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Analysis of Concrete with Chaff

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Abstract

Can the reintroduction of a traditional building material lessen the emission of greenhouse gas emissions of the construction industry? The study below will present the search for the answer to this question. Given that the used hemp shives, compared to cement, have low mechanical strength but act as a great thermal insulator, I tried four recipes to find the best ratio among the elements after determining the bending, compressive and tensile strengths. The study also analyzes the price of hempcrete, comparing it to the price of hollow bricks, to examine the material's viability from a financial perspective. Additionally, it compares the carbon dioxide emissions of hempcrete and bricks.

Keywords: *environmentally friendly, sustainable, pollutant-free, natural, thermal insulator.*

1. Introduction

In recent years, there has been a growing trend towards using green building materials, and it is expected that this market will double by 2030 **[1]**. The needs of this market can be met by creating new and innovative materials or by improving existing ones.

In recent years, the textile industry has reintroduced hemp into production. As the demand for hemp fiber increases, and this industry only utilizes the outer fiber of the plant, the rest of the plant is considered waste. This „waste" consists of the woody fiber, from which hempcrete is made.

The construction and manufacturing industries together account for 21% of greenhouse gas emissions, while also influencing energy consumption, which constitutes 40% of the emitted gases **[2]**. A well-insulated building needs 10% less energy **[3]**, so the use of materials with lower thermal conductive properties results in saving energy.

Hemp shives have a density of 85–90 kg/m^3 **[4]**, can be mixed with cement and lime to obtain a material with low thermal conductivity and low mechanical strength. This material has been studied for years by the scientific community.

2. Materials and methods

2.1. Materials used

To establish a starting point, we replicated the HH1 recipe developed by Nguyen et al in 2010 **[5]**. In this recipe, the ratio between the binder and the shives is 2.12, and the ratio between water and binder is 1.52. The shives used were from Hempflax Romania, the cement was Holcim ExtraDur 52, and the hydrated lime was Carmeuse Super Calco M. The compaction was done manually.

The hemp shives had a diameter of less than 3 millimeters. The cement was of high strength, grade 52.5.

In all mixes, there was 2.14 times more binder than shives and 1.52 times more water than binder. The difference among the four recipes lay in the composition of the binder: in the control recipe (R0), we used 100% hydrated lime, in the first recipe (R1) 33% cement and 67% hydrated lime, in the second recipe (R2) 67% cement and 33% hydrated lime, and in the third recipe (R3) 100% cement.

1. táblázat. *Quantities for 5.43 dm³ of material*

	Hemp (g)	Cement (g)	Lime (g)	Water (L)
R0	535	0	1145	1.74
R1	535	378	767	1.74
R2	535	767	378	1.74
R3	535	1145	0	1.74

2.2. Determining the density

We conducted all tests under laboratory conditions at a temperature of 15-20°C and a relative humidity of 30-50%.

To determine the initial density, the prepared material was placed in a 1-liter (1000 cm³) cylinder, and then the mass of the material was measured.

For determining the density curve, the mass of the test samples was measured before the mechanical strength tests.

2.3. Determining the bending strength

To determine the material's bending strength, tests were conducted at 3, 7, 14, 28, and 90 days using a hydraulic press.

The bending strength can be calculated using formula (1) .[6]

$$R_{ti} = \frac{3}{2} \cdot \frac{P \cdot l}{b \cdot h^2} \quad (1)$$

where R_{ti} is the strength, P is he force expressed in Newtons, l the distance measured in millimeters between the supports of the machine, b the width, and h the height of the cross-section, expressed in millimeters.

2.4. Determining the compressive strength

To determine the material's compressive strength, tests were conducted at 3, 7, 14, 28, and 90 days using a hydraulic press. The compressive strength can be calculated using formula (2).

$$R_c = \frac{P}{A} \quad (2)$$

where R_c is the strength, P is the force in newtons, A is the cross sectional area.

