INFLUENCE OF VOLCANIC POZZOLANA ON PROPERTIES OF MIXTURES FOR 3D CONCRETE PRINTING

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Challenges in Cement Industry

- Severe influence of **CO_2 factor** on feasibility of clinker production

Opportunities

- Capturing and depositing **CO_2** emissions
- **Reduction** of cement **consumption** in concrete
- Use of **SMCs** to replace OPC in blended cements
  - Side-products from other industries (Blast furnace slags, silica fume, fly ash)
  - Natural (pozzolanas, limestone)

Volcanic pozzolana as an optional SCM

- Abundant raw material, volcanic pozzolana, available throughout the world, which after being grinded to **fineness of OPC** shows pozzolanic activity when used in blended cementitious binders.
- When used in binders for 3DCP mixtures, where are grinded to **higher fineness**, additional effect can be gained by developing additional **flocculation** centers in early age mortar system.

The aim of the research

- Analyse the influence of different amounts and fineness of volcanic pozzolana in binary and ternary binders with OPC and LF on the properties of 3DCP mixtures.

Materials Used In The Study (A)

A. Binder's components

- C4 - Portland cement, CEM I 42,5R, Blaine 410 m^2/kg , C_3S – 58%, C_2S – 15%, C_3A – 8%, C_4AF – 10%
- LF - Limestone filler R0, Blaine 340 m^2/kg, D_{50} – 27 μm)
- VPI – Volcanic pozzolana, Blaine 1167 m^2/kg D_{50} – 4,6 μm (VP8) and 916 m^2/kg D_{50} – 7,6 μm (VP9)

Chemical composition by XRF

Material	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	K2O	Na2O	L.O.I.
C4	19.2	4.7	2.9	61.9	3.9	3.4	0.9	0.3	2.2
VP8	43.0	13.7	13.5	12.5	9.3	0.1	0.4	1.7	3.2
Limestone	11.4	2.6	1.6	41.0	3.1	0.7	1.3	0.1	37.9

Lambfjäll volcanic pozzolana (Iceland) XRD

Phase composition of volcanic pozzolana by XRD, Smart Lab TM (Rigaku)

- **Crystalline** (34%):

