



Development of sustainable lightweight mixtures for 3D printing

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Additive manufacturing

Benefits of lightweight concrete in 3D printing:

- Decrement of unit weight,
- Improved thermal properties,
- Improved acoustic properties,
- Optimized performance of building envelopes
- Possibility to incorporate various (lightweight) waste materials.

3D printing with cement mortar

Source: gcc.sika.com





Experimental protocol

1. Development of lightweight printable concrete mixture (3DPLWC)
2. Development of ultra-lightweight foam concrete (ULFC) in-fill material
3. Thermal evaluations (best printing pattern - topology)
4. Final printing



Printable lightweight concrete mixture

Mixture composition:

Cement (CEM III 42.5 N)

Limestone powder

Basalt fibres

Sika PerFin 300 – defoaming admixture

Basalt fine aggregate

Waste glass aggregate (50 vol.-%, 100 vol.-%)

Expanded thermoplastic microspheres (ETM) – Expancel 461 WE 20d 36

True density = $36 \pm 4 \text{ kg/m}^3$



Brown soda-lime waste glass

Local recycling company



Washing (company)



Grinding



Sieving

Mix designation	Binder	Water	ETM	Aggregate	PerFin 350 [%]**	Fibres [%]**
G0	1*	0.35	0 (3%)	0.44	0.7	0.3

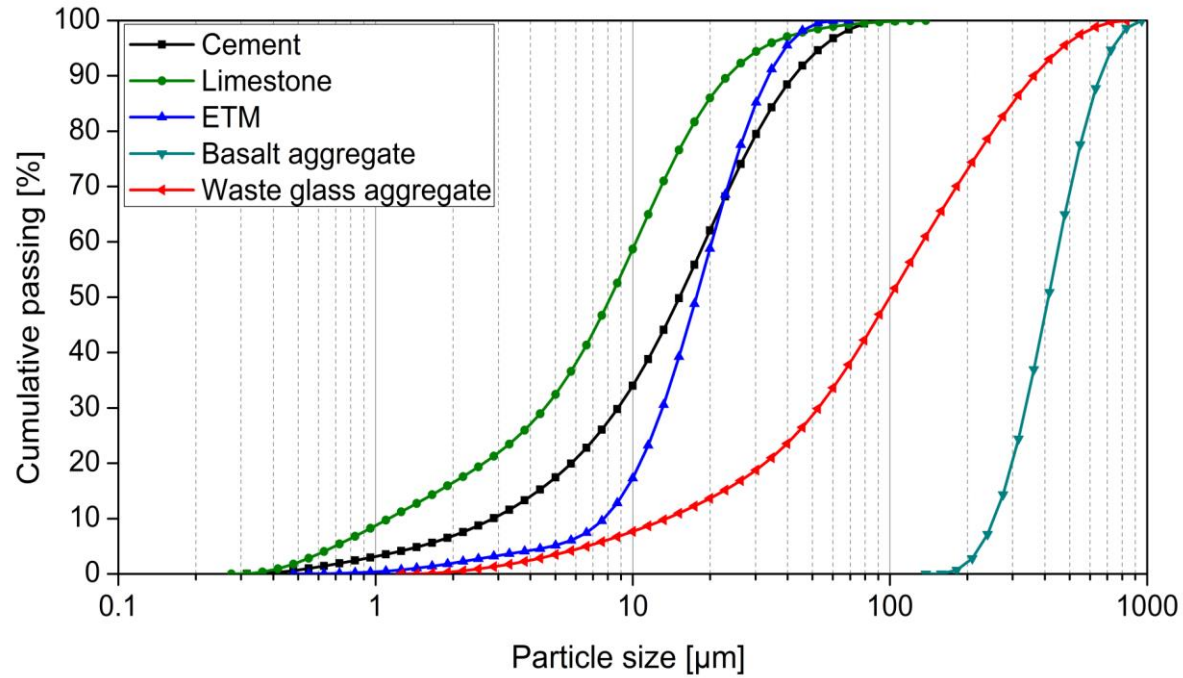
*cement:limestone ratio 1:0.52; **fixed 0.3 wt.-% **by weight of binder

