DEVELOPMENT OF LIGHTWEIGHT 3D PRINTED CONCRETE WALL SYSTEM

Pawel Sikora[1,*], Karla Cuevas[1], Jarosław Strzałkowski[2], Ji-Su Kim[1], Mehdi Chougan[3], Seyed Hamidreza Ghaffar[3], Sang-Yeop Chung[4], Mohamed Abd Elrahman[5], Didier Lootens[6], Dietmar Stephan[1]

[1] Building Materials and Construction Chemistry, Technische Universität Berlin, Germany
[2] Faculty of Civil Engineering and Environmental Engineering, West Pomeranian University of Technology Szczecin, Poland
[3] Department of Civil and Environmental Engineering, Brunel University London, Uxbridge, Middlesex, UB8 3PH, United Kingdom
[4] Structural Engineering Department, Mansoura University, Mansoura City, Egypt
[5] Department of Civil and Environmental Engineering, Sejong University, Seoul, Republic of Korea
[6] Sika Technology AG – Central Research, Zürich, Switzerland

Corresponding author:
pawel.sikora@zut.edu.pl

INTRODUCTION

Additive manufacturing (AM), also referred to as 3D printing, is a technology that allows building physical components of a three-dimensional object in a layer-by-layer manner. It is one of the most rapidly developing field in civil engineering and is considered one of the key pillars of the Industry 4.0 concept. AM technology provides new freedom in concrete design with a resource-efficient use of materials at the same time. Building envelopes have to meet tightening thermal performance requirements in order to follow EU nearly zero-energy buildings strategy. Therefore, composite building envelopes consisting of materials with low thermal conductivity are encouraged. AM technology enables to develop wall systems with complex topologies. However, to achieve this goal there is a strong need to balance between cavities and 3D printed material as well as decide on proper in-fill material.

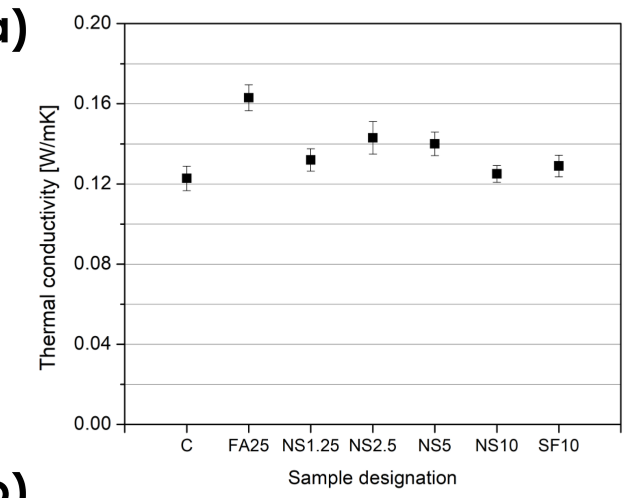
AIM OF THE RESEARCH AND EXPERIMENTAL PLAN

The purpose of this work is to develop a sustainable 3D printable wall system composed of lightweight and ultra-lightweight cementitious composites. For this purpose printable lightweight aggregate concrete (load-bearing/structural material) as well as ultra-lightweight foam concrete (in-fill material) were developed.

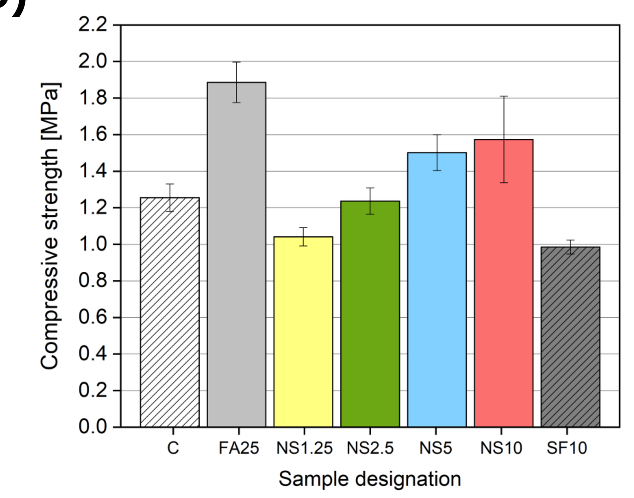
DEVELOPMENT OF ULTRA-LIGHTWEIGHT IN-FILL MATERIAL

As an in-fill material ultra-lightweight foamed concrete mixtures composed of cement, silica fume, nanosilica, fly ash and foam were developed.

