

FILLING MATERIALS ON THE BASIS OF RAPIDLY RENEWABLE SOURCES

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Abstract

Within the current building industry, there can be seen some efforts to change non-renewable (or more precisely slowly renewable) building raw materials (such as wood, limestone, etc.) for the secondary raw materials or rapidly renewable ones (such as ash, slag, straw, reed, technical hemp) primarily due to environmental and economic reasons. The article is framed towards the use of technical hemp, which is a very required natural raw material intended for the building materials production due to its fast recoverability, high profits and good mechanical characteristics. As one of the possible ways of the technical hemp use, it seems to appear a preparation of non-supportive filling materials for vertical structures, with testing suitable kinds of binders to achieve the required mechanical and at the same time the thermal-technical parameters.

Key words: *technical hemp, filling materials, cement, lime, gypsum.*

1. INTRODUCTION

The use of rapidly renewable raw materials in the building industry is seen as very promising with regard not only to the environmental issues but also to its economic aspects. A number of producers, not only in this country, have been trying to replace fine construction materials with secondary raw materials or rapidly renewable ones. As an example, technical hemp is a very promising material due to its good mechanical and thermal insulation characteristics. One of possible variants is its use as filling component for vertical filling materials.

2. TECHNICAL HEMP

It is an old crop with origins in central Asia. The first mentions of hemp, its effects and use can be found on ancient scrolls from India and China dating back to about 600 BC. Hemp resin was used initially, then hemp fibre in paper manufacture. Later, its good effects in medicine were discovered as well as a wide sphere of use in building.

Hemp types:

- *Cannabis sativa* (less than 0.3% of THC)
- *Cannabis indica*
- *Cannabis ruderalis*

2.1 Parameter

Technical hemp (*cannabis sativa*) is an annual thermophilic crop, the *Cannabaceae* family. It is a plant with a long, thin and straight stalk that lignifies rapidly and is branches out slightly; the serrated leaves are arranged into a palm-like shape and there are small, oval achene fruits. The main stalk reaches 3 to 5 metres in height and 30 mm in diameter. It is grown everywhere in the temperate zone, apart from soils that are permanently wet or dry. The whole plant can be processed and no waste material is produced. The stalks of bred variants yield the highest content and the best fibre; the stalks must be thin and long, recommended harvest during the period of peak florescence. New variants reach fibre yield comparable to that of flax. The obtained fibres are of a cellulose character differing from other textile fibres not only in their anatomic structure but also in chemical composition and in many physical characteristics. Hemp is a valuable crop. It is necessary to bear in mind that only *Cannabis sativa* is allowed to be grown in the Czech Republic; due to its low content of THC (tetrahydrocannabinol) to 0.3 % it cannot be used as an intoxicant (*Cannabis indica* contains more than 7.0 % of THC). [1]



Figure 1. Technical hemp in growth and pre-harvest. [2]

2.2 The potential range of use of cannabis in the Czech Republic

Depending on the development of various processing industrial sectors such as:

- textile industry (including geotextile, ropes, canvas, clothing, sound and heat insulation)
- paper industry (bank notes, filters, cigarettes)
- construction material industry (wide spectrum of use)
- fuel industry (pellets)
- car industry (filling materials and sheeting)
- oil industry (foodstuffs, varnishes, cosmetics)
- litter for pets

2.3 Use of technical hemp in the technical construction

Technical hemp has already found a wide range of uses in the building industry. The hemp plant is a perfect alternative for wood as a construction material (from building timber to plywood and particleboard) that surpasses the properties of wood in many respects.

- INSULATION MATERIALS from HEMP CHAFF

This material may replace glass wool whose production is energy demanding and, in contrast to glass wool insulation, it does not irritate the lungs or skin. A special technology allows hemp fibres, processed and treated with fireproof material, to be sprayed in between walls. The fibres can also be in the form of mats.