Total 6 mixes: G0, G50, G100 + G0-ETM, G50-ETM, G100-ETM

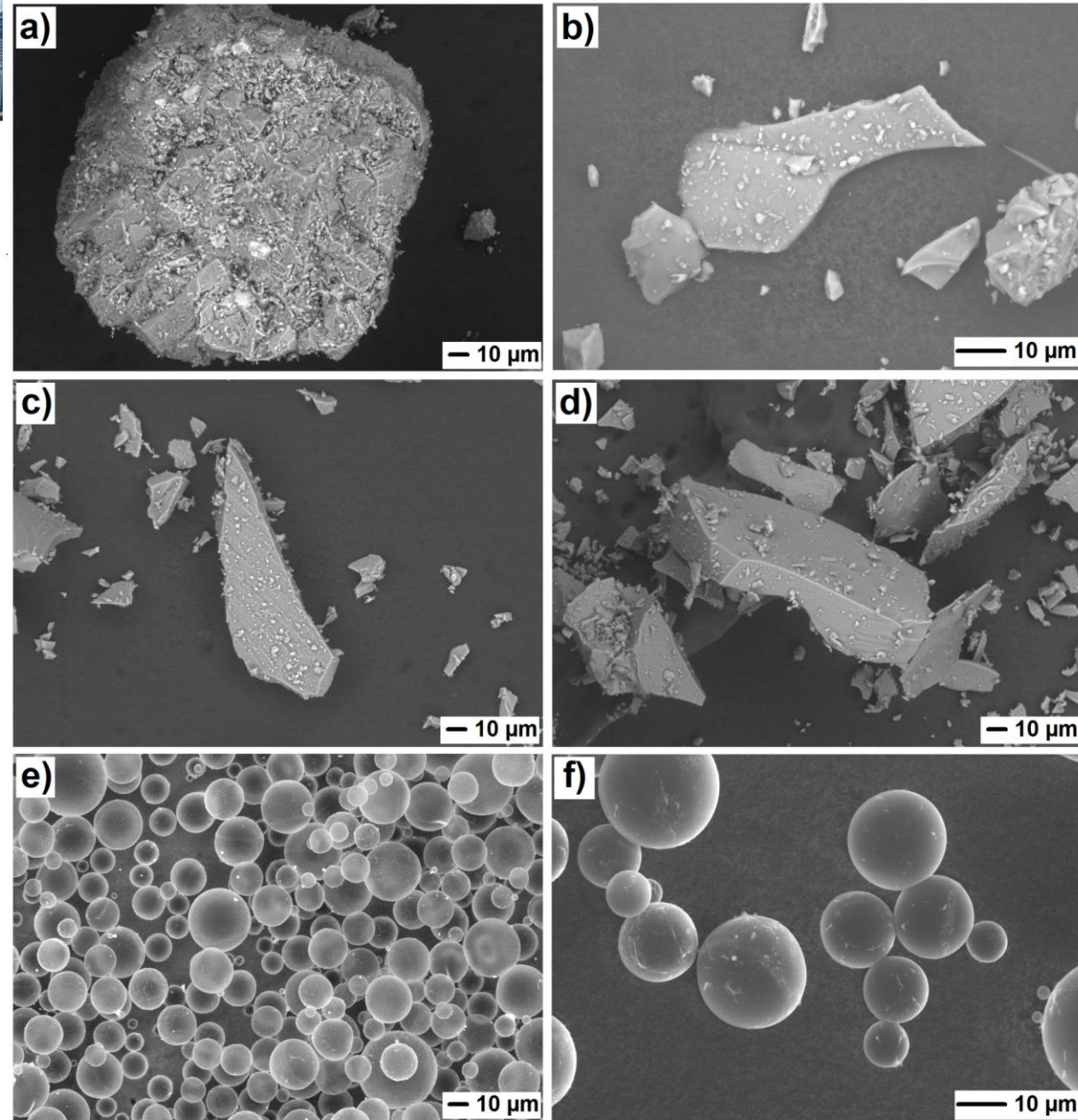


Materials

Particle size distribution of dry materials



SEM micrographs of basalt (a), WG (b-d) and ETM (e-f)





Testing protocol

Testing methods:

- Rheometer
- Mini-slump/flow-table
- Setting time
- Buildability (shape retention)
- Flexural and compressive strengths
- Thermal conductivity

