3D printing concrete: Fresh Properties and Rheology

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Increase of population, need more houses, infrastructures, etc

World population on **Sept 26, 2017** at **19:25 pm GMT**
7,570,100,000

World population on **Sept 26, 2017 at 19:30 pm GMT**
7,570,101,000
(+1000)

Conservative estimation of the amount of concrete produced every year on the planet:

more 15,000,000,000 t

…over 2 ton/inhabitants; and there are good reasons for this …. is cost (cheaper!)

Conventional Construction of buildings

- Labour intensive and inefficient, time of construction, health and safety insurance, society, ..
- Wasteful and Climate Change : emission of CO_2 (carbon foot print)
- Modern slaves in some countries, Corruption prone (tender, during construction, market, etc),
- High cost

Solutions

• We used robotics now to produce our cars, appliances, mobiles, TV, computers, iphone, Ipad, iwatch, clothes, shoes, foods, mails, etc

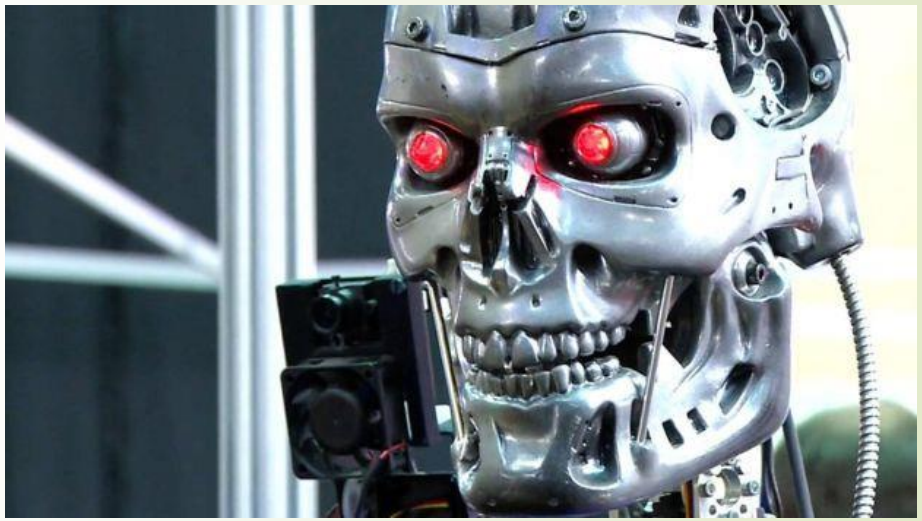
Digital – future with robots→ buildings

Race to build first 3D-printing building

- The race to build the first 3D-printed building is already started.
- Would you live in a house that came out of a printer? Would you prefer Concrete, or Plastic? Biodegradable, or Weather resistant? Canal house or futuristic spider's nest?
- The phrase "form follows function" was coined in 1896, just as it became clear that concrete, glass and steel would free architects to design buildings in completely new ways that had nothing to do with what came before. What's going to happen to the buildings we erect with 3D printers?

A future with robots

- It seems every week we hear a new doom-laden prediction about the impact of robots and other forms of automation on jobs. But are we looking at this the wrong way - too inclined to hang on to the world of work as it is today, too unimaginative about how it could be transformed for the better by technology?
- The robots, like other tools invented by humans, can help us or harm us.
- **But they are not going away.**



Not all robots would be good to live with

Benefits of 3 D printings

- **We can enumerate the benefits of 3D printing in construction:** ***"It is always worth reiterating, the main benefits of concrete-3D printing on a large scale are as follows:***

    1. ***Higher customisation potential*** **(flexibility in design, and environmental impact)**
    2. ***Very low construction waste*** ***(Formwork represents 35-60% of the overall cost)***
    3. ***Reduced need of more labour*** ***(Health and safety)***
    4. ***Reduced time of the construction*** ***(Cost-effective)***

University Loughborough (UK)

(Free Construction Research Project – 2010)

(Le et al. 2012)

First 3D bench

On 16 Feb - 2017

Objectives

- The aim of this study is to characterize the effect of the fly ash, silica fume, the dosage of SP, dosage of fibres, and the type of viscosity modifying admixtures on the workability, the rheological behavior and opening time of 3D printing mortar.

Experimental program

Parameter	Values
W/CM	0.50
Fly ash	24%
Silica fume	8%
SP	(0.55%, 0.28%) SP – ½ SP
Polypropylene Fibres (6mm)	(1.2kg/m^3); PP-2PP-3PP
VMAs – Diutan gum(DG) & Nano-clay(nC) (by mass of CM)	0.05% - 0.10%

Materials

- Ordinary Portland cement : Class 42.5 N (BS ENV 197-1 CEMI)
- Fly ash – BS EN 450
- Silica fume (BS EN 13263-1)
- Sand (1.18 mm)
- SP - polycarboxylic ether (30% SC, 1.05)
- VMAs - diutan gum (Polysaccharide gum), Nano-clay
- Polypropylene fibres

Experimental Program

- Tests
  - **Fresh tests methods**
    - 1) Flow table test
      - Consistency
    - 2) Penetrometer test
      - Consistency
    - 3) Cylindrical slump flow
      - Semi-empirical yield stress
      - Mixes were too stiff to be characterised by the viscometer
    - 4) Gun test
      - Extrudability
    - 5) Time gap test
      - Build up rate of cement based material
      - Limit of stiffness for extrusion
      - Measurements every 15 min