Advantages of hemp insulants:

- they do not contain any environmentally harmful substances; they are fully recyclable
 - the insulating material can be used in various forms, such as for roof, wall or floor insulation
 - their good diffusion properties allow optimum humidity passage and they ensure an ideal healthy climate in rooms
 - they do not contain any proteins, that is why they cannot be attacked by pests and they are not liable to rotting
- Hempcrete

Hempcrete is an environmentally friendly replacement of concrete. It is a mixture of hemp, lime, sand, gypsum and cement; it can be used similarly to concrete. It is more flexible, less brittle and it is resistant to rot and pests. [3]

- FILLING MATERIALS FOR VERTICAL STRUCTURES

Combining binders on the basis of non-hydraulic lime with hemp chaff yields a range of new construction materials. These products offer excellent work characteristics for permanent, environmentally sustainable buildings. These products as a whole form a natural composite construction material that can be used to build insulation walls, floor and roof insulation layers, and to obtain excellent heat and acoustic characteristics of buildings.

• **Construction**

Hemp chaff with a binder on the basis of lime has typical compression strength of about 0.2-1.0 MPa; that is why it cannot be used for load-bearing structures. Even though this material could be used in load-bearing structures of low building, in most cases it is used in combination with a wooden or iron-concrete frame. Consequently, building height is dependent on the used construction system not on filling materials.

These composite materials are used as insulating wall filling material in the systems of wooden or iron-concrete frames. The composites offer excellent vapour permeability, which protects wood quality from damaging effects and extends material life. In steel and concrete structures, the vapour permeability also creates protective environment against corrosion.

Similarly to building new structures, hempcrete is suitable for renovations and repairs of old buildings of a wooden construction frame structure. It is a viable and satisfactory replacement of original wall filling materials.

- **APPLICATION**

The mixture consisting of a lime binder and hemp chaff can be processed well; it is plastic and its handling time is optimal, which results in easy application and waste material reduction. These mixtures can be poured into boxing or moulds; they can be sprayed in the same way as concrete or plaster.

Pouring into boxing – it is suitable for projects that implemented as self-built housing or for small projects (less than 70 cubic metres). In this kind of application, the boxing is fixed in a wooden frame by means of cylindrical braces to form the final wall dimensions and shape. The material is poured into the boxing and compacted slightly. The boxing can be removed after 12 to 24 hours.



Figure 2. Pouring into boxing [4]

Spraying – Application by spraying is suitable for large projects (more than 70 cubic metres) where rapid building is required. The material is sprayed on a temporal or permanent sideboard and it is levelled as necessary. If there is boxing, it can be removed after 24 hours.



Figure 3. Application by spraying [4]

3. PROPOSAL RECIPES

Six different recipe sets were proposed. A different binder was used in each set as well as different treatment of hemp chaff. The fine fraction of hemp chaff was also excluded in some cases. Cement, gypsum and lime were used as binders. Hemp chaff was mineralized with whitewash or sodium silicate.

Table 1 – Recipe with cement binder; hemp mineralized with sodium silicate.

Recipe	Weight [kg]			
	Cement	Hemp	Water	Water glass
R1	2	1	2.2	0.073
R2	2.5	1	2.4	0.085
R3	3	1	2.8	0.098

Table 2 – Recipes with lime binder.

Recipe	Weight [kg]		
	Lime	Hemp	Water
R4	0.5	0.5	0.9
R5	1	0.5	1.25
R6	1.5	0.5	2.2
R7	2	0.5	2.3
R8	2.5	0.5	2.4
R9	3	0.5	2.5

Table 3 – Recipes with lime binder; hemp mineralized with whitewash.

Recipe	Weight [kg]		
	Lime	Hemp	Water
R10	0.5	0.5	0.2
R11	1	0.5	0.45
R12	1.5	0.5	0.65
R13	2	0.5	0.75
R14	2.5	0.5	1.1
R15	3	0.5	1.4

Table 4 – Recipes with lime binder without hemp fine fraction.

Recipe	Weight [kg]		
	Lime	Hemp	Water
R16	0.8	0.4	1.4
R17	1.2	0.4	1.5
R18	1.6	0.4	1.7

Table 5 – Recipes with lime binder a minor cement content.

Recipe	Weight [kg]			
	Lime	Cement	Hemp	Water
R19	1.2	0.16	0.4	1.2
R20	1.2	0.48	0.4	1.4

Table 6 – Recipes with lime binder and minor gypsum content.

