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Cement-Chip Boards with Technical Hemp and Their Use in Building Industry

Assoc. Prof. Jiří Bydžovský, Ph.D. [1] **and Šárka Keprdová, M.Sc.** [2]

[1]*Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic, e-mail: Bydzovsky.j@fce.vutbr.cz.*
[2]*Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic, e-mail: Keprdova.s@fce.vutbr.cz.*

ABSTRACT

Cement-chip boards are suitable for all-round use within building industry practice, thanks to their favourable characteristics achieved by combination of wood and cement. The boards can be used both in interior and exterior, especially as floor, wall, lower ceiling, roof and facade systems, sacrificial formwork, etc. The main advantages of these boards are their flexibility, strength, easy workability, low weight, environmental characteristics, hygienic safety, their possibility of surface treatments and other adjustments. Cement-chip board consists of binding components, e.g. cement, wood chips fillers and additives to form the final products. The disadvantage is that they are still relatively expensive, which can be eliminated by substitution of in-let raw materials. The article aims at the use of technical hemp as an ecological and rapidly renewable organic raw source for the preparation of cement-chip boards and their subsequent use in building industry practice.

INTRODUCTION

Cement-chip boards have the good qualities of wood and the cement in common; their characteristics predetermine them to be used in many different cases, be it for the construction of walls, bars, lower ceilings, facades, floors etc. The disadvantage of cement-chip boards however is the high price, which reflects mainly the price of input materials. The main component, which forms the filler of the cement-chip boards, is wood. The wooden chips are derived from the stems of cut trees, which means, that the chips must be produced from the wooden mass first.
This part of the production can be partially or completely avoided using alternative fillers. Using alternative, quickly renewable raw-materials in construction materials creates the opportunity to decrease production costs and eliminate ecological burden. A great advantage of alternative fillers is in their fast growth:, their renewal period in this temperate climate is usually one year compared with wood, which grows for several tens of years. It must also be taken into account that wood can be used much more effectively in the building industry, i.e. in the form of timber, boards etc., where it cannot be substituted with other materials.

An interesting possibility to use alternative, quickly renewable sources is the application of technical hemp as the full or partial substitute for chips. Thanks to its very good mechanical features, technical hemp is a perspective solution in the building material production. It can be assumed that the technical hemp is a suitable renewable source of raw materials for the production of construction materials, which can compete with other commercial products using natural as well as secondary raw materials. [3]

This document considers the utilization of technical hemp as a quickly renewable source instead of chips as fillers in cement-chip boards. A most suitable mix composition was explored, namely from the view of various combinations of fractions and methods of pre-adjustments of hemp shives, the modification of the cement and mixing water amounts. Furthermore, the possibility of substituting a binder fraction with secondary raw materials, especially scoria, and the addition of a setting accelerator to enhance the initial board solidness, were investigated.

To evaluate the future utilization possibilities in building constructions, physical-mechanical characteristics were investigated, the stress being laid mainly on the bulk strength and elastic modulus firmness tests, depending on the proportion of individual components. The mixture must fulfil the required technical parameters for the cement-chip boards; however, a decrease in the total price for the raw materials used during production must be achieved.

Cement-chip boards

Cement-chip boards belong to the group of fiber composites. They are made using the cement matrices, usually Portland cement, and stemmed chips, namely of pines and firs. The boards are pressed under 2 ~ 3 MPa to obtain the required thickness (ca. 1/3 of the apparent thickness). According to the shape of wooden parts and their bulk weight, the cement-chip boards can basically be divided into:

- Boards from the excelsior with a low bulk weight (up to 400 $kg.m^{-3}$), they are used for the heat insulation of walls and ceilings, to produce bars, dividing walls etc. These boards are known under the name Heraklit.

- Boards from heavy chips with medium bulk weight (400-800 $kg.m^{-3}$), they are produced from wooden particles with the thickness between 0,5 - 5 mm, width 2 - 10 mm, length 20 - 50 mm. The shape of wooden particles is not determining during the production of this type of boards; various unit wastes can be used, e.g. wood and heavier chips are used. Wooden particles are usually mineralized with potassium silicate, which at the same time decreases the absorbing power and increases the resistance of boards to pests and moulds. Boards with an additional insulation layer of foam polystyrene are used as a lost form during the production of enclosure walls, namely in the residential construction.

