2024 yCAM

MEASUREMENT OF RHEOLOGICAL CHARACTERISTICS FOR 3D PRINTED MORTAR

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LIÈGE université

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

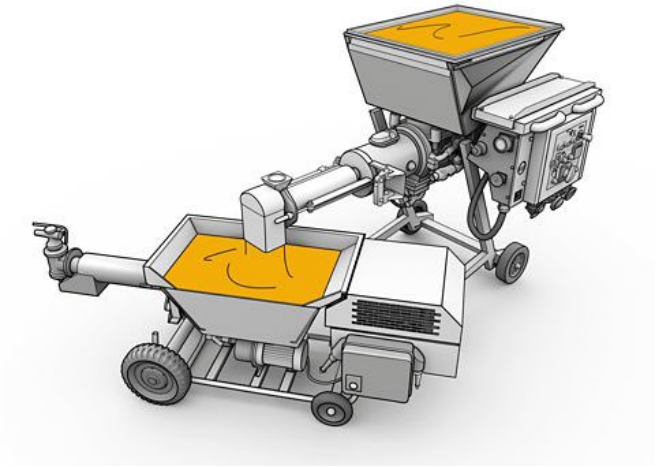
Accurate and controlled consumption of raw material, reducing waste

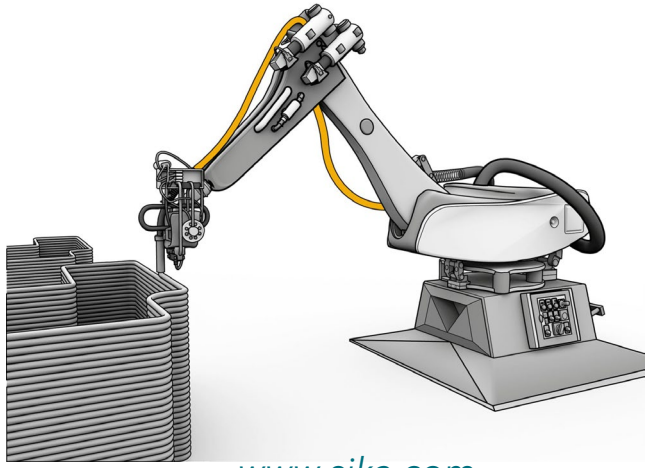
Social

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

3D PRINTING in CONSTRUCTION

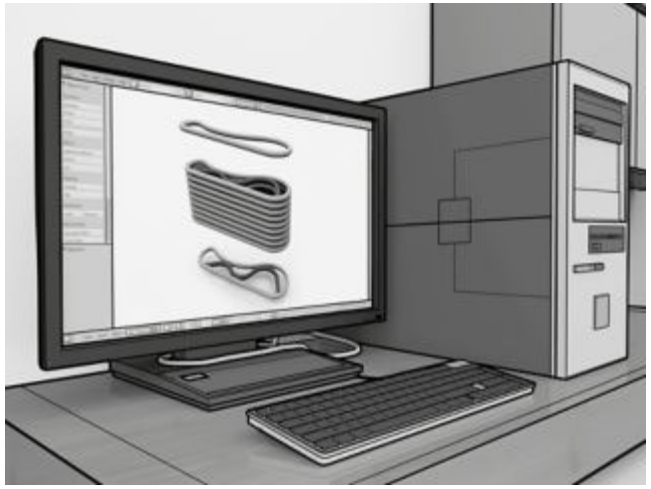
Equipment





www.sika.com

Software



www.sika.com

Material

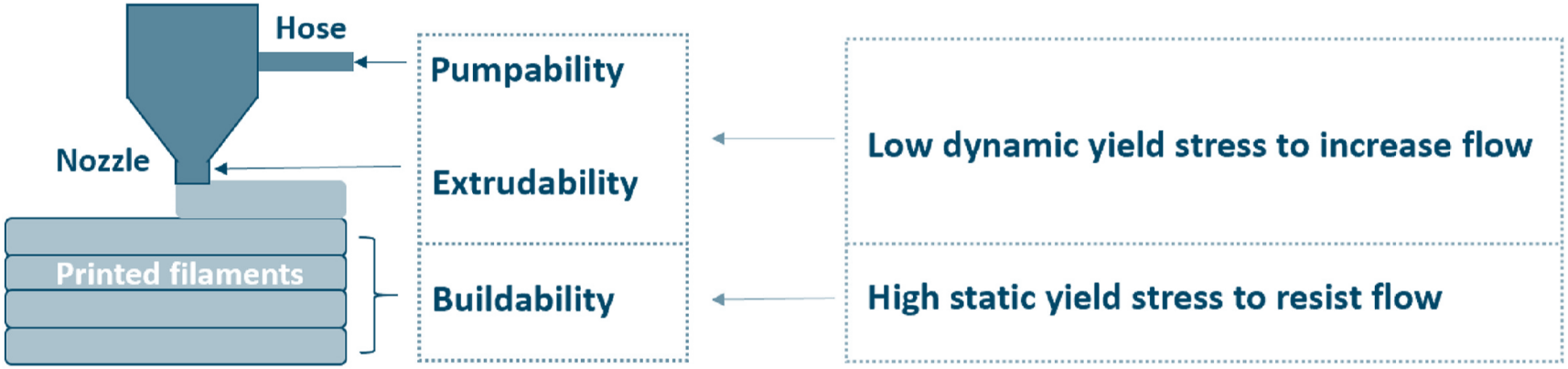