Recipe	Weight [kg]			
	Lime	Gypsum	Hemp	Water
R21	1.2	0.16	0.4	1.4
R22	1.2	0.48	0.4	1.5

3. THE RAW MATERIAL USED

Technical hemp shaves

- Powder density 120 kg/m³



Figure 4. Fine and coarse fraction of hemp chaff.

Cement – CEM I 32,5 R Hranice

Lime – C 90

Gypsum – G-2 BII

4. PRODUCTION SAMPLES

Individual powdery components of the given recipes are placed into a mixing container. Then the material is mixed with a mixer. Measured amount of water is added to the mixture during the process. The mixture further homogenizes.

A three-part metal mould, coated with oil on the inside, is placed on a vibrating table. The well-blended mixture is poured into the three parts of the mould and then it is vibrated. Test specimens, sized 100 x 100 x 100 mm, are removed from the mould after 24 hours and they are placed into a wet chamber where they mature for 7 and 24 days.



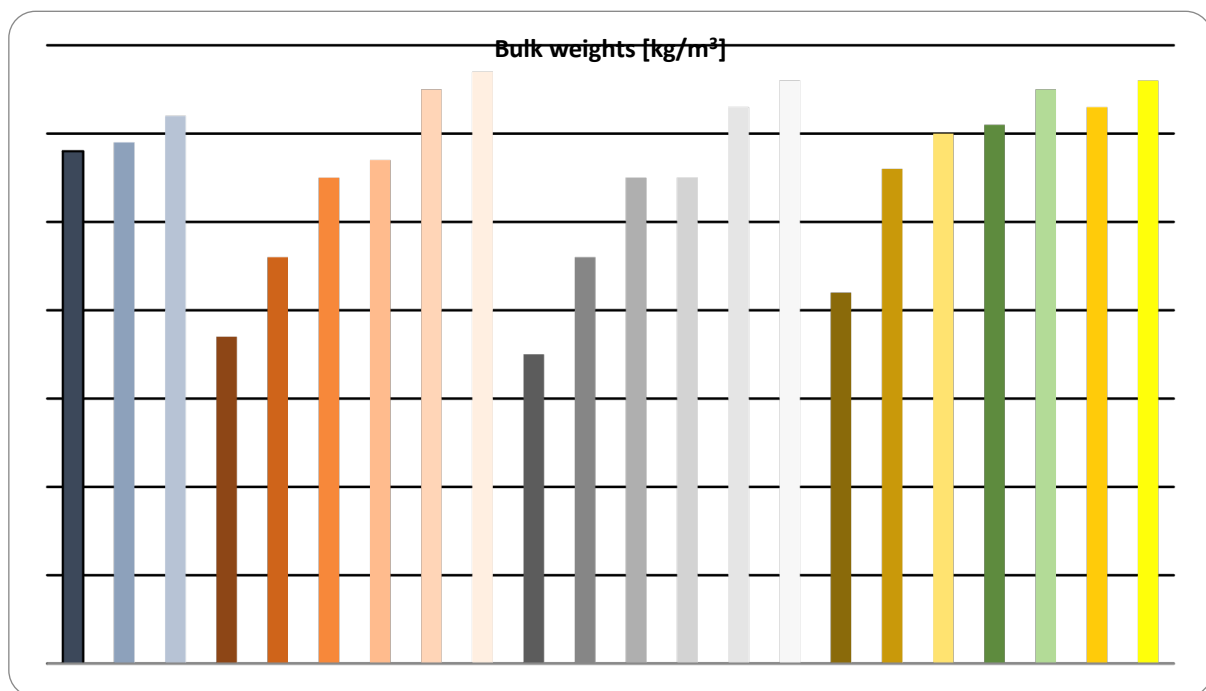
Figure 5. Test specimens in a mould and after removal from the mould.

