

2024 BCerS

SUITABILITY TESTS FOR 3D PRINTING WITH CEMENTIOUS MORTARS



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Faculty of Applied Sciences

R.U. Urban and Environmental Engineering

- **200** professors, researchers, technicians
- **11** laboratories
- **230** students (bachelors & masters)
- **87 PhD** students
- **17×10⁶ euros** cash flow
- **93** on-going research projects

“Building materials : rheological behaviour of 3D printed mortar”

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01 INTRODUCTION

3D PRINTING TECHNOLOGY

- Largely developed in recent years
- Several industry sectors concerned

Space Industry



eos.info/en-us/industries/space

Medical



Dental crown
Collaboration CRIBC - CERAMATH

Construction



Street furniture Construction 3D

3D PRINTING in CONSTRUCTION



Street furniture Construction 3D

Economical

Reduce cost because of faster process

Environmental

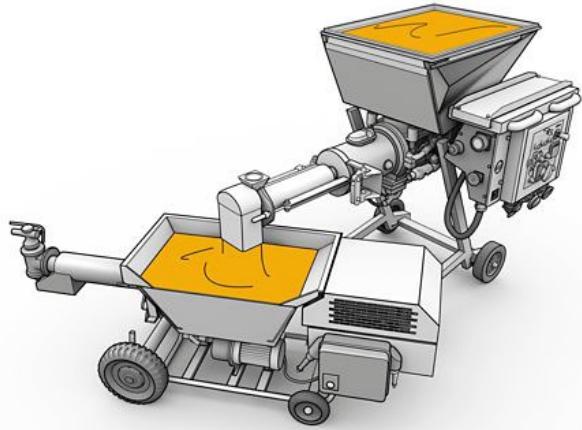
Accurate and controlled consumption of raw material, reducing waste

Social

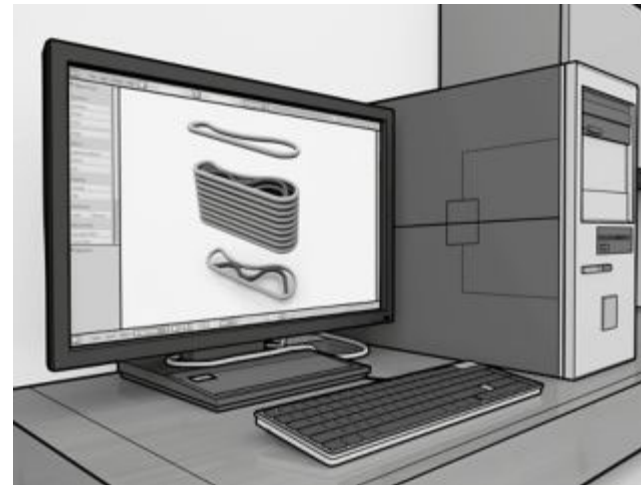
Less risky for workers on sites (work on high, demolition the formwork,...)

