FACULTY OF ENGINEERING
AND ARCHITECTURE

**DEPARTMENT OF STRUCTURAL ENGINEERING AND BUILDING MATERIALS**
MAGNEL-VANDEPITTE LABORATORY

# MAGNETO-RHEOLOGICAL CONTROL OF CEMENTITIOUS MATERIALS FOR 3D PRINTING

Geert DE SCHUTTER

ACI Spring Convention 2024, New Orleans

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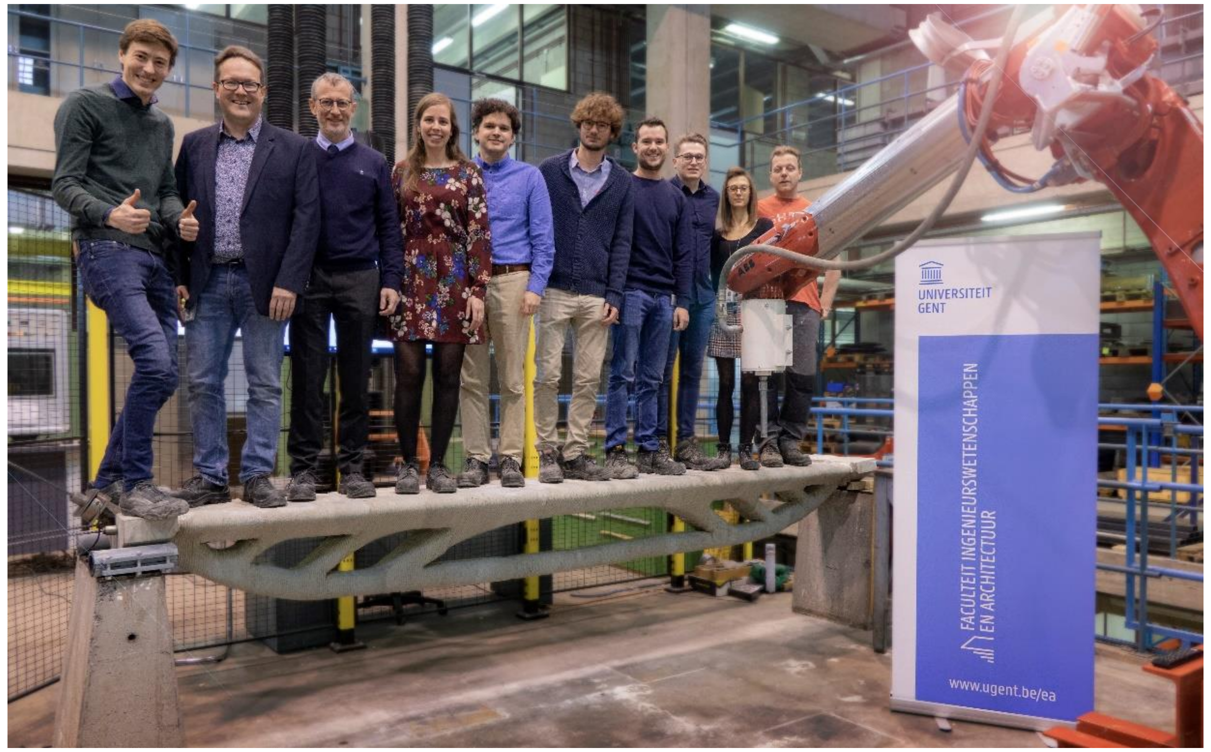
# INTRODUCTION




## Traditional and innovative casting processes

Traditional casting:

Contradictory requirements pumping, formwork leakage, formwork pressure

3D Printing:

Contradictory requirements flowability, extrudability, buildability

One mixture can never be optimal for all processing steps, unless we can actively intervene…

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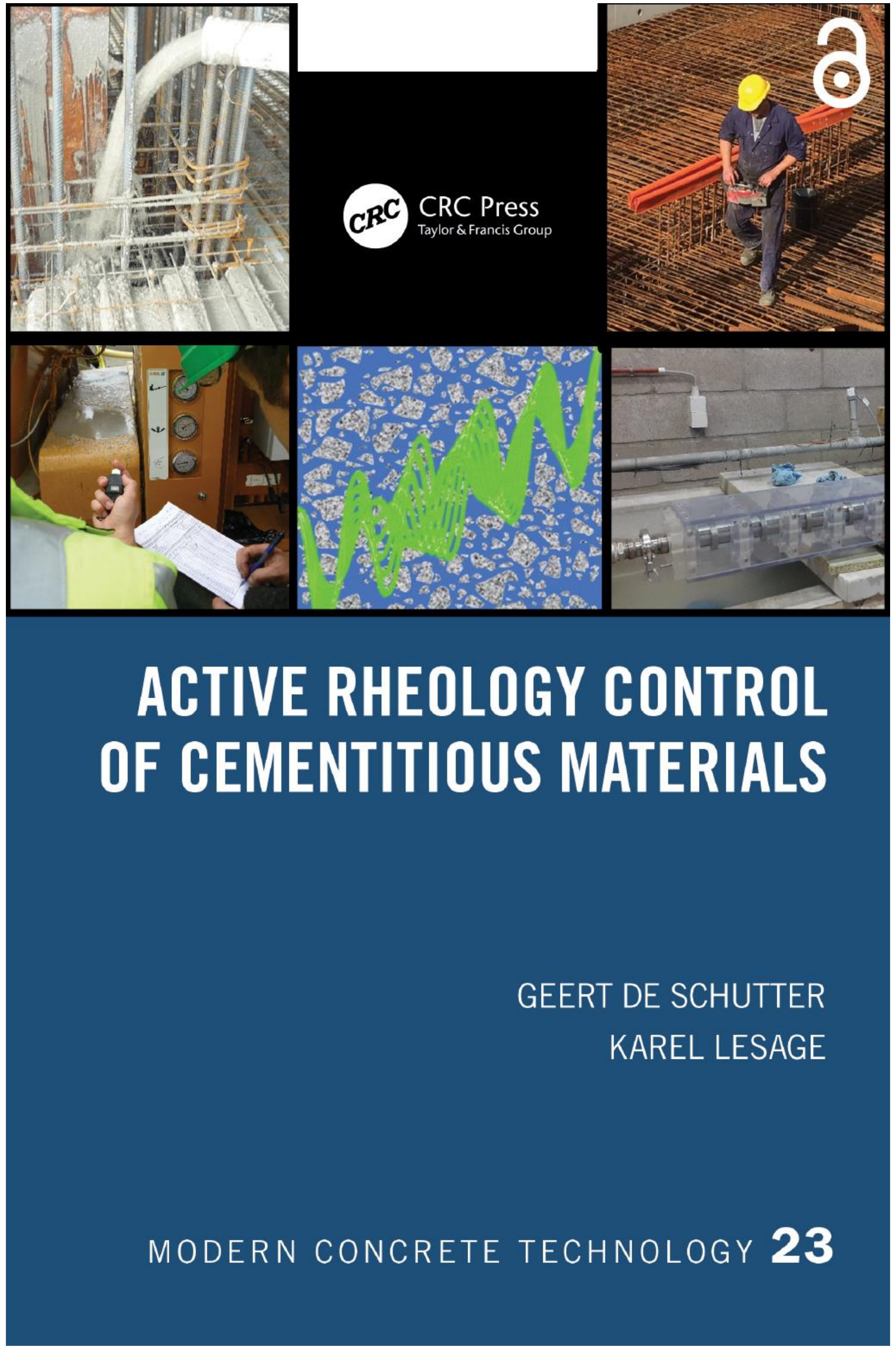
# OPEN ACCESS BOOK

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# Smart casting of concrete structures by active control of rheology (SmartCast)