5. TEST RESULTS

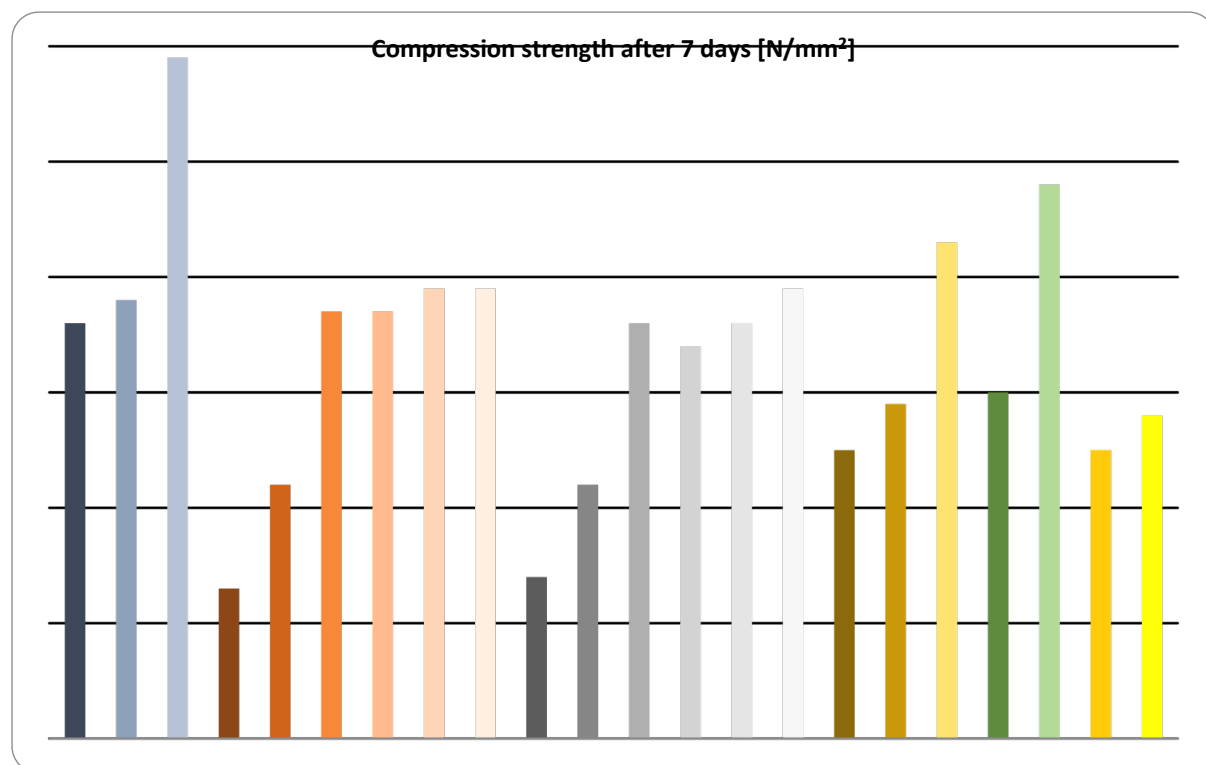
The test specimens were tested after 7 and 28 days of maturing. The specimens were measured and weighed; their bulk weight was calculated. Then they were tested for their compression strength. The samples of the recipes that showed sufficient strength underwent further heat-mechanical tests and a modulus of elasticity test.

Table 7 – Table of bulk weights and strength after 7 and 28 days.