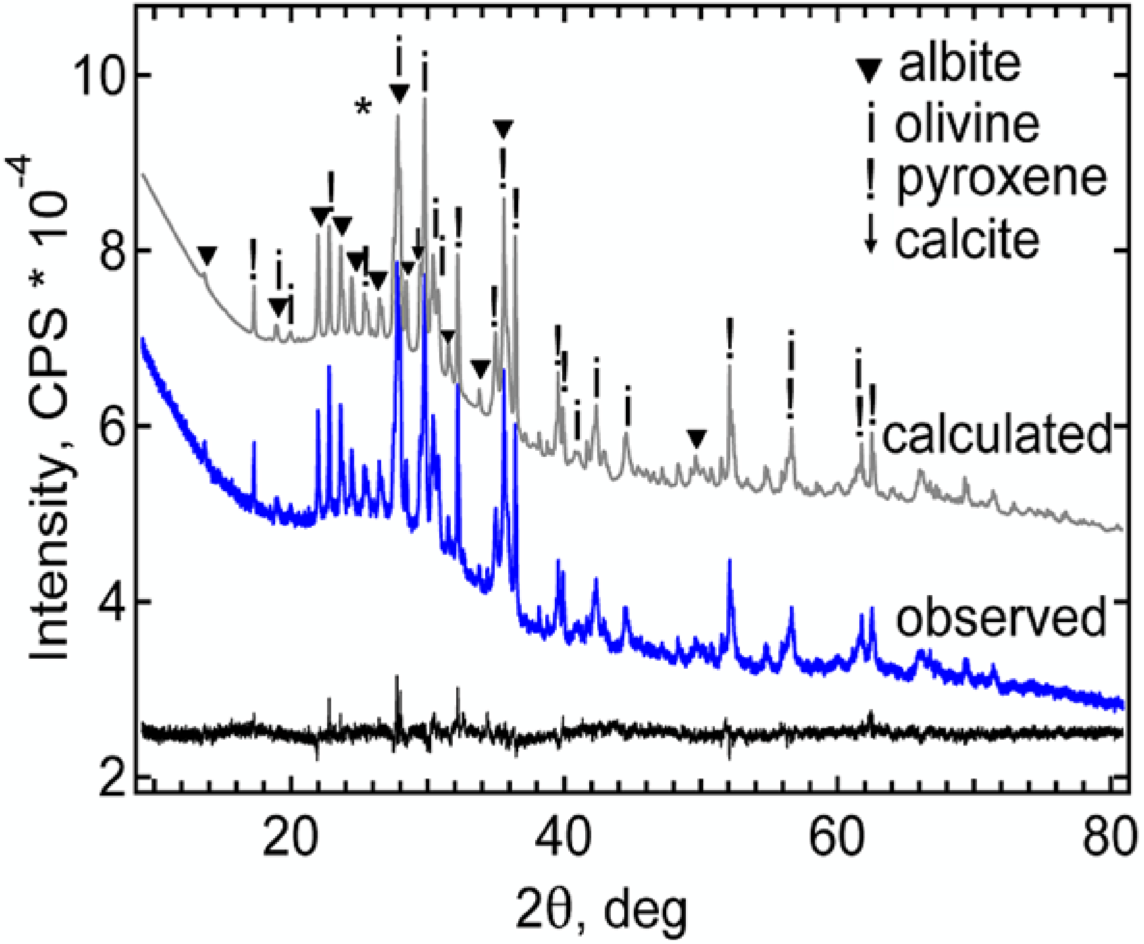
— Pyroxenes (augite,hedenbergite, clinopyroxene) - 14.0%;

— Feldspars, albite type (plagioclase,anorthite) - 11.0%;

— Olivines (Forsterite) - 8.0%;

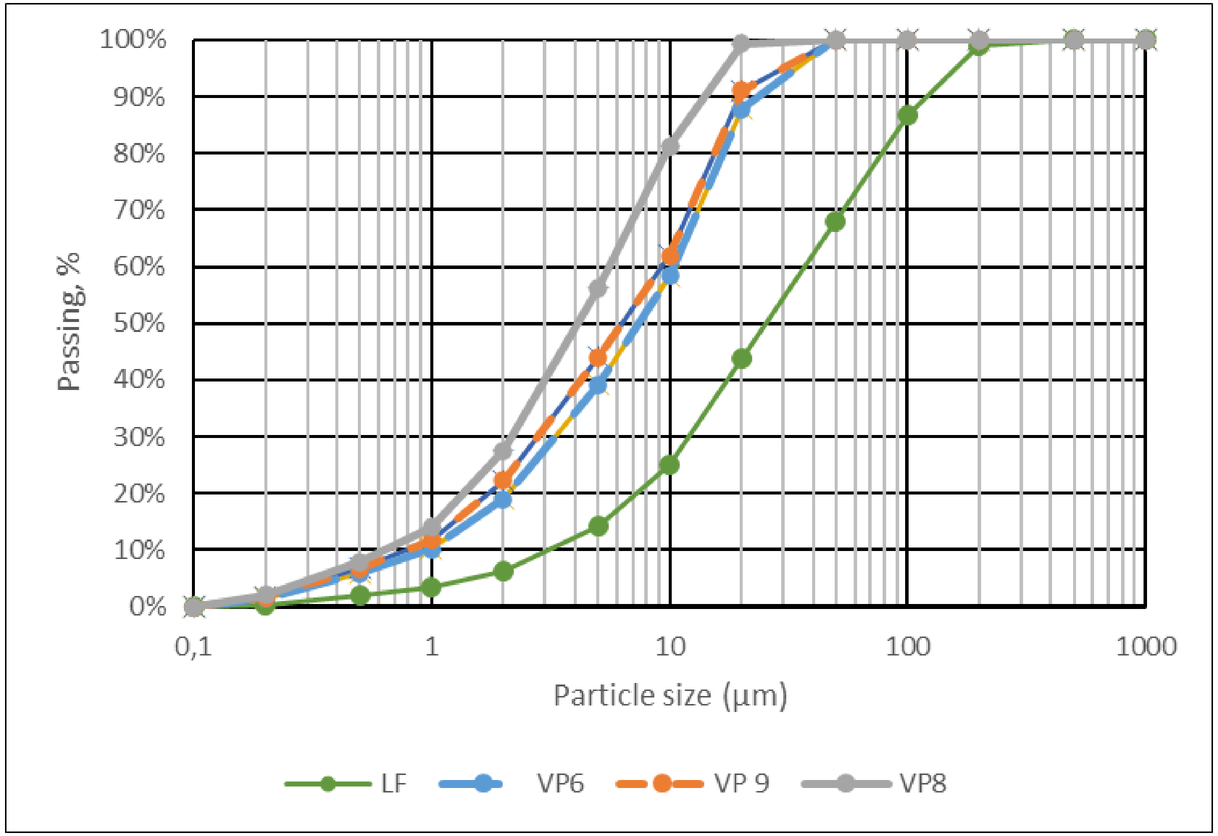
— Traces of calcite and quartz – below 1%;