a)



b)



c)

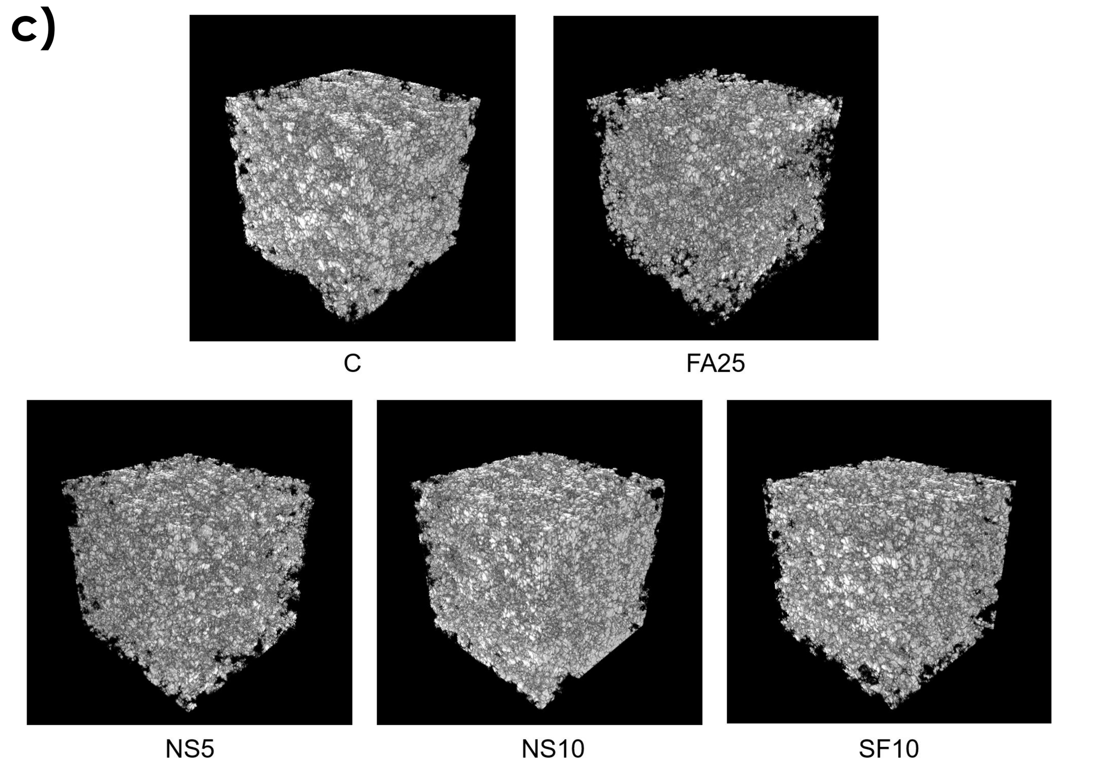


Figure 1. Thermal conductivity (a), compressive strength (b) and pore structures (c) of developed ultra-lightweight foamed concretes (C – control, FA – mix containing fly ash, NS – mixes containing nanosilica, SF – mix containing silica fume).

DEVELOPMENT OF PRINTABLE LIGHTWEIGHT CONCRETE

Eco-friendly 3D printable lightweight concrete mixture containing binder compsoed of cement and limestone filler, waste glass aggregate and expanded thermoplastic micropsheres was developed (Figure 2).
For comparison purposes reference printable mixture containing basalt aggregate was developed (Table 1).

Table 1. Mass-related mixing ratio.

Mix designation	Binder	Water	Expanded microspheres	Basalt aggregate	Waste glass aggregate	Defoamer [%]*	Fibres [%]*
Normal-weight mix	1	0.35	0	0.44	0	0.7	0.3
Lightweight mix	1	0.39	0.03	0	0.44	0.7	0.3