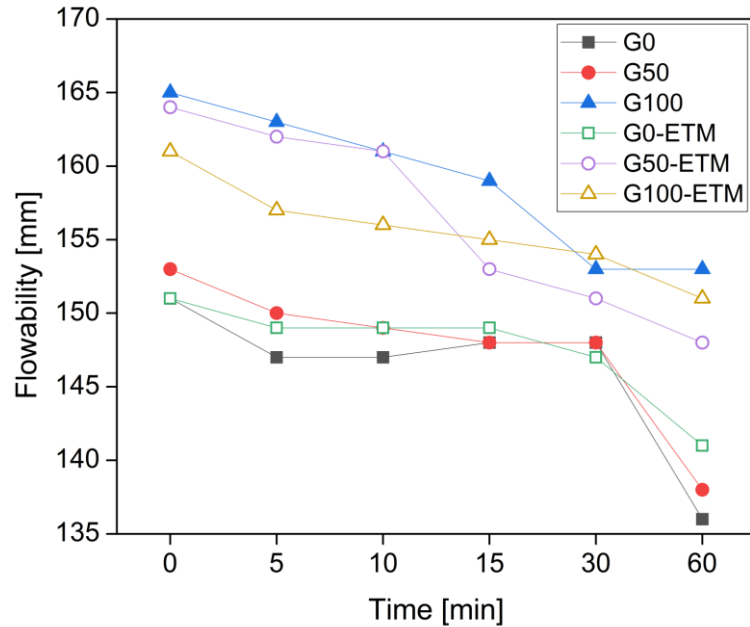


Printing proces of specimens and testing

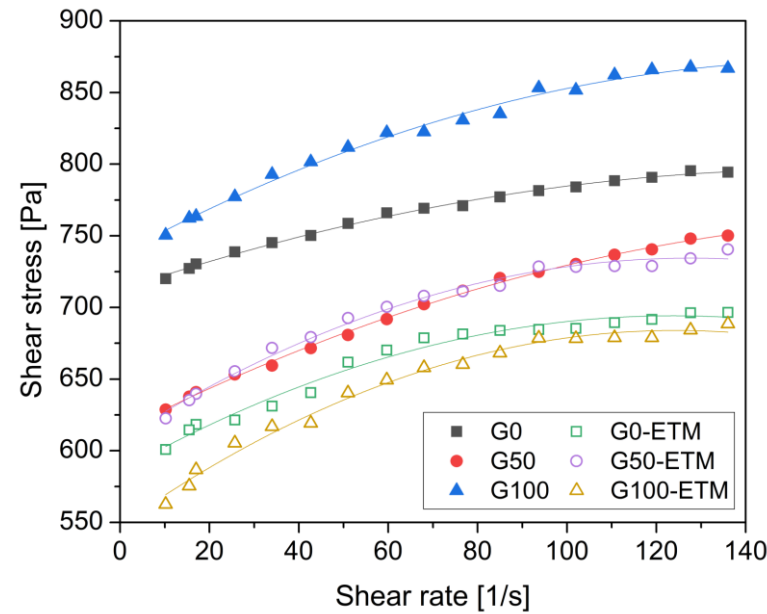


Fresh properties

Initial and final setting times of mixtures

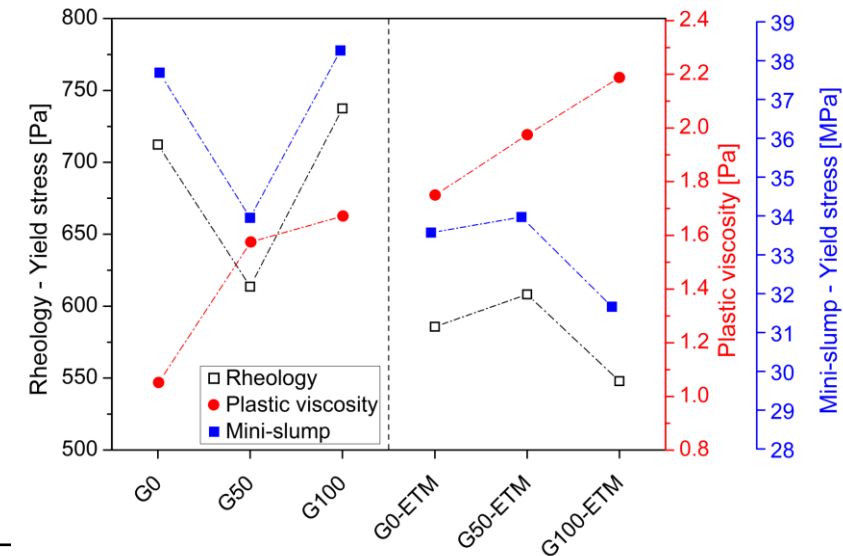
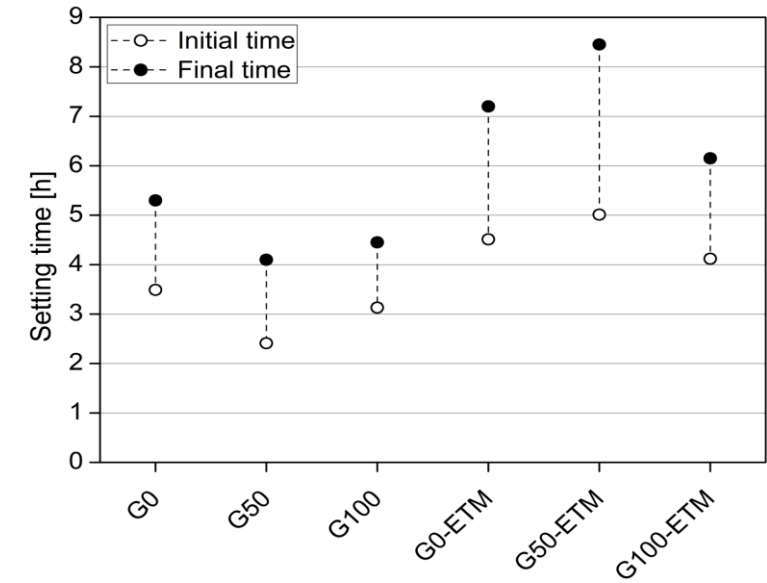


Flow of mixtures determined by flow-table method

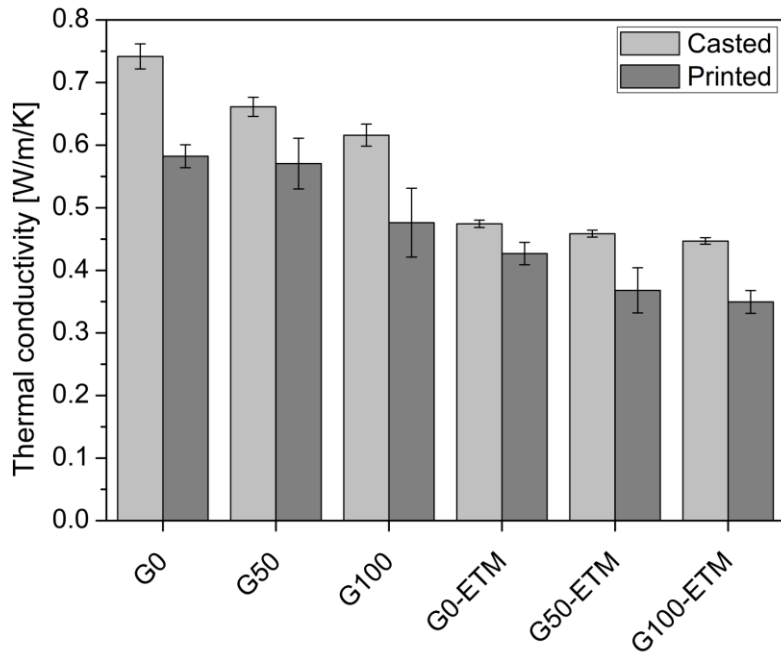


Shear stress of printable mixtures under a varying shear rate

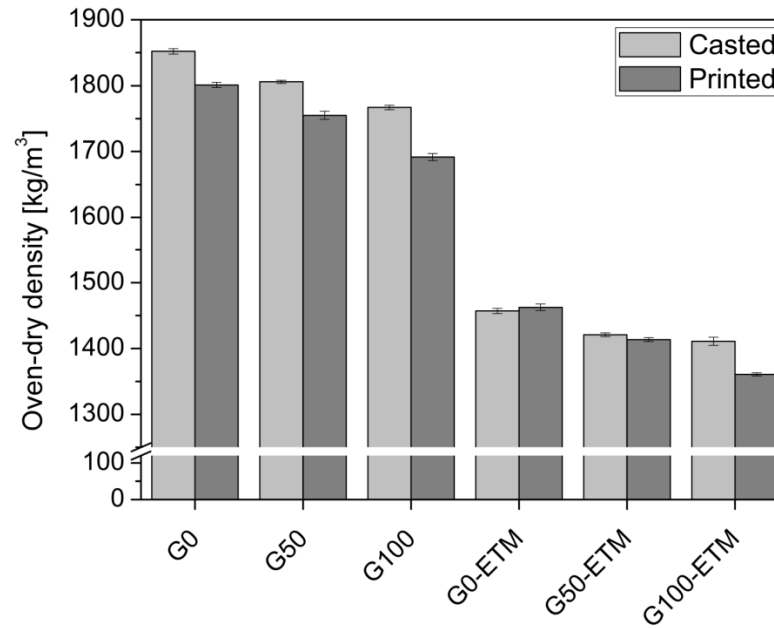
Rheological parameters calculated through the rheology tests and mini-slump test.