- Boards from soft chips with a high bulk weight (over 800 $kg.m^{-3}$) are made from softer chips and contain a higher quantity of cement (25 % and more in weight) than the previous kinds. The usual production thickness is between 8 and 40 mm. They are trimmed to an exact size; they can be equipped with a pen and a fold.

Characteristics: the bulk weight of the cement-chip boards from the soft chips ranges from 1 000 to 1 500 kg/m^3. The boards have a relatively high strength in tension in the bent (over 10 MPa), and according to the reactions to fire belong to the A2 group. Like all materials containing wooden mass rate, they have relatively high linear expandability depending on the humidity, therefore, the boards should be left to dilate. The cement binder increases the thermal conductivity to values around 0,3 W/mK. The boards also have excellent acoustic features (the airbone sound transmission loss is 30 - 35 dB), however they have a low sound absorbability. They are resistant to freeze, insect and mould. They resist dampness, therefore are generally used in exteriors; they practically do not expand, and are ecological and hygienic [1], [2].

The requirements for the features of cement-chip boards according to the ČSN EN 634-2 are:

- The bulk weight: min. 1000 kg/m^3
- The bending strength: min. 9 N/mm^2
- The modulus of elasticity: min. 4500 N/mm^2

The use of the cement-chip boards is very broad, as they are a quality board material with extraordinary features. The boards can be used for floor systems, loft building, roof buildings, aerated facades, anti-fire applications, lower ceilings, walls and bars, garden fittings, forms and many others.

Technical hemp

It is an ancient culture plant originating from the Middle Asia. Hemp, its effects and use were mentioned in ancient papyrus from India and Chine around 600 B.C. for the first time In Europe hemp was grown around 400 B.C. originally, the hemp resin and hemp fiber were used for the paper production. Later, its healing effects in medicine and especially the possibility of its wide use in the building industry were discovered.

There are four kinds of hemp: India hemp (Cannabis Indica), Cannabis ruderalis and Cannabis sativa.

Technical hemp (cannabis sativa) is an annual, thermophilic plant in the Cannabaceae family. It is a plant with a long and straight stem and little branching, which lignifies quickly, and with palmated, jagged leaves and small, oval fruits. The main stem can be up to 3 - 5 m long and 30 mm wide on average. It is grown everywhere in the temperate zones, except where the soils are permanently wet or dry. The whole plant is used during processing, there is no waste. Cannabis is a valuable crop. It is important to realize that only the Cannabis sativa can be grown in this country, as its low content of THC (Tetrahydrocannabinols) – less than 0,3% - prevents its use as a narcotic. [3]

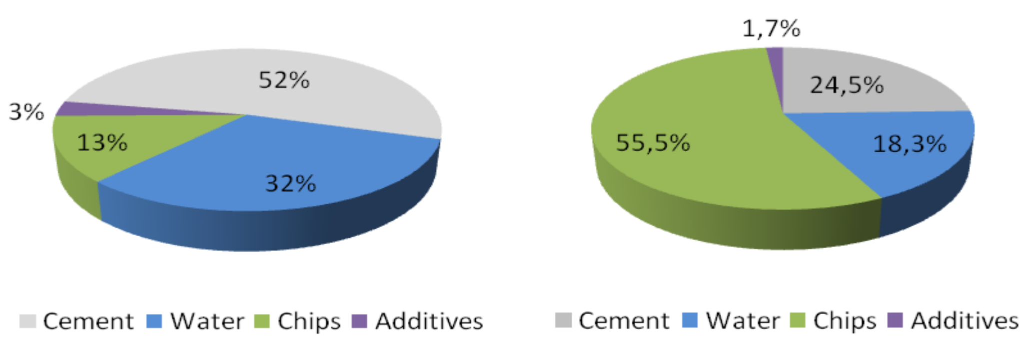
Fig. 1: A field of technical hemp during the growth and before the harvest [4]

Technical hemp used in the document: Fraction A, particle size to 8 mm, powder weight 133 kg/m^3 Fraction B, particle size over 20 mm, powder weight 43 kg/m^3

Fig. 2: Technical hemp fraction A and fraction B

WORK METHODOLOGY

Chart 1. The raw material representation in the reference mixture: mass (left) and weight (right)



All the following mixtures are described only as changes in the amounts of individual raw materials against the basic - reference – mixture, whose components and relative proportions are described in chart 1. Reference mixture was based on previous research. They are always stated in mass in % related to 100% of the base weight.