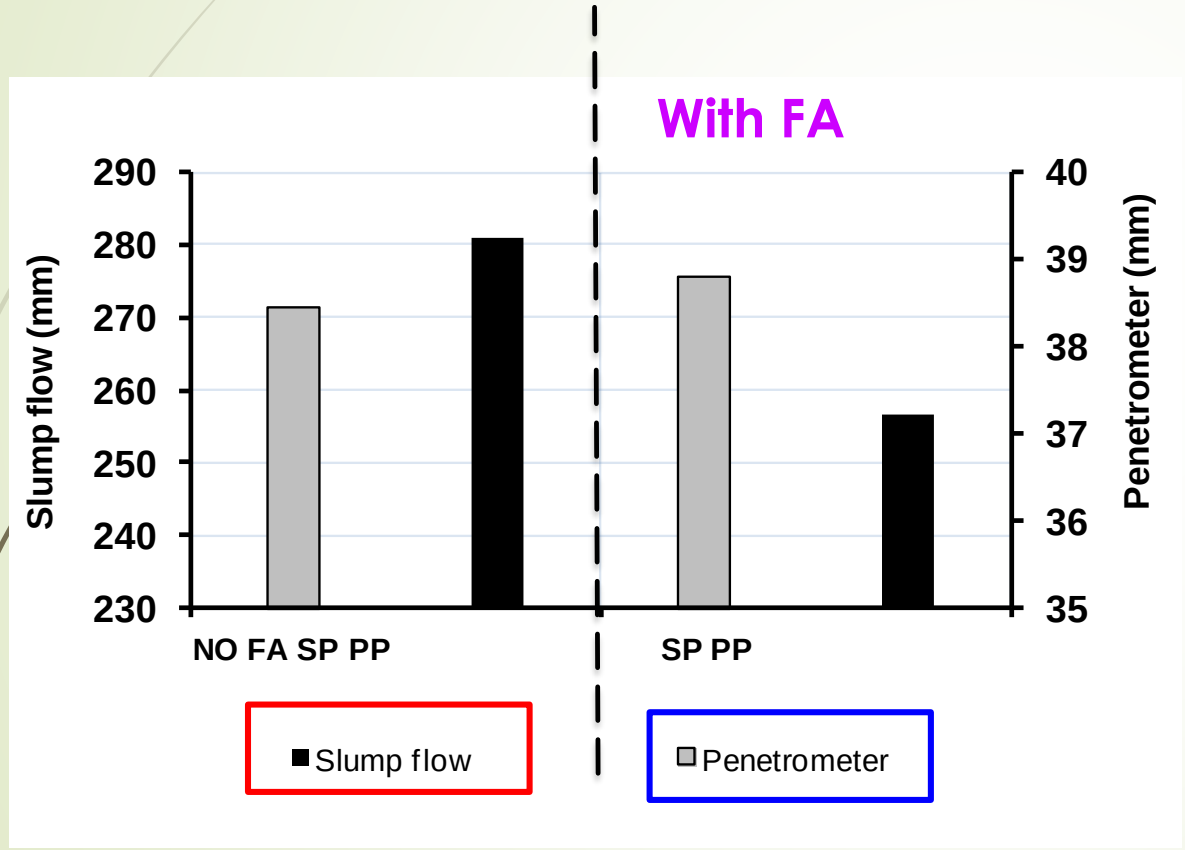

1


2

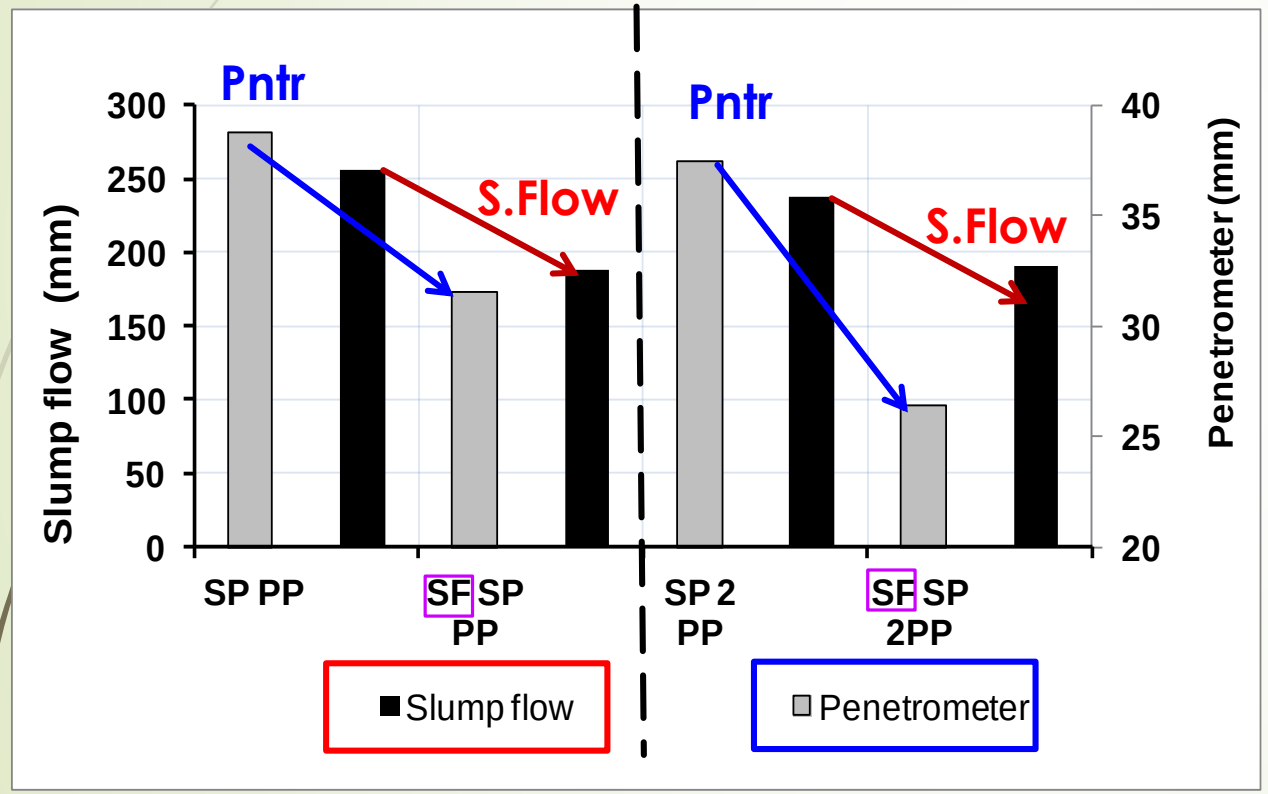

3


4

Effect of fly ash on fresh properties of 3D printing



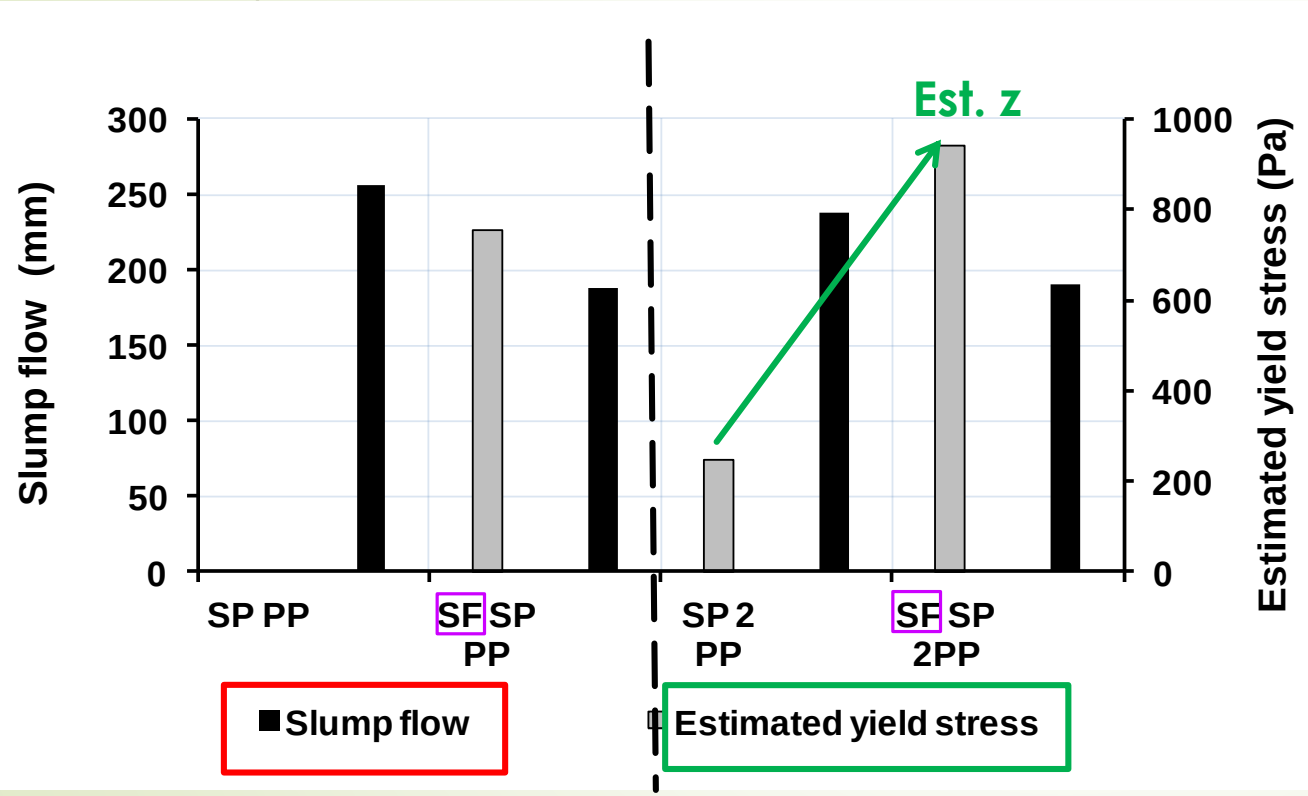
Effect of Silica fume on fresh properties of 3D printing