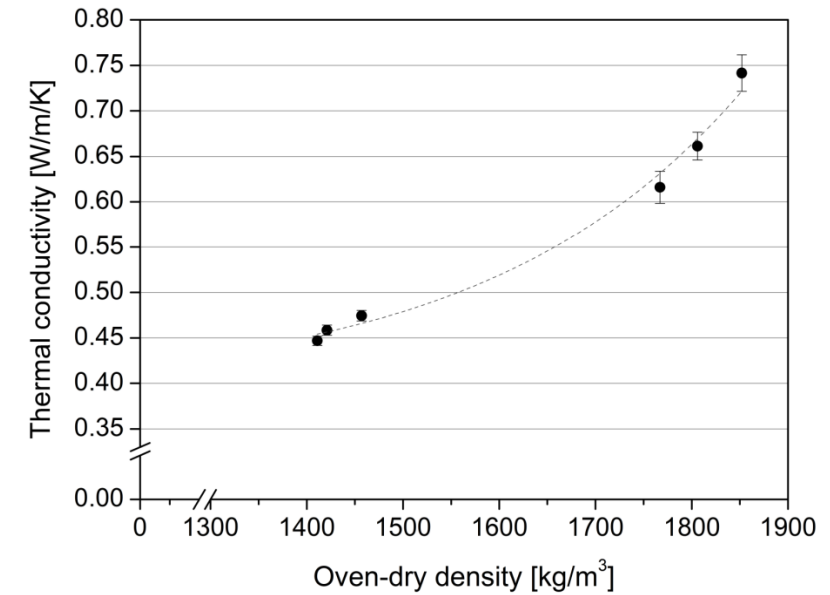
Thermal conductivity and density of 3DPLWC



Thermal conductivity of casted and printed specimens



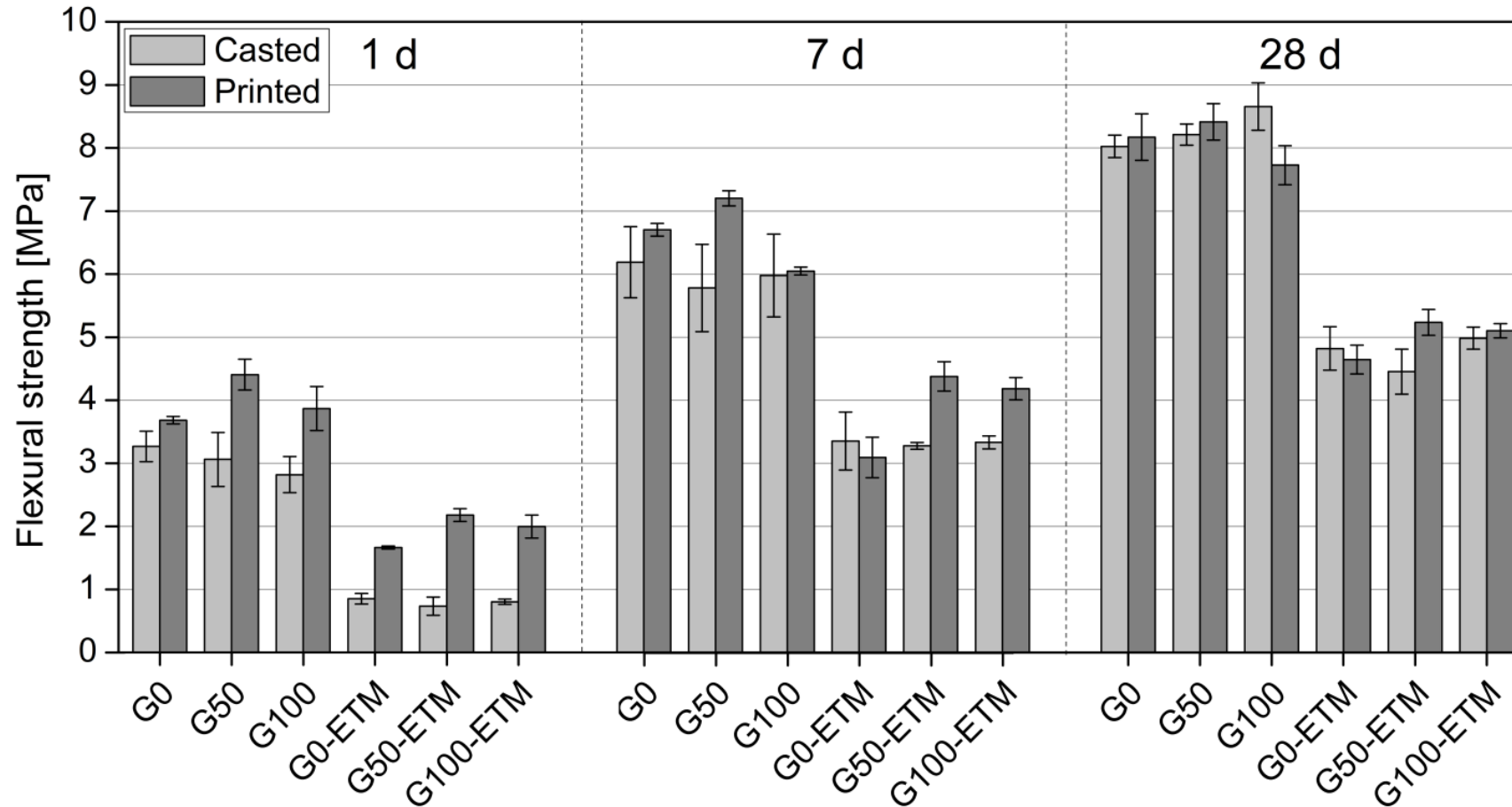
Oven-dry density of casted and printed specimens