- **Amorphous** (66%).

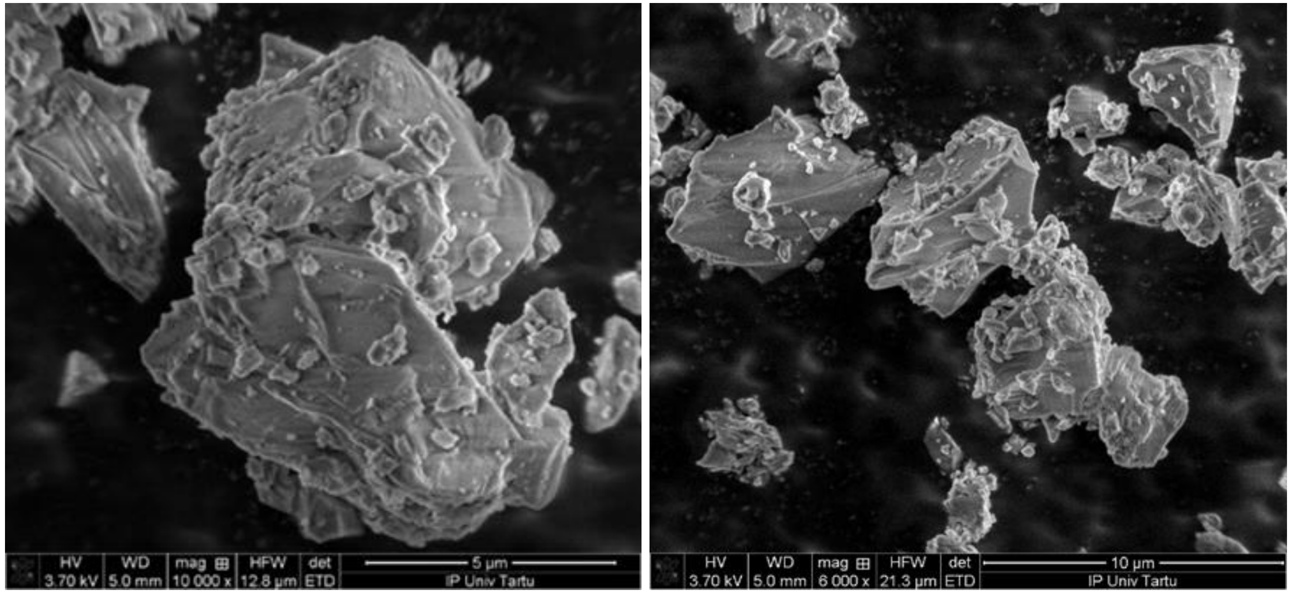


Lambfjäll volcanic pozzolana, LD and SEM

Particle size distribution of components by Laser Diffractometry Mastersizer 3000