NO SF

SF

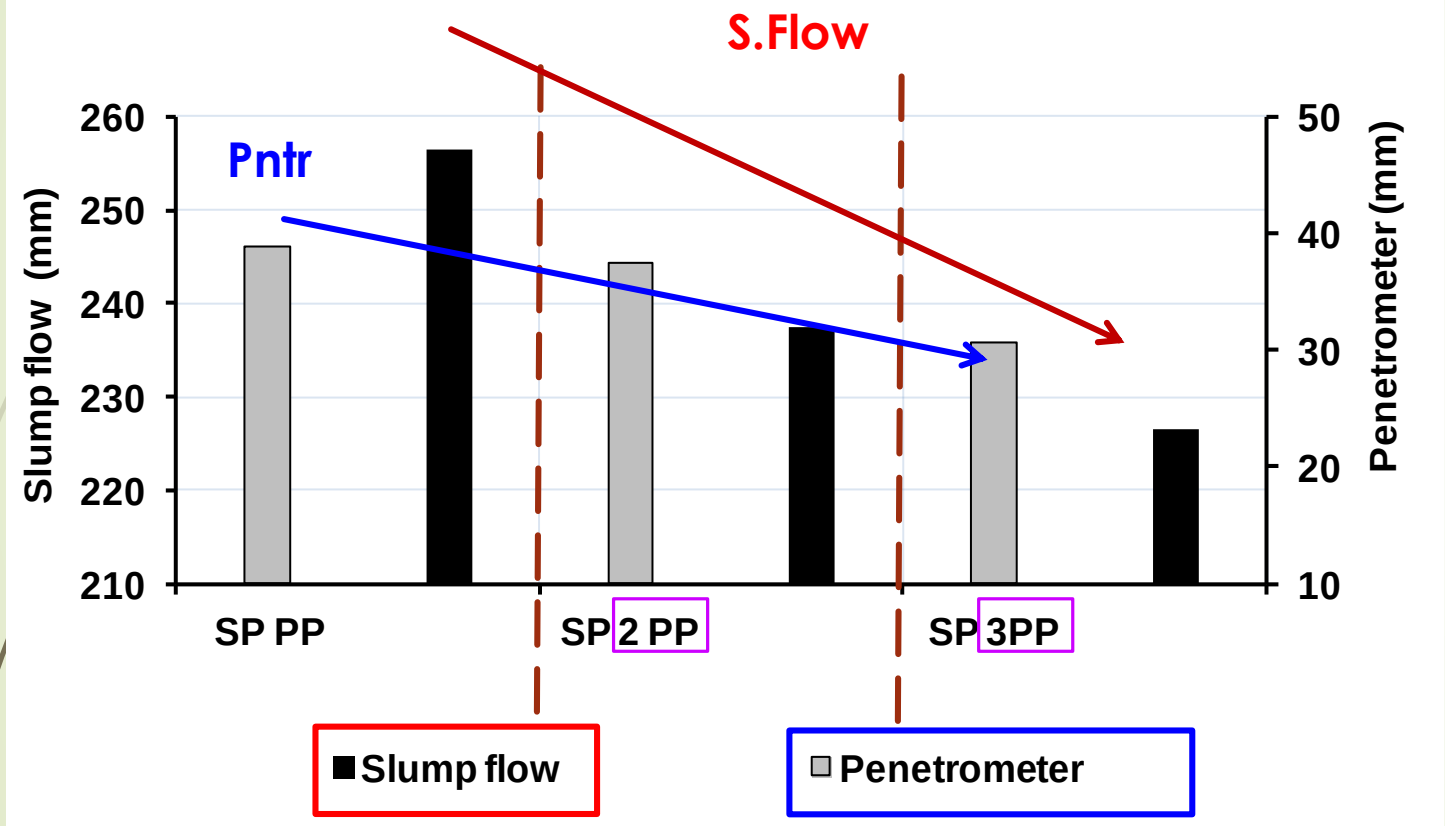
Effect of SF on fresh properties of 3D printing