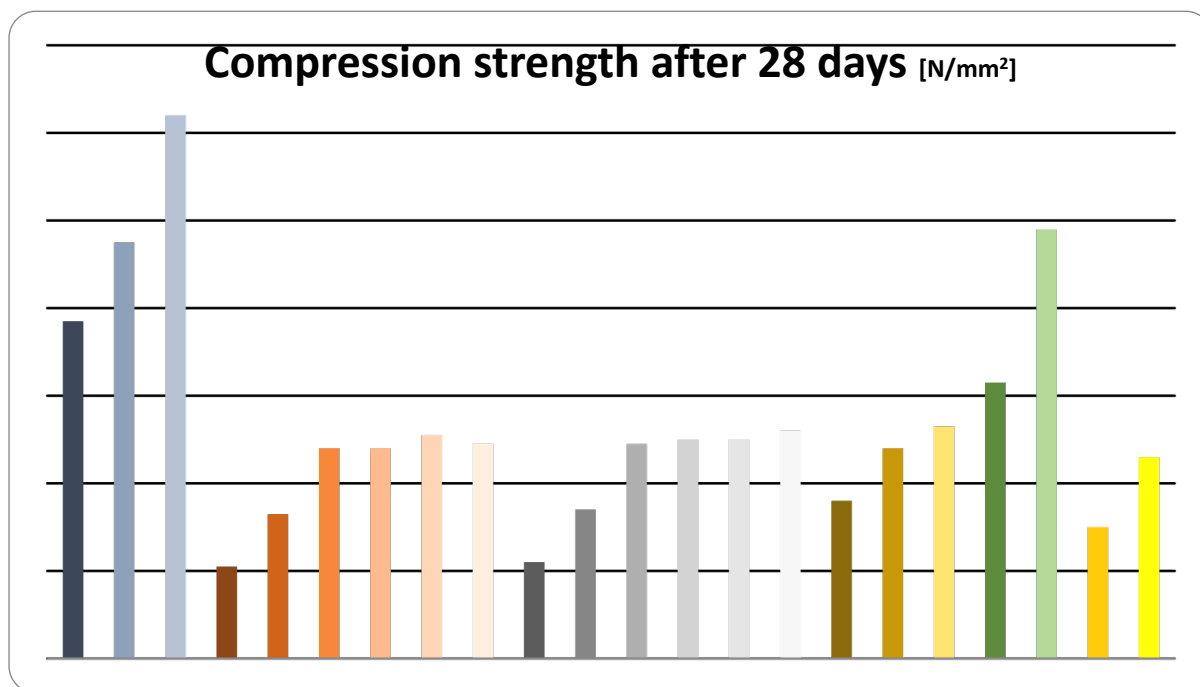
Recipe	Bulk weight [kg/m ³]	Compression strength after 7 days [N/mm ²]	Compression strength after 28 days [N/mm ²]
R1	580	0.36	0.77
R2	590	0.38	0.95
R3	620	0.59	1.24
R4	370	0.13	0.21
R5	460	0.22	0.33
R6	550	0.37	0.48
R7	570	0.37	0.48
R8	650	0.39	0.51
R9	670	0.39	0.49
R10	350	0.14	0.22
R11	460	0.22	0.34
R12	550	0.36	0.49
R13	550	0.34	0.5
R14	630	0.36	0.5
R15	660	0.39	0.52
R16	420	0.25	0.36
R17	560	0.29	0.48
R18	600	0.43	0.53
R19	610	0.3	0.63
R20	650	0.48	0.98
R21	630	0.25	0.3
R22	660	0.28	0.46



Graph 1. Bulk weight of specimen recipes 1 – 22



Graph 2. Compression strength after 7 days for specimen recipes 1 – 22



Graph 3. Compression strength after 28 days for specimen recipes 1 – 22

COMPRESSION Static MODULUS OF ELASTICITY

Table 8 – Measured values for specimen R19 and R20.

Recipe 19

Step	Power [KN]	Strain gauge I	Strain gauge II
1	0.5	0.12	0.11
2	2	0.35	0.55
3	0.5	0.3	0.45
4	2	0.37	0.58
5	0.5	0.31	0.47
6	2	0.37	0.59
7	0.5	0.34	0.45
8	2	0.38	0.6
h _b	0.5	0.34	0.42
h _a	2	0.39	0.6

equation (13) $\Delta I' = 0.05$ and $\Delta I'' = 0.18$

equation (14,15,16) $\Delta \epsilon' = 0.0005$ and
 $\Delta \epsilon'' = 0.0018$, $\phi \Delta \epsilon = 0.0015$

equation (17) $E = 130.44 \text{ MPa}$

Recipe 20

Step	Power [KN]	Strain gauge I	Strain gauge II
1	0.5	0.01	0.03
2	3	0.24	0.2
3	0.5	0.06	0.09
4	3	0.25	0.21
5	0.5	0.08	0.11
6	3	0.25	0.23
7	0.5	0.08	0.11
8	3	0.25	0.24
h _b	0.5	0.08	0.12
h _a	3	0.25	0.25

