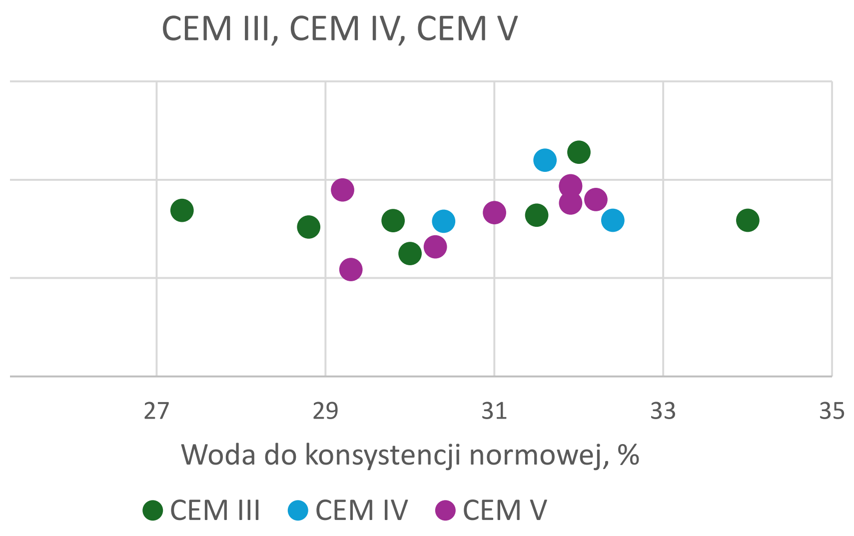


Requirements for strength and setting time with less clinker in cement → increasing cement specific surface area.