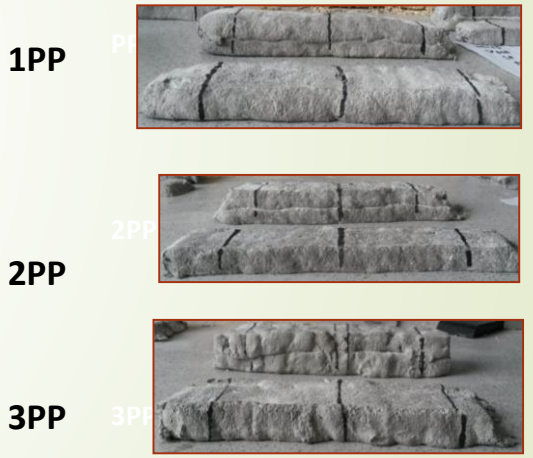


NO SF

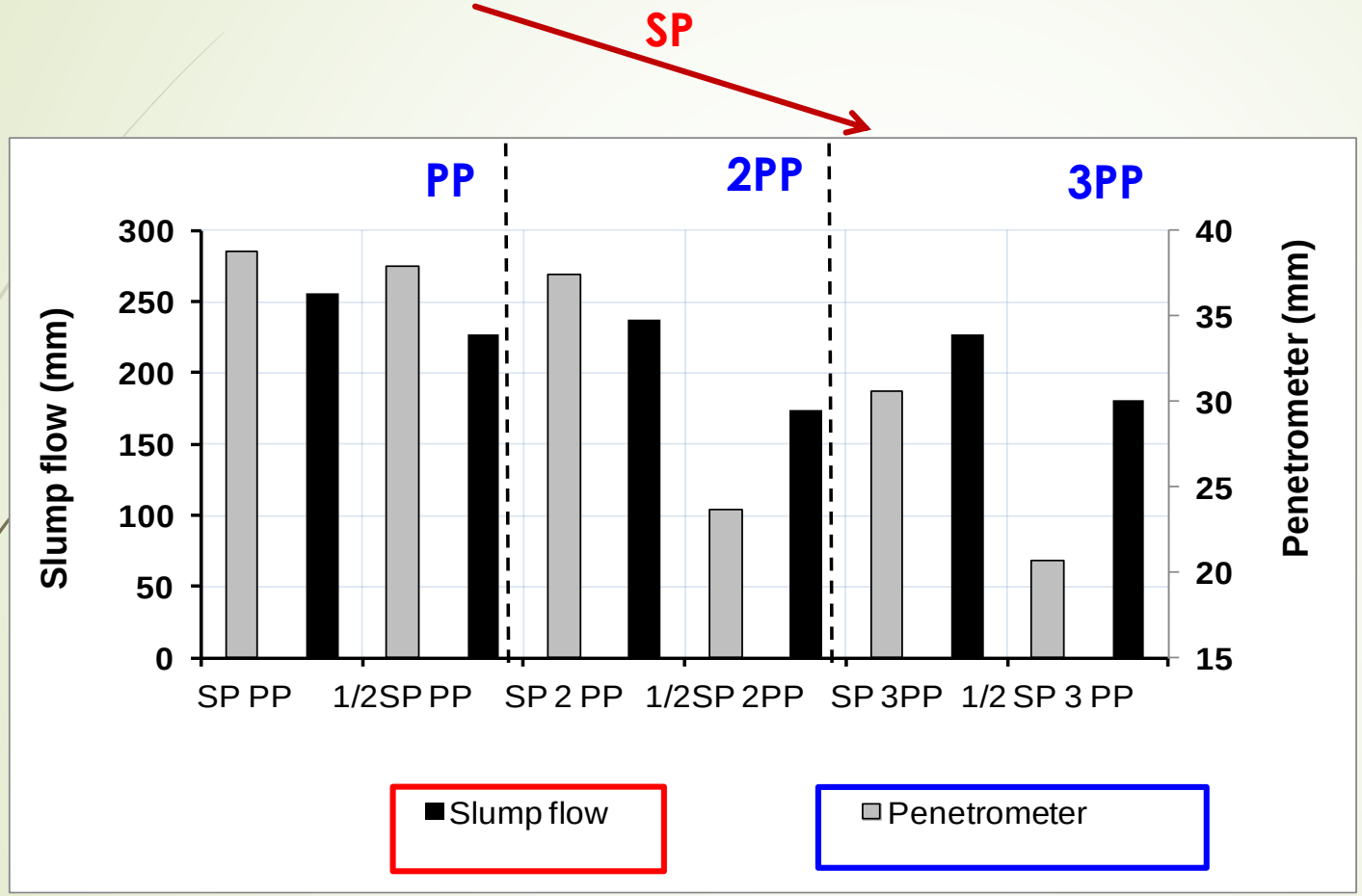
SF

Effect of PP fibre on fresh properties of 3D printing





Effect of reduction of SP on fresh properties of 3D printing



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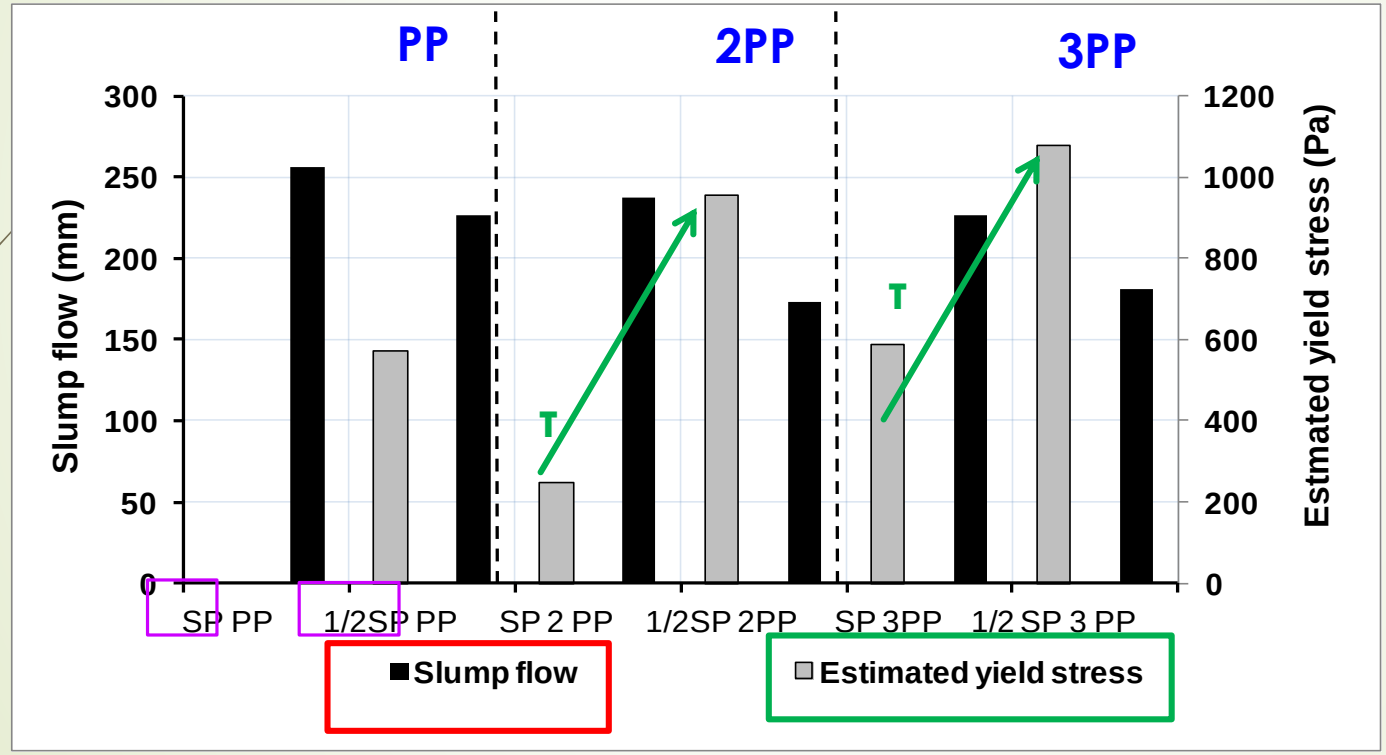
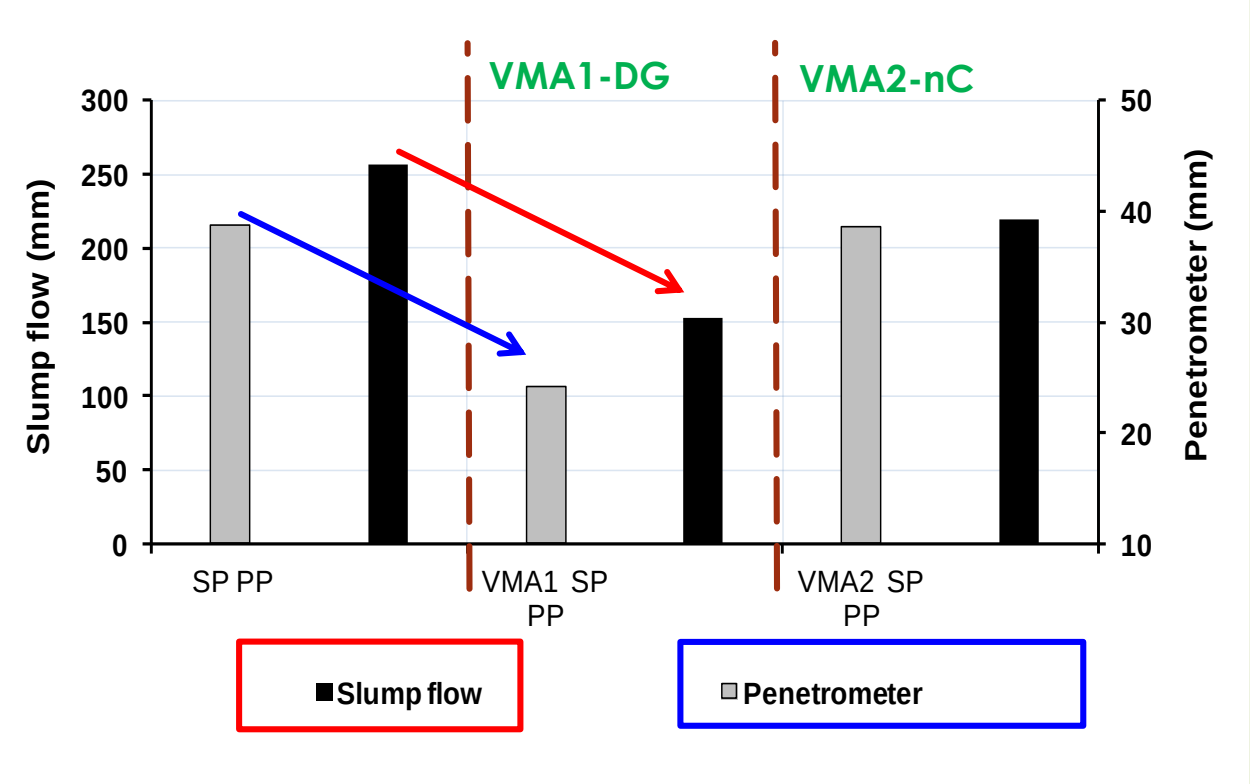