Morphology and microstructure of volcanic pozzolana by SEM Helios Nanolab 600 (FEI)



Platy agglomerated particles of VP8 with fractured structure

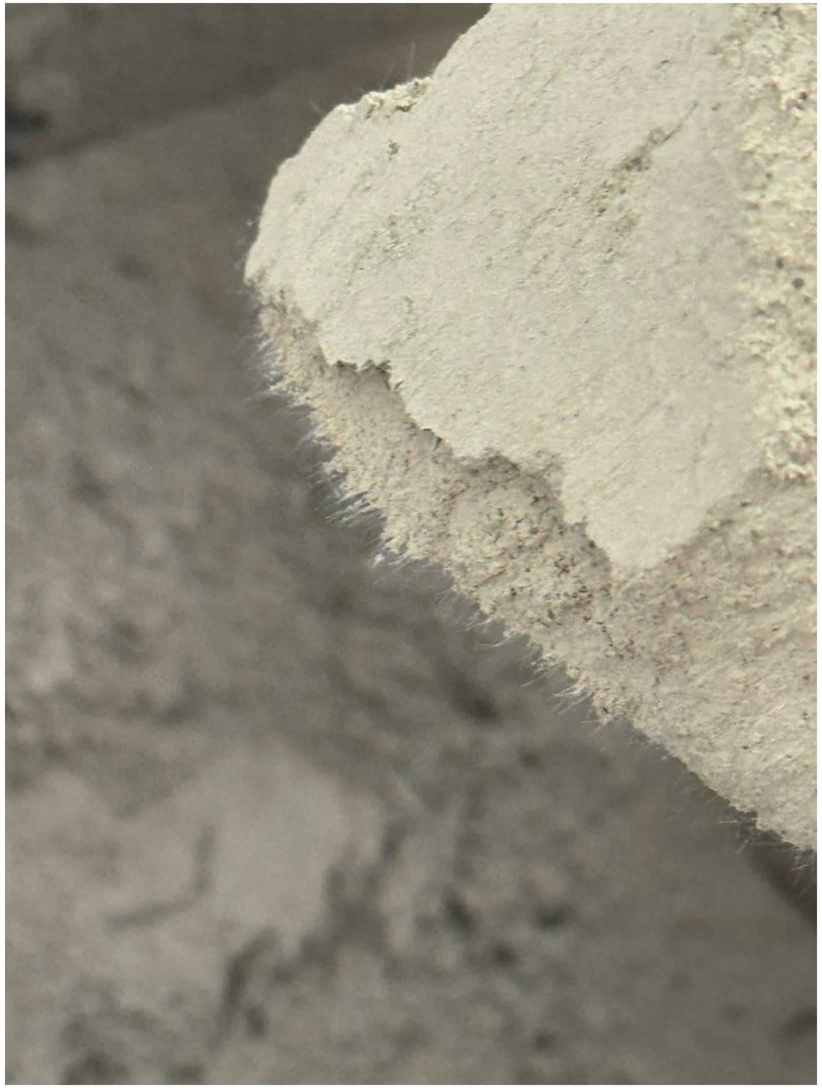
Materials Used In The Study (B)

B. <u>Aggregates and admixtures to the dry mix</u>

- Quartz sand from EMG Kuiv Liiv, fraction 0-0.5mm (SF) and 0.5-1.2mm (SC)
- Printing mixture modifying admixtures (dry powders)
  - Superplasticizer (SP) - Polycarboxylate ether PCE (up to 0.05% from the binder mass)
  - Viscosity modifying admixture (VMA) – hydroxypropyl methylcellulose Hpmc (up to 0.1% from the binder mass)
  - Fibres (PF) - Polypropylene fibres 6mm (up to 0.1% from the binder mass)