The effect of SP on the rheological properties of fresh LCC

W/C ratio

Temerature

Mixing procedure

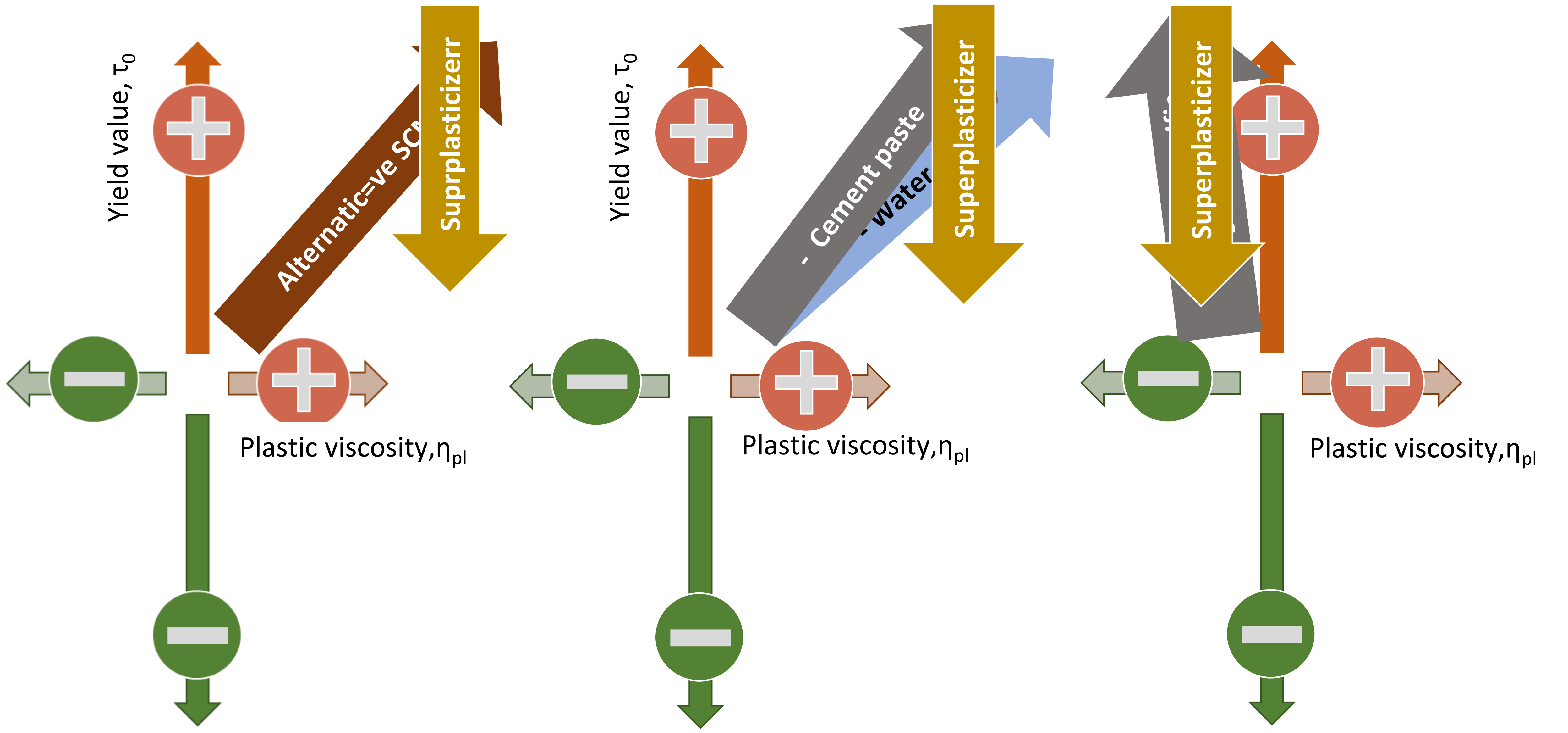
Effectivnes of SP

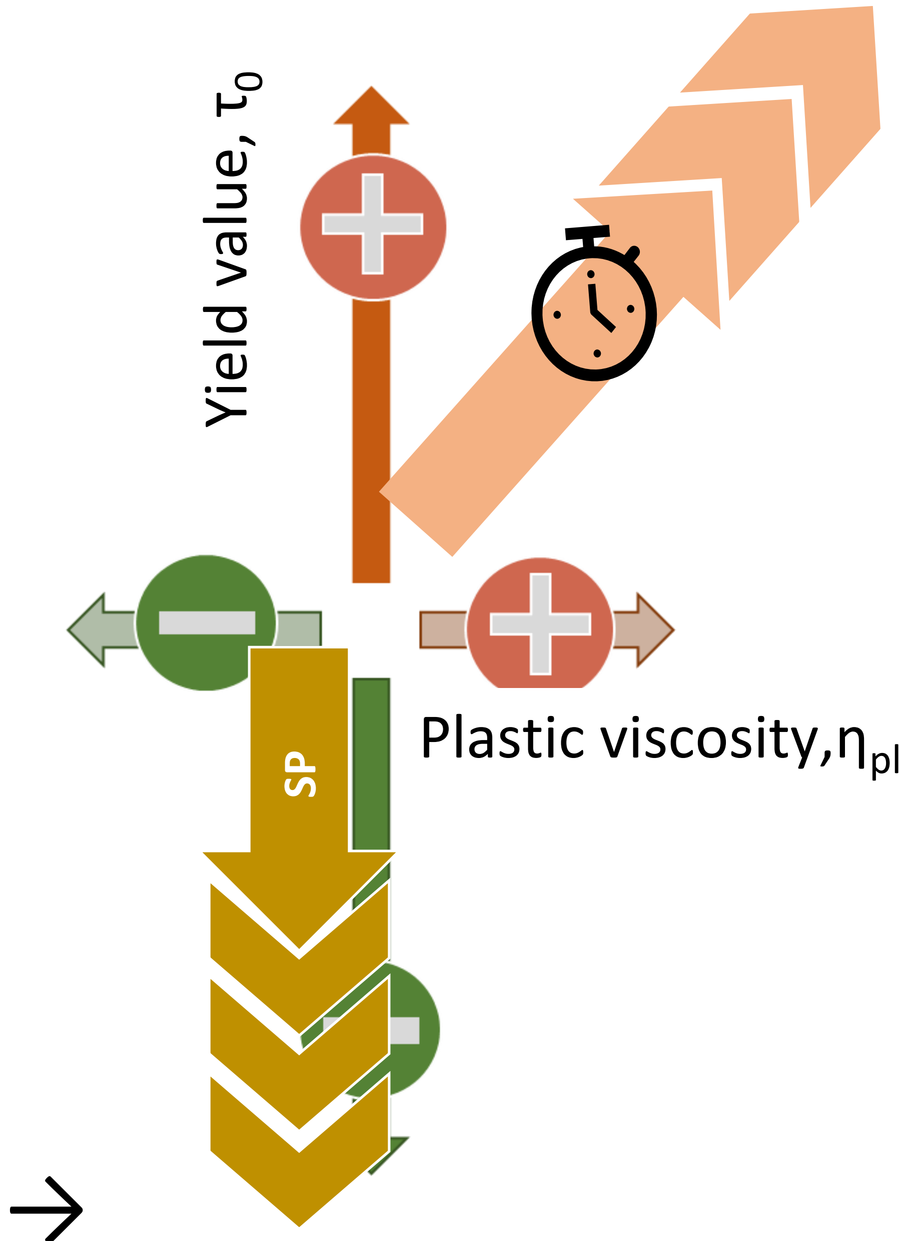
Properties of SP