Effect of type of VMA on fresh properties of 3D printing



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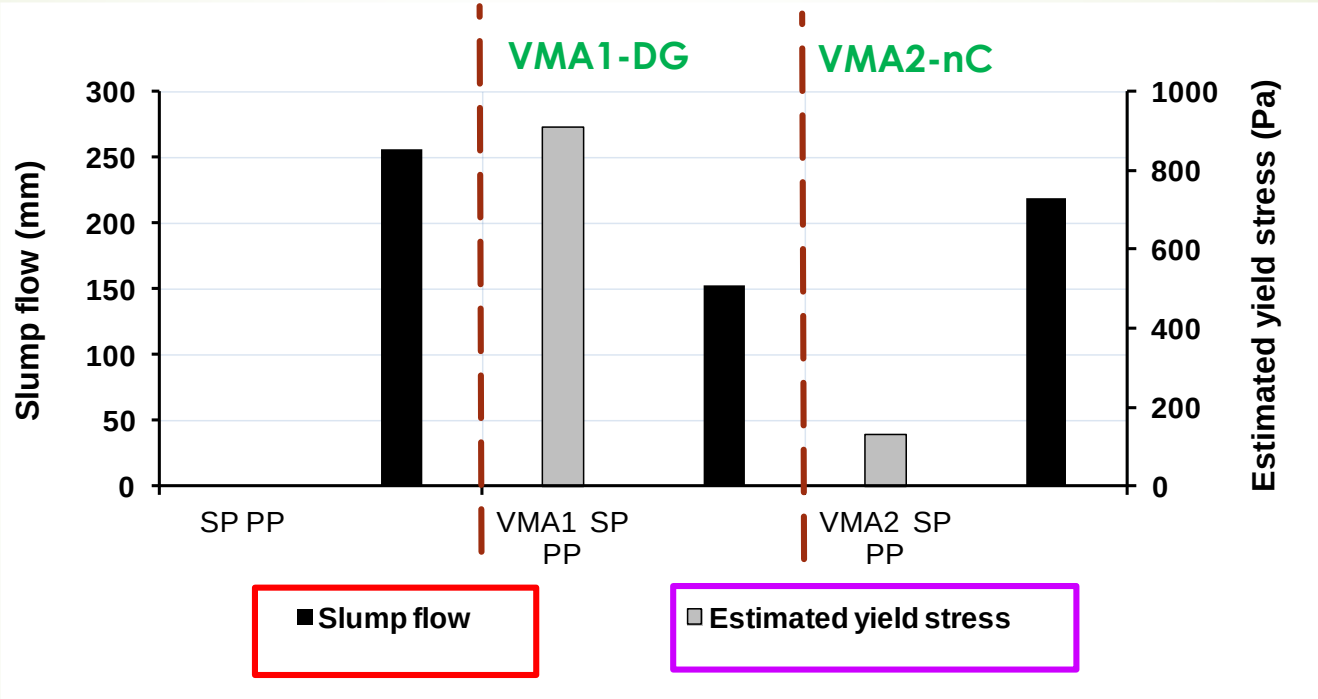
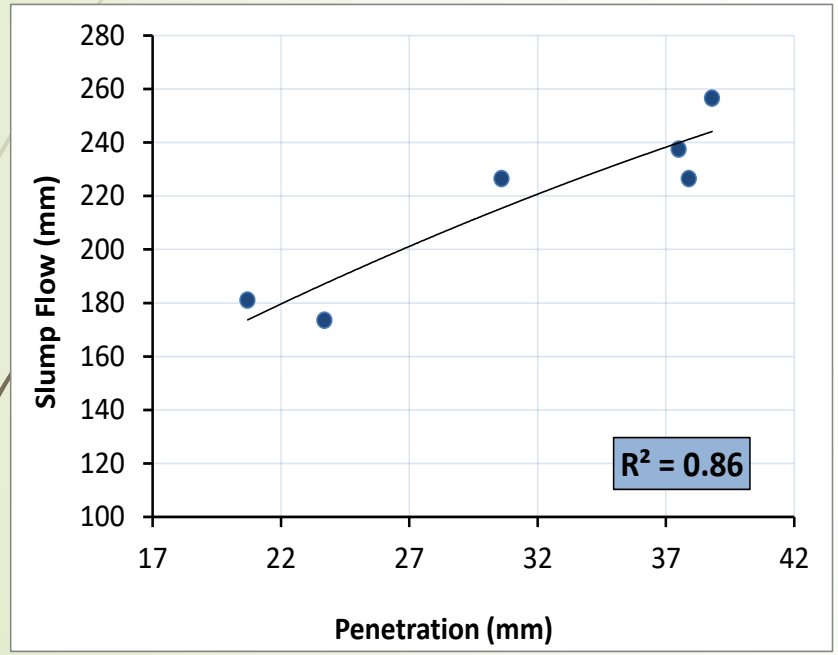
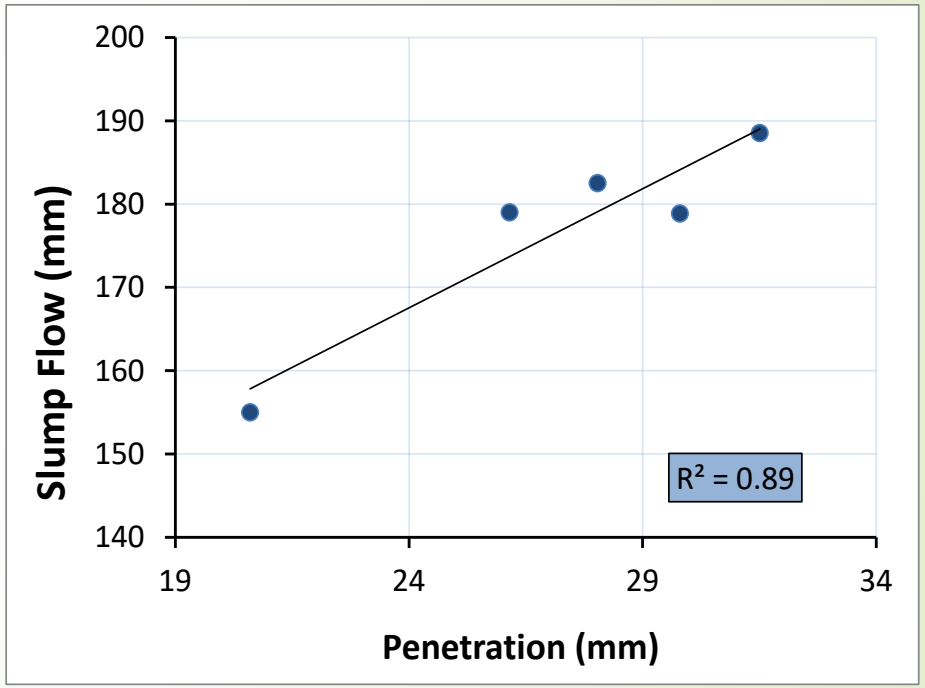