* By mass of binder

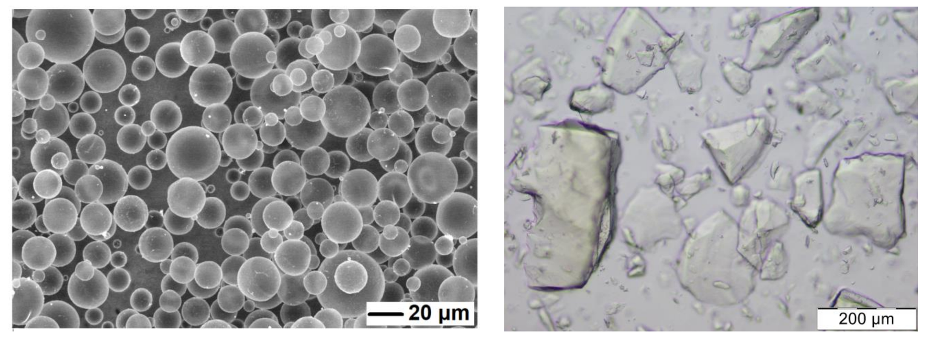


Figure 2. SEM micrograph of expanded microspheres (left) and optical microscope micrograph of waste glass aggregate (right).

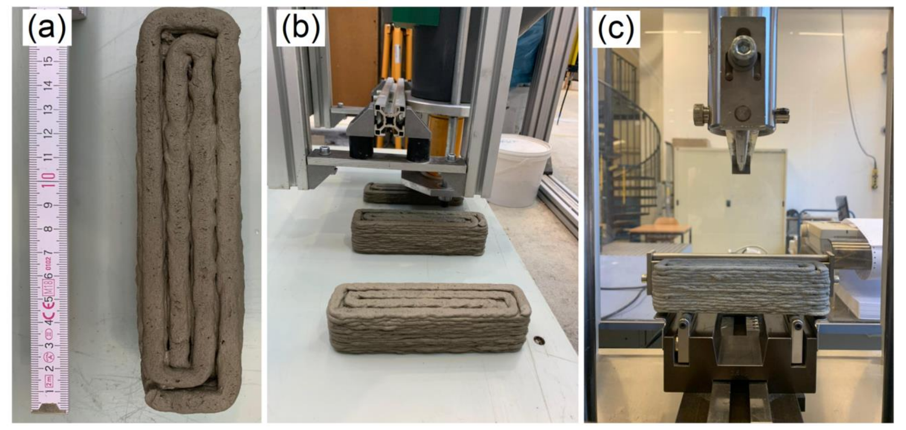


Figure 3. Printing process of specimens (a) and (b) and flexural strength determination (c).