The requirements for the features of cement-chip boards with technical hemp are:

- ***The bulk weight: min. 1000 kg/m^3***
- ***The bending strength: min. 9 N/mm^2***
- ***The modulus of elasticity: min. 4500 N/mm^2***

The research was divided into four phases.

The first phase studied a suitable way of mixing. It was bean suggested 5 mixtures: the bending strength and modulus of elasticity were measured, and a subjective appraisal of the mixture process ability was performed. Based on the results, an optimum way of laboratory production of boards was suggested.

Second phase

In the second phase, a first set of specimens was produced by modifying the amount of hemp (from 90 to 110%), water and addictives (added plasticizer), cement (90 and 110 %) and the graininess of the hemp (softer or rougher fraction). The mixture comparison was made based on the modulus of elasticity and bending strength.

Third phase

The third phase consisted of detailed testing of test specimens made with a variation of the recipe, e.g. adding aggregate in amounts varying from 5 to 50%, cement amount modification from 90 to 140%, adding the accelerator (is a aluminium sulphate - $Al_2(SO_4)3.n\ H_2O$) ranging in 1, 2, 3% of the cement amount, various hemp fractions, hemp mineralization with calcium hydroxide, potassium silicate or pre-wetted with water and the following comparison with wood. In the testing units of individual formulas the bending strength and modulus of elasticity values of the different recipes were measured and compared, and the optimum formula for the phase four was defined.

Fourth phase

In the last phase, final mixtures were created, the result parameters of which fulfilled standard requirements.

- <u>Mixture 59</u> – made of softer cannabis, particle size up to 8 mm (marked A)
- <u>Mixture 60</u> – made of rougher cannabis, particle size more than 20 mm (marked B)
- <u>Mixture 61</u> – made of filler wood,
- <u>Mixture 62</u> – made of fraction A + B cannabis in the ratio of 1:1

TESTS

Bending strength and Modulus of elasticity

They are determined according to standard ČSN EN 310- Determination of modulus of plasticity in strength and bending strength.

The width of the sample shall be 50 ± 1 mm, which is then placed on two supports (supports distance 240 mm) and the load on centre, while measuring the deflection of the specimen (under the load head) with an accuracy of 0.1 mm. Furthermore loads values have been recorded with an accuracy of 1% of measured value.

l - Distance between the centres of the supports [mm]
b - Width of specimen [mm]
t - Size of specimen [mm]
F_{max} - maximum load [KN]
F_1 - 10 % maximum load [KN]
F_2 - 40 % maximum load [KN]
F_2 - F_1 - increase of loading value in linear part of loading curve [KN]
a_1 - Deflection in centre of loading F1 [mm]
a_2 - Deflection in centre of loading F2 [mm]
a_2 - a_1 - increase of deflection value in the middle of length of specimen [mm]
E_m - Modulus of elasticity [N/mm]
f_m - Bending strength [N/mm]

Modulus of elasticity

$$E_m = \frac{t^3 (F_2 - F_1)}{4 \times b \times t^3 \times (a_2 - a_1)}$$

Bending strength

$$f_m = \frac{3 \times F_{max} \times l}{2 \times b \times t^2}$$

Fig. 3: The tests of modulus of elasticity and bending strength

TEST RESULTS

First phase
As a result of this phase, the best board production laboratory procedure was found: it consisted of mixing warm water and addictives with cannabis, cement added last. A form for their production made (see Fig. 3).

Fig. 3: A form for the board pressing.

Second phase

Reducing or increasing the amount of cannabis, the features have not changed much; we can say that the initial amount of cannabis is advantageous, therefore a modification of the cannabis, e.g. through mineralization or pre-wetting was made in the further procedure (see 3rd phase).