Thermal conductivity vs oven-dry density



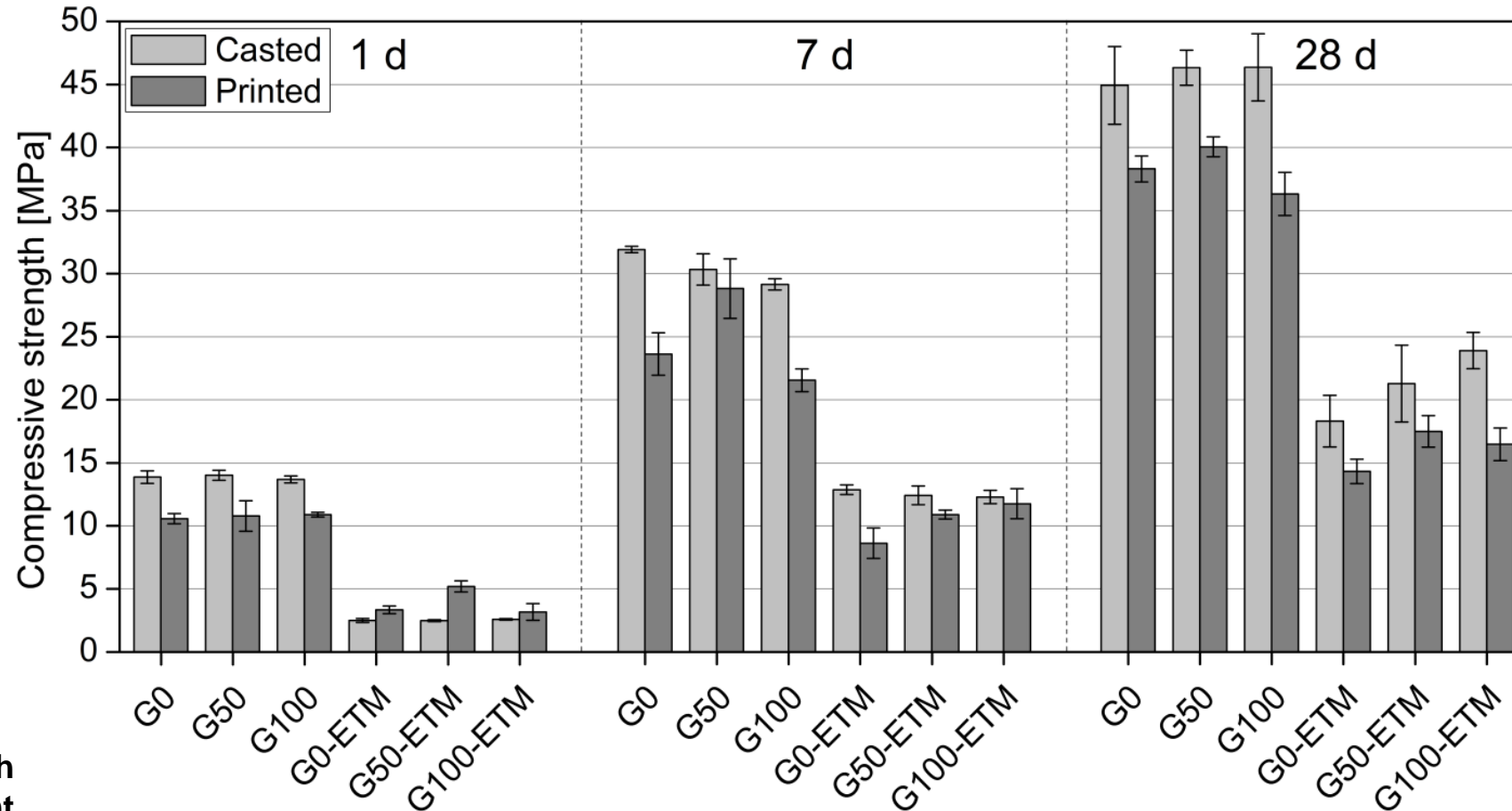
Flexural strength



Flexural strength
development



Compressive strength



Compressive strength
development