3D PRINTING in CONSTRUCTION

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

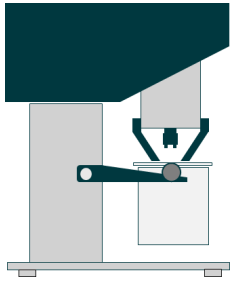
Pumpability

Flow table test

V funnel test

Fall cone test

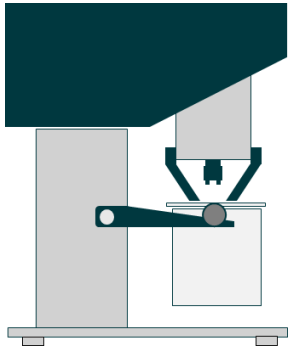
Rheometer
(modeling, formulation)

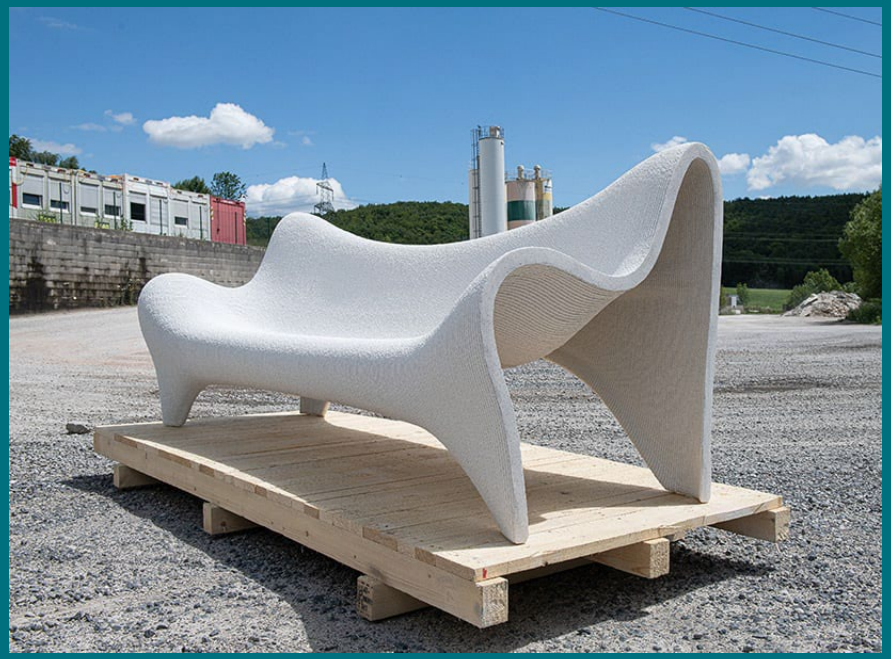


Buildability & Extrudability

Pistol test

Rheometer
(modeling, formulation)

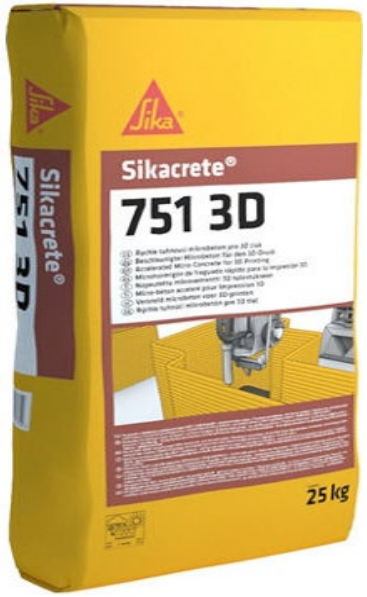




02 RHEOLOGICAL CHARACTERISTICS

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 ats 28 days
- **Density** : 2140 kg/m^3
- **Water content** : 18% of weight