3D PRINTING in CONSTRUCTION

Equipment

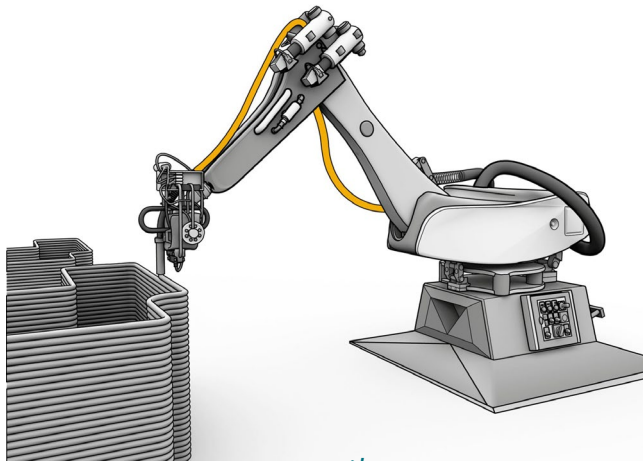


Software



www.sika.com

Material



www.sika.com

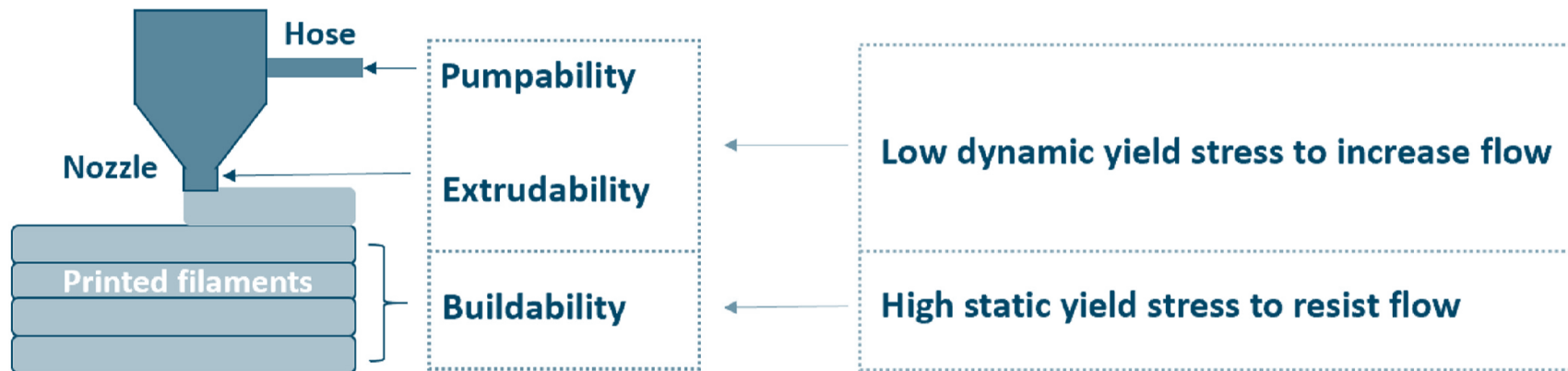
3D PRINTING in CONSTRUCTION

Material requirements

Pumpability: to be transported in the pipe under a pressure

Extrudability: can be continuously extruded through a nozzle (a continuous filament)

Buildability: printed up to a certain height (or layers) without deformations/collapse



3D printing concrete

(Zhang et al., 2021)

3D PRINTING in CONSTRUCTION

Tests for 3D printing construction material

Pumpability

Flow table test



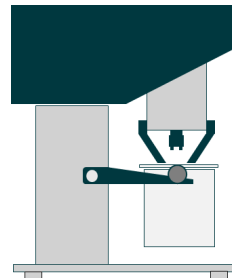
V funnel test



Fall cone test



Rheometer
(modeling, formulation)

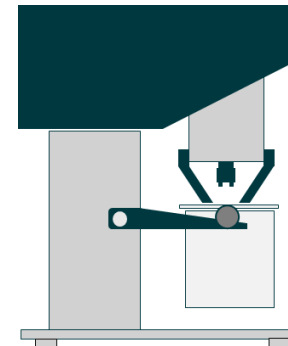


Buildability & Extrudability

Pistol test



Rheometer
(modeling, formulation)





02 RHEOLOGICAL CHARACTERISTICS

MATERIALS OF THE RESEARCH

Sikacrete®-751 3D



Commercial product of Sika company
Specialized for 3D printing construction

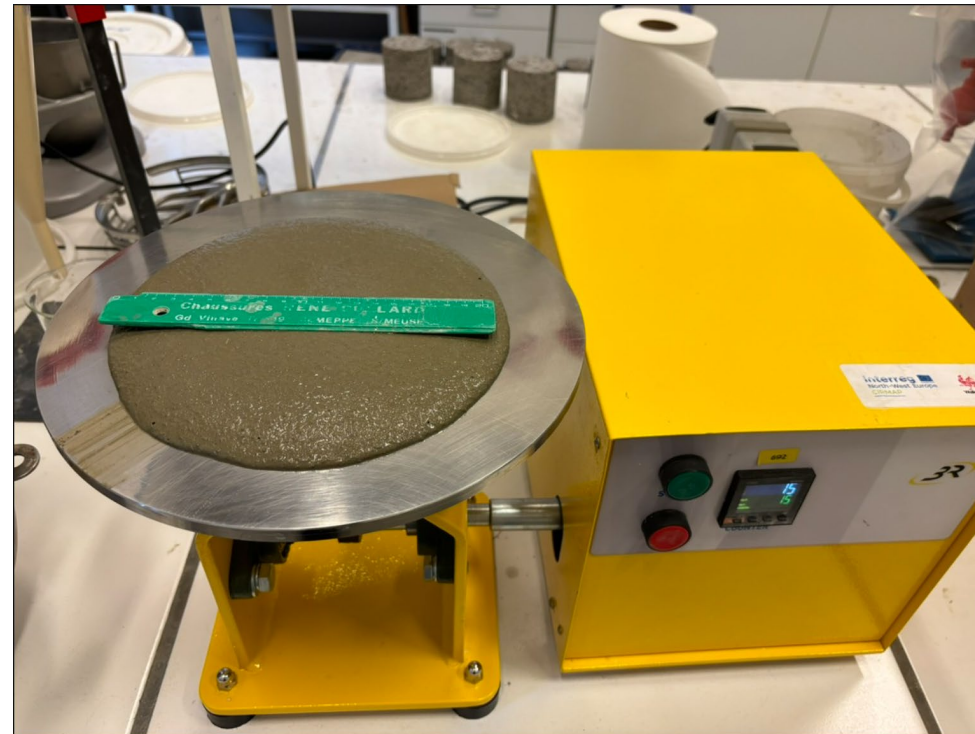
- **Setting Time** : 45 to 60 minutes
- **Compressive Strength** : 50MPa at 28 days
- **Tensile Strength in Flexure** : 10MPa at 28 days
- **Density** : 2140 kg/m³
- **Water content** : 18% of weight