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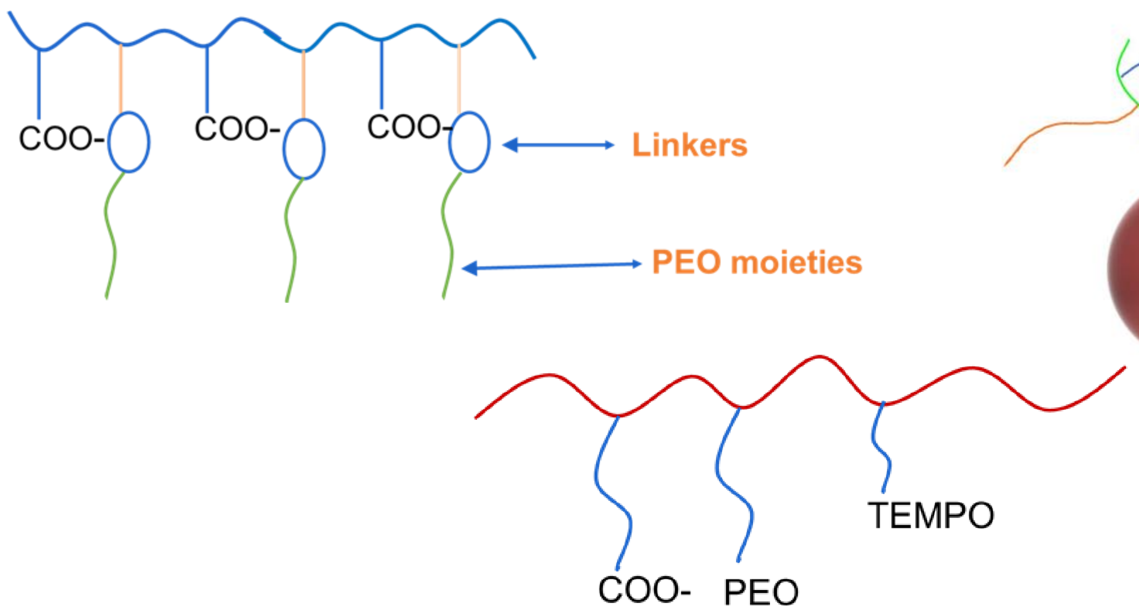
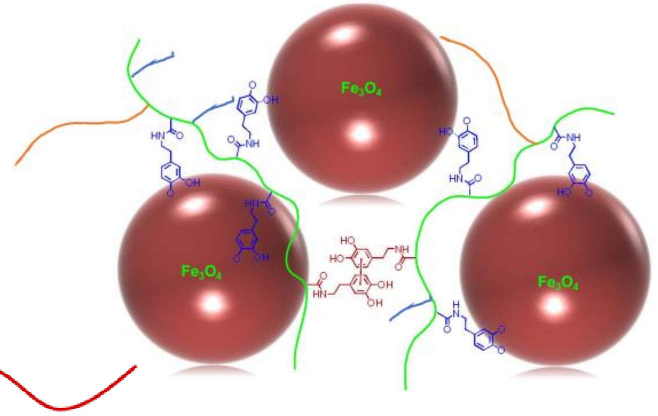
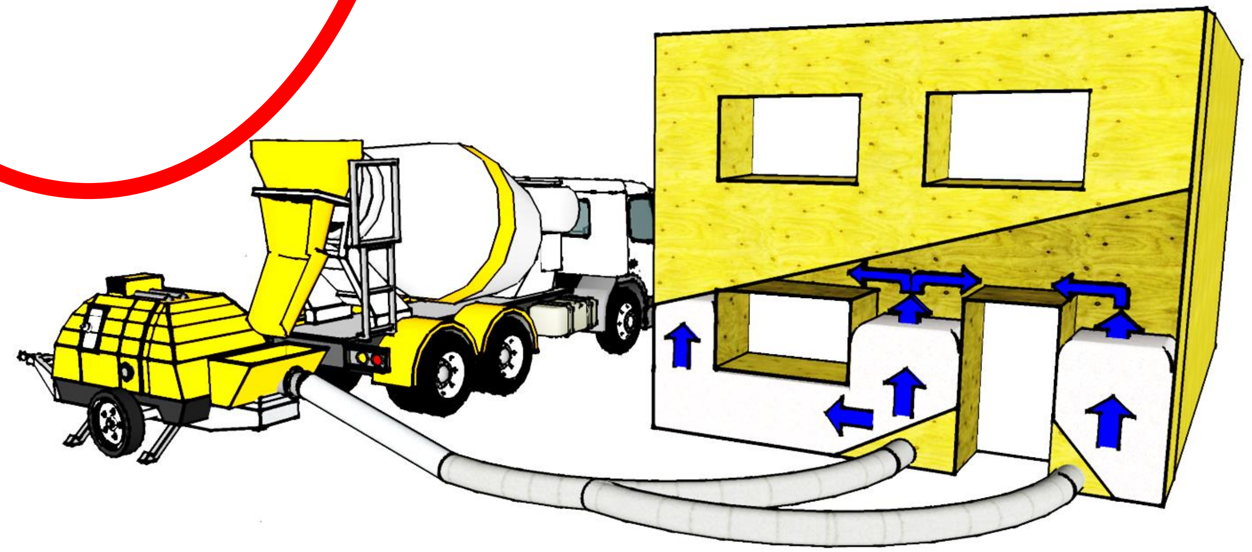
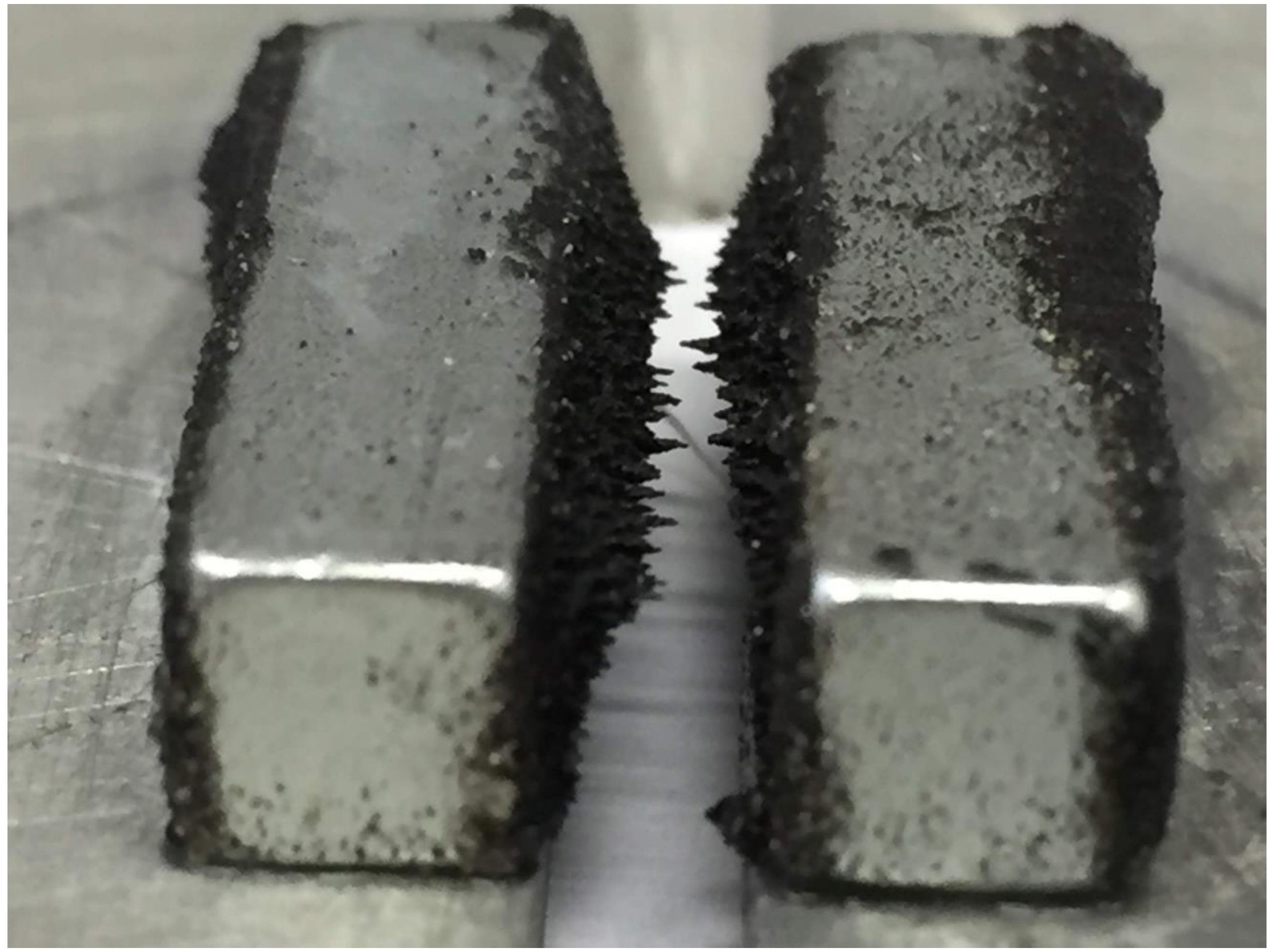
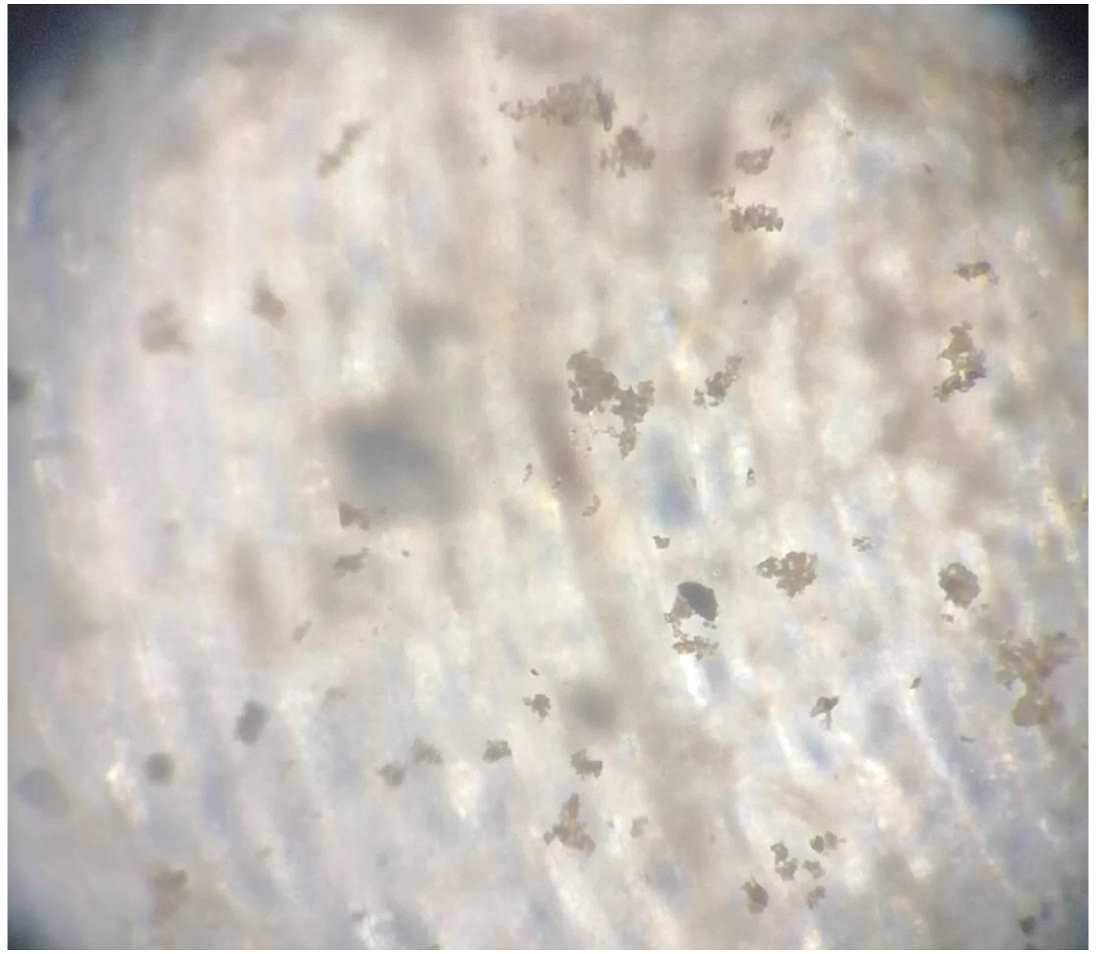
| Route A – Newly developed polymers | | | | Route B – Existing products | | |
|---|---|---|---|---|---|---|
| (A1) Electro-responsive superplasticizer with linker elements to trigger release of side chains | (A2) Redox-responsive superplasticizer with controllable adsorption | (A3) Magneto-responsive superplasticizer with magnetizable elements | XXX… | (B1) Magnetic nano-particles and other magnetizable materials | (B2) (Responsive) Polymers / Hydrogels from other fields | (B3) Available admixtures and additions for cementitious materials |