Mixture preparation methods

- Binary-binder mixtures OPC-VPI with replacements from 10 to 50% of volcanic pozzolana of two fineness (VP8 and VP9) were prepared in 2,5 kg batches in Hobart planetary mixer by homogenizing 4 min. at low speed.
- A semi-industrial 3DCP mixture, produced with ternary binder C4-50%, LF-30% and VP8-20% and two fractions of quartz sand SF/SC at 60/40% with S/B ratio of 1,0 in Mira Ehitusmaterjalid OÜ was used for technology testing.
- Specific properties of mixtures for 3DCP were obtained by adding small amounts of modifying admixtures during production of dry mixtures.

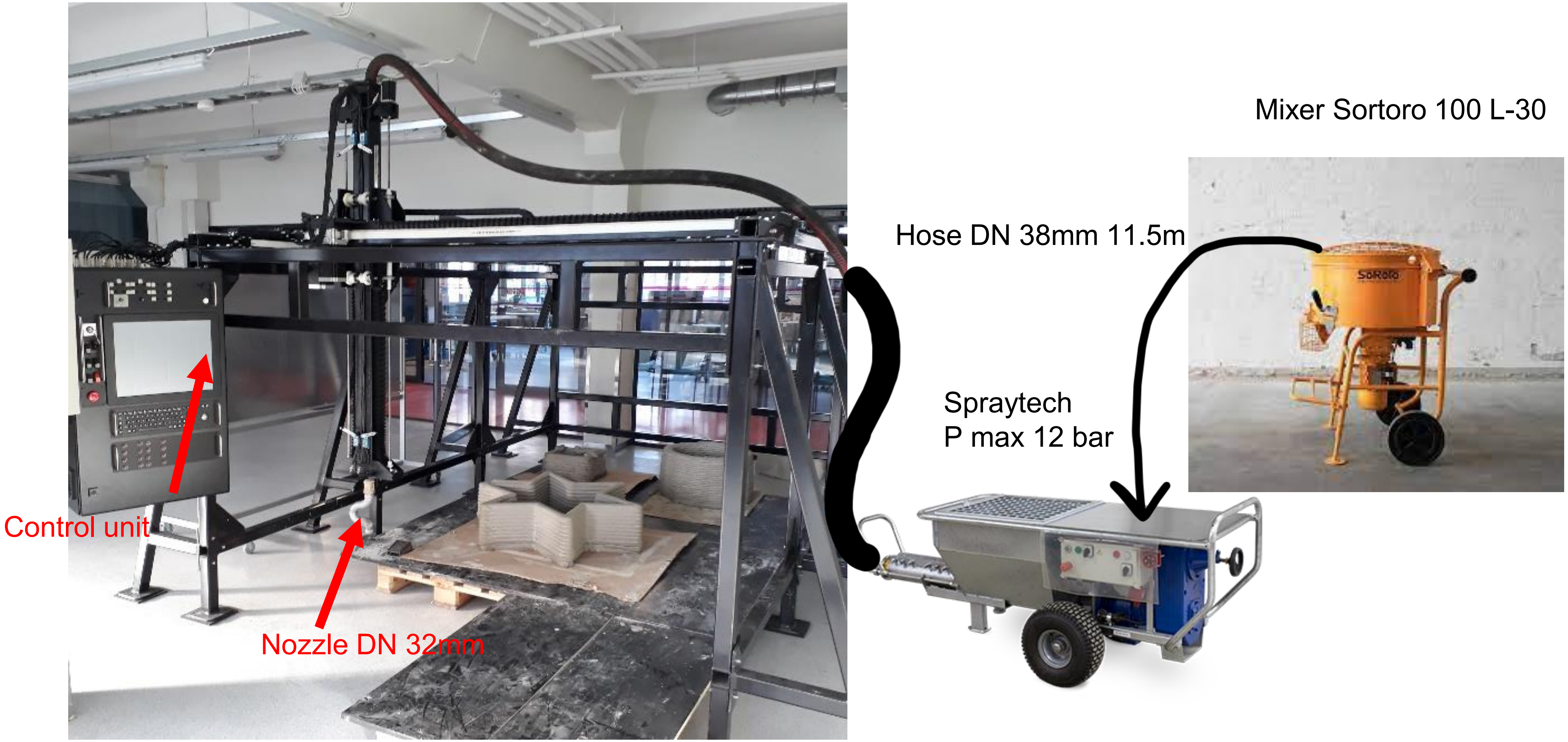


Testing methods of Mixtures

- Mixing in batches of 2,5 kg with water at W/M 17% took place in Hobart planetary mixer for 2 min. at low speed, and after pause for scraping the walls, for another 1.5 min. at low speed.