Correlation between slump flow vs. penetration of 3D printing

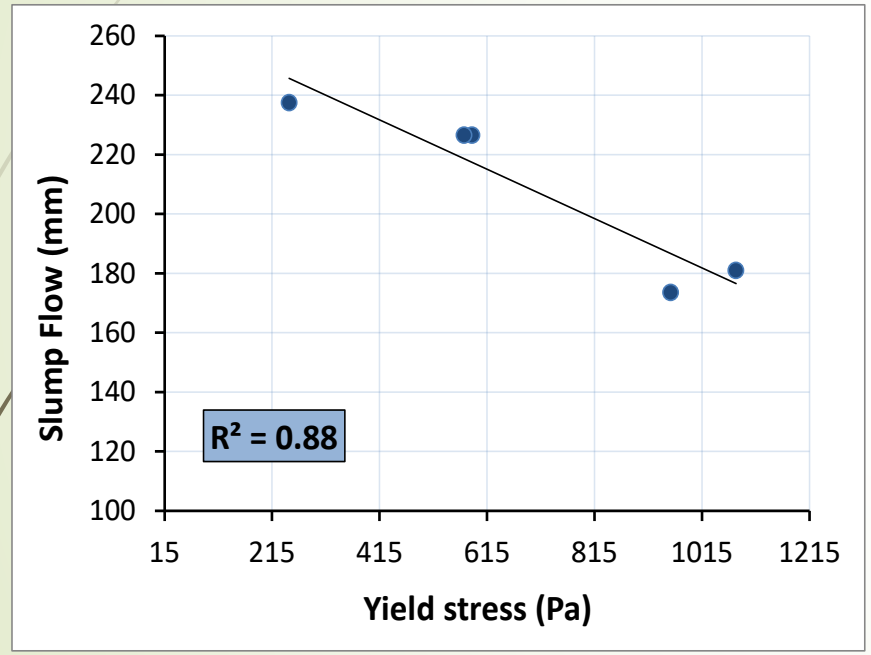


(a) different PP and SP

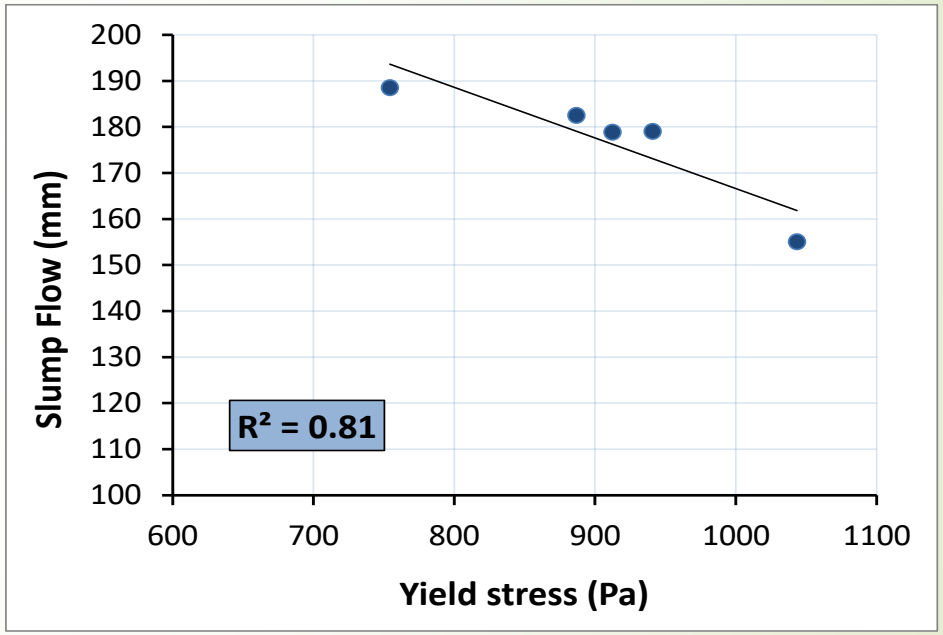


(b) with and without SF

Correlation between yield stress flow vs. penetration of 3D printing

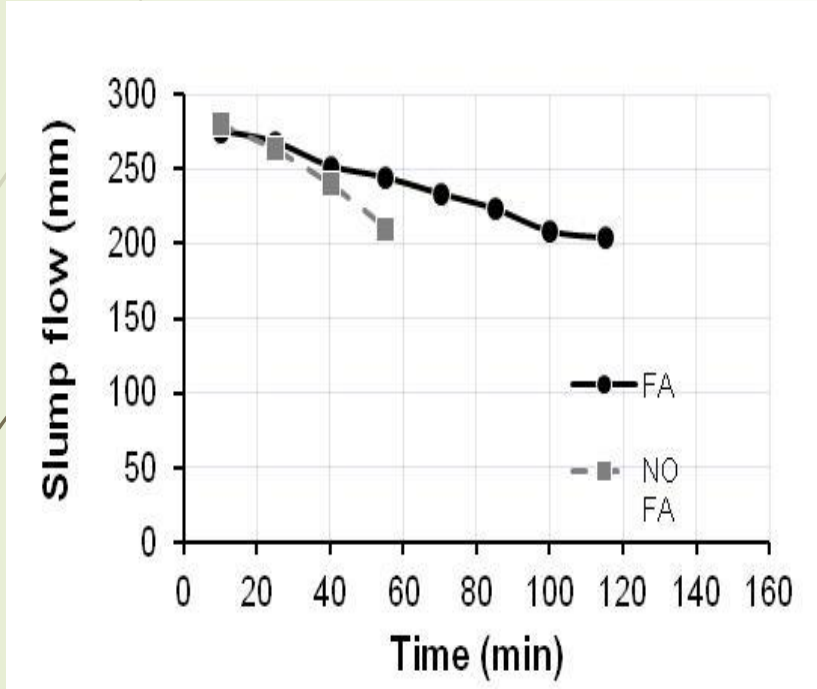


(a) different PP and SP

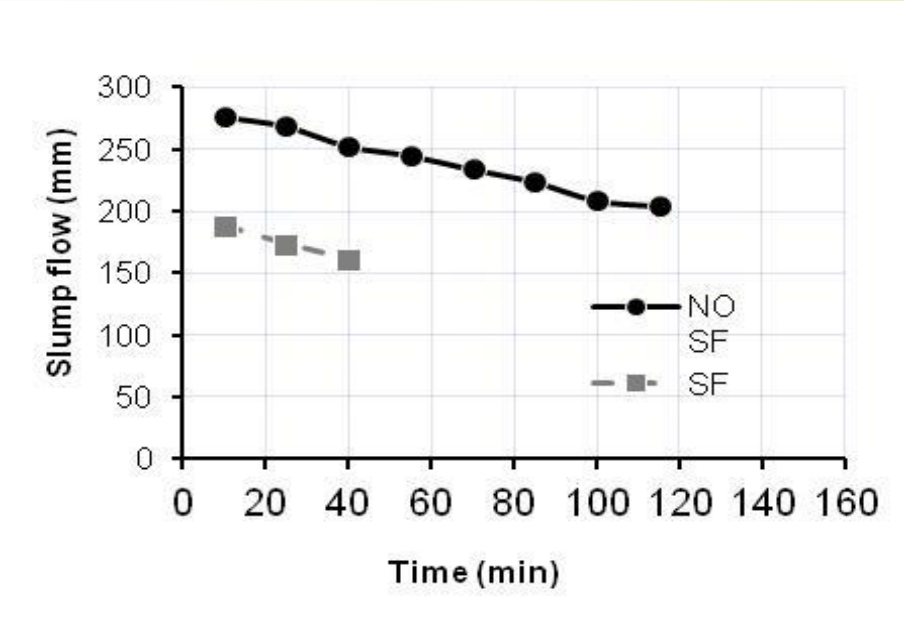


(b) with and without SF

Opening time – Effect of FA & SF on 3D printing