# TWO CONTROL MECHANISMS

| ASC | ARC |
| --- | --- |
| by “clustering” or “bridging” | by “internal vibration” |
|  |  |
| Static Magnetic Field | Alternating Magnetic Field |

Effects can be studied with SAOS, Flow Curves, Pumping…

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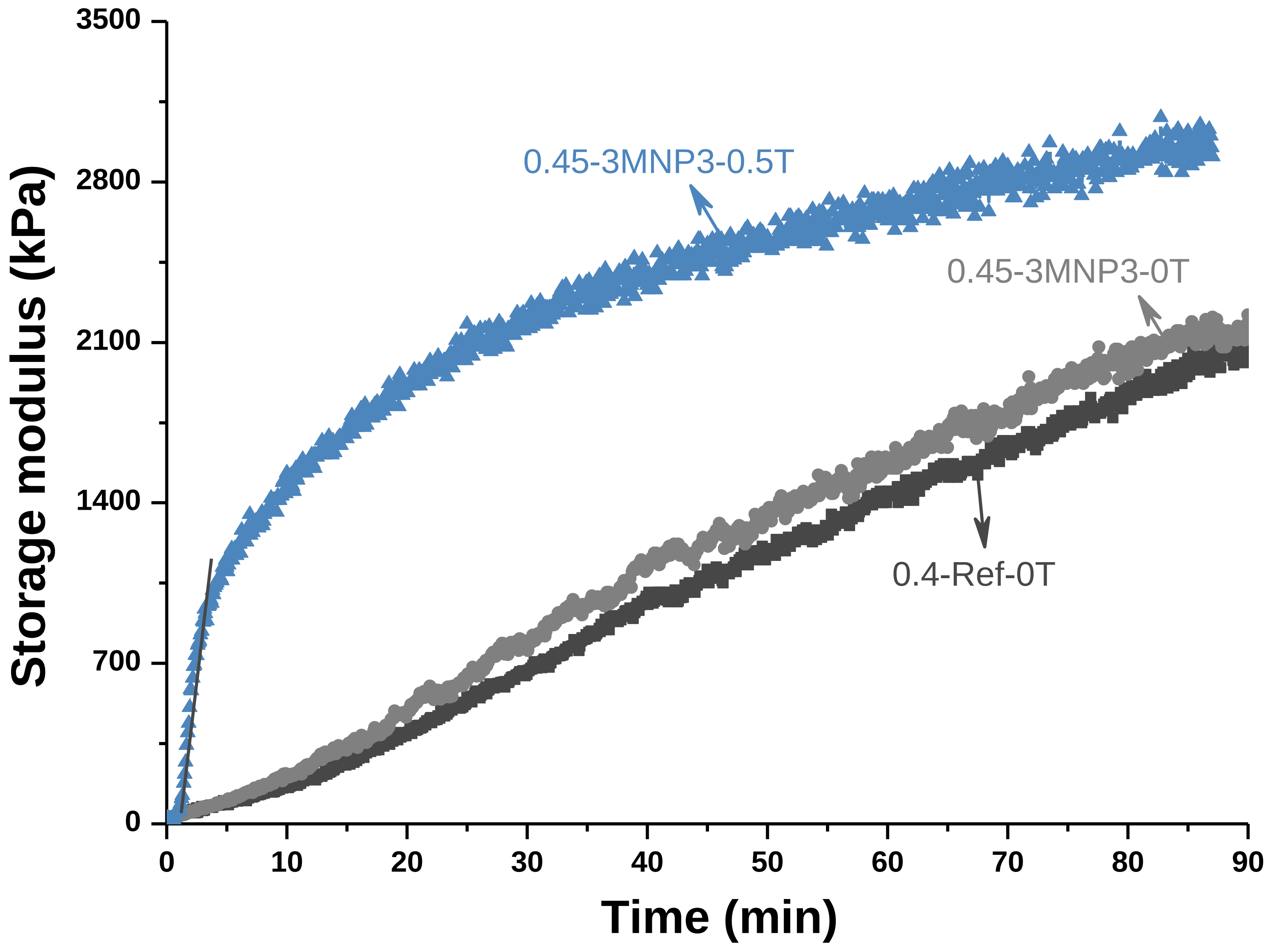
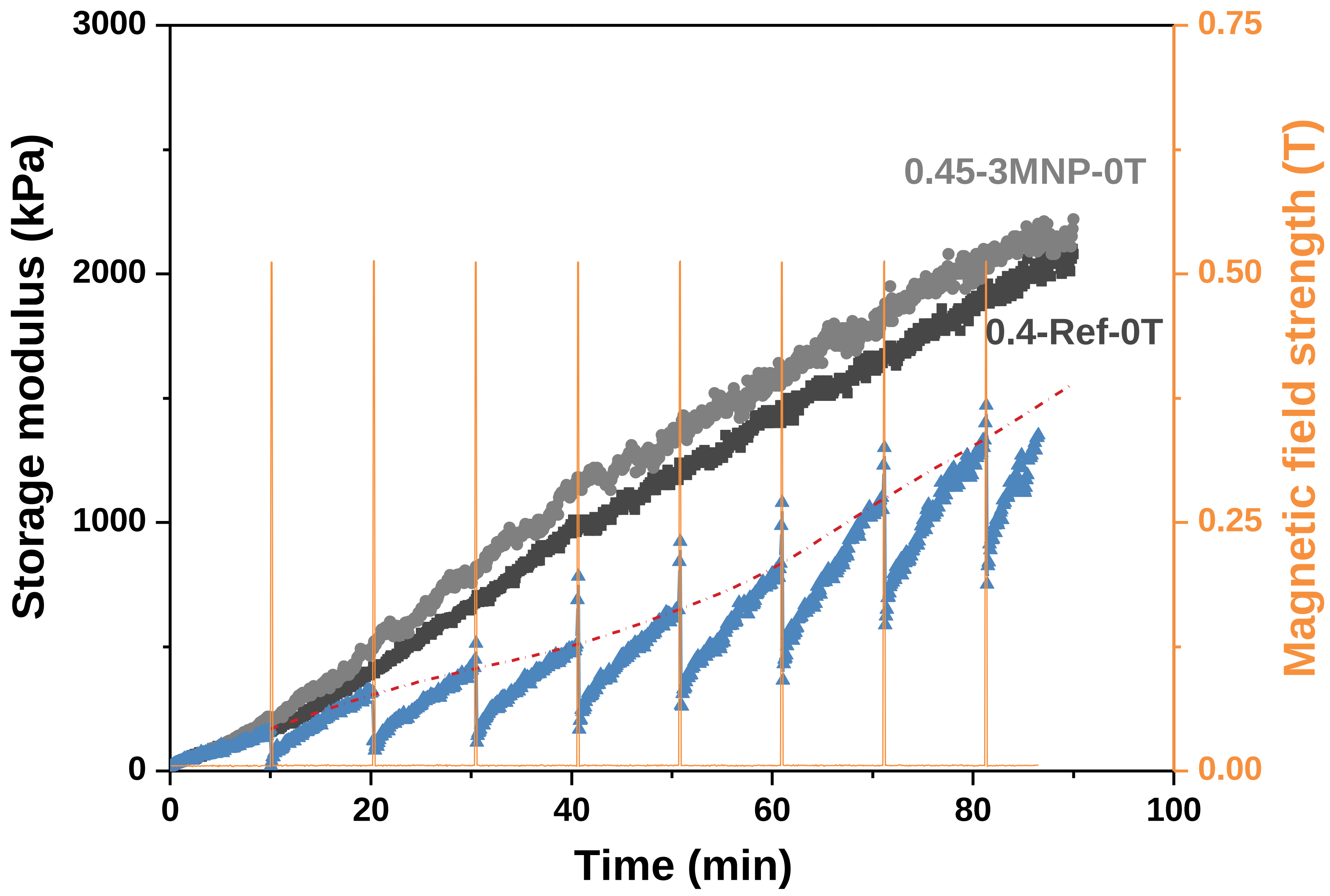
# POSSIBILITIES OF ACTIVE RHEOLOGY CONTROL