FLOW TABLE TEST

Pumpability: to be transported in the pipe under a pressure

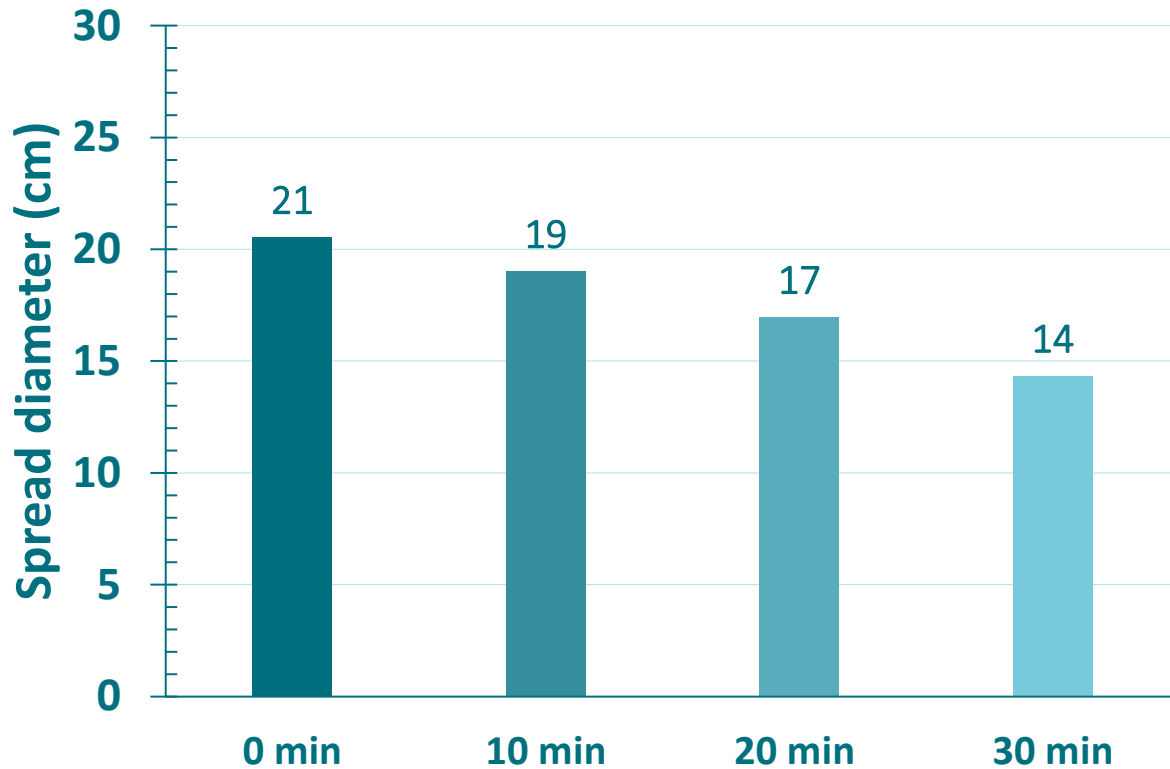
- Standard: EN 13395-1: 2002
- Measure the diameter of the sample (cm)
- Repeat the test 4 times (0, 10, 20, 30 minutes)