The change in the filler graininess resulted in an increase of the deformation when bending; therefore, these modifications were not further developed.

The interaction of the technical hemp and the increase of the amount of cement, the testing units gained better characteristics. Decreasing the amount of the mixing water resulted in degradation. Technical hemp absorbs extremely well, therefore it is necessary to adequately measure the water for the cannabis in order to achieve the required processability. The characteristics of the testing units did not improve significantly after adding the plasticizer (Glenium SKY 505); therefore, it will not be included in further testing with regards to its higher purchase price.

Third phase

From this phase, it resulted that the increase of the binder caused an improvement of the mechanical properties and positively influenced the aesthetic of the boards. By contrast, the longer the cannabis parts, the rougher and more unsightly the surface of the desks will be. The mixtures with the aggregate showed little short-term firmness, therefore the aggregate should not be used as a consequence need of a relatively fast growth of the initial solidness. The mineralization of the cannabis did not improve the resulting mechanical properties; however, it helps prevent biodegradation in the long term. Adding the accelerator caused an increase of the initial firmness, which enables an earlier de-formation. That is a significant factor, in view of the eventual future industrial production.

Table 1. Flexure strength and elasticity coefficient with selected samples

Mixture	Description	Bending strength after 28 days [N/mm^2]	Bending strength after 60 days [N/mm^2]	Modulus of elasticity after 28 days [N/mm^2]	Modulus of elasticity after 60 days [N/mm^2]
20	100% of cement reference mixture (basic formula)	1,0	1,3	938,8	1486,0
23	110 % of cement	1,9	1,8	1928,3	1811,8
28	135 % of cement	2,4	2,9	2790,2	3194,3
31	fraction A + B 1:1 hemp	2,4	1,2	1497,2	816,6
33	Fraction B hemp in mass	2,6	4,0	964,5	2050,3
34	wood in mass	2,4	3,6	2584,8	2510,8
45	mineralization 1h - reference	1,4	1,8	2524,4	1623,1
48	Mineralization 1h – added water	1,3	2,7	1508,7	2772,1
51	accelerator 3 %	1,1	1,8	896,2	1801,4
52	accelerator - reference	1,1	2,1	1564,3	1615,8

Chart 2. Flexure strength of selected samples

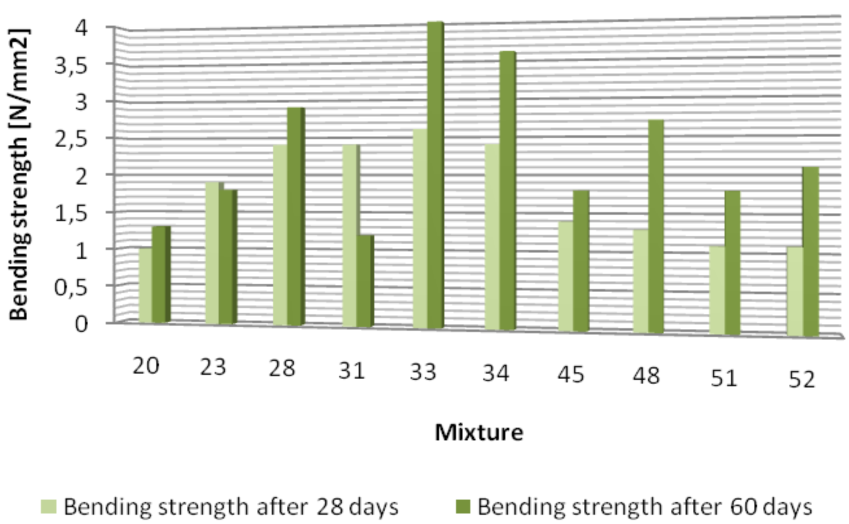
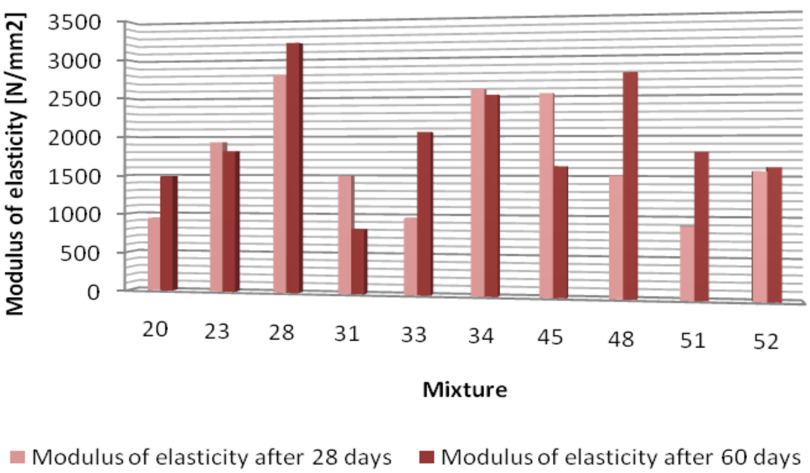


