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The Influence of Physical-Mechanical and Thermal Properties of Hemp Filling Materials by the Addition of Energy Byproducts

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Abstract**—**This article describes to what extent the addition of energy by-products into the structures of the technical hemp filling materials influence their properties. The article focuses on the changes in physical-mechanical and thermal technical properties of materials after the addition of ash or FBC ash or slag in the binding component of material. Technical hemp filling materials are made of technical hemp shives bonded by the mixture of cement and dry hydrate lime. They are applicable as fillers of vertical or horizontal structures or roofs. The research used eight types of energy by-products of power or heating plants in the Czech Republic. Secondary energy products were dispensed in three different percentage ratios as a replacement of cement in the binding component. Density, compressive strength and determination of the coefficient of thermal conductivity after 28, 60 and 90 days of curing in a laboratory environment were determined and subsequently evaluated on the specimens produced.

Keywords**—**Ash, binder, cement, energy by-product, FBC ash (fluidized bed combustion ash), filling materials, shives, slag, technical hemp.

I. INTRODUCTION

BY using a combination of binders based on air or hydraulic lime with technical hemp shives there is a group of new building materials. These products have excellent operating characteristics for durable, environmentally sustainable constructions. Together these products form a natural composite building material that can be used to create insulation wall layers for floors and roofs as well as providing excellent thermal and acoustic characteristics for buildings.

Technical hemp shives with a lime-based binder has typical pressure strength of around 0.2-1 N·mm^{-2}; therefore it cannot be used in load-bearing structures. In the vast majority of cases, it is used in combination with a timber or reinforced concrete frame. Thus, the building height is determined by the structural system and not by the material of the fillers.

Systems made from timber or reinforced concrete frames use these composite materials as a filler of the walls providing them with insulation features. The composite materials provide excellent permeability for steam; therefore they prolong the life of the wood and form a protection against the negative effects in these structural systems.

As well as for construction of new buildings, this composite material is also suitable for the reconstruction and repair of old buildings with a timber frame construction system. This is a viable and acceptable replacement for the original wall fillers [1], [9].

A mixture consisting of lime binder with technical hemp shives has good plasticity and handling time, which affects the ease of application and waste reduction. These mixtures may be stored in the shuttering or they could also be applied by spraying as well as for concrete or plaster [2].

II. THE PROPOSE OF THE REFERENCE FORMULATION

Standard reference formulation is composed of 38% filler mineralised by sodium water glass with a concentration of 12%, 42% binder (70% dry hydrate and 30% cement) and 20% water; this formula has shown to be the most appropriate in the previous experimental work [4]. It achieved the best strength characteristics whilst also maintaining very good technical thermal properties. To verify the possible use of energy by-products in the materials structure, the basic formula was changed only in the binder component in a way that the proportion of cement was replaced from 5%, 10% and 15% [6]-[8].

The work used FBC ash from Hodonín, Tisová and Pořící power plants and the Olomouc heating plant, ash was used from Dětmarovice and Chvaletice power plants, and slag from the Dětmarovice power plant. Clear labelling of the composition of each formula can be found in Table I.

TABLE I
DESIGNATION OF RECIPES FOR THE PRODUCTION OF TEST SPECIMENS

Type of refund		Replacement of cement		
		5%	10%	15%
FBC ash	Hodnonín	H1	H2	H3
	Tisová	T1	T2	T3
	Pořící	P1	P2	P3
	Olomouc	O1	O2	O3
Ash	Dětmarovice	D1	D2	D3
	Chvaletice	Ch1	Ch2	Ch3
Slag Dětmarovice		S1	S2	S3

III. RAW MATERIALS USED

Technical cannabis (*Cannabis sativa*) is an annual thermophile plant of *Cannabaceae* family. It is a plant with

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long thin, straight, quickly and lightly branched woody stem with palmate curly serrated leaves and small, oval fruits. It is grown everywhere with a moderate climate, with the exception of soils permanently waterlogged or permanently over-dried. When processing, the entire plant is useful and has no waste. The highest content and the most quality fibres are located in the stems of compensating varieties, mainly in thin and long stems from the harvest in full bloom season. Hemp is a valuable agricultural crop. It is important to note that in our country only sown hemp is allowed to be grown, which due to a small content of THC (tetrahydrocannabinol) to 0.3% cannot be abused as a narcotic substance [3], [5].

Basic properties of ash and the slag used in the work are listed in Tables II, III and IV. The following type of *cement* was used - CEM I 42.5 R; *lime hydrate* CL 90-S, *sodium water glass* 42-44 Bé.

The hemp shives used in this work was originally from France, where it is known under the trade name of CHANVRIBAT, its bulk density is 92 kg/m^3; coefficient of thermal conductivity is 0.048 W/mK, a shives sample is shown in Fig. 1.