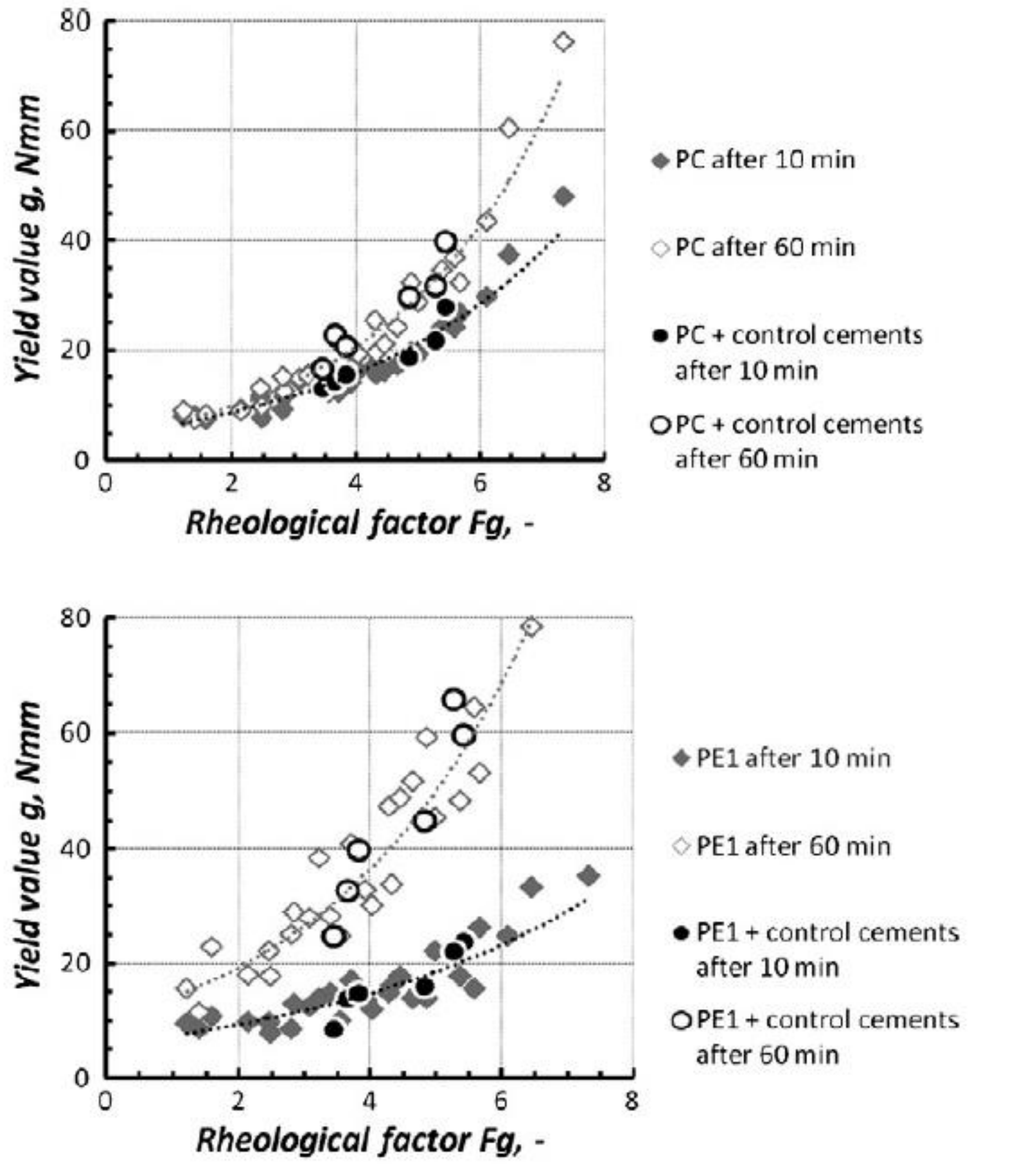
Properties of cement

Properties of mineral additives

Properties of admixtures



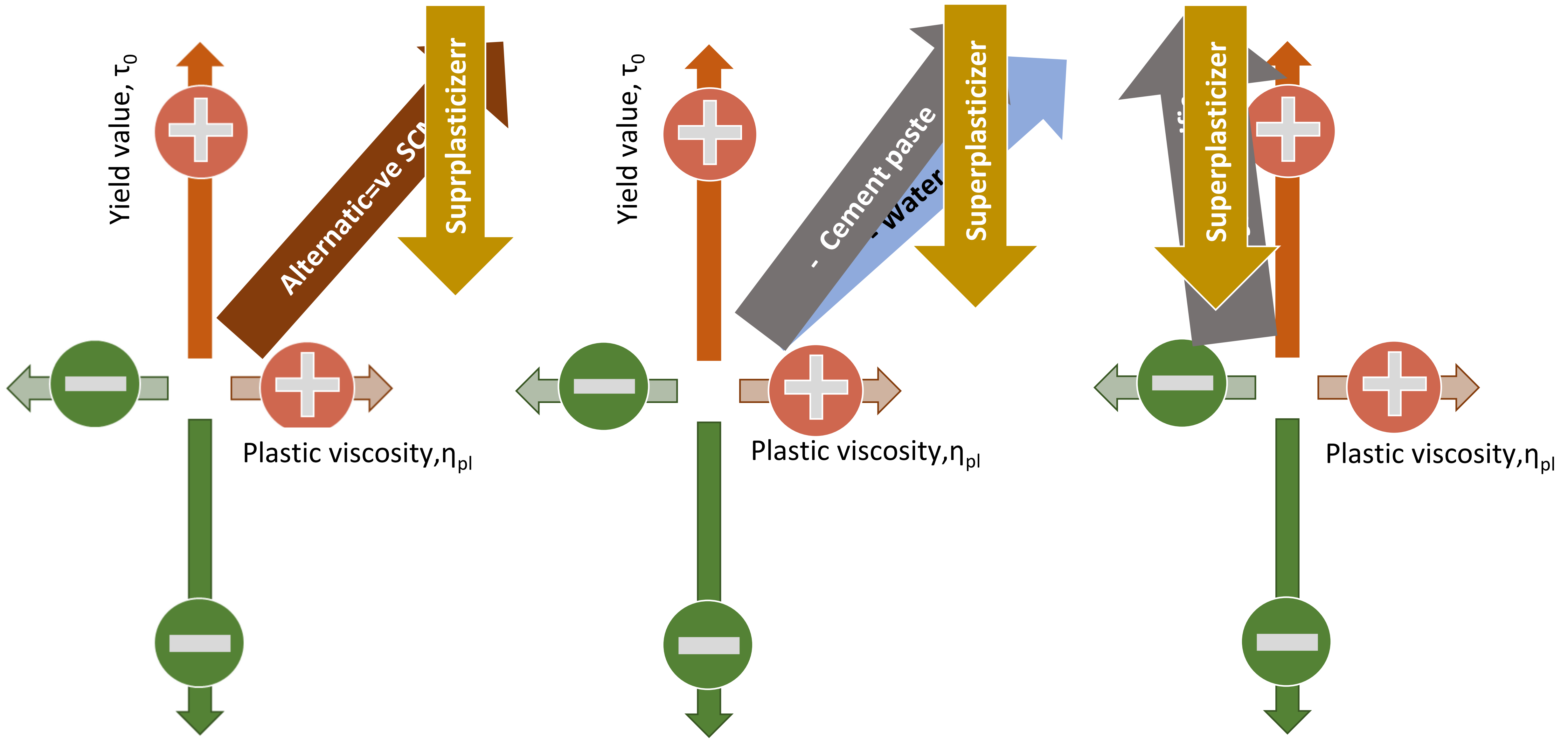




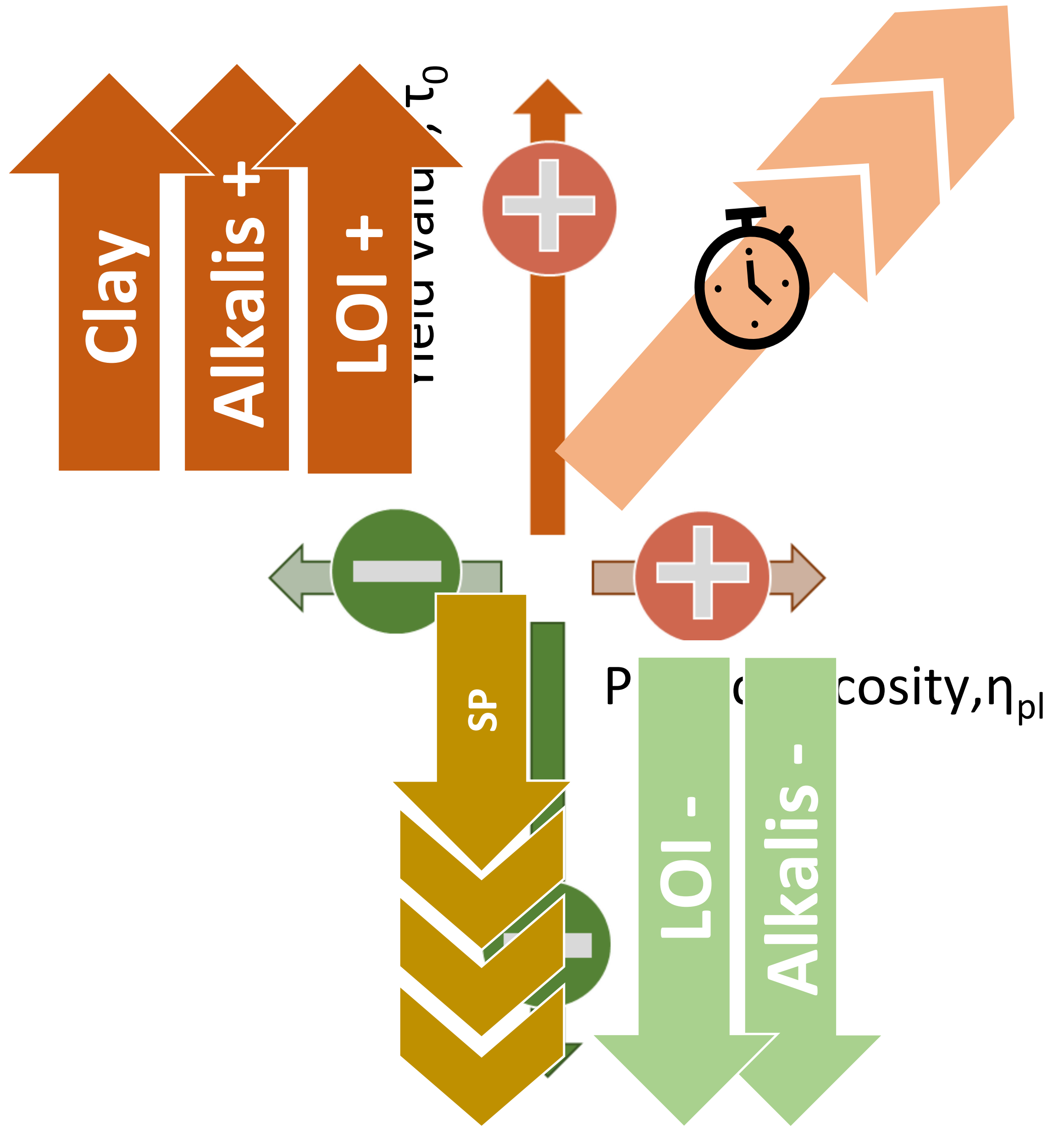