Chart 3. Elasticity coefficient of selected samples



Fourth phase

The mixture was dosed into the form in mass, 5 kg of the mixture was used with each sample, a thin layer of cement was applied through a sieve to a half of the surface form (samples marked with a C) in order to achieve a better surface appearance; the other half was left without cement. (The form was spread with oil.) The prepared mixture was screened into a wooden frame 60 mm high, first through a2 mm sieve (the first thin surface layer), then through a 16 mm sieve. All the mixture was put in the form, pressed slightly to avoid spilling the mixture whilst removing the wooden frame. Once prepared, the mixture was covered with further oil-handled steel sheet and the whole procedure was repeated once more. After that, a pre-stress was brought in the form through tightening the screws and, pressing the boards to a thickness of about 16 mm. The boards were pressed in this phase to the minimum possible pressure, in order to achieve the best results for reaching parameters, required in the standard for cement-chip boards.

Table 2. Characteristics of the final mixtures

Mixture	Description	Bulk weight [kg/m^3]	Bending strength after 28 days [N/mm^2]	Modulus of elasticity after 28 days [N/mm^2]
Mixture 59	fraction A hemp	1332	6,1	4801,7
Mixture 59-C	fraction A hemp + with a cement sub-base	1291	5,7	5580,1
Mixture 60	fraction B hemp	1321	6,6	5584,9
Mixture 60-C	fraction B hemp + with a cement sub-base	1400	7,2	5831,3
Mixture 61	wood	1219	9,5	7156,9
Mixture 61-C	wood + with a cement sub-base	1397	9,3	8034,0

Mixture 62	fraction A + B 1:1 hemp; 115% of cement	1374	7,1	6686,7
Mixture 62-C	fraction A : B = 1:1 hemp; 115% of cement + with a cement sub-base	1438	7,2	7216,3