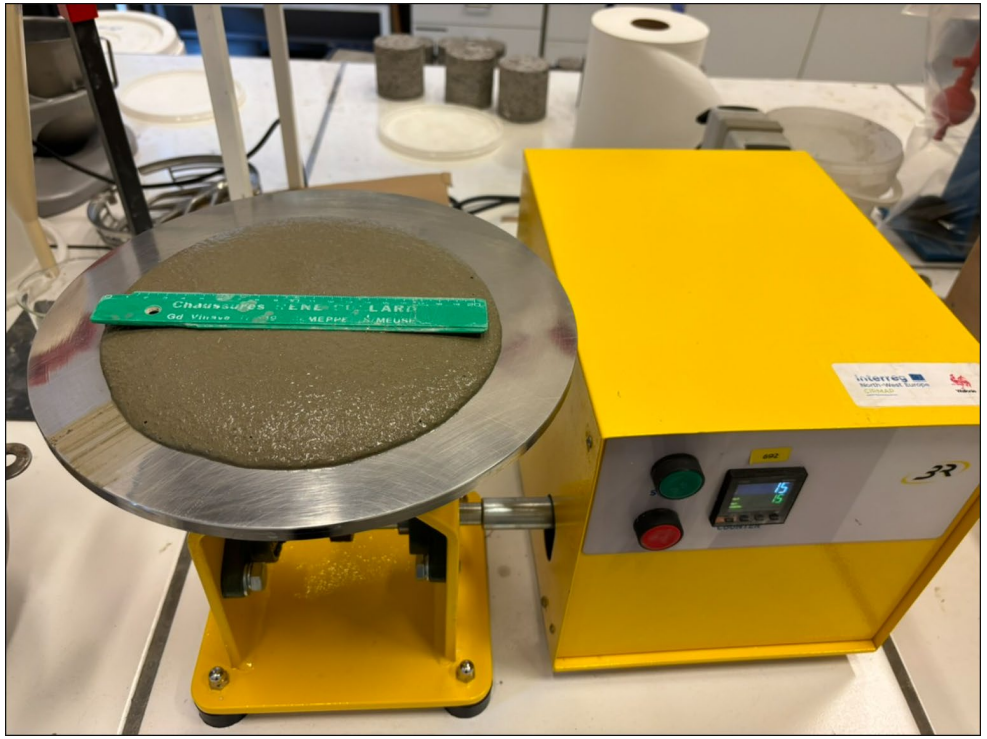
FLOW TABLE TEST

***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

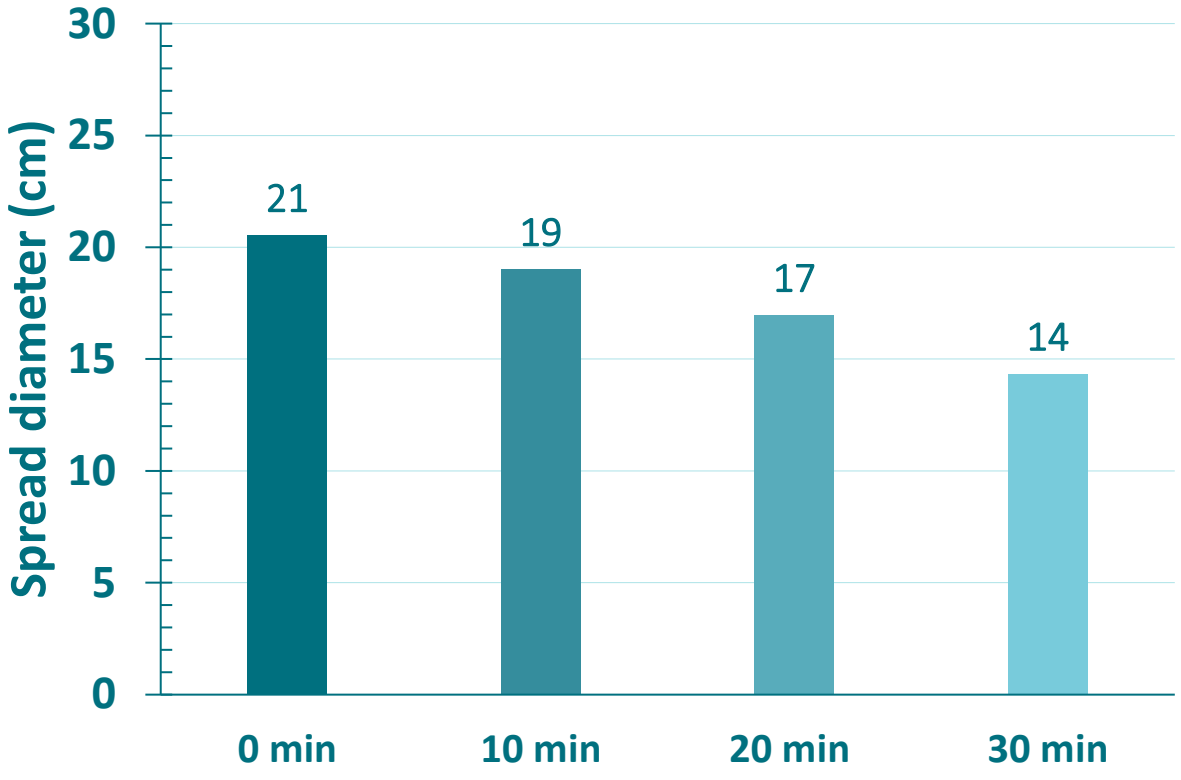
(0, 10, 20, 30 minutes)

Flow table test



FLOW TABLE TEST

***Pumpability**: to be transported in the pipe under a pressure*



Conclusion

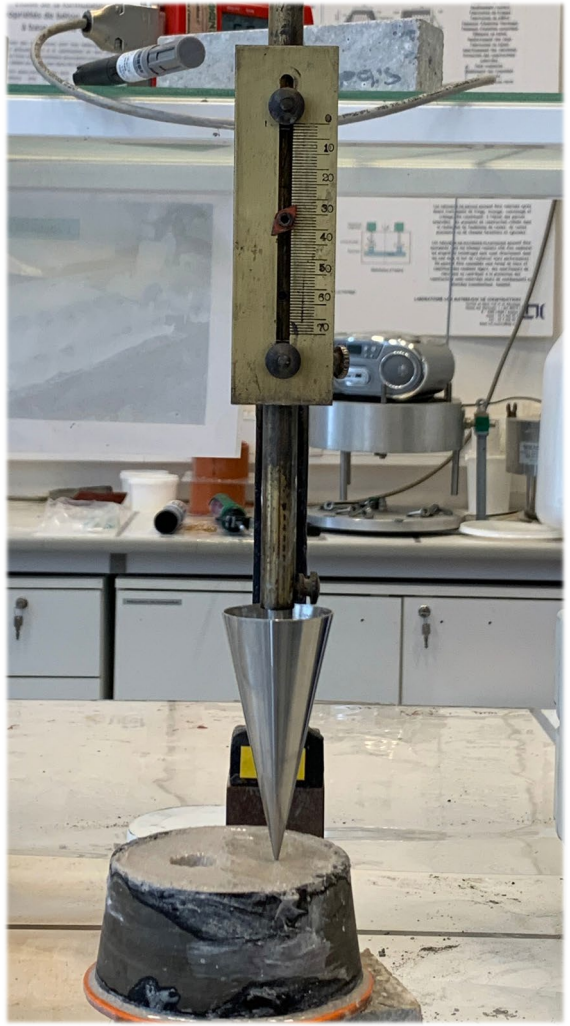
- Accurate for showing modification of properties of 3D printed mortar with time