## Structural Evolution




**Constant magnetic field**




**Pulsed magnetic field**

**w/c: 0.45; MNPs: 200 nm**

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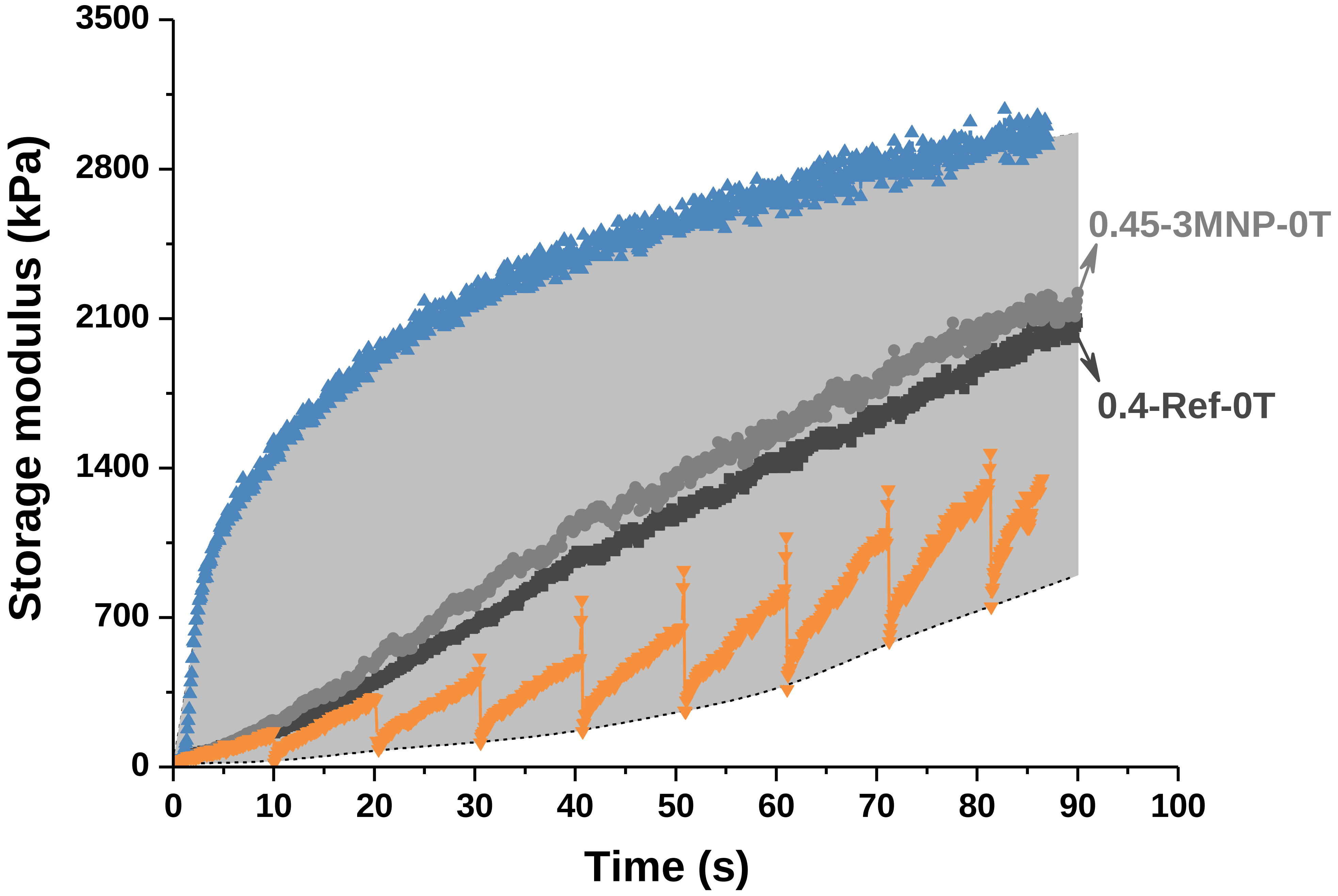
# POSSIBILITIES OF ACTIVE RHEOLOGY CONTROL

## Adjustment Range of Storage Modulus By A Magnetic Field




w/c: 0.45; MNPs: 200 nm

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# 3D CONCRETE PRINTING

(First 3DCP house in Belgium)

(optimized 3DCP bridge at UGent)

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# 3D CONCRETE PRINTING

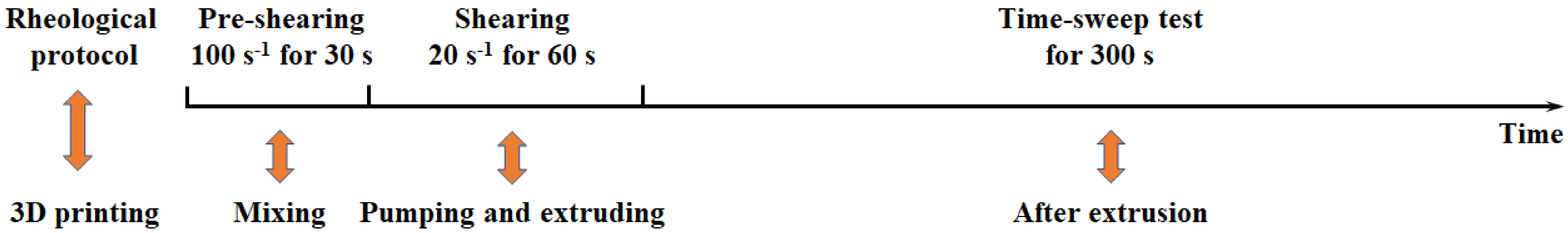
## 3DCP Research at UGent

- Rheological behaviour of 3DP materials
- Active control mechanisms
- Twin-Pipe Pumping + static mixer
- Mix design
- Structural behaviour
- Durability behaviour
- Topological optimization
- Quality control
- …


(Youtube: Concre3DLab Ghent)