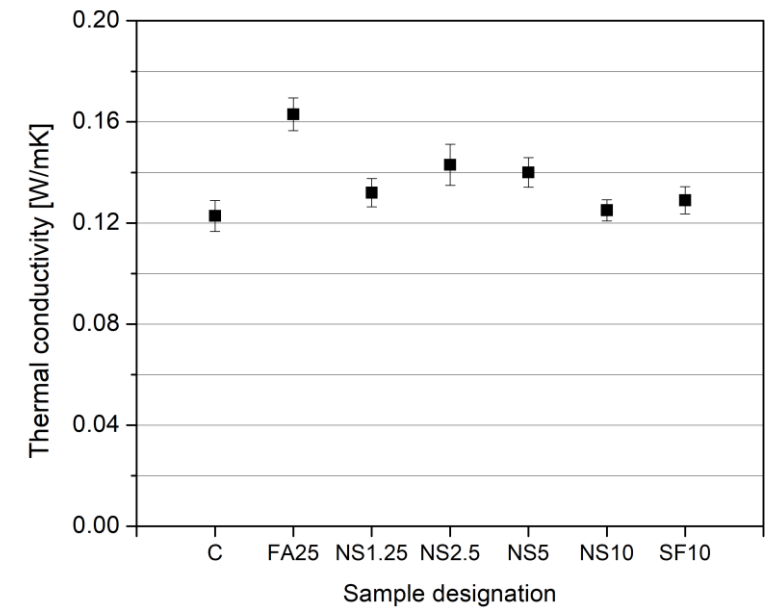
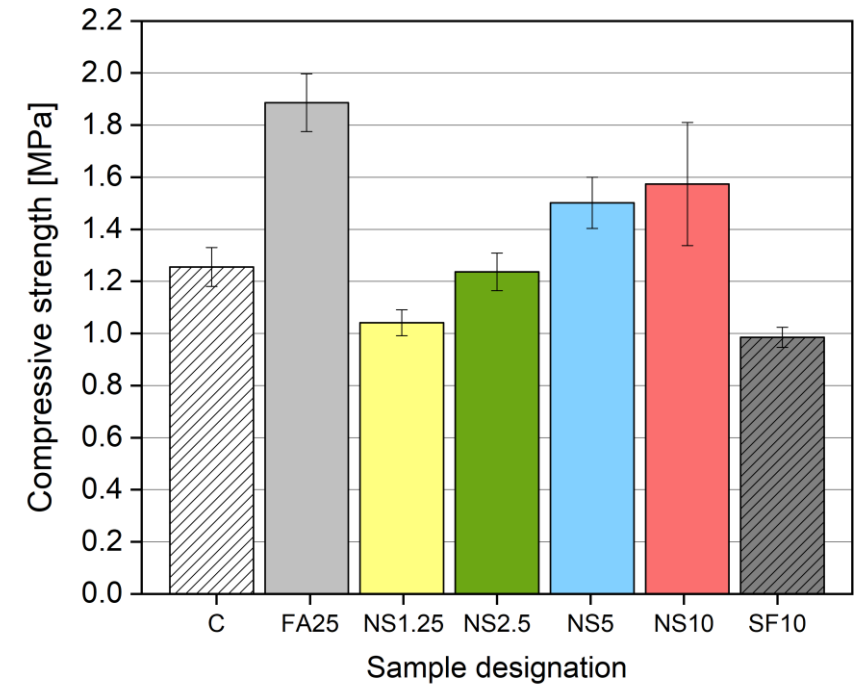
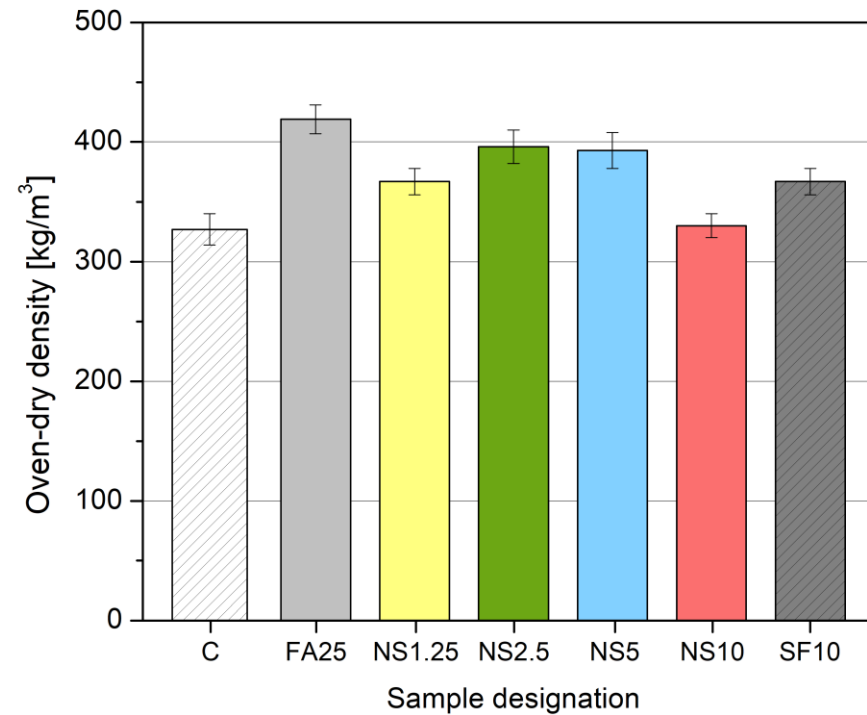
In-fill ULFC



Flow 49-55 cm

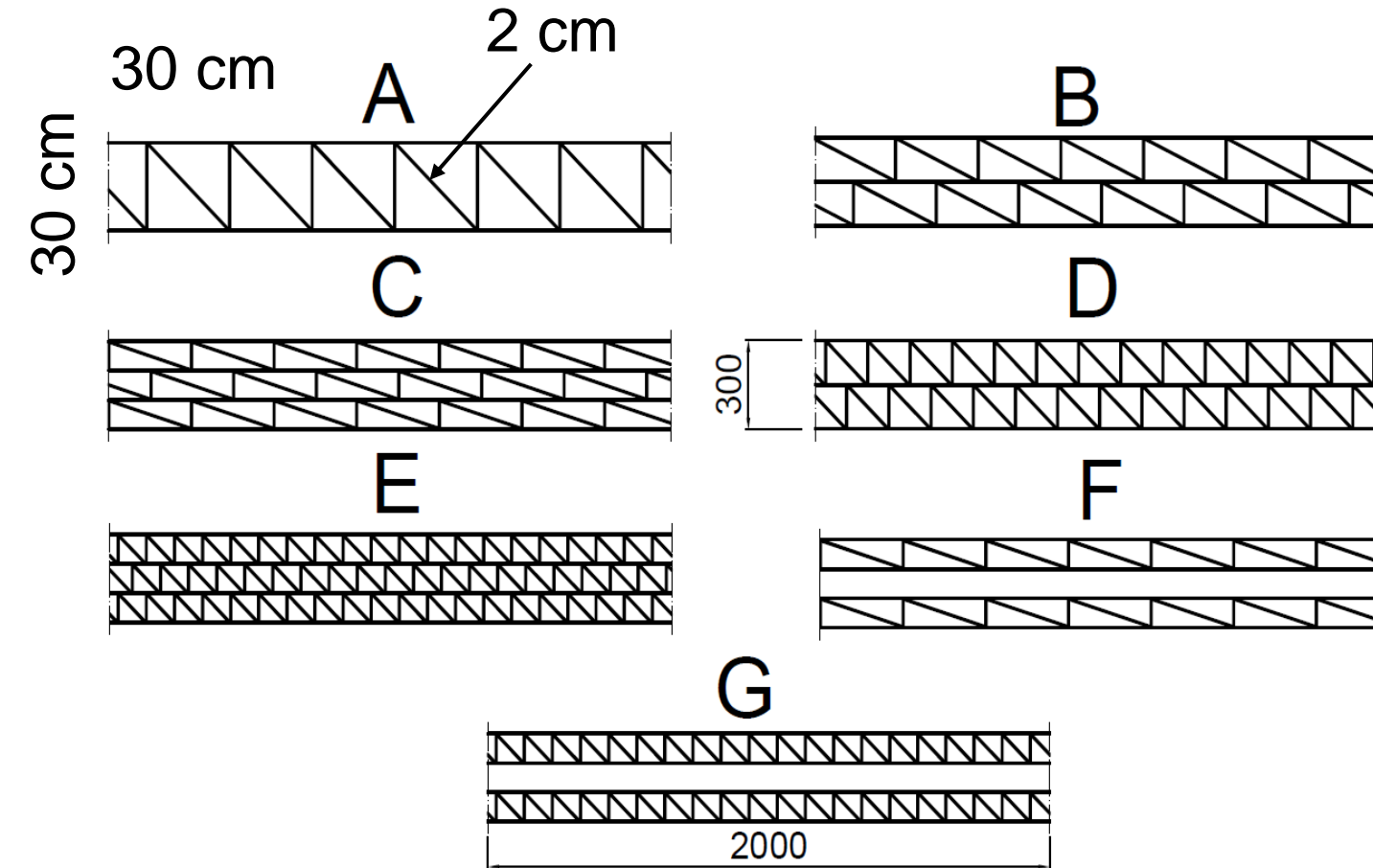
Mix composition [kg/m³]