Flow table test



FLOW TABLE TEST

Pumpability: to be transported in the pipe under a pressure



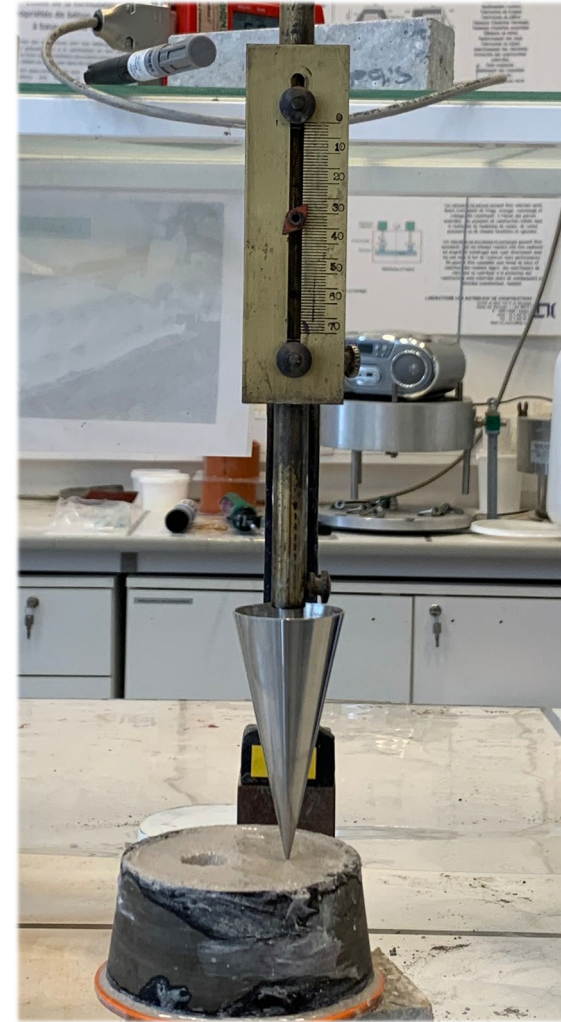
Conclusion

- Accurate for showing modification of properties of 3D printed mortar with time

FALL CONE TEST

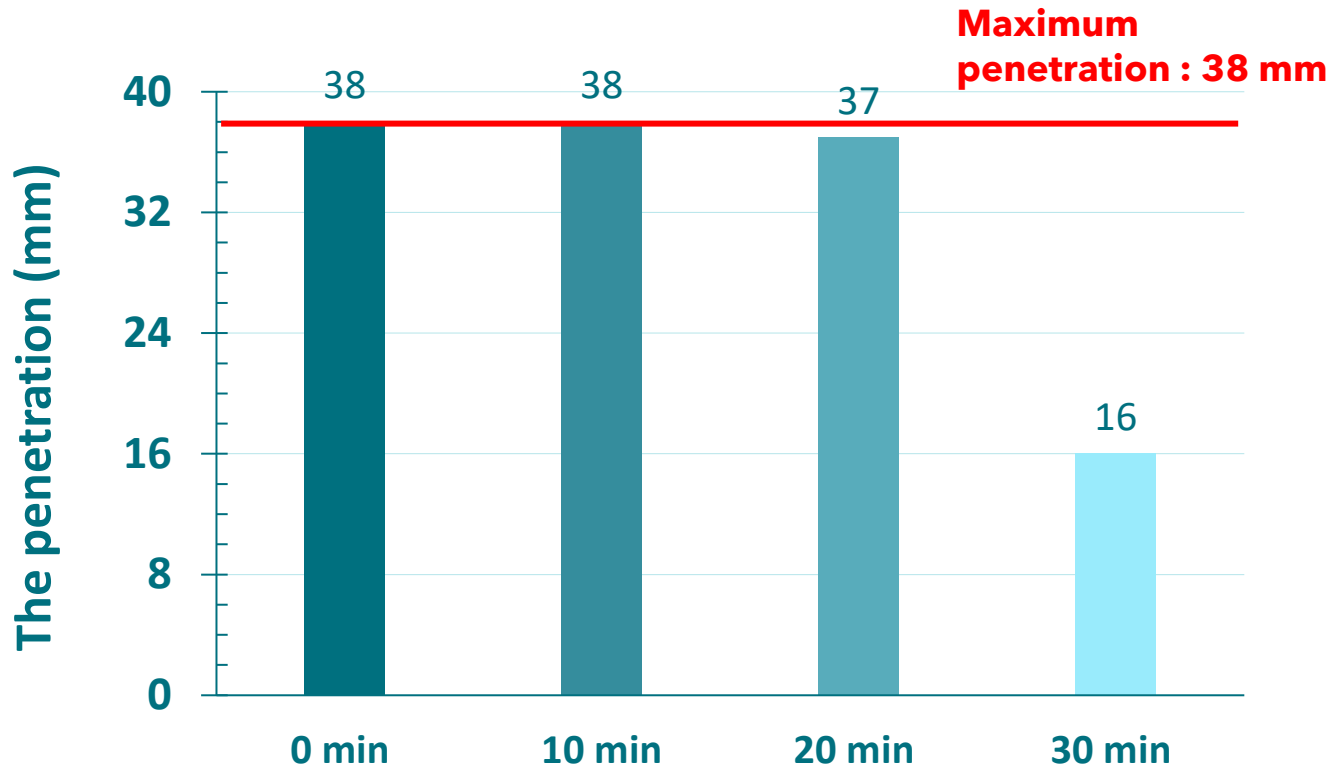
Pumpability: to be transported in the pipe under a pressure

- Standard: BS 1377-2:1990
- Measurement: cone penetration (mm)
- Repeat the test 4 times
(0, 10, 20, 30 minutes)



FALL CONE TEST

Pumpability: to be transported in the pipe under a pressure



Conclusion

- Fall cone test shows some changes with time but not obviously.