- A Hägermann cone flow of fresh mortar after 15/30 jolts was performed according to EN 1015-3.
- Specimens 40x40x160mm for estimating flexural and compressive strength were prepared by filling the moulds in 2 equal portions and compacting after each filling by dropping the mould from the height of about 20mm 10 times against a concrete floor and tested at the age of 1, 7, 14 and 28 days of curing at 20oC and 90% RH according to EN 1015-11.
- Technological tests were performed using printing facility set up in TTK UAS.
- A set of wall elements for landcellar was printed. The element itself served as integrated formwork to be filled with insulation layer and concrete.

Printing Facility Set Up

Technological tests were conducted at TTK UAS, where a Gantry-type of printing facility is set up.



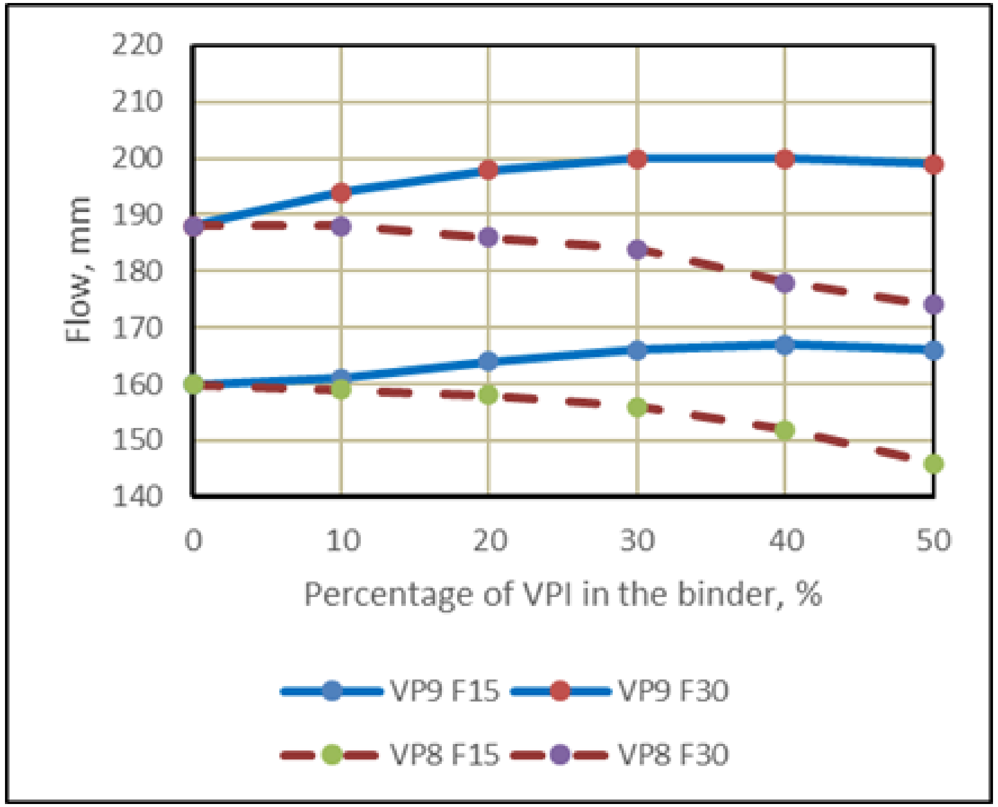
Properties Of Fresh Mixtures For 3D Concrete Printing