3. Results

3.1. Density

As observed in Figure 3, the material density significantly decreased in the first 3 days when the water content fell dramatically from an average of 50.88% to 47.64%.

Figure 1. *Mixing the ingredients.*

Figure 2. *Determining the density.*

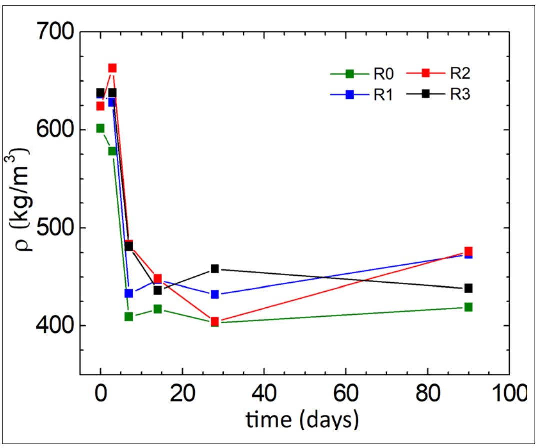

Figure 3. *Variation of binder density as a function of drying time.*

By the 7th day, the density had almost reached the final value for all samples. The recipes containing a significant amount of cement (R2 – 66.67% binder, R3 – 100% binder) dried more slowly compared to lime-based recipes.

Despite talking about drying, the density of lime-based recipes increased during the drying period - the last two weeks were rainy, leading to increased environmental humidity.

3.2. Tensile strength

Concrete is not known for its tensile strength and hemp shives are too short to significantly resist tension in a way that steel would have. The results support this observation.

The maximum tensile strength of the control material (R0) was 0.41 N/mm² after 14 days, and its final value was 0.24 N/mm². The modeled recipe had a tensile strength of 0.105 N/mm² after 90 days. The difference in results was caused by the lime used, as they were not of the same brand - the shives were the same size for both materials.

In terms of tension, the best resistance was achieved by the R2 mix, where 33.33% of the binder was lime and 66.67% was 52.5-grade cement, because cement-based mortar has higher strength than lime-based ones. The high initial resistance was due to additives in the cement, which was labeled ‚R,' indicating the rapid-setting cement used.

3.3. Compressive strength

The shives have low density and mechanical strength, causing the resulting hempcrete to have lower strength properties than traditional concrete.

The final compressive strength of the control recipe (R0) reached 0.2625 N/mm², contrasting with Nguyen's result of 0.7 N/mm². Although the material based on the R0 recipe achieved better values than Nguyen's HH1, it performed worse during the compressive strength test, suggesting a different orientation of the hemp shives. Despite identical mixing methods, it is possible that during manual compaction, the fibers in the model material aligned along their length, significantly contributing to tensile strength at the expense of compressive strength.

4. Economic considerations

4.1. Price of raw materials

The price of a 40-kilogram bag of Holcim Extradur 52 cement is 35 RON. The price of a 20-kilogram bag of CL-70-S lime is 30 RON. The price of a

