Building materials for 3D print

I Wawrek

1 Technical University of Košice, Slovakia, Faculty of Civil Engineering, Institute of Architectural Engineering, e-mail: igor.wawrek@tuke.sk

Abstract. The paper maps the current level of knowledge in 3D printing of construction objects. It introduces different approaches to creating wall structures of two world companies dealing with the problem of 3D print. It confronts their solution with the normative requirements for the territory of the Slovak Republic valid after 2021. It also presents proposals for possible improvement of the thermal-technical properties of the perimeter wall, modification of the design of the internal structure and properties of the printed material towards the normative requirements.

1. Introduction
The beginning of the use of concrete in construction practice was a major breakthrough in construction. It allowed to build higher, lighter structures and span longer distances. It has given freedom to architectural design and in many cases concrete become a material that defines architectural styles or ages. In combination with steel reinforcement, it became a representative of a progressive way of construction. The development of concrete as a building material, in its various transformations, has essentially never ended. It even appears to be one of the best usable materials for 3D printing in buildings. This is evidenced by its wide application in many world research centres dealing with the implementation of printing into the construction process.

2. Current way of construction
One of the main disadvantages of 3D printed structures is their low thermal insulation property. This weakness of the structure is caused by the design of the shape of the inner wall structure, which in most realized examples is adapted to create ideal paths for the print head and to help shorten the construction time of the object. It focuses only on one of the advantages of 3D printing technology, namely the speed of construction. However, 3D printing technology has other advantages, such as accuracy and the ability to shape the layered object freely. That are precisely these advantages that underpin the proposal for adjustment, which are presented in this research. In order to start thinking about possible solutions to a problem, we need to define the requirements that the solution must meet.

3. Requirements
The design of the modification has to meet the requirements for perimeter structures according to the standard STN 73 0540-2: 2012 [4].

According to energy efficiency, buildings are divided into energy classes. By the end of 2015, it was sufficient to reach the upper limit of Class B (global primary energy indicator) for new buildings for their successful certification. From January 1, 2016 to the end of 2020 it is necessary to get to class A1 and after 2020 to class A0. Table 1 shows the heat transfer coefficient U requirements for building envelope structures set by the standard.
Table 1. U values for building envelope structures according to STN 73 0540-1: 2012.

| BUILDING STRUCTURES                        | U (W/(m².K)) |
|--------------------------------------------|--------------|
| CREATING PACKAGING CONSTRUCTION OF THE BUILDING | Do 31. 12. 2015 / Od 1. 1. 2016 / Od 1. 1. 2021 |
|                                            | NED ...B / UNB ...A1 / TNB (PD) ...A0 |
| Exterior wall, pitched roof with slope above 45° | 0.32 / 0.22 / 0.15 |
| Flat and sloping roof (up to 45°) ceiling above exterior | 0.20 / 0.10 / 0.10 |
| Ceiling over unheated space | 0.25 / 0.15 / 0.15 |
| Windows and glazed walls, skylights | 1.40 / 1.00 / 0.60 |
| Door with / without vestibule | 3.00/3.00 / 2.50 / 3.00 / 2.00 |
| Average U building (for shape factor 0.3 to 1.0) | 0.39 - 0.58 / 0.27 - 0.38 / 0.20 - 0.25 |

4. Increasing effectivity of building materials

If we look at traditionally used building materials such as brick can be seen as its size, shape and internal structure gradually evolved figure 1. This development was motivated by the ever-increasing requirements for streamlining the building's perimeter structures. The peripheral structures created by 3D printing are currently at the beginning of their development. By knowing how to modify traditional materials to improve their thermal insulation properties, we are able to propose possible solutions for improving the properties of 3D printed structures.

Modification of the building elements to improve their thermal insulation properties is realized in traditional materials mainly in three ways.

Adjusting the internal structure of the preform

By keeping the original material by adjusting the inner structure of the preform we can increase its insulating property. The increase in thermal resistance creates a reduction in heat transfer through the enclosed air cavity. Such higher the density of these cavities is in the fitting as the higher its resulting thermal resistance R is.