Varying content and properties of mineral additives→ affecting effectivnes of SP

Jacek Gołaszewski, Influence of cement properties on new generation superplasticizers performance, Construction and Building Materials, Volume 35, 2012, https://doi.org/10.1016/j.conbuildmat.2012.04.070.

The effect of SP on the rheological properties of fresh LCC



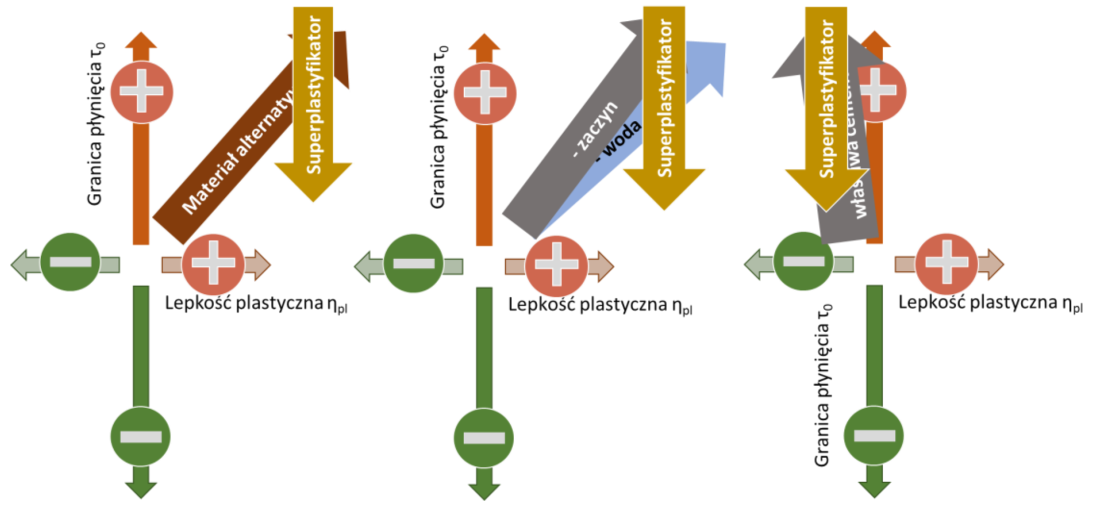
The effectivness of SP (and other additives) may vary.