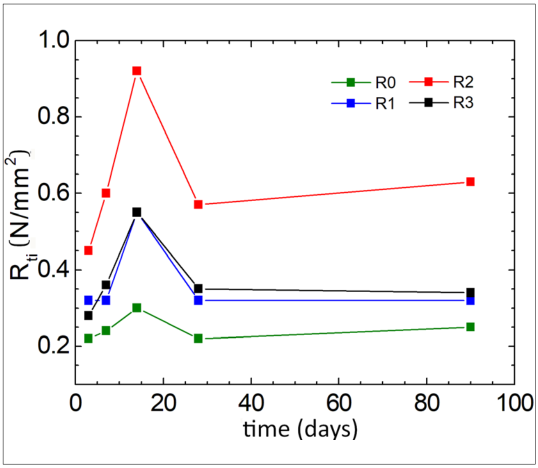

Figure 4. *Tensile strength*

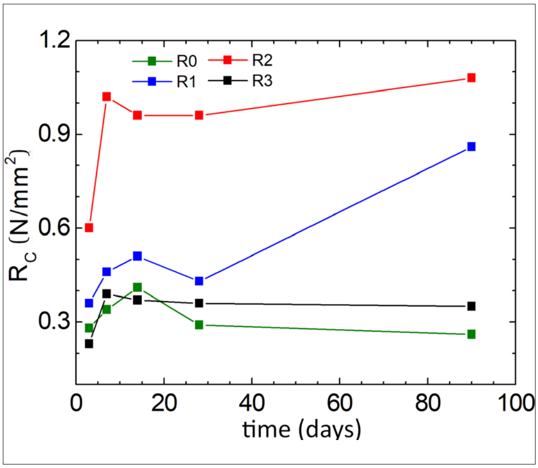

Figure 5. *Compressive strength variation*

Figure 6. *Prices of recipes.*

Table 2. *Prices of materials*

Recipe	5.43 dm3= 0.00543 m3				1 m3	1 m3
	Hemp	Cement	Lime	Total	RON	Euro
R0	1.0165	0	1.7175	2.734	503.056	100.6112
R1	1.0165	0.33075	1.1505	2.49775	459.586	91.9172
R2	1.0165	0.671125	0.567	2.254625	414.851	82.9702
R3	1.0165	1.001875	0	2.018375	371.381	74.2762

14-kilogram bag of hemp is 5.4145 euros, which is equivalent to 1 kilogram costing 1.92 RON.

Comparing the price of 1 cubic meter of hempcrete with 1 cubic meter of hollow bricks (520 RON/m^3), it can be concluded that each tested recipe is more economical than a brick wall.

These prices need to be supplemented with indirect costs (water, laboratory services, labour) that are not included in the material costs and account for 10% of the formulation's cost. In the case of larger procurement, negotiations with suppliers regarding the prices of raw materials (cement, lime, hemp) are possible, leading to reduced production costs.

4.2. Ease of implementation

The successful implementation of new technologies largely depends on how easy it is to transition from the old model. In the case of hempcrete, the process is intuitive as it closely resembles traditional concrete work: everything is mixed in a concrete mixer, gradually adding water, and then poured into molds.

The only drawback to this method is that due to the lime content, the walls reach their final strength only after 90 days. This delay can cause issues if the project schedule doesn't account for the new method.

5. Ecological considerations

5.1. Carbon-dioxide emissions

An environmentally friendly material should have a low carbon dioxide emission compared to the „old" alternative. Every kilogram of cement used produces 0.81 kg of CO_2 [7], and every kilogram of used lime generates 0.75 kg CO_2 [8]. 1 kg of hemp absorbs 1.29 kg CO_2 [9].

Table 3. *Emissions of 1 m^3 hempcrete*

	Kender (kg)	Cement (kg)	Mész (kg)	Összesen (kg)
R0	–127.12	0	157.5	31.925
R1	–127.12	56.94	105	36.36
R2	–127.12	113.87	52.5	40.80
R3	–127.12	170.81	0	45.23

It can be stated that hempcrete is nearly carbon neutral. Converted, it emits 50.8-71.43 kg of CO_2 per ton. Considering that a ton of bricks emits 258 kg of CO_2 [10], the difference is significant.

6. Conclusions

Ultimately, it can be concluded that hempcrete can serve as an alternative to bricks, but only in non-structural functions as it lacks the necessary properties for a structural task – in this regard, it falls short of traditional bricks.

From an environmental perspective, the material produced emits one-third of the carbon dioxide compared to glass bricks, but its carbon dioxide balance is still not negative, so it can be considered only a partial success.

From an economic standpoint, the material is more cost-effective than traditional brickwork, making it an improvement in the construction industry, even if it doesn't consider the positive environmental impact.

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