Mix	Cement	FA	SF	NS (slurry) *	Fine Liaver aggregate	Water	SP	ST	Paste : Foam (volume)
C	240	-	-	-	60	96	1.6	1.0	1:3





Thermal transmittance of envelope



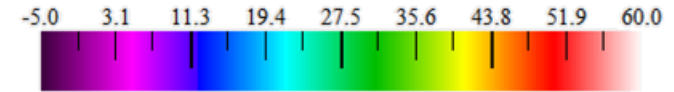
In-fill materials:

- Air
- Developed ULFC
- Polyurethane foam



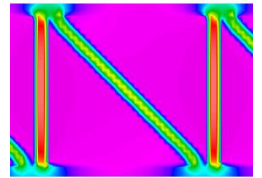
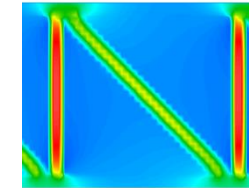
Thermal transmittance of envelope

W/m²

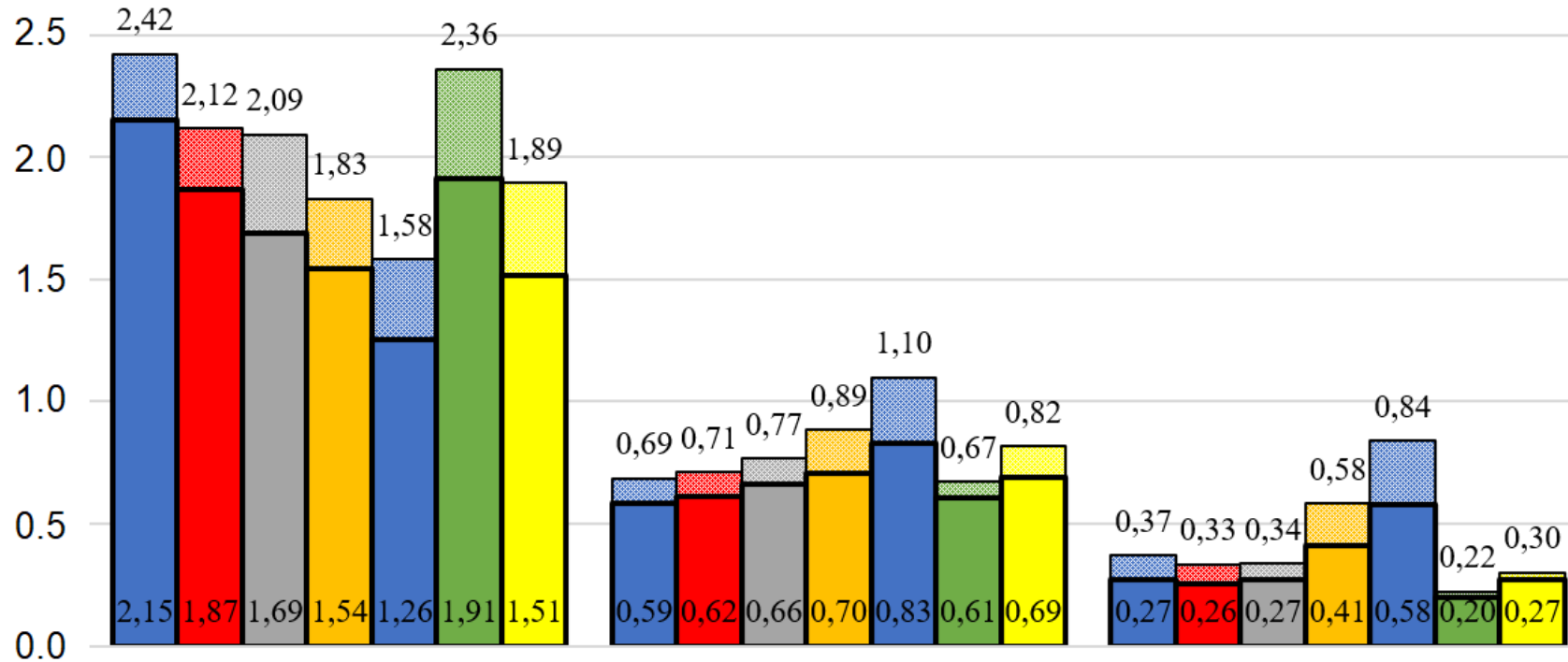
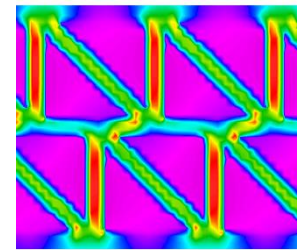
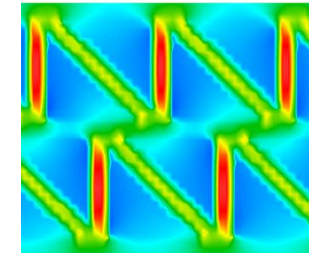