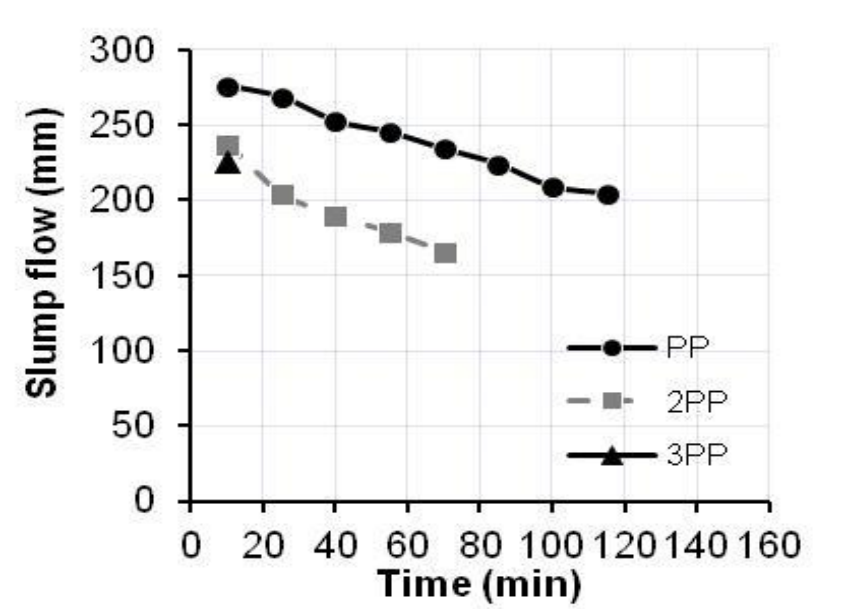


(a) FA

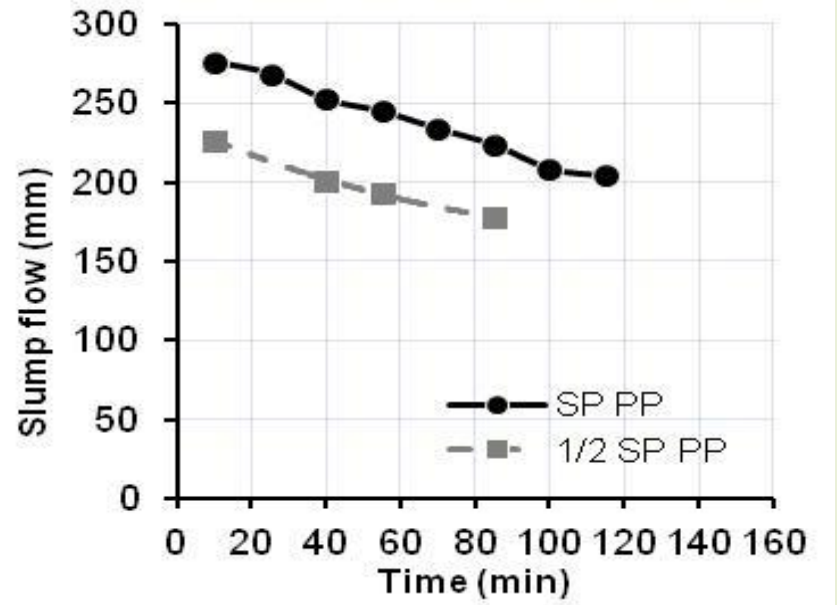


(b) SF

Opening time – Effect of PP fibre & SP on 3D printing

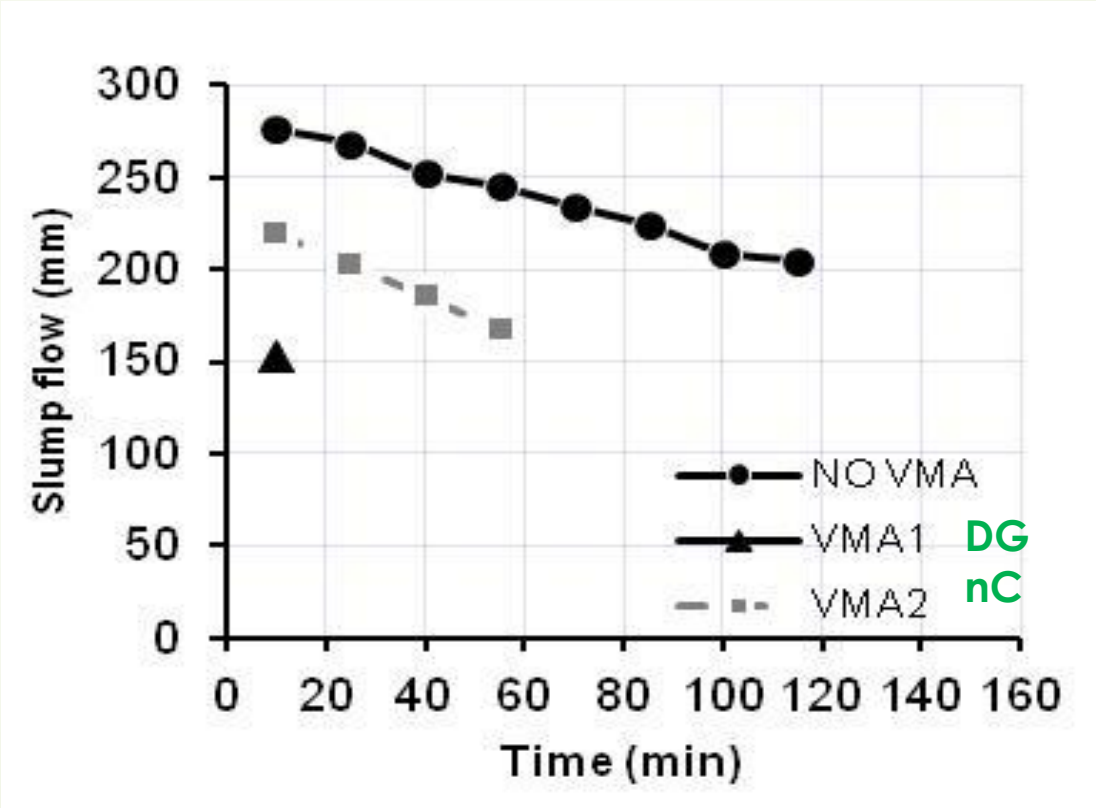


(a) PP fibre

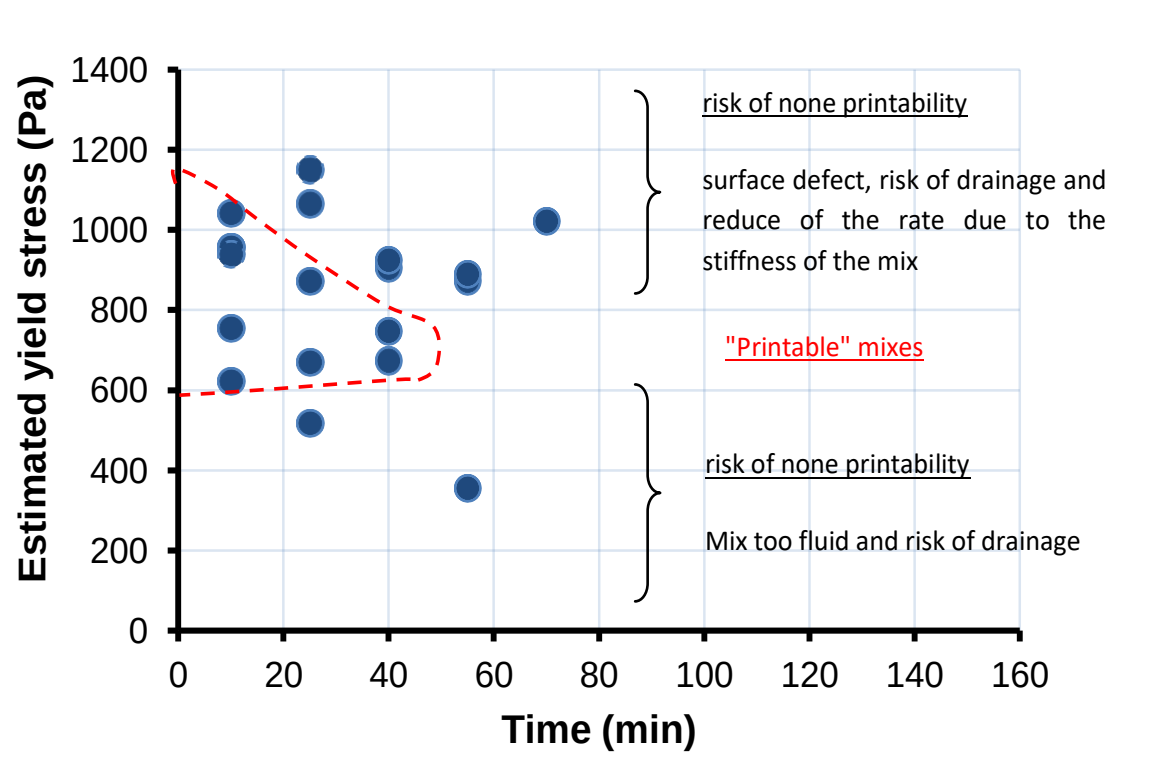


(b) SP

Opening time – Effect of type of VMA on 3D printing



Printability



Cold joints

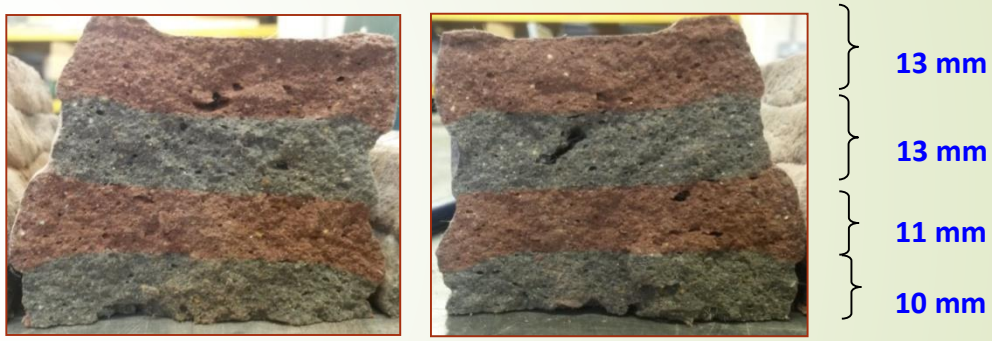
- **If layers of concrete have limited intermixing and if the critical