Performance of volcanic pozzolana in binary binders on properties of 3D concrete printing (3DCP) mixtures

Properties of fresh mixtures

Flowability – expresses plastic viscosity, shear stress, static and dynamic yield stress of fresh mixture. Measured by the flow of the Hägermann cone (EN 1013-5) after 15/30 jolts. W/M ratio 17%.

Influence of volcanic pozzolana of two fineness classes VP8 and VP9 on the flow of fresh mixture



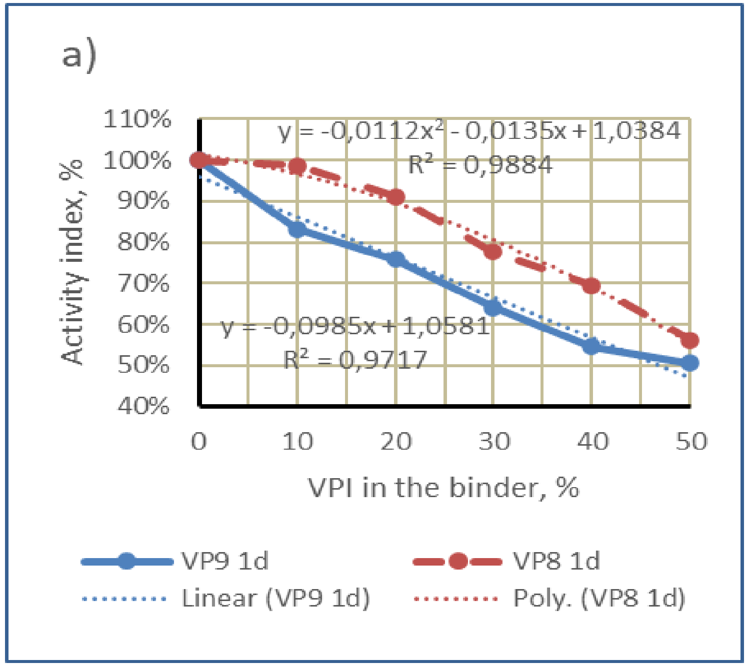
With the increase of amount of volcanic pozzolana in the Binder Flow decreases (VP8) and slightly increases (VP9).
At equal water content of 17% for both mixtures, it was not enough to lubricate finer particles of VP8, while for coarser VP9 it was sufficient

Properties Of Hardened Mixtures For 3D Concrete Printing

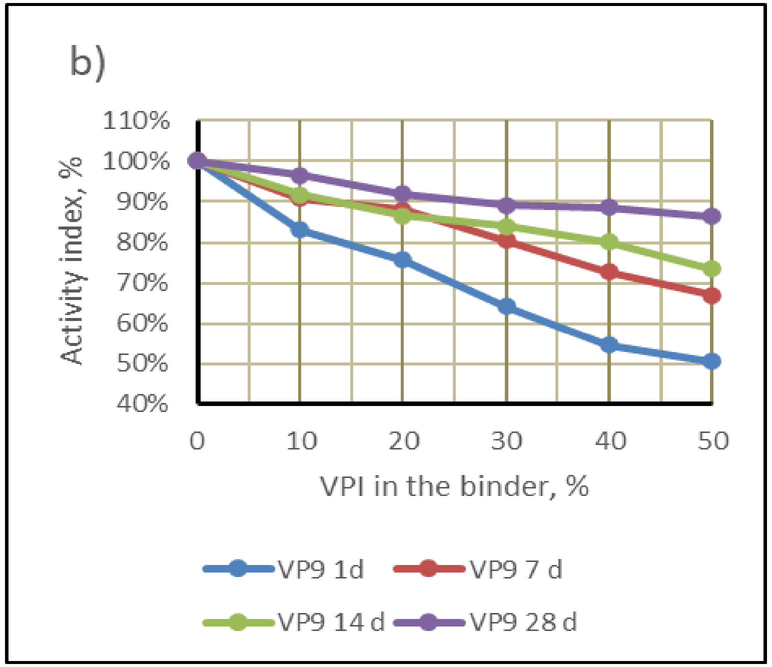
<u>Development of the strength of hardened mortars at different ages after curing at 90%RH and 20⁰C</u>