# APPLICATION OF ARC/ASC TO 3DP

## Experimental simulation with rheometer tests




*Rheological testing protocol simulating extrusion-based 3D concrete printing*

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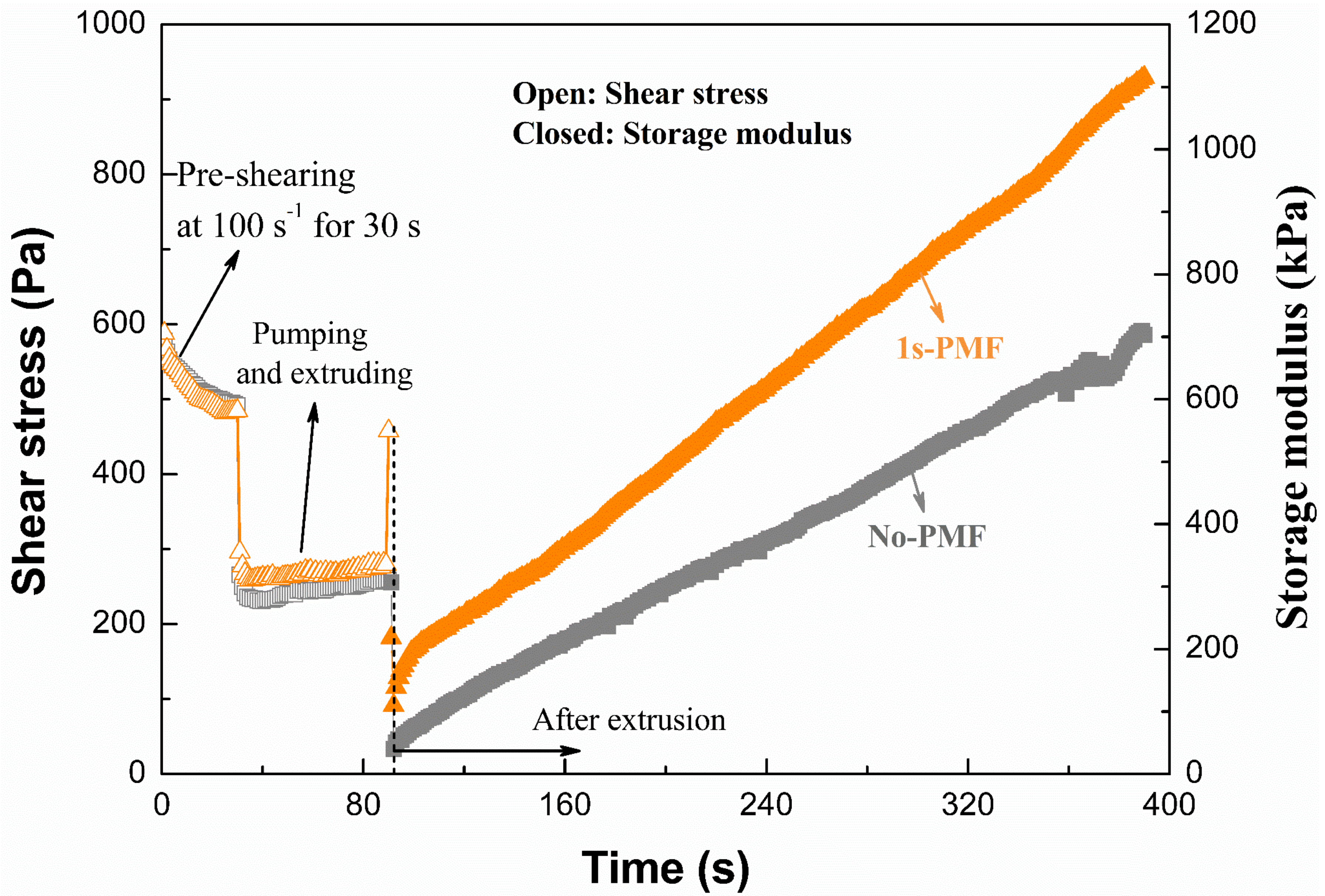
# APPLICATION OF ARC/ASC TO 3DP

## Experimental simulation with rheometer tests




*Typical evolution of shear stress and storage modulus of cementitious paste (w/c=0.35, MNPs (100 nm) = 3%) (PMF = Pulsed Magnetic Field)*

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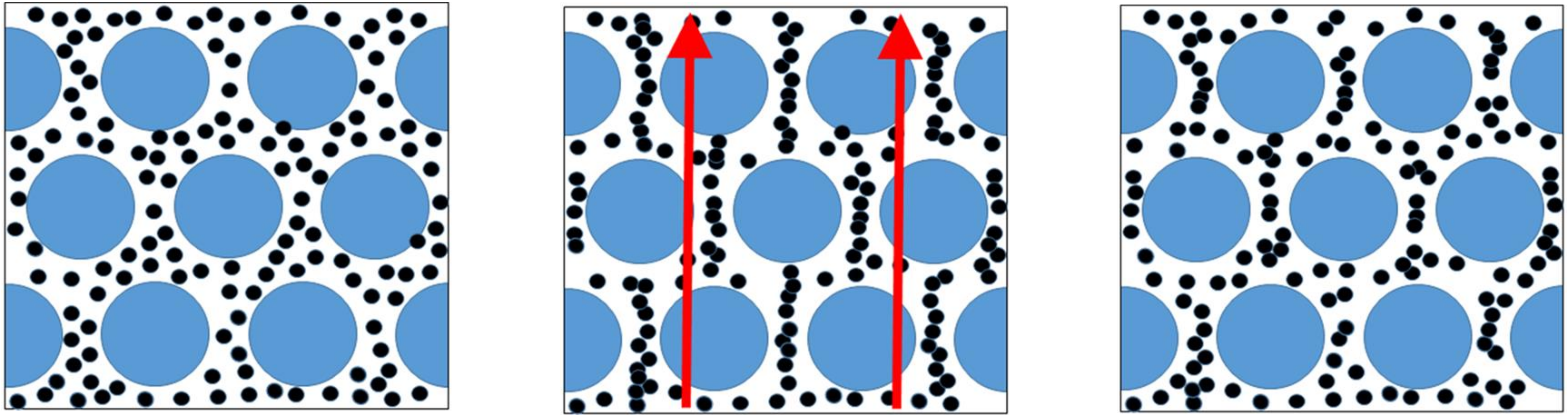
# APPLICATION OF ARC/ASC TO 3DP

## Experimental simulation with rheometer tests



*Schematic diagram illustrating nanoparticles distribution (a) before, (b) during application and (c) after removal of the pulsed magnetic field. Blue circles represent the cement particles, and dark dots indicate the nano-$Fe_3O_4$ particles*

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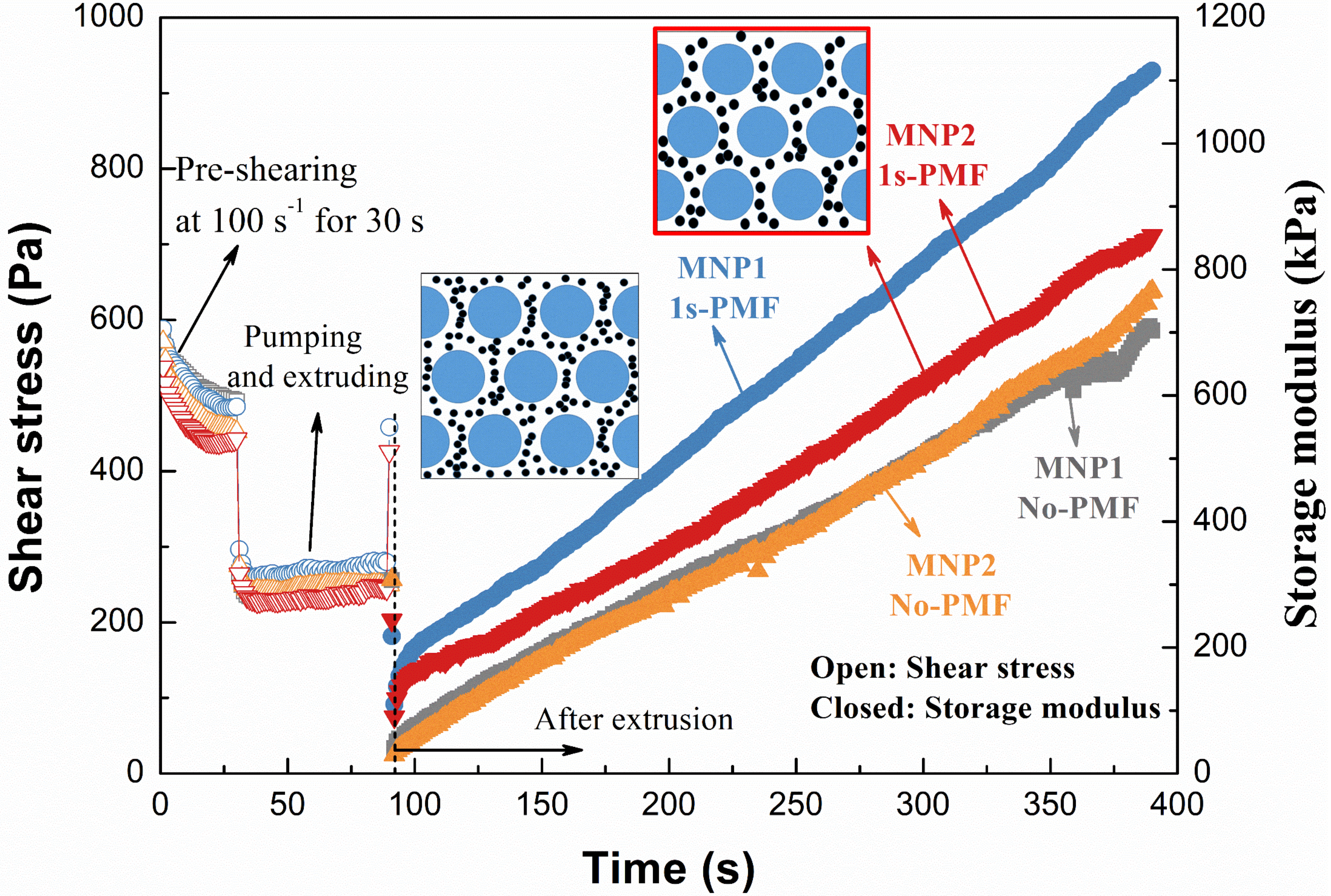
# APPLICATION OF ARC/ASC TO 3DP

## Experimental simulation with rheometer tests




*Effect of nano-$Fe_3O_4$ type on the magneto-induced structural build-up of cementitious paste (w/c=0.45, 3% nano-$Fe_3O_4$, MNP1 and MNP2 have particle size and remanent magnetization of 100 nm and 14.82 $Am^2/kg$, and 200 nm and 10.23 $Am^2/kg$ respectively)*