Chart 4. Bulk weight

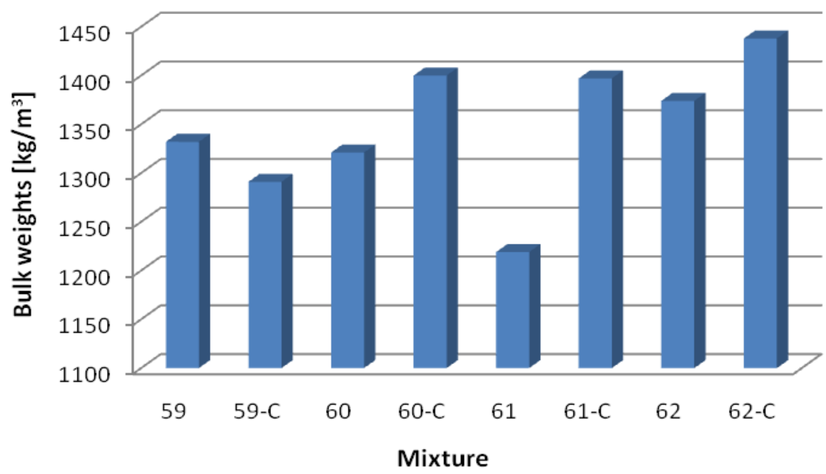


Chart 5. Bending strength after 28 days

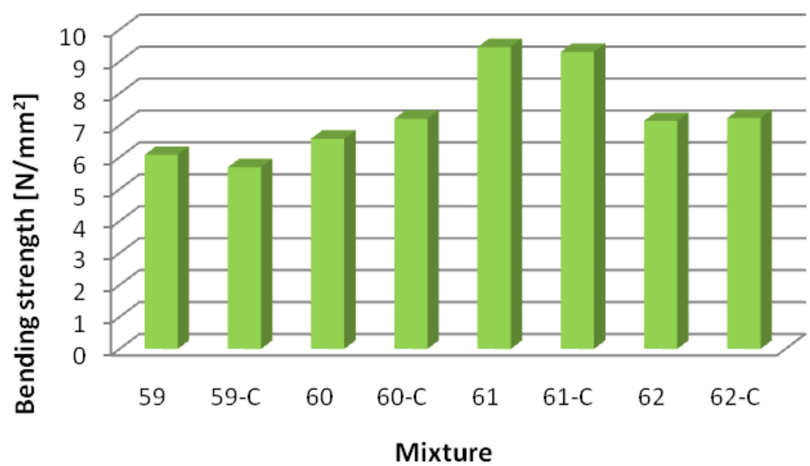
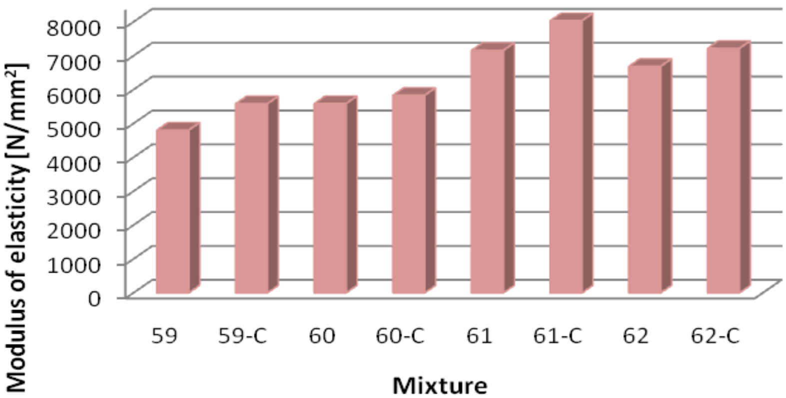


Chart 6. Modulus of elasticity after 28 days



The result of this phase is that the best results have been achieved with mixture No. 61, these samples contained a wood chip. Second best test results were mixed at No. 62, which was formed by a combination of fractions A and B of the technical hemp and 115% of cement. Samples with cement sub-base have been achieved better results.

Examples of produced boards

Fig. 4: on the right, a board made from the mixture 59 (fraction A cannabis); on the left, without a cement sub-base

Fig. 5: on the right, a board made from the mixture 60 (fraction B cannabis); on the left, without a cement sub-base

CONCLUSIONS

This work has focused on the optimization of the cement-chip board's characteristics using various combinations and adjustment of the initial materials. Because we could not achieve the same conditions for the production as in the mechanical production, several reference samples were created in the laboratory using the basic formula derived from the CETRIS Company. Other samples could be compared with these reference samples.

In a subjective appraisal of the appearance of cement-chip and cement-hemp boards, the cannabis boards had a clearly smoother surface and uniform colour comparing to the reference samples from the chips. This will be of an advantage for these boards, regarding not only the exposed applications.

Several mixtures with different amounts of cement were made and the dependence of the flexure strength and elasticity coefficient was assessed the increase of the amount of cement up to 115% brings to better firmness of the samples. When combining a greater amount of cement and cannabis, we can see an improvement of the surface as well as exposed features. The produced boards fulfilled the requirements for the cement-chip boards and we can decrease the production costs for these boards whilst using quickly renewable raw materials.
The final samples were made with the effort to approximate to the production process used at CETRIS Company. The boards from cannabis were very similar to the boards made from chips. With regards to the low price of hemp (the wholesale price of cannabis is ca. 2,000 CZK/t, wholesale price of wood ca. 4,000 CZK/t), the cannabis boards could find their place on the market in the near future. There is no need for such great mechanization using cannabis, it is easy to dry and cut, it is quickly renewable and the yield of cannabis is up to 4 times higher than wood.

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