SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

Action number: CA17133

STSM title: ***Examining the potential of 3D printing of hemp-based biocomposite building materials as a nature-based solution for circular economy in cities***

STSM start and end date: 03/02/2020 to 09/03/2020

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PURPOSE OF THE STSM:

To evaluate the potential of 3D printing of environmentally friendly and carbon negative hemp-clay biocomposite building material which could be a nature-based solution for circular economy, by using agricultural waste of hemp cultivation and implementing it in the building's envelope. This was done using the WASP clay printer at the Alchemia-Nova institute in Austria.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

The lab work consisted of examining printed and handmade samples of varying hemp-to-clay mass ratios. The hemp hurds were finely shredded down to an average length of 2 mm to be able to be streamed in the extruder (the manufacturer advised not to stream particles larger than 5 mm). As a reference, two samples of pure clay were printed first, and the proportion of hemp in the clay matrices was increased stepwise. The highest fraction of hemp in the clay mix which could still be streamed through the extruder was 10%. In addition, hand-made samples with hemp fractions higher than 10% were prepared in order to have a complete sample series to test for physical, thermal and mechanical properties, while assuming that these could be printed using a larger machine which is suitable to process such samples, as well as lime-based binders.

For each type of mix between two and four samples were printed/cast manually and were left to dry at room temperature. After 6 days, preliminary thermal conductivity and specific heat capacity of samples with hemp fraction of 0-6% were measured using a KD2-PRO thermal analyzer [1] (Fig.1) ne. The rest of the samples needed more time to dry and were shipped to Israel, where further measurements on all mixes will take place.

Clarification on the non-use of lime

After realizing that the examination of lime-based samples is not relevant in the time frame of the research, and that lime is not suited to be streamed through the printer (according to the manufacturer), we decided not to use lime (which is the most common binder for hemp-based composites) at this point.

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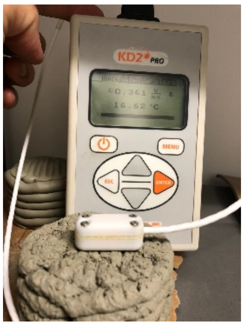

Figure 1. Thermal measurements of the first samples printed using the KD2-PRO thermal analyzer.

Printing preparations

The preparations for each print trial were labor intensive (Fig.2) and included:

1. Taking apart all parts of the extruder, including the charging cartridge for cleaning.
2. Weighing materials for a total of 3 samples: clay, shredded hemp hurds and water.
3. Mixing the materials.
4. Loading the cartridge.
5. Re-assembling the extruder
6. Adjusting air pressure.
7. Calibrating the height of the first layer.
8. Start printing.

Figure 2. Preparation for each printed trial, from upper-left clockwise: taking apart for cleaning, measuring materials (shredded hemp hurds), mixing, loading the cartridge and printing trials of mixes with hemp fraction of 0% (no hemp) and 6%, respectively.

In addition, the outlet of the charging cartridge is flat, and hemp fraction greater than 6% could not flow through it. Our solution was 3D printing a plastic cone with the pellet extruder, and this cone was placed at the bottom of the cartridge to better direct the flow of the mix (Fig. 3).

The clay printer comes with varying nozzle openings, ranging from 1-8 mm. We decided to cut one of the nozzles in order to also have a 12 mm opening for hemp fractions greater than 6%.

Figure 3. 3D printed plastic cone as a solution to better direct the flow of the mix from the cartridge to the extruder

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The factors influencing the outcome of the samples vary, and include: (1) material ratios, (2) water content, (3) air pressure, (4) moving speed of the printer's arms, (5) streaming velocity of the extruder, (6) height of the first layer, (7) layers thickness and (8) diameter of the nozzle opening. By trial and error, we examined how each factor influences the streaming quality and printing outcome as well as understanding the correct combination of these factors for each type of mix. Table 1 presents the final settings for each successful printing.

Table 1. Final settings of factors for each mix.

Fraction of hemp in the mixture (%)	Water content (% of total dry mass)	Air pressure [bar]	Moving speed of printer arms [mm/sec]	Streaming velocity of extruder [rpm]	Height of the first layer [mm]	Thickness of layers [mm]	Diameter of nozzle opening [mm]	Printing outcome
0 %	4	6	10	60	8	8	8	successful
6 %	6	6	10	60	8	6	8	successful
8 %	8	2	5	120	12	10	12	successful
10 %	10	2	5	120	12	10	12	successful
> 12 %		1 – 6	5	60-180	12	12	20 - without nozzle	Unsuccess-ful

The printing trials of mixes above 10% were not successful, due to the size and limits of the specific printer. We found that the most critical influencing factor is the amount of hemp in the mix. Even with water content and air pressure doubled, the threshold value of shredded hemp that could be streamed was 10% by mass of the total mix. An example of an unsuccessful printing with a 10% hemp in the mix is presented in Figure 5.

Each charged cartridge can load enough material for printing two cylindrical samples with radius and height of 5 cm each. The first printing attempts of the same mix usually had a higher water content than the latter attempts, due to both the air pressure and gravity pushing the water downward and draining the upper part of the cartridge.

Air pressure was kept relatively high (at 6 bars) during the printing of the first mixes (hemp between 0-6%) while a lower pressure range of 1-3 bars was used for the latter mixes (hemp fraction 8-10%). Unsuccessful printing trials had pressure ranges varying from 1 to 7 bars.

The height of the first layer was set to be the same as the dimeter of nozzle opening for each mix.

The drying rate of samples with high hemp content was faster than the those with lower content under the same conditions, due to the porous microstructure of hemp which makes the mix more breathable. Figure 4 presents the range of printed and hand-made samples. Color difference indicates the water content in each sample, which is due to the difference in drying time: 7 days for the 0% sample, and only 24 hours for the 20% and 33% samples.

Figure 4. 3D printed and handmade hemp-clay samples with varying fraction of hemp in the clay. ; mixes with 0-10% hemp were printed, while mixes with 20% and 33% hemp were made by hand.

Figure 5. Unsuccessful printing trial with hemp content of 10% by mass.

As of the submission of this report, the samples successfully arrived in Israel. Thermal, physical and mechanical measurements will be conducted, and the report will subsequently be updated with the rest of the results.

FUTURE COLLABORATIONS

The research concludes that 3D printing of hemp-clay biocomposite is possible, however only applicable if using a suitable printer which can properly stream larger aggregates and accommodate various binders such as lime. Thus, future collaboration between Alchemia Nova, Hempstatic, Ben-Gurion University of the Negev and a supplier of 3D printers for building materials (possibly WASP Ltd., based in Italy) should be pursued in order to further examine and refine the 3D printing of biocomposites for the construction of building envelope.