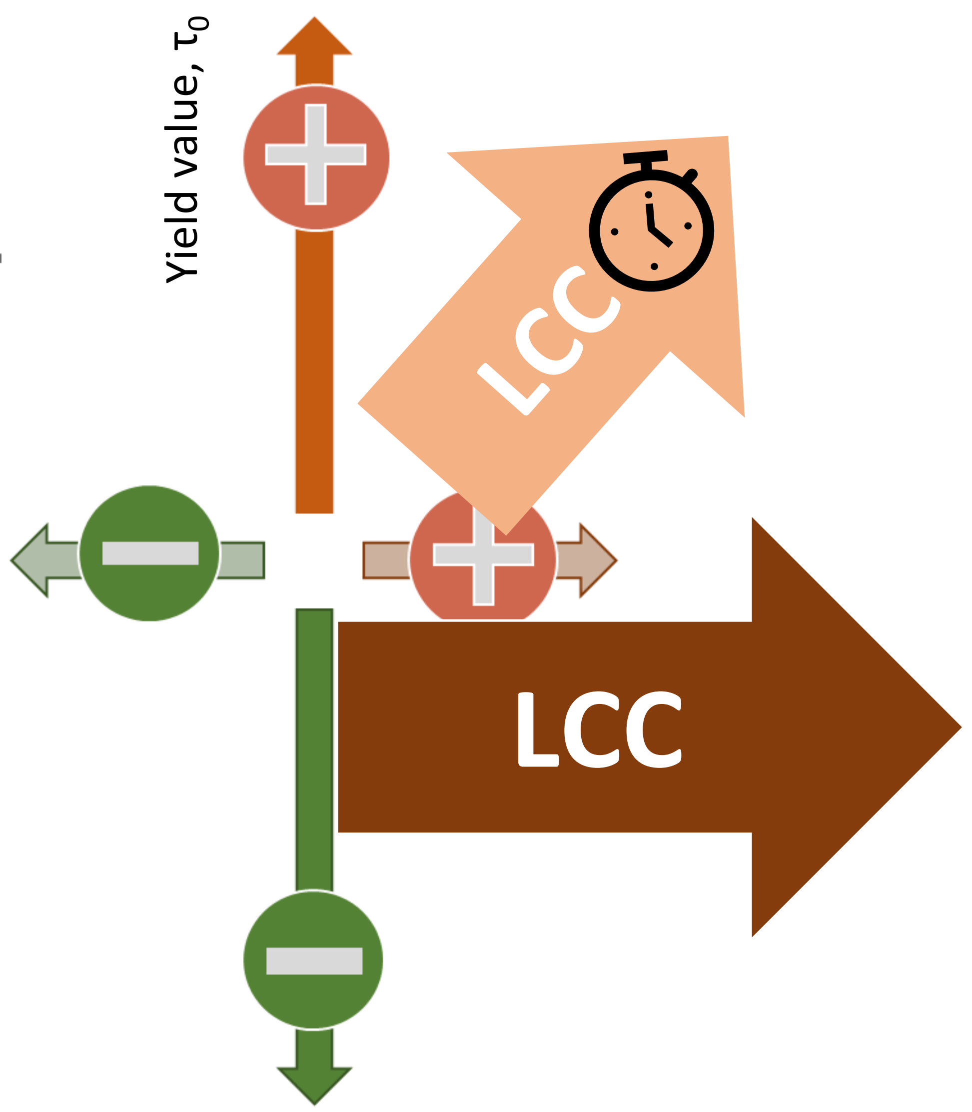


Presence of unburned carbon – fly ashes
Alkali content – fly ashes
SP adsorption – e.g. clay, calcined clay, recycled dust