FALL CONE TEST

***Pumpability**: to be transported in the pipe under a pressure*

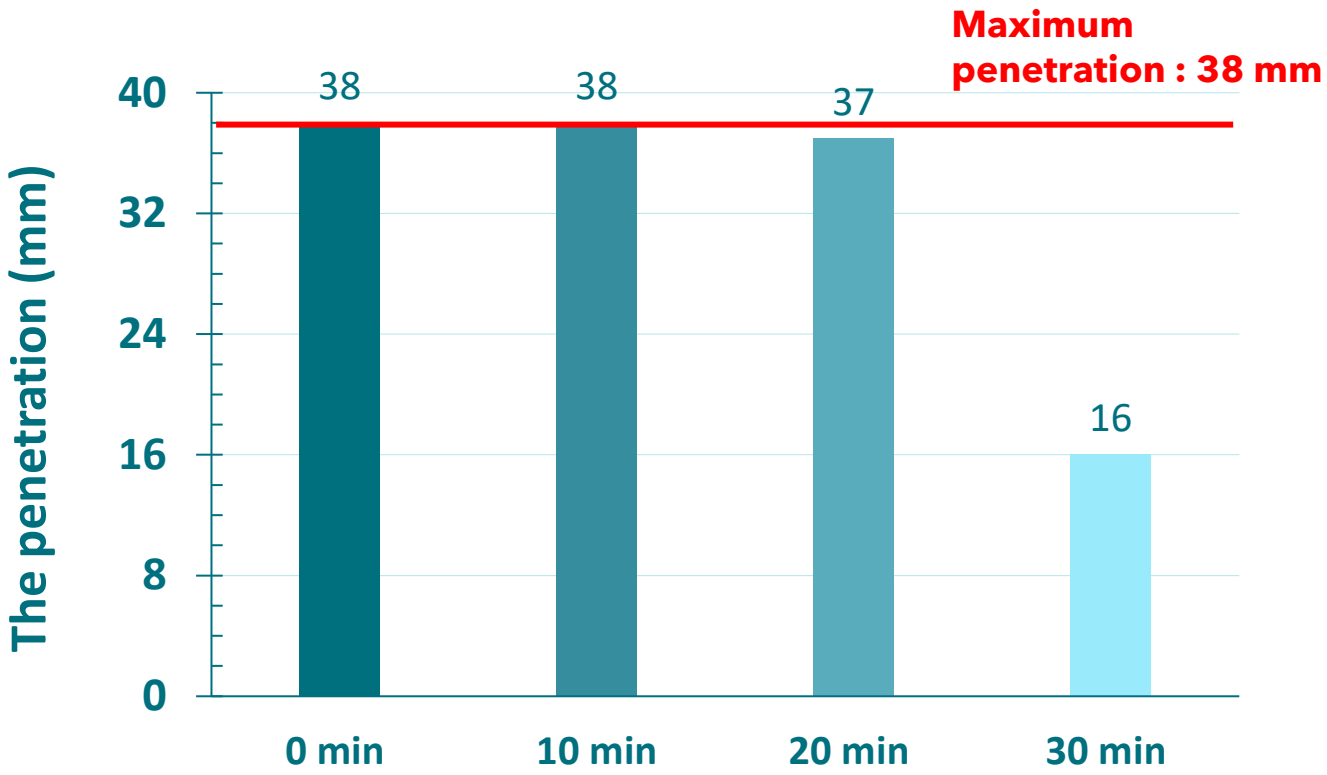
- Standard: BS 1377-2:1990
- Measurement: cone penetration (mm)
- Repeat the test 4 times

  (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.