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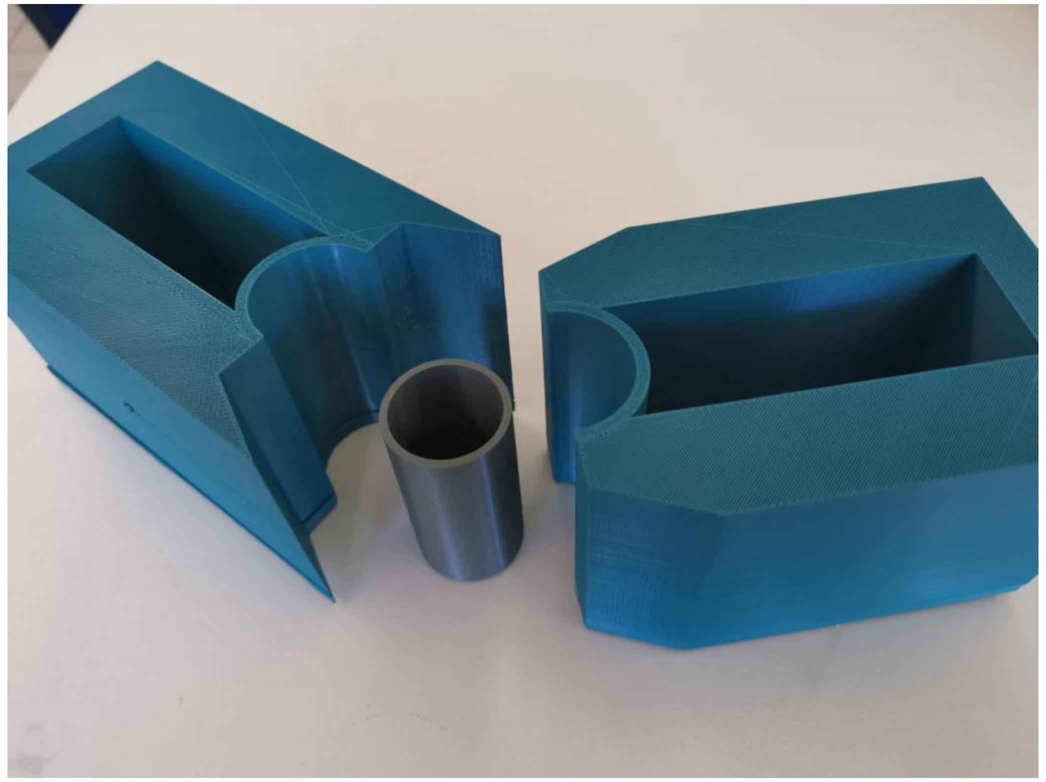
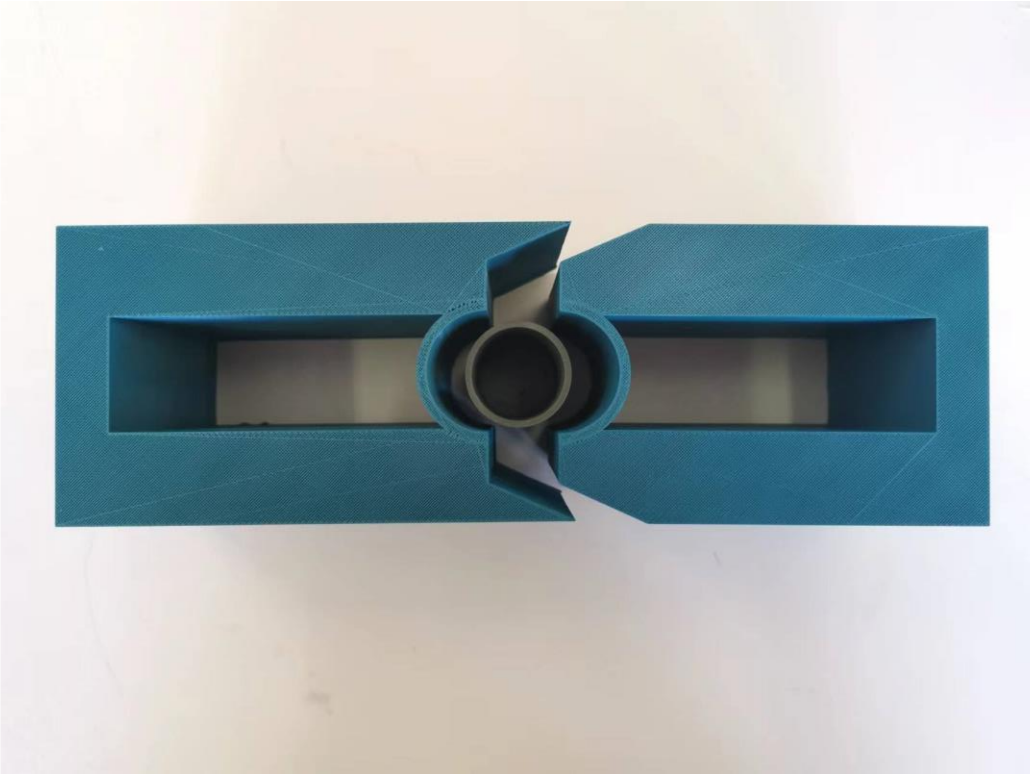
# RHEOMETER-BASED IMPROVED RHEOLOGICAL TEST SET-UP





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# RHEOMETER-BASED IMPROVED RHEOLOGICAL TEST SET-UP

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# RHEOMETER-BASED IMPROVED RHEOLOGICAL TEST SET-UP

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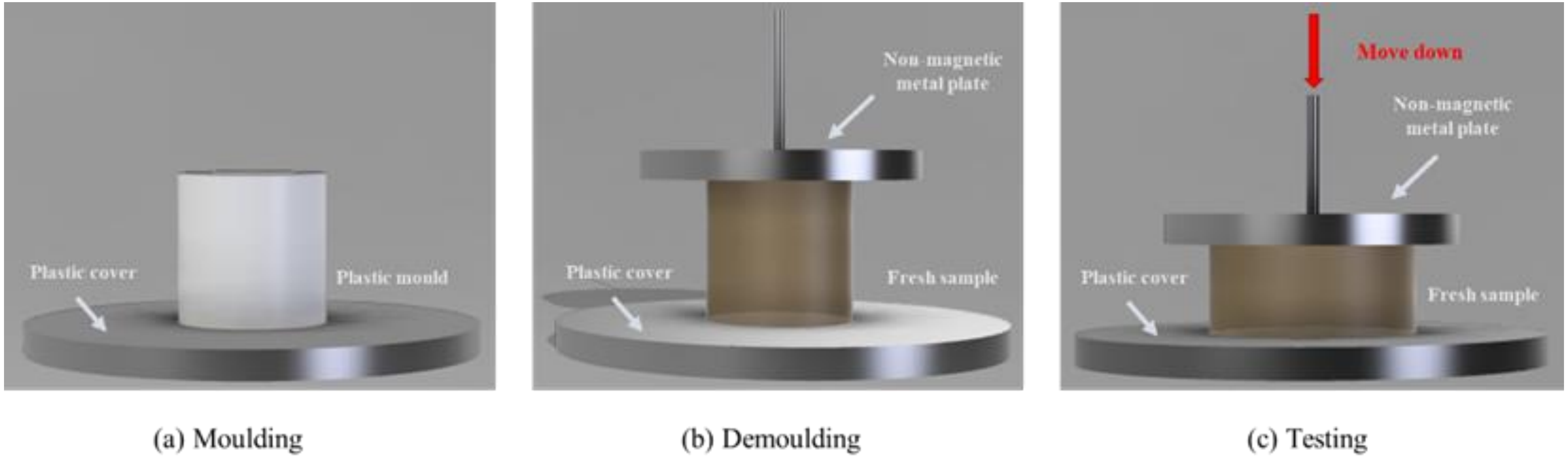
# SQUEEZE FLOW TESTS




*Schematic presentation of testing protocol of squeeze flow tests.*
*(a) casting with the plastic mould; (b) demoulding sample and installing the rotor;*
*(c) squeezing sample with a constant normal force.*