Select the appropriate SP
Use of PL and SP (redosage)

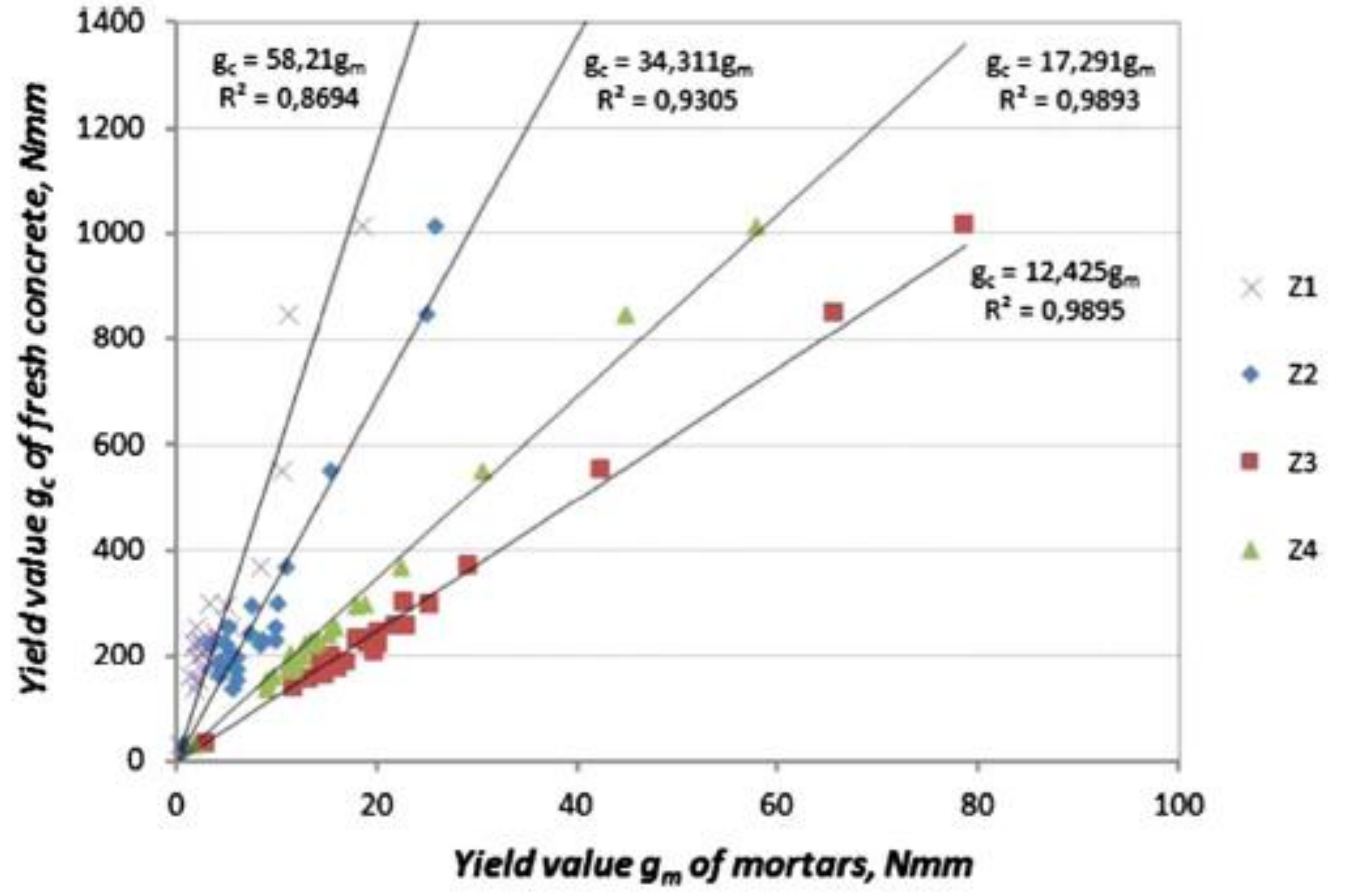
Design and control of fresh LCC workability