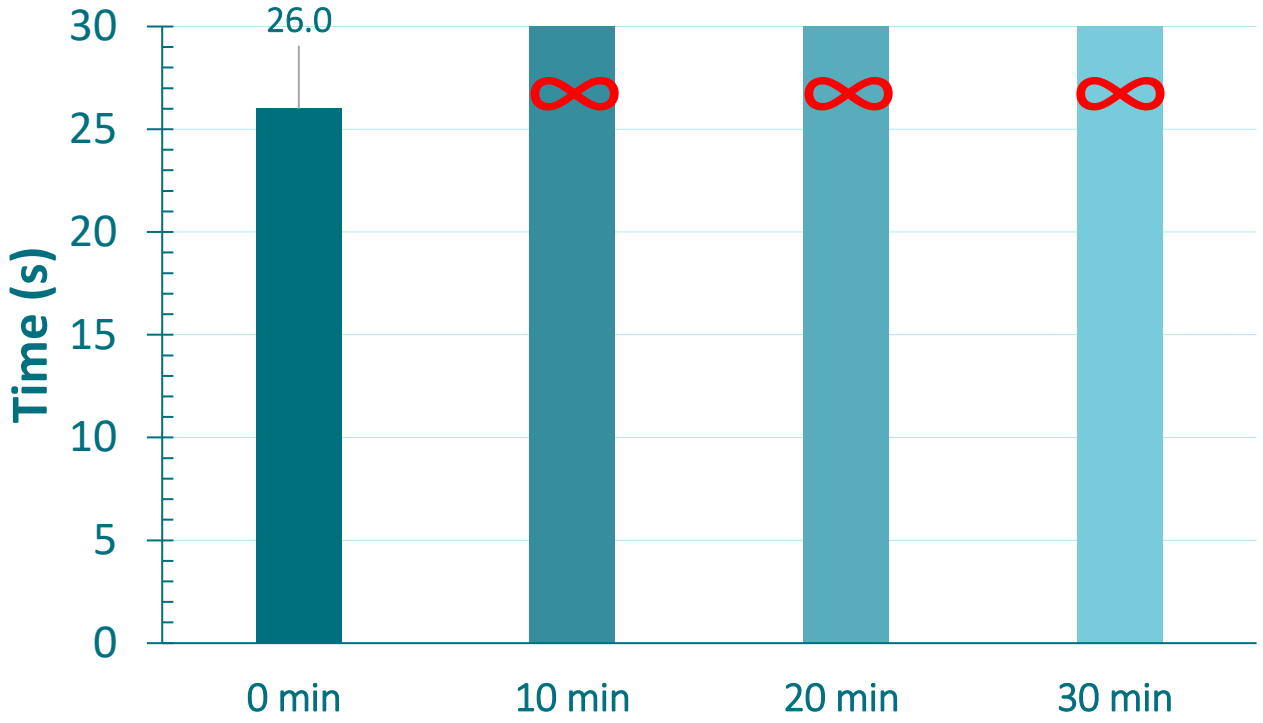
V- FUNNEL TEST

***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

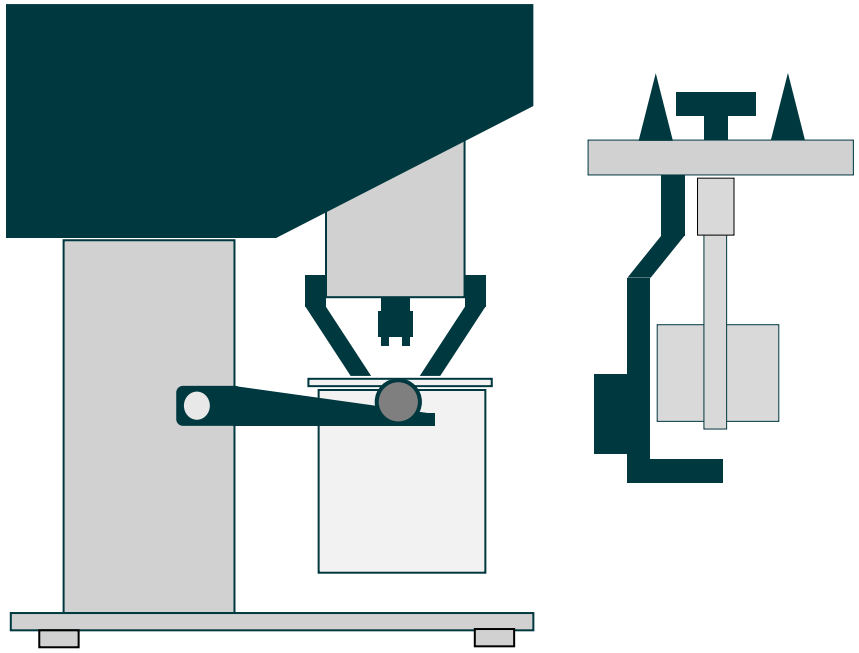
Conclusion:

- 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×N.

Reiner-Rivlin equation :

(Feys et al., 2013)