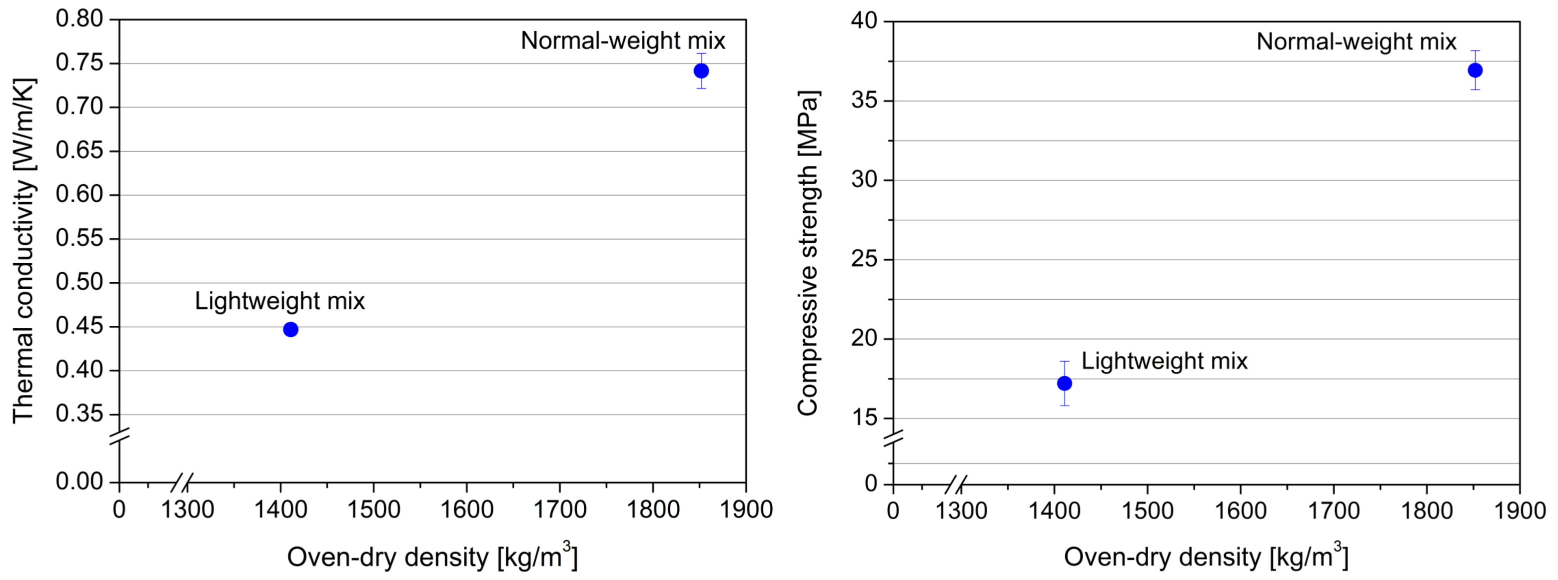


Figure 4. Thermal conductivity of casted specimens determined by Transient Plane Source (TPS) method as a function of oven-dry density (left) and compressive strength (14 d) of specimens as a function of oven-dry density (right).

CONCLUSIONS

Various wall configurations were designed and their thermal performance was evaluated. Through experimental and numerical simulation studies, the most thermally-effective wall system was developed in order to meet the thermal transmittance values regulated by EU towards applying them as a building envelopes.

THERMAL PROPERTIES OF WALL SYSTEM

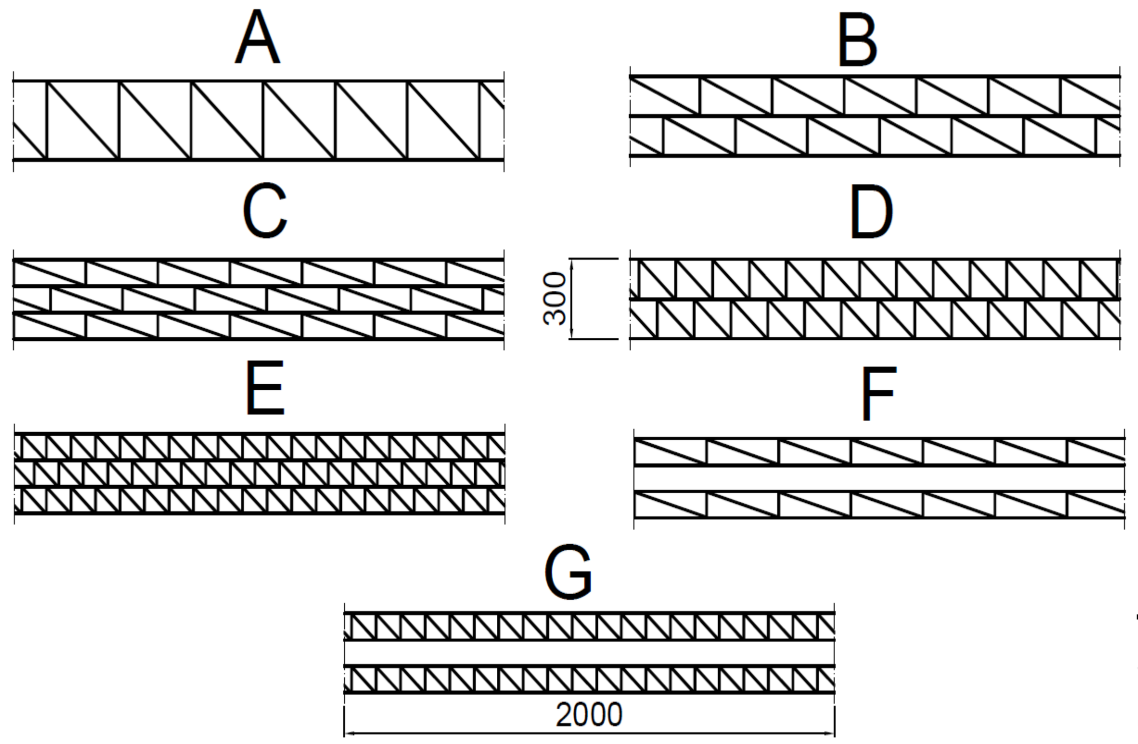


Figure 5. Types of evaluated wall systems.

Types of in-fill materials evaluated:

- Air,
- Ultra-lightweight foamed concrete,
- Polyruethane foam.