Changes in strength development are axpressed using Activity Index (AI) which is calculated as ratio of strength of the mortar with blended Binder to the reference Binder with no additive.

a) AI of VP8 and VP9 at the age of 1day



b) AI of VP9 at diferent ages of hardening



1d Strength of reference mortar decreases with the increase of amount of volcanic pozzolana in the binder by 50% (VP9) and 45% (VP8). With the age, the drop decreases.

- Increase of W/C ratio from 0,34 to 0,68 with the increase of VPI content in the mixture. Excess of unbound water in the cement stone increases capillarity.
- With age, the pozzolanic reaction gradually starts to have more influence on structure formation

Technological Properties of Mixtures for 3D Concrete Printing

Influence of volcanic pozzolana on technological parameters of mixtures for 3D concrete printing

Mortars of semi-industrial mixture MC4-15LF-10VP8 were prepared in Soroto 100 L-30 mixer with water to dry mixture ratio of W/M – 16% during 4 min before poured into Spraytec conveying pump and delivered to the printing nozzle DN32mm by a 11,5m long hose of DN 38mm. Flow of the mixture was measured and kept between 140-150mm which was suitable for fluent printing.

<u>The following parameters were analysed:</u>

- Extrudability – seamless filament production, expressed by **solidity ratio (SR=1000Q/Av),** dependant on material flow rate Q (ml/s), nozzle size A (mm^2) and speed v (mm/s). At measured flow rate of 86 ml/s, nozzle size of 804mm^2 and printing speed of 158 mm/s the solidity ratio was 0,68 which ensured required filament quality. Resulted filament dimensions were measured - width b=47mm and height h=10mm. Smooth, even glossy surface was obtained.
- Buildability – ability of deposited filaments to retain its geometry under the load from upper layers. A set of wall elements with a contour length of 10 667mm was printed and its parameters measured. The height of the wall element (H = 380mm) and number of layers (n = 38) was achieved.

Mixture with additive of volcanic pozzolana showed good buildability, caused by additional flocculation centres in the mixture, provided by finely ground volcanic pozzolana.

3D Concrete Printing Mixtures Use In Practice

Printed wall element for experimental 3D printed cellar



Concluding remarks

The study leads to the following findings

- The flow of the fresh mortar decreased with the increase of the content of finer volcanic pozzolana (VP8) in the Binder but increased in case of coarser one (VP9). It can be attributed to the enhanced absorption of mixing water by the fine-grained particles of volcanic pozzolana of platy morphology and increase of finer fractions in the mixture. At equal water content of 17% for both mixtures, it was not enough to lubricate all fine particles of VP8, while for coarser VP9 it was sufficient
- The strength of the hardened mortar, expressed by activity index, decreased with the increase of content of volcanic pozzolana in the binder. It can be explained by the increase of W/C ratio from 0,34 to 0,68 with the increase of VPI content in the mixture. Excess of unbound water in the cement stone increases capillarity. With age, the pozzolanic reaction gradually starts to have more influence on structure formation, where pores are gradually filled with products of pozzolanic reaction.
- Suitability of finely ground volcanic pozzolana in 3DCP mixes is mostly based on availability of additional flocculation centers, provided by fine particles of platy morphology in the fresh mortar.

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Thank you !