V- FUNNEL TEST

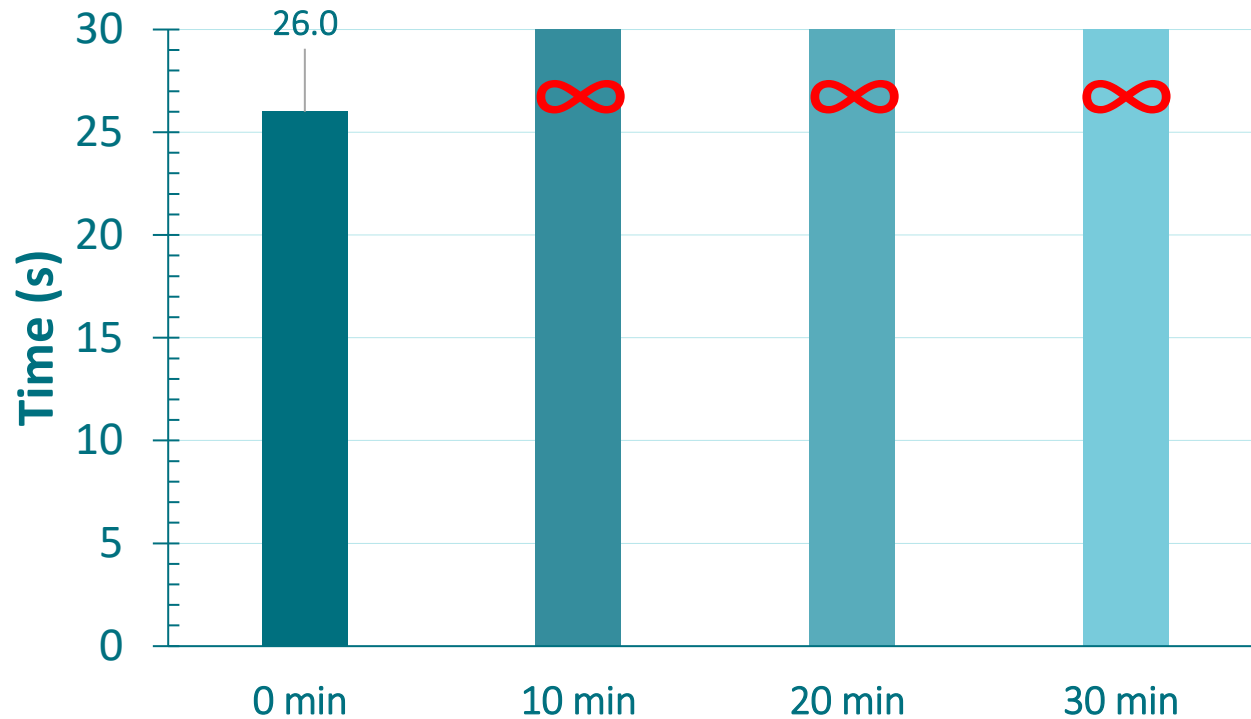
Pumpability: to be transported in the pipe under a pressure

- Standard: EN 12350-9:2010
- Measure flow time (s)
- Repeat the test 4 times (0, 10, 20, 30 minutes)



V- FUNNEL TEST

Pumpability: to be transported in the pipe under a pressure



Conclusion

- No adapted for 3D printed mortar.

PISTOL TEST

Extrudability: can be extruded through a nozzle continuously (a continuous filament)

Buildability: printed up to a certain height (or layers) without deformations

- Standard: None
- Purpose:

Extrudability (smooth surface, continuous filament),

Buildability (5 layers)

- Repeat the test 4 times
(5, 10, 20, 30 minutes)



PISTOL TEST



5 min



10 min



20 min



30 min

- **5 minutes:** bad buildability, extrudability
- **10 minutes:** bad buildability, extrudability
- **20 minutes:** good buildability, extrudability
- **30 minutes:** good buildability, extrudability