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

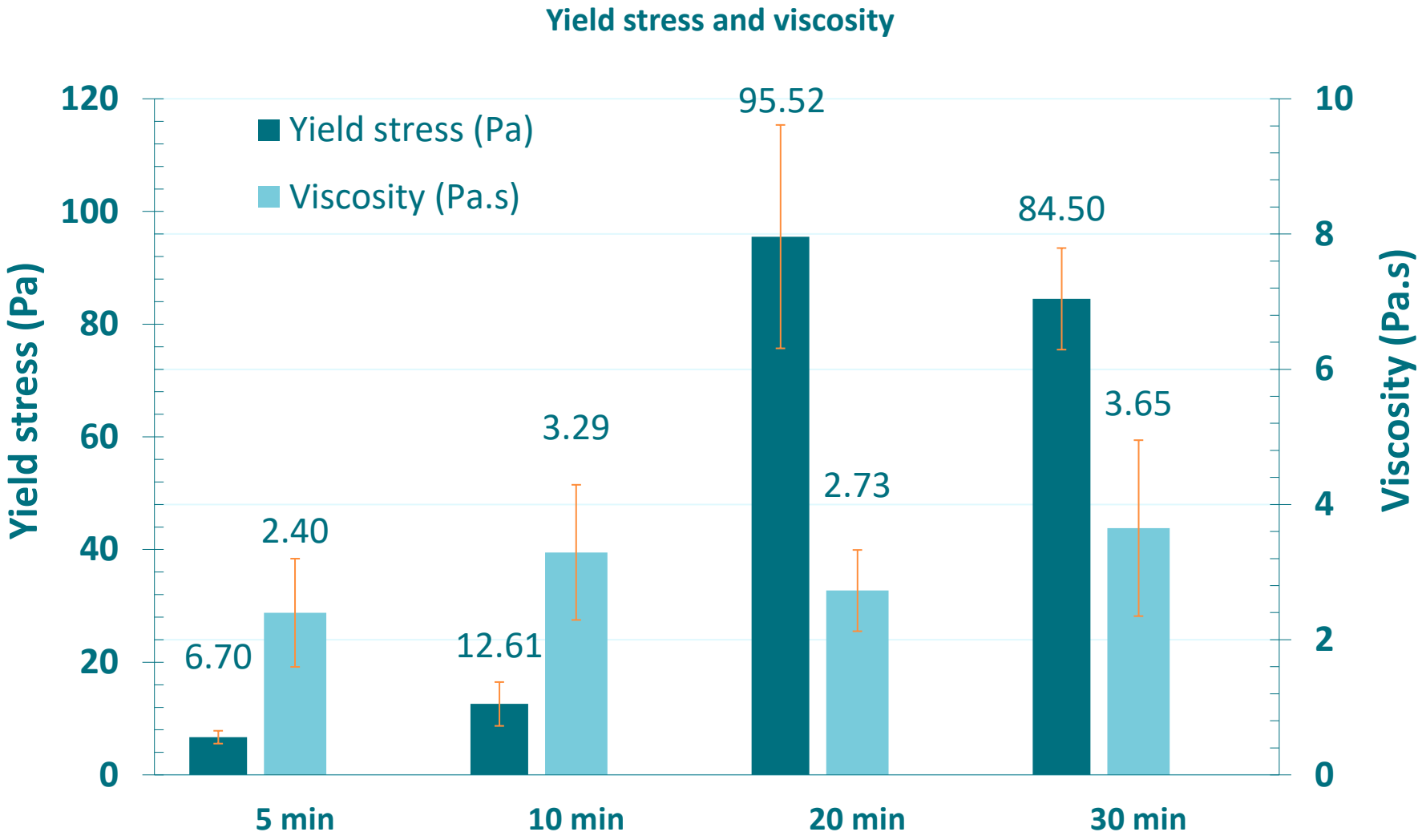
Bingham:

$\tau = \tau_0 + \mu \dot{\gamma}$

τ_0 - Yield stress(Pa)

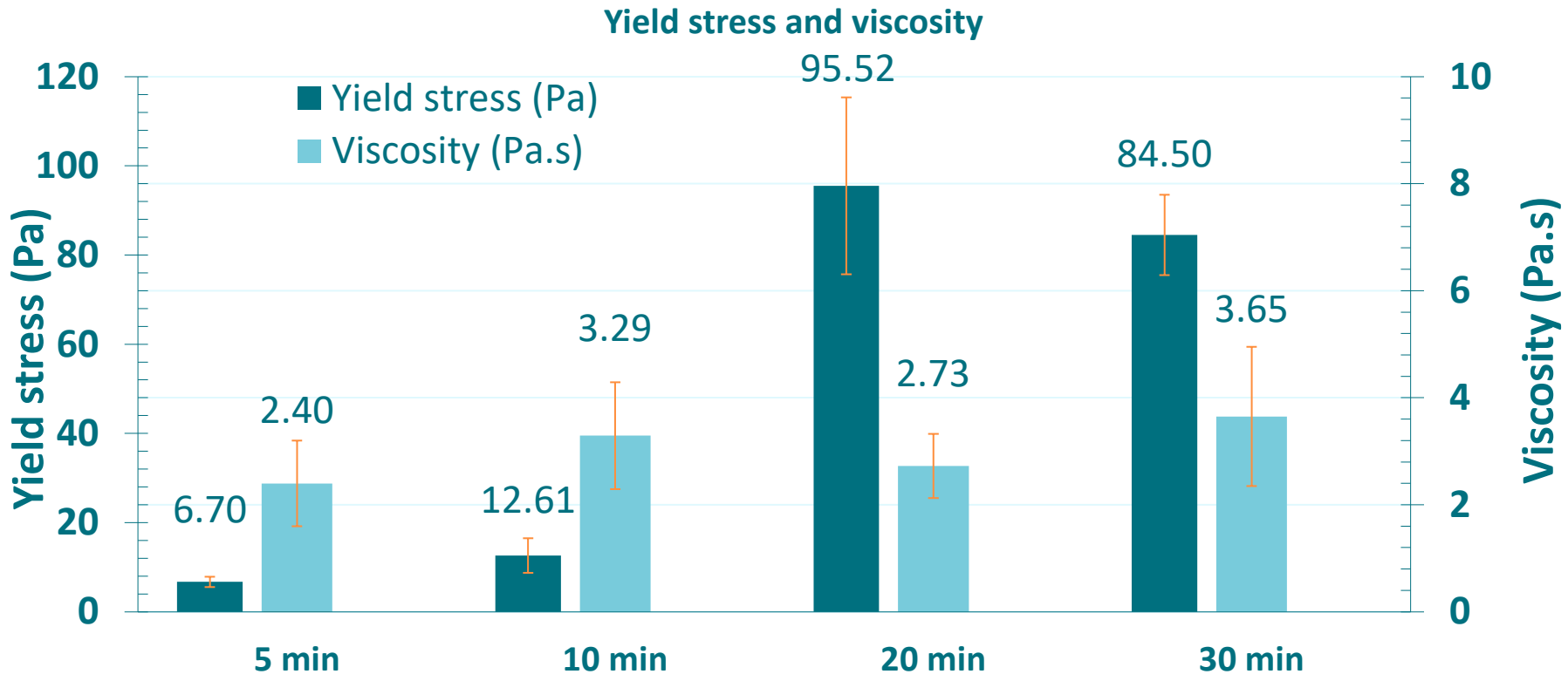
μ - Viscosity (Pa.s)