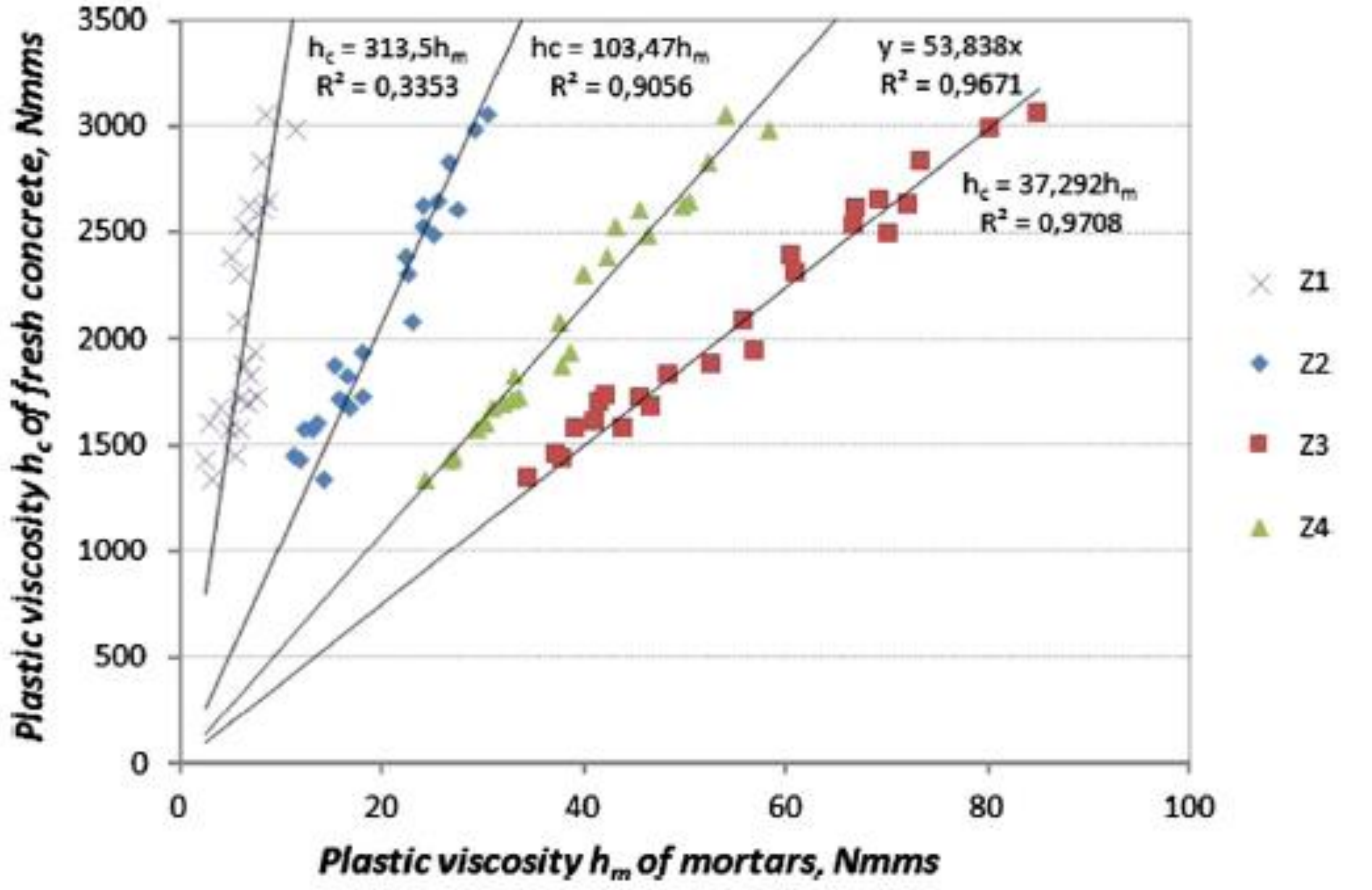




Inadequacy of consistency tests – the need to use rheometer measurements

The use of rheometers for mortars in the design and control of concrete production





Jacek Gołaszewski, Aleksandra Kostrzanowska-Siedlarz, Grzegorz Cygan, Michał Drewniok, Mortar as a model to predict self-compacting concrete rheological properties as a function of time and temperature, Construction and Building Materials, Volume 124, 2016, https://doi.org/10.1016/j.conbuildmat.2016.08.136.

Summary

- Controlling workability is a key element of the LCC strategy.
- The use of low-carbon cements, alternative components and related modifications to the composition make it difficult to control the workability of LCC.
- An individual approach to the selection of components and optimisation of the mix design is necessary, based on a thorough knowledge of their properties and variability, effects and interaction in a way that has not been used in the case of ordinary concrete.

”

...everything flows, nothing lasts...
...you cannot step into the same river twice...

Heraclitus
from Ephesus

”