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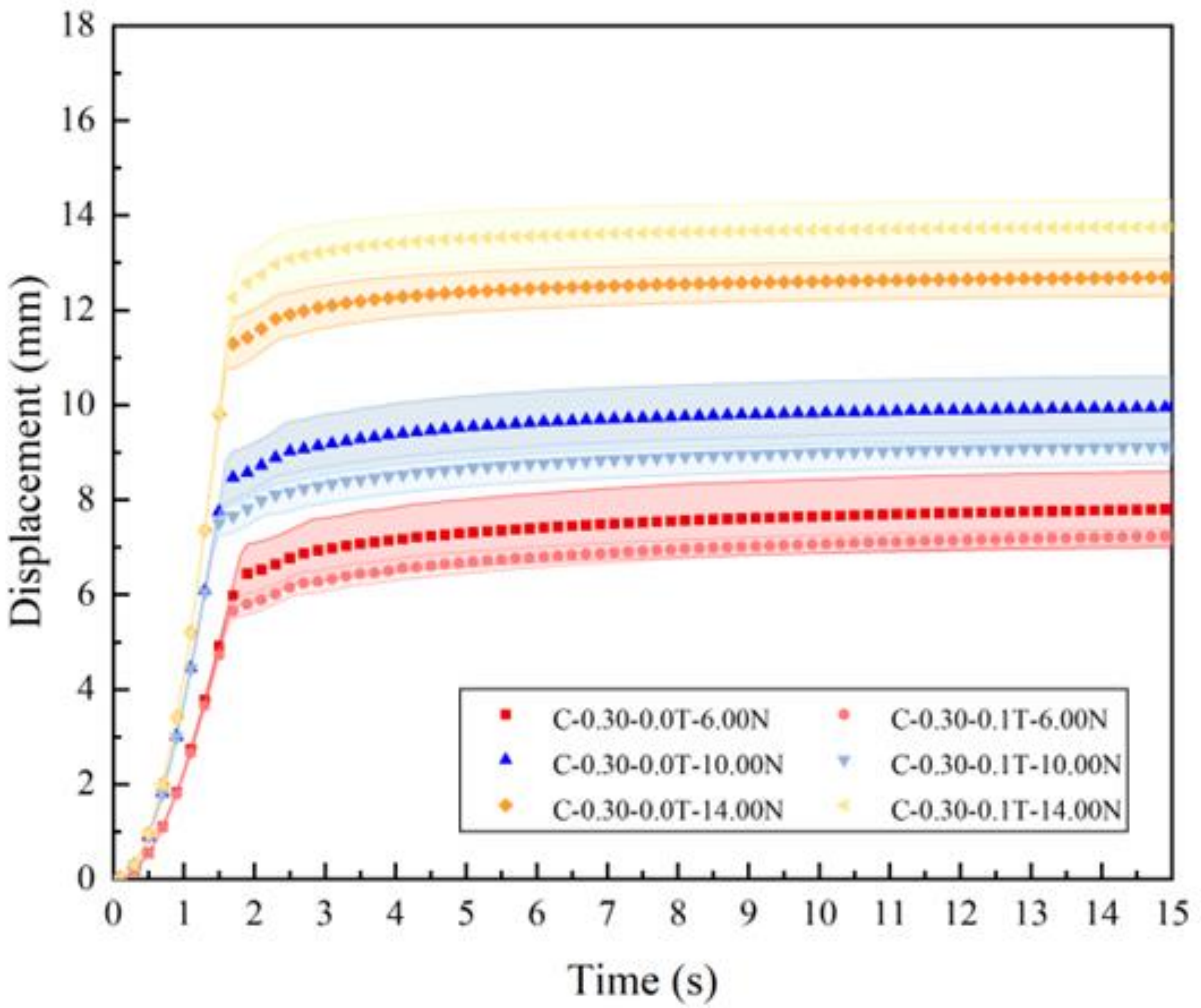
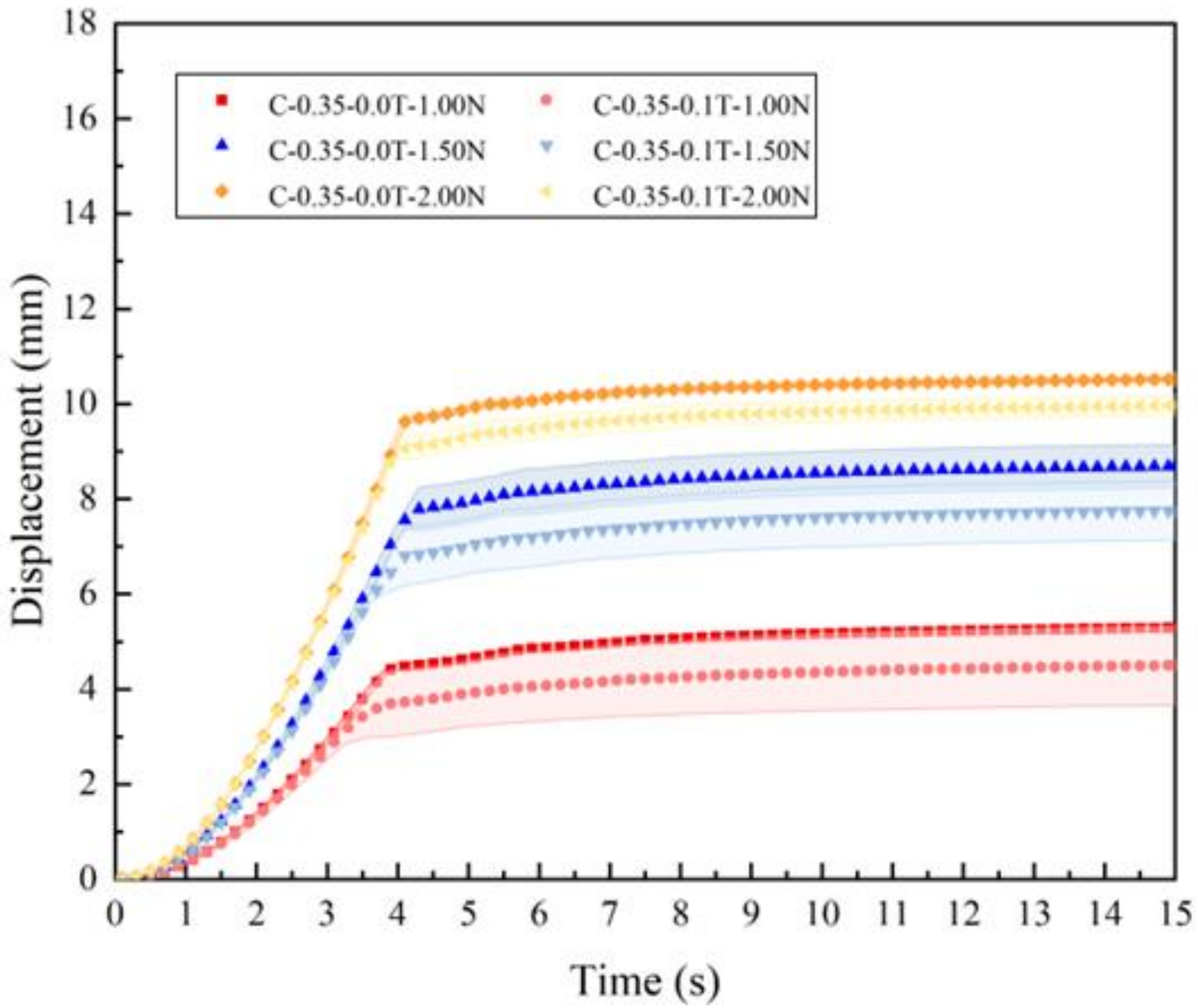
# SQUEEZE FLOW TESTS




*Displacement versus time of magneto-responsive cement pastes (left: w/c = 0.30 / right: w/c = 0,35), with and without previous magnetization (0.1 T, 120 s). The $Fe_3O_4$ particle content was fixed at 3% by weight of binder and water.*