resting time value has been exceeded, cold joints are susceptible to appear.**

Coloured layers-intermixing

3 D printing layers

2 printed layers

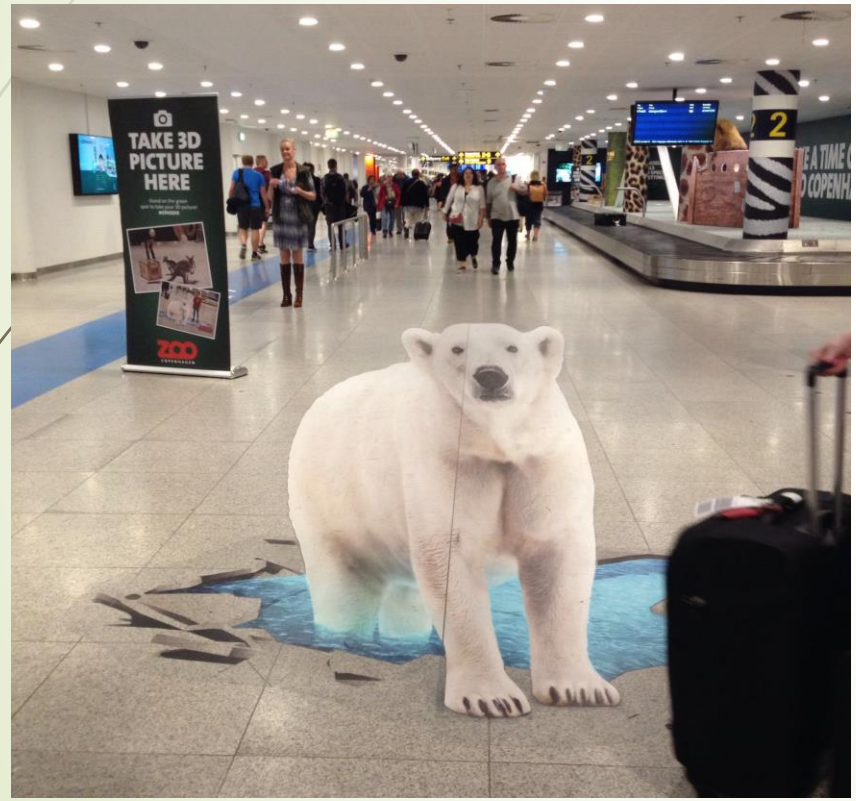
4 printed layers



Recommendations of 3D printing mortar

- 155 mm < spread diameter < 235 mm
- open time <100 min
- 600 < τ_0 <1050 Pa
- 20 < Penetration < 39 mm

3D polar bear at Copenhagen Airport – Aug. 2016



Visual illusion
(3D vs. 2D)

Thank you for your attention