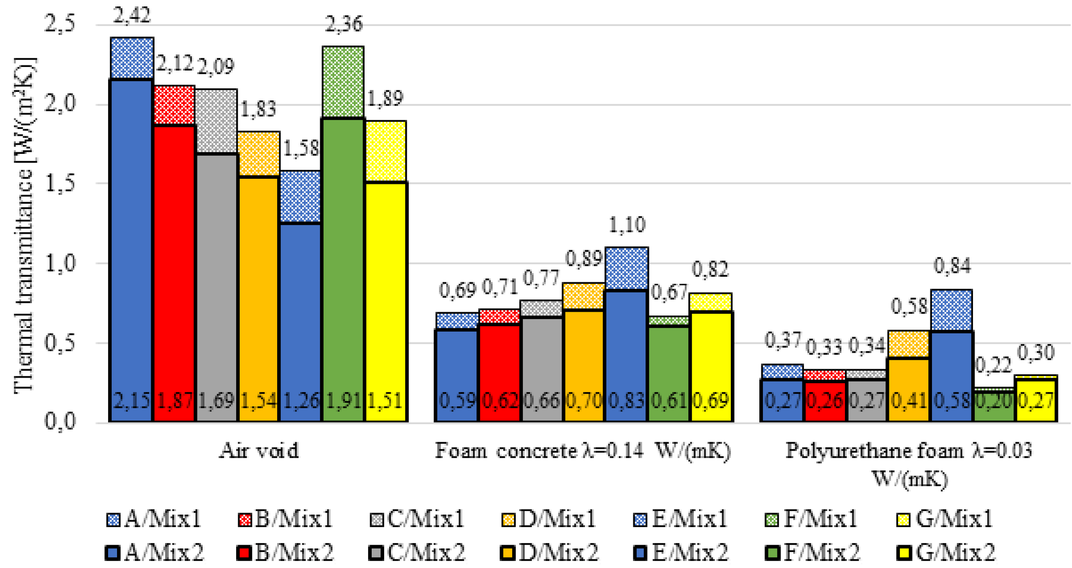


Figure 6. Thermal transmittance of wall systems with 3D printable normal-weight (mix 1) and lightweight (mix 2) structural layers and various in-fill materials.

Table 2. Heat flux density of the most thermal effective variants (A, E) designed with printable lightweight structural layer.

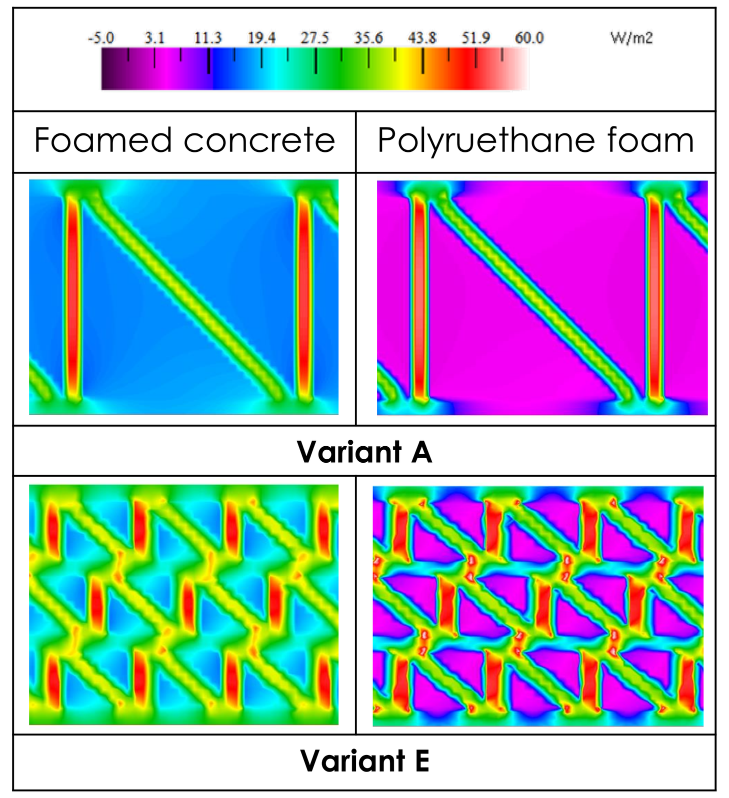


Figure 7. Example of the 3D prined lightweight structural element (Variant A).

ACKNOWLEDGEMENTS

This project received funding from the European Union's Horizon 2020 research and innovation program, as part of Marie Skłodowska-Curie Grant agreement no. 841592.

Project website: www.ultralightcon3d.com