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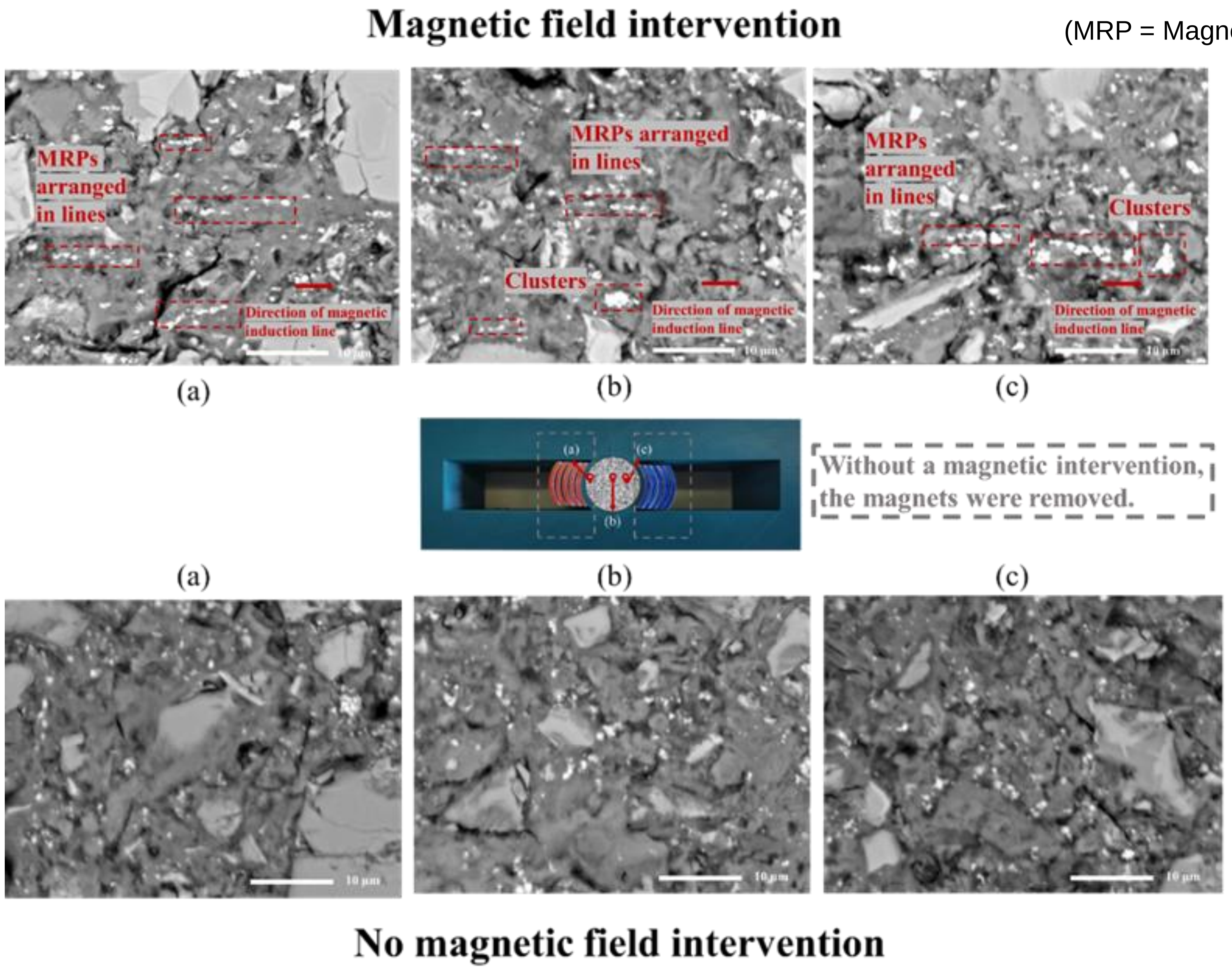
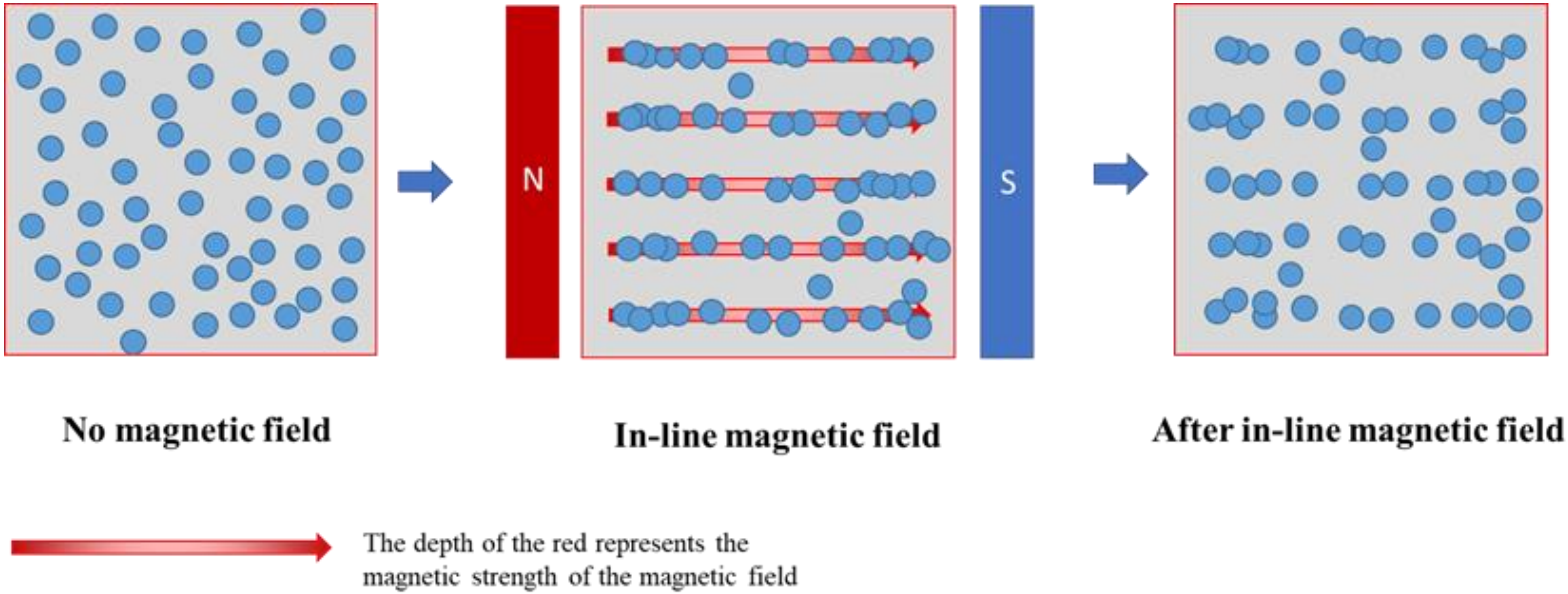
# MICRO-ANALYSIS

*Morphology of C-0.35 at different testing points determined by SEM*

(MRP = Magneto-Responsive Particles)



# MICRO-ANALYSIS




*Schematic diagram illustrating the distribution of magneto-responsive particles in the limestone and cement pastes before, during and after the intervention*

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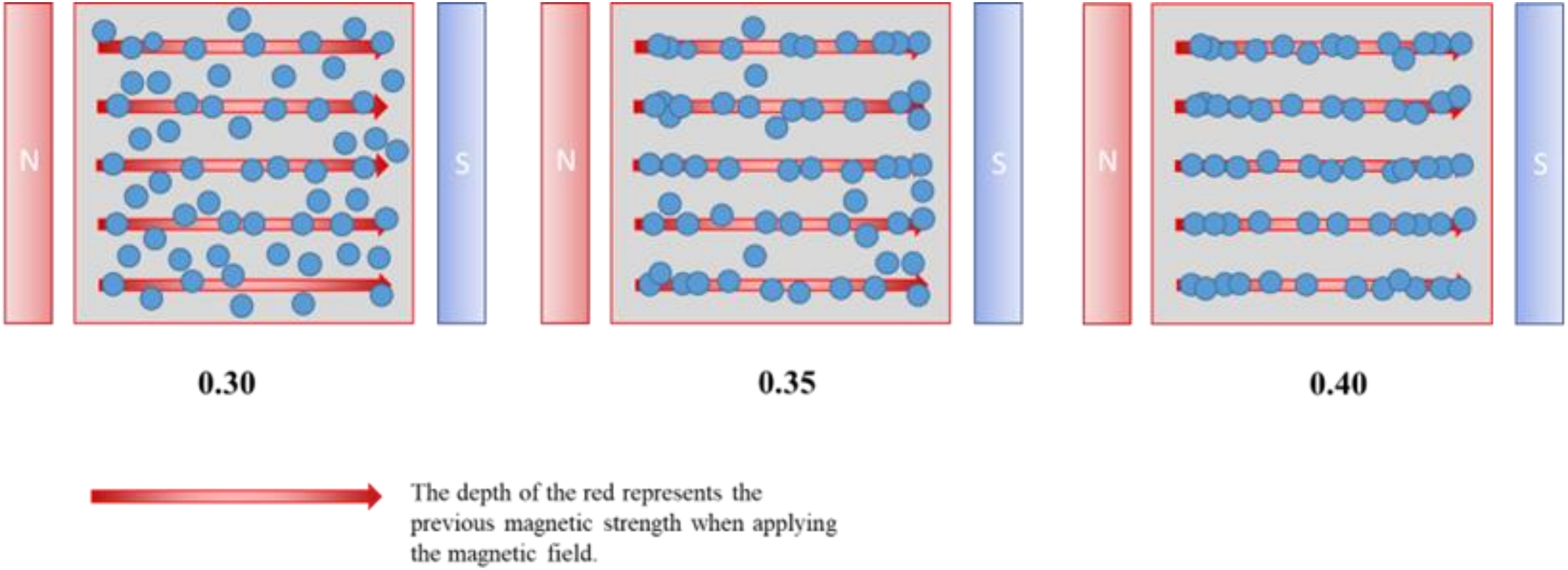
# MICRO-ANALYSIS




*Schematic diagram illustrating the effect of W/P ratio on the distribution of magneto-responsive particles in the cement pastes*

# CONCLUSIONS

A preliminary investigation was performed regarding the application of inline magnetic field in case of 3D Concrete Printing, using a newly custom-developed setup.

With the intervention of an inline magnetic field, the magneto-responsive particles were able to move in the magneto-responsive pastes, even if the magnetic field strength was only 0.1 T.

With an optimized water to powder ratio, the magneto-responsive particles were able to form clusters and alignments. These structures remained as remnant structures after removing the magnetic field, which altered the displacement under the normal force (squeeze flow).

# CONCLUSIONS

The water to powder ratio had a significant influence on the magneto rheology response of cementitious paste after inline magnetic intervention. The high water to powder ratio benefited the migration of magneto-responsive particles when applying the magnetic field, but also accelerated the collapse of magnetic clusters after inline magnetic intervention due to the limited hindrance, which led to a quick loss in the strength increment. A low water to powder ratio caused difficulties in the structure formation of magneto-responsive particles.

Further research actions are ongoing to optimize and upscale the magnetic stiffening control in case of 3D concrete printing.

# THANK YOU

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