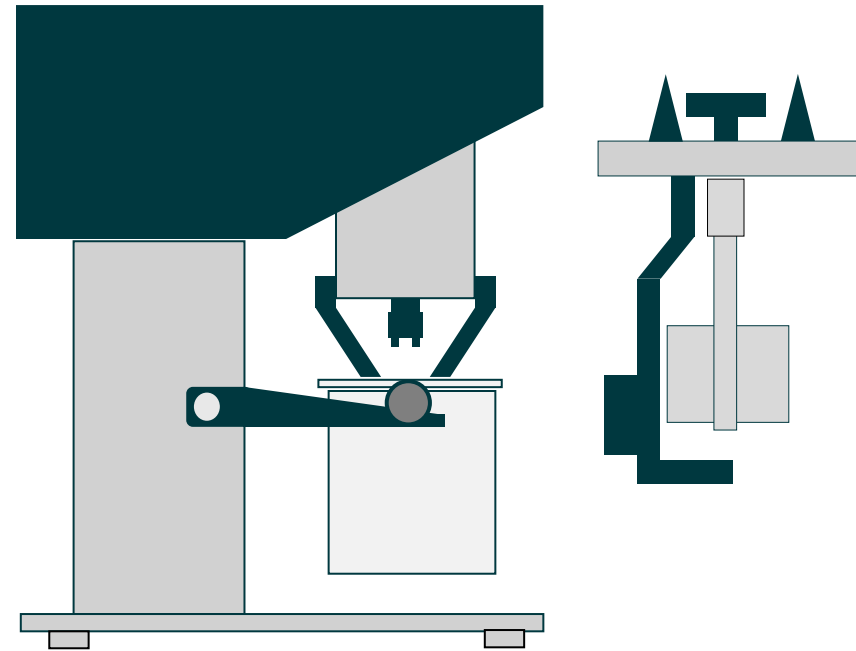
Conclusion:

- This test is very good for buildability and extrudability evaluation



RHEOMETER – RheoCAD

- Standard: None
- Purpose: viscosity, yield stress
- Repeat the test 4 times
(5, 10, 20, 30 minutes)



Results of RheoCAD

(Torque - T
Rotation speed - N):
 $T = G + H \times N$.



Reiner-Rivlin equation :
(Feys et al., 2013)

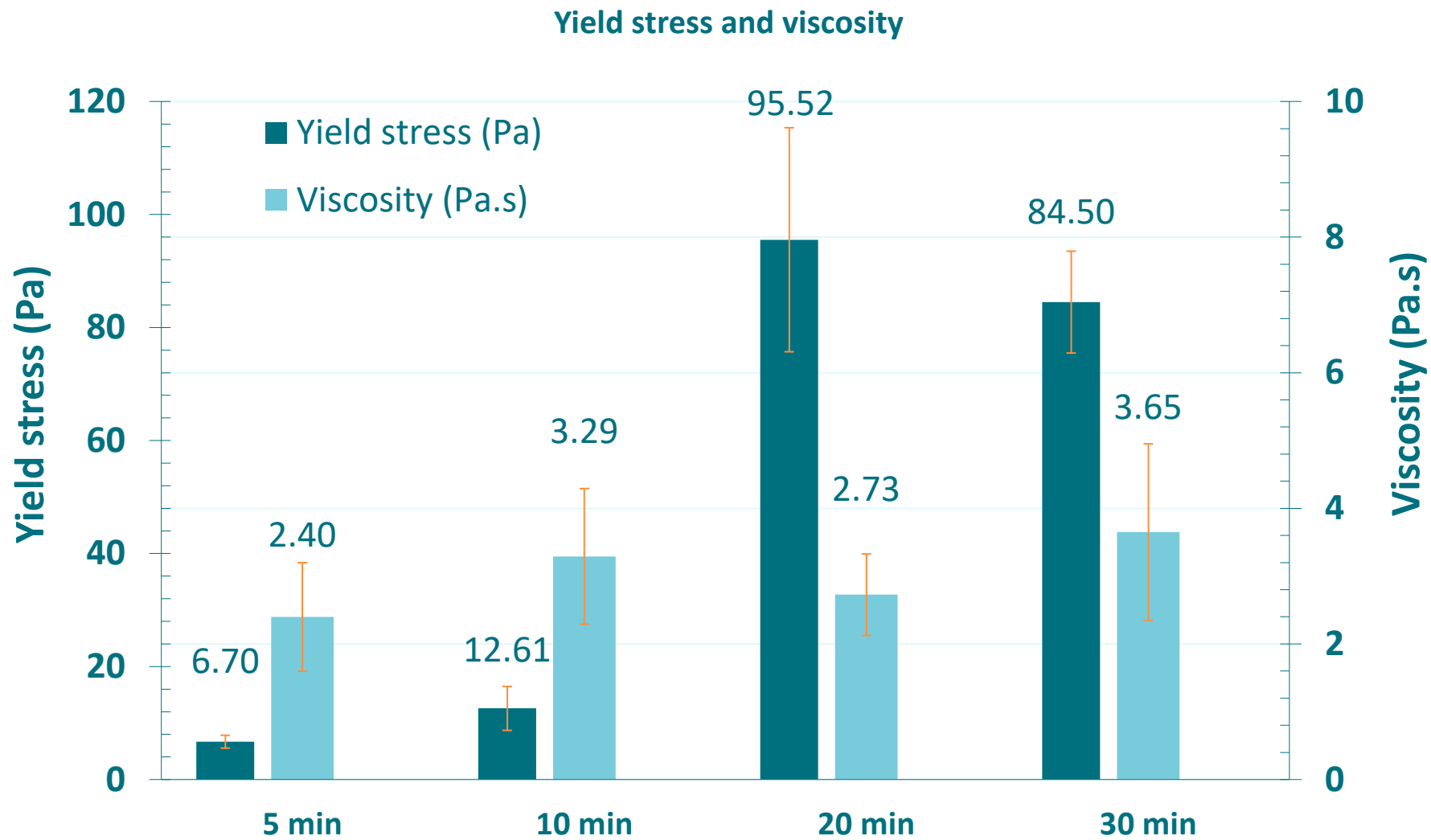
$$\tau_0 = \frac{\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)}{4\pi h \ln\left(\frac{R_o}{R_i}\right)} G \text{ et } \mu = \frac{\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)}{8\pi^2 h} H$$