Foam concrete Polyurethane foam

Variant A



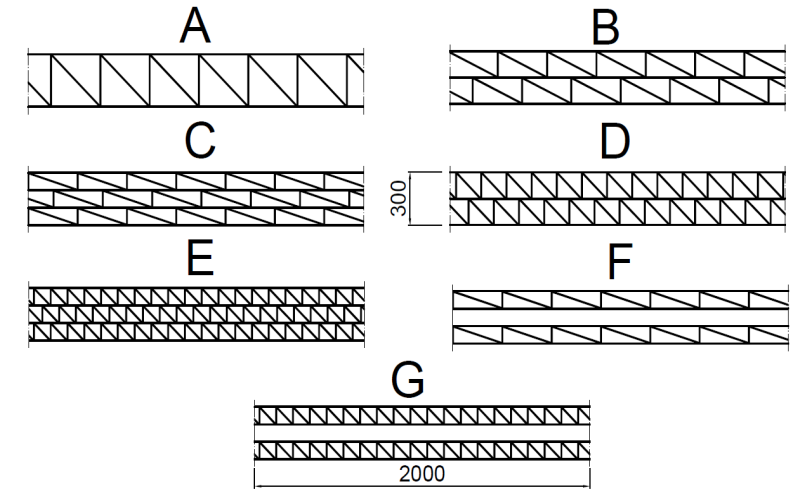
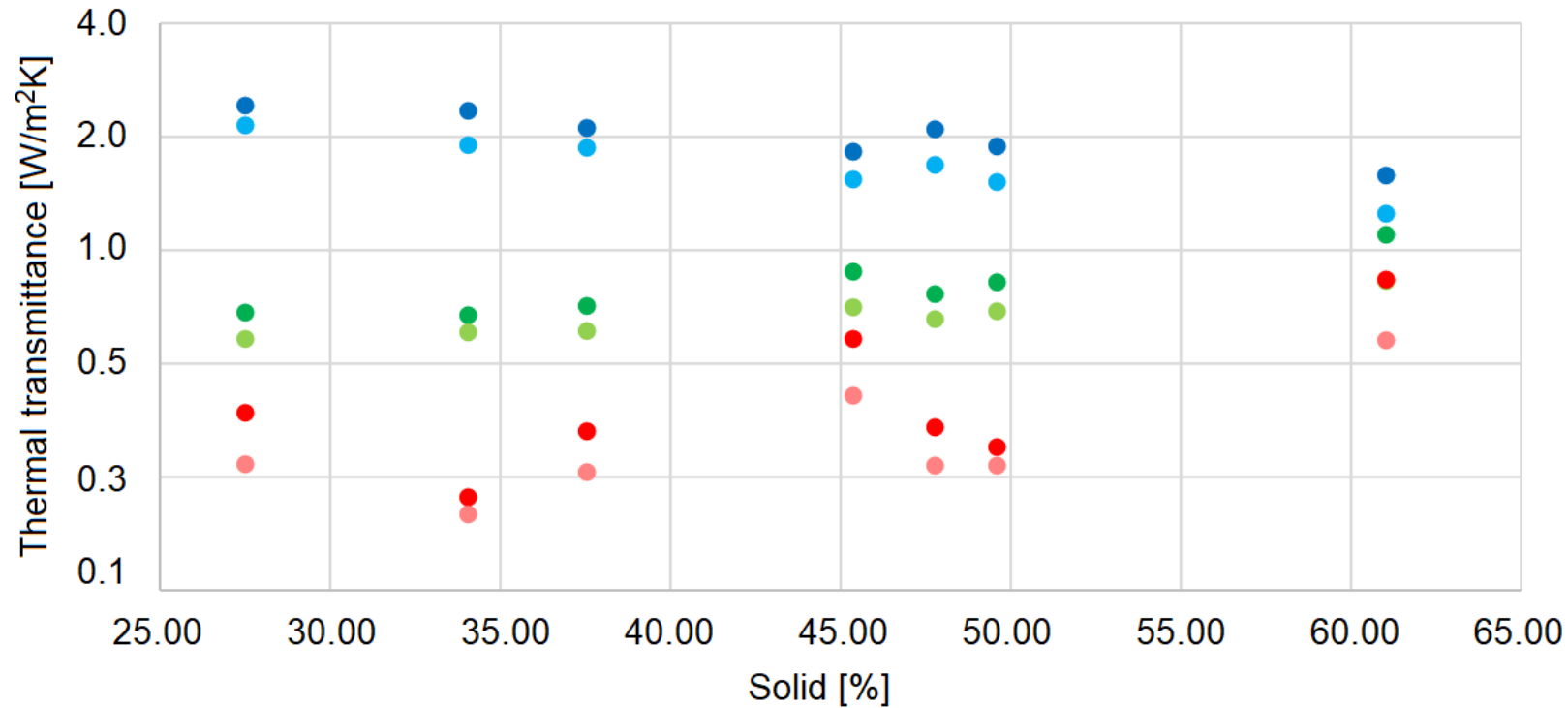
Variant D



- A/G0
- B/G0
- C/G0
- D/G0
- E/G0
- F/G0
- G/G0
- A/G50-ETM
- B/G50-ETM
- C/G50-ETM
- D/G50-ETM
- E/G50-ETM
- F/G50-ETM
- G/G50-ETM



Thermal transmittance of envelope



- G0 / Air Void
- G0 / Foam concrete $\lambda=0.14$ W/(mK)
- G0 / Polyurethane foam $\lambda=0.03$ W/(mK)
- G50-ETM / Air Void
- G50-ETM / Foam concrete $\lambda=0.14$ W/(mK)
- G50-ETM / Polyurethane foam $\lambda=0.03$ W/(mK)



Testing of printed wall elements





Conclusions

1. Waste glass (WG) as well as expanded thermoplastic microspheres (ETM) can be successfully used to produce 3DPLWC, however, minor mixture composition modifications are required to replace conventional (basalt aggregate) with WG up to 100 vol.-% to satisfy the flowability requirements of 3D printing process.
2. Incorporation of fine WG aggregate results in shortening of the initial and final setting times of printable composites. Addition of ETM, due its inert nature, results in retardation of mixtures setting times.
3. The inclusion of ETM can lead to improved final buildability of the printed objects by modifying the rheological behaviour of mixtures. After incorporating ETM spheres, G50-ETM shows the most preferable shape retention.
4. 3DPLWC can be used as a core element to print out building envelopes with satisfactory thermal performance. The U-value can be controlled by proper topology and thickness of printed element.
5. Further studies towards mechanical (anisotropic behaviour) and static performance are required.



Thank you for your attention

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