Increasing the thickness of the structure

while maintaining the original material and the spatial arrangement of the internal structure of the preform. By increasing the parameter d (thickness of the structure), the thermal resistance R of the given cross-section resulting from the relation $R = d / \Delta (W / (m².K))$ is directly proportional to it.

Insulation

of the fitting with another material with a higher thermal resistance parameter R (the material is applied to the outer wall of the cross-section or directly inserted into the cavities of the internal structure, thus increasing the total sum of resistances $R = R_1 + R_2 + R_3...$ of the perimeter wall construction.

By adjusting the properties of the material

of which the block is made to improve the thermal insulation properties of the product. By reducing the thermal conductivity coefficient $\Lambda$, we increase the ability of the material to withstand the temperature changes induced by heat conduction.
Design optimization of wall construction for printing combining above mentioned methods. Comes from knowing way of increasing insolation values properties of traditional materials.

5. Material requirements
For optimal material design it was necessary to determine the input requirements to suit the way of construction by 3D printing.

Requirements:
- flow through nozzle d = 10mm
- set speed of solidification
- consistency
- strength
- use of recycled materials as concrete admixture
- reducing the proportion of cement in concrete

Figure 2. The final form of the concrete mix.

The mixing ratio of the resulting concrete mixture, which meets predefined material requirements, came from experimental verification figure 3. At the moment when the mixture met the properties of the 3D printing machine layering, it began to improve its thermal insulation properties. The polystyrene granulate was mixed into the concrete mixture in various percentages to the total weight of the sample of figure 3.

The samples were then measured by the pulse method at different time intervals during their drying time. Comparison of the measured values of λ can be seen in the graphical representation of figure 4 for concrete mortars and figure 5 for concrete pastes. The measured values show that the use of polystyrene granulate as a filler indeed increases the thermal resistance R for the material. By comparing the results of measurement of thermal conductivity and compressive and tensile strength of given samples, we are able to focus more precisely the area of development of concrete material for printing in terms of its more effective action in the peripheral bearing structure.

6. Impulse measure method
Measurement is based on analysis of the temperature response of the analysed material to heat flow impulses. Heat flow is excited by electrical heating of resistor heater inserted into the probe which is in direct heat contact with the tested specimen. Evaluation of thermal conductivity and volume heat capacity is based on periodically sampled temperature records as function of time, provided that heat propagation occurs in unlimited medium.
Figure 3. Prepared samples for pulse measurement.

Table 2. Measured properties of tested materials.

| Paste | Cca 28 days | | | | Volume weight | lambda |
|-------|-------------|-------------|-------------|-------------|-------------|-------------|
| Bend | std | pressure | std | | D | |
| f_c | MPa | MPa | | | MPa | |
| 0 | 2,80 | 1,30 | 106.6 | 4.9 | 2150 | 0.231 |
| 20 | 3.00 | 0.35 | 35.9 | 3.5 | 1660 | 0.358 |
| 40 | 2.60 | 0.20 | 21.8 | 1.9 | 1250 | 0.209 |
| 60 | 2.15 | 0.55 | 6.2 | 0.8 | 1025 | 0.149 |
| 80 | na | na | na | na | 325 | 0.131 |

| Mortar | | | | | | |
|-------|-------------|-------------|-------------|-------------|-------------|-------------|
| Bend | std | pressure | std | | | |
| f_c | MPa | MPa | | | | |
| 0 | 7.85 | 0.70 | 53.8 | 2.1 | 2090 | 0.208 |
| 20 | 4.60 | 0.30 | 23.1 | 1.5 | 1635 | 0.169 |
| 40 | 2.50 | 0.20 | 8.0 | 1.1 | 1205 | 0.138 |
| 60 | 0.75 | 0.05 | na | Na | 710 | 0.103 |
**Figure 4.** Graph of measured values for mortar.

**Figure 5.** Graph of measured values for pastes.
7. Conclusion
The measured values of the thermal conductivity coefficient $\lambda$ in combination with the measured values of strength are the starting points for a more precise orientation of the future research of building material for 3D printing. The measured values confirmed the assumption of an increase in the thermal resistance $R$ of the material using polystyrene granulate. The measurement results will be used as input values in the future simulation of the perimeter wall for printed buildings.

8. References
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