equation (13) $\Delta I' = 0.165$ and $\Delta I'' = 0.13$

equation (14,15,16) $\Delta \epsilon' = 0.00165$,
 $\Delta \epsilon'' = 0.0013$, $\phi \Delta \epsilon = 0.001475$

equation (17) $E = 169.5 \text{ MPa}$

DETERMINATION OF HEAT CONDUCTIVITY FACTOR λ FOR BOARD MATERIALS

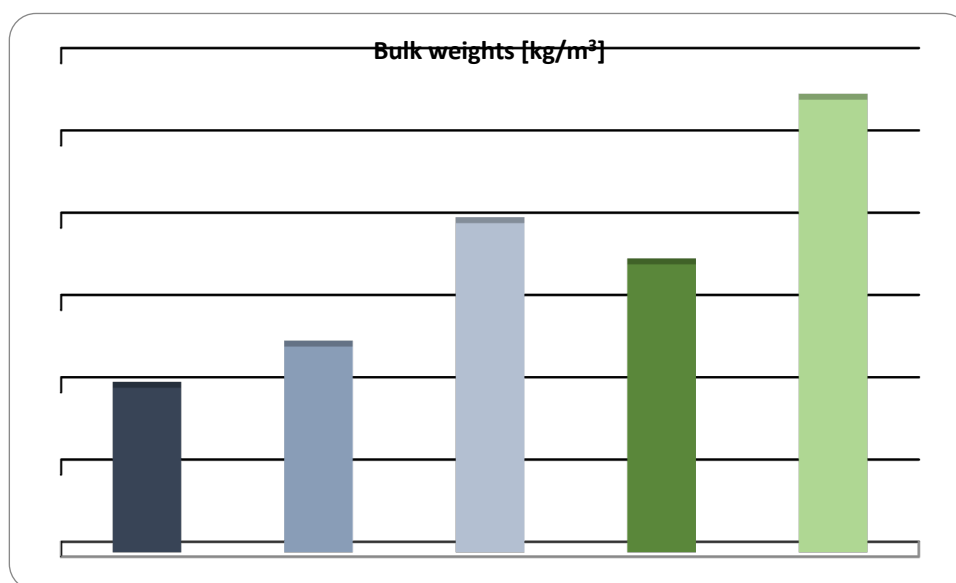
Table 9 - Measured values for specimen R19 and R20

Specimen	Dimensions [mm]			Weight [g]	Bulk weight [kg/m ³]	Heat conductivity factor λ [W/mK]
	a	b	h			
R19a	250.45	250.65	51.55	2040	630	0.143
R19b	249.85	249.95	52.45	2015	615	0.148
R20	250.20	250.40	52.00	2120	650	0.155

5.1 Bulk weight

The graphs show that bulk weight increases with the increasing amount of binder.

Bulk weights range from 370 to 670 kg/m³. The bulk weights for recipes R19 and R20 that are considered as the most suitable for practical applications reached 610 and 650 kg/m³. With these values, necessary mechanical parameters (about 1.0 MPa) and a relatively favourable value of the heat conductivity factor were reached.