Bingham:

$\tau = \tau_0 + \mu \dot{\gamma}$
 τ_0 - Yield stress (Pa)
 μ - Viscosity (Pa.s)

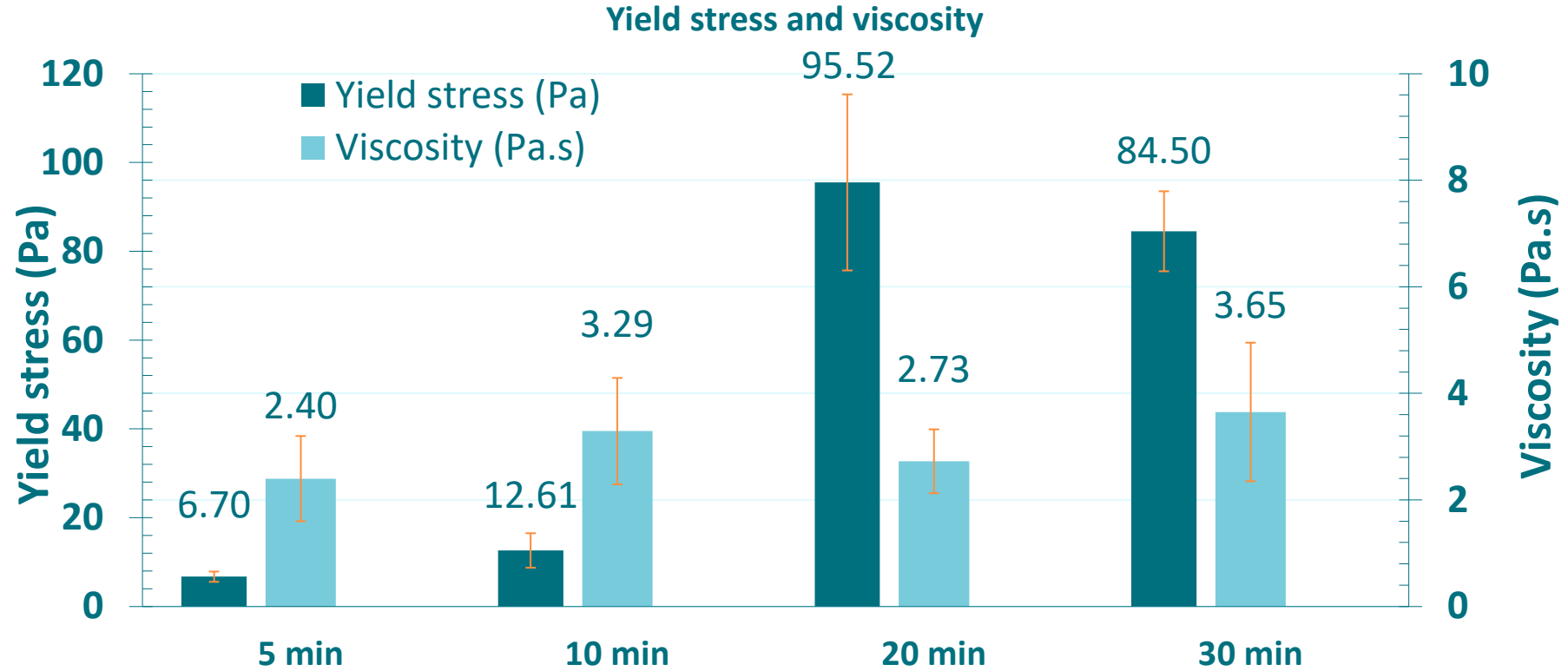
RHEOMETER – RheoCAD



MEASUREMENT
CHARACTERISTICS

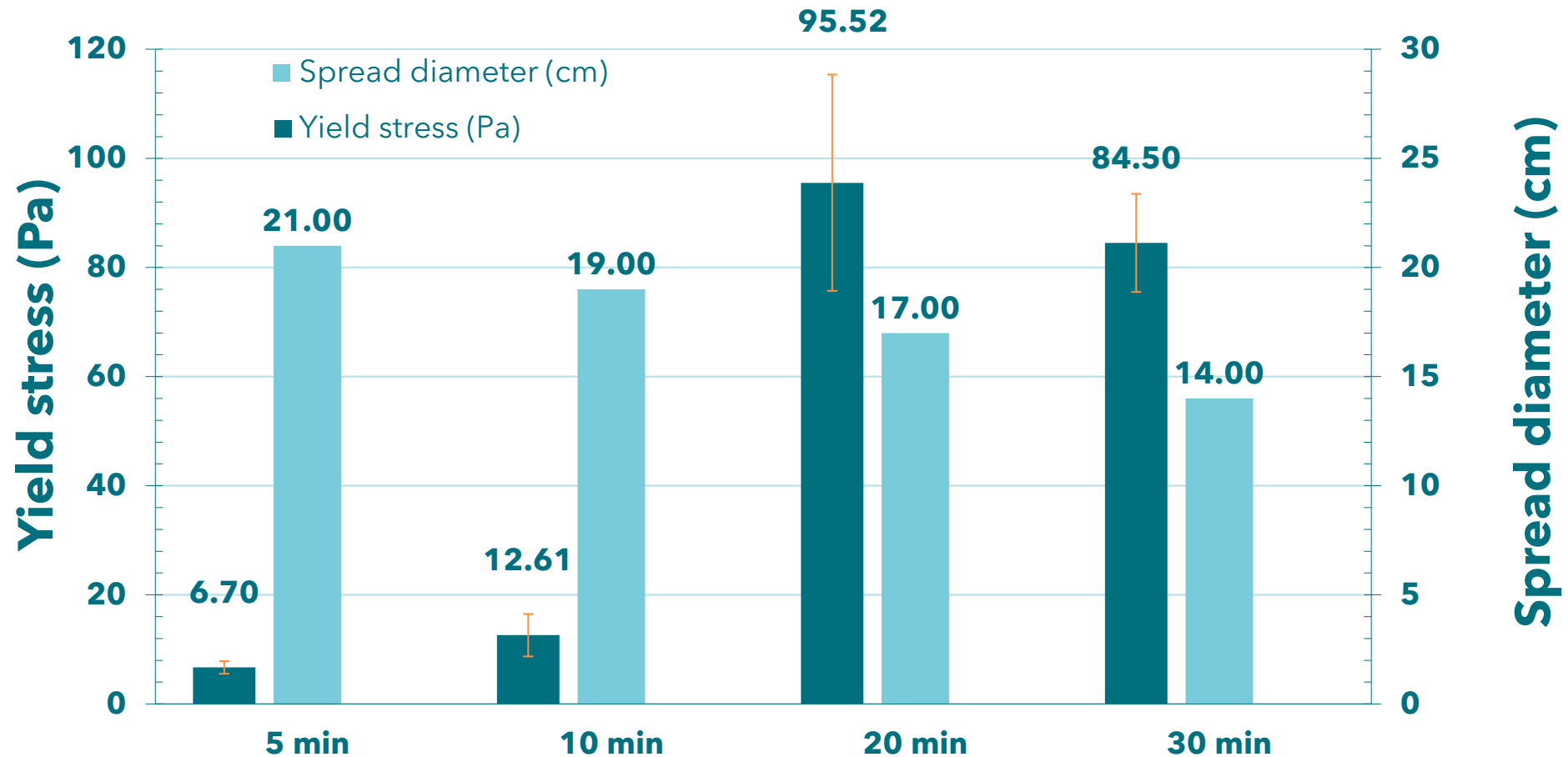
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Comparison between RheoCAD and pistol test



RHEOMETER – RheoCAD

Correlation between RheoCAD and flow table



03 CONCLUSION



CONCLUSION

RHEOLOGY TESTS

- **Pumpability:** only **flow table test** is suitable, fall cone test and V- funnel test can not show the difference in the behaviour of mortar with time. RheoCAD is an accurate test but less adapted for on site measurements
- **Buildability & extrudability:** **pistol test** is suitable and can show the evolution of the mixture with time. The parameters collected from rheoCAD can explain the behavior of pistol test

RHEOLOGY PARAMETERS

- High yield stress is needed to have a good buildability and buildability



*3D printed components
CirMAP project - ULiège*



THANK

YOU *for your attention!*

BEXTRUS