RHEOMETER – RheoCAD



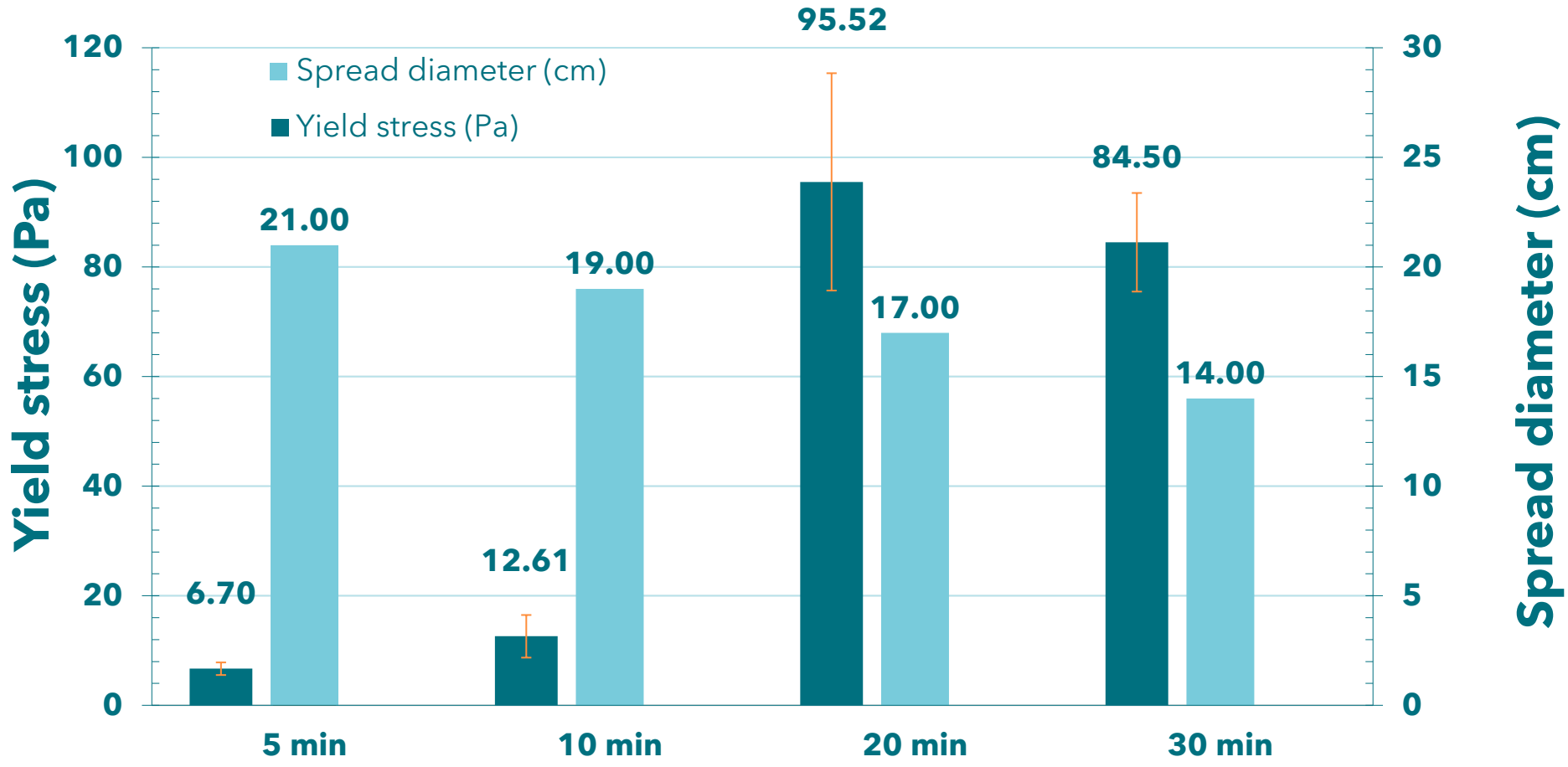
RHEOMETER – RheoCAD

Comparison between RheoCAD and pistol test

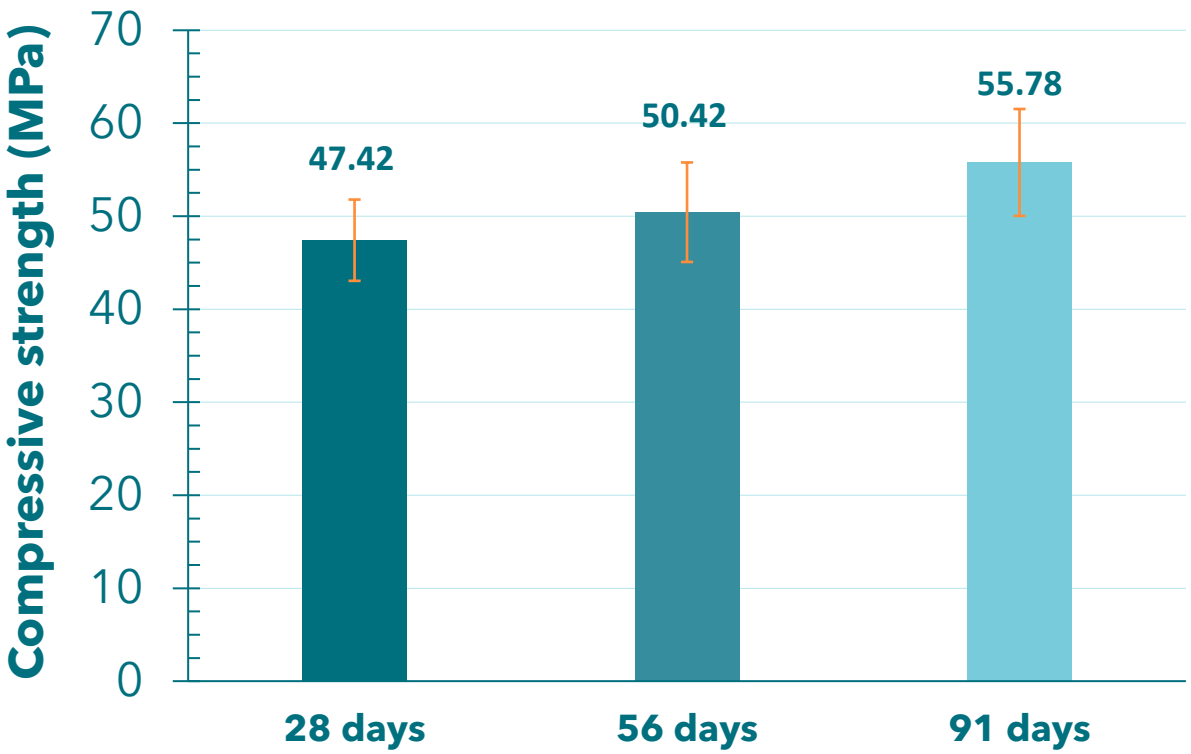


RHEOMETER – RheoCAD

Correlation between RheoCAD and flow table

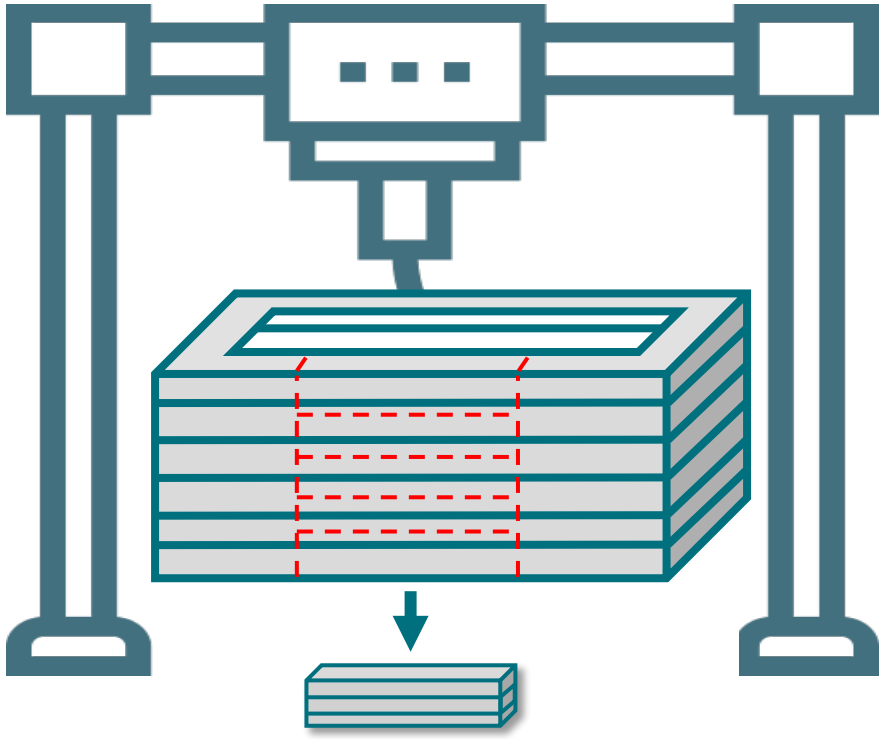


MECHANICAL TEST

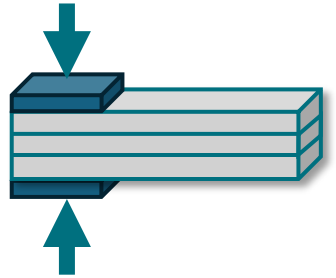


Conclusion

- High compressive strength



Standard dimension samples
4×4 × 16 cm



Compressive test

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

INISMa
Belgian Ceramic Research Centre

LIÈGE université

Buildwise

Wallonie

SPW
Service public de Wallonie