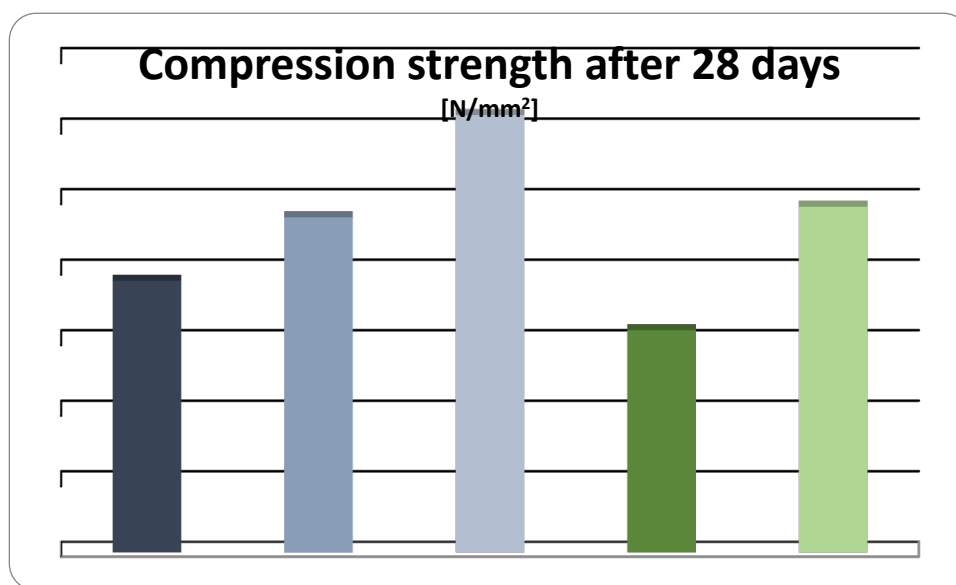


Graph 4. Bulk weight for selected best recipes.

5.2 Compression strength

The test specimens underwent compression-strength tests after 7 and 28 days. Recipes R4 – R18 and R21, R22 reached strength values after 28 days between 0.2 – 0.53 MPa (see Graph 3), which is considered as insufficient strength for self-supporting insulation filling material. The highest compression-strength values were obtained from recipes R1-R3 and R19, R20 – from 0.63 to 1.24

MPa (see Graph 5); these strength values enable a comparatively wide range of use in the building industry.



Graph 5. Compression strength of selected recipes after 28 days.

5.3 Compression static modulus of elasticity

This test was used for recipes R19 and R20 that showed sufficient values of compression strength and consequently they were suitable for further testing. The given values of compression modulus of elasticity are 130.44 MPa and 169.5 MPa respectively. With regard to strength and bulk weight and experience of foreign companies that use materials of the same base in everyday practice, the modulus of elasticity for our test specimens can be considered as satisfactory.

5.4 Determination of heat conductivity factor λ for board materials

This test was used for R19 and R 20. The resulting measured values are 0.148 W/mK and 0.143 W/mK respectively 0.155 W/mK. Porous concrete designated P2 - 400 has heat conductivity of 0.115 W/mK. Our results yield heat conductivity values higher than those of porous concrete designated P2 – 400 but, considering higher bulk weight of our test specimens, our measured values are satisfactory.

6. CONCLUSION

The objective of this project was to develop filling materials for vertical structures using technical hemp, and to verify a suitable kind of binder.

Technical hemp is rapidly renewable waste-free plant material that is becoming increasingly popular in many construction applications. Its physical-mechanical and thermal-mechanical characteristics are close to those of wood and it can be estimated that it will become an alternative to wood.

The article proposes some recipes with various binders. Basic available binders (cement, hydrate of lime, gypsum) were tested. Filling materials based on hemp in combination with cement binder

reached the highest values of compression strength in mixtures designated R1-3. Lime binder was tested in other recipes – numbered R4-18. These mixtures did not yield sufficient strength values after 28 days; therefore they do not seem practically usable as heat insulation filling materials. This composition is used abroad but its strength is tested after 90 days.

There also other alternatives here, e.g. use in technological systems where no self-supporting function is required. To increase strength of the lime recipes, a small amount of cement R19 and R20 was added. This step proved a good one for these recipes reached sufficient compression strength values. For these mixtures the modulus of elasticity and the heat conductivity factor were measured because one of the basic advantages of these materials is their relatively favourable heat insulation capacity. The last tested binder was gypsum that was added in small amounts to lime binder R21, R22. Test specimens with sulphate binder did not yield satisfactory results; apart from that there are problems with controlling the rate of hardening.

The mixture designated R20 can be considered as an optimal recipe usable in practice. The filling material prepared in accordance with this recipe reaches compression strength values after 28 days of 0.98 MPa, modulus of elasticity 169.5 MPa and heat conductivity factor 0.155 W/mK. In accordance with the experience of foreign companies, it can be stated that the filling material with these parameters is suitable as separate heat insulation material.

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