TABLE II
THE BASIC PROPERTIES OF ASH AND SLAG

Material		Specific gravity [kg/m^3]	Bulk density in bulk [kg/m^3]	Bulk density shaken off [kg/m^3]	Specific surface area [m^2/kg]
FBC ash	Hodonín	2568	493	691	291
	Tisová	2808	538	817	361
	Poříčí	2679	593	856	347
ash	Olomouc	2735	590	815	278
	Dětmarovice	2250	753	1070	362
	Chvaletice	2235	736	994	334
	Slag	2350	1390	1600	364

TABLE III
THE CHEMICAL COMPOSITION OF ASH AND SLAG – PART 1

		Chemical composition [%]					
		SiO_2	CaO	Al_2O_3	Fe_2O_3	P_2O_5	MgO
FBC ash	Hodonín	33.10	23.77	17.70	7.52	0.28	4.65
	Tisová	26.05	20.14	23.00	7.00	0.36	0.80
	Poříčí	35.25	25.80	19.60	5.68	0.29	0.81
ash	Olomouc	39.40	13.77	25.75	8.82	0.85	2.38
	Dětmarovice	52.40	4.40	23.90	7.14	0.40	2.34
	Chvaletice	54.10	3.10	24.90	11.17	0.17	1.52
	Slag	32.4	35.7	10.7	1.3	1.4	11

Fig. 1 Shives technical hemp used of the work

TABLE IV
THE CHEMICAL COMPOSITION OF ASH AND SLAG – PART 2

		Chemical composition [%]			
		MnO	K_2O	Na_2O	loss on ignition
FBC ash	Hodonín	0.09	0.88	< 1	4.49
	Tisová	0.06	0.54	< 0,9	3.12
	Poříčí	0.06	1.25	< 0,8	5.90
ash	Olomouc	0.07	1.35	< 1	1.92
	Dětmarovice	0.10	2.80	< 0,9	3.37
	Chvaletice	0.10	1.33	< 0,8	1.15
	Slag	0.12	1.2	0.7	4.3

IV. THE PRODUCTION OF TEST SAMPLES

The procedure of mixing and compaction of solids was always carried out in the same manner. Technical hemp shives was left for 24 hours in a 12% solution of sodium water glass. When mixing, firstly the dry ingredients were mixed and then water and hemp were added, everything was thoroughly homogenised and stowed into thirds into moulds using an input pressure of 10kg weight. Three sizes of moulds were used - 100x100x100mm for testing the density and compressive strength, after 28, 60 and 90 days of ripening. Furthermore, moulds of 300x300x50mm for testing to determine the thermal conductivity coefficient after 28 days of steady dried state using the stationary method (The Plate Method) according to ČSN 72 7012-3 [10]. In Fig. 2, you can find a sample of test specimens and the texture of filling materials. Table V presents the results of all tests performed which are mathematical averages of the minimum three measurements.

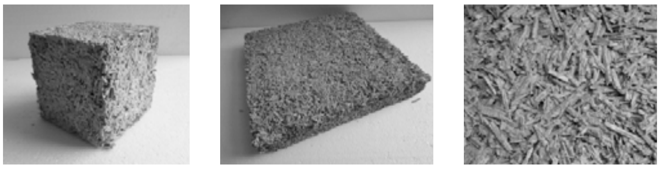

Fig. 2 The illustration of test specimens and the texture of filling materials

TABLE V
THE RESULTS OF THE TESTS

Mixture	Density [kg/m^3]				Compressive strength [N/mm^2]			Coefficient of thermal conductivity [W/(mK)]
	0 time	28 days	60 days	90 days	28 days	60 days	90 days	
Ref	927	860	724	637	1.21	1.73	1.92	0.0812
H1	873	787	659	534	1.08	1.59	1.67	0.0761
H2	865	799	651	562	1.17	1.39	1.54	0.0773
H3	840	712	549	489	1.06	1.22	1.38	0.0764
T1	873	701	656	541	0.88	1.14	1.26	0.0789
T2	796	709	629	520	0.66	0.82	1.11	0.0781
T3	803	692	563	504	0.54	0.92	1.16	0.0732
P1	867	747	698	616	0.94	1.29	1.68	0.0773
P2	839	764	675	587	***0.97***	***1.46***	***1.71***	0.0751
P3	824	734	698	556	1.02	1.32	1.54	0.0767
O1	826	761	659	602	0.87	1.02	1.24	0.0736
O2	789	672	597	554	0.61	0.86	1.09	0.0712
O3	***723***	***641***	***593***	***537***	0.74	0.99	1.15	***0.0701***
D1	873	701	656	541	0.88	1.14	1.26	0.0789
D2	796	709	629	520	0.66	0.82	1.11	0.0781
D3	726	689	634	602	0.69	0.91	1.09	0.0776
Ch1	886	764	703	652	0.78	0.98	1.28	0.0777
Ch2	771	697	631	603	0.84	0.94	1.20	0.0769
Ch3	764	687	634	578	0.98	1.04	1.19	0.0754
S1	796	709	629	557	0.87	1.02	1.24	0.0746
S2	803	692	563	542	0.65	0.87	1.16	0.0722
S3	785	683	604	576	0.78	0.96	1.21	0.0724

V. DISCUSSION OF THE RESULTS

Based on the graphic observation, we can conclude that the addition of energy by-products causes a decrease in compressive strength compared to the reference formulas, but it still achieves acceptable values for applications such as filling materials. The size of loss of strength can be compared to the percentage replacement of cement in the binder component. The addition of up to 10% does not lead to drastic decreases of strength in favourable reduction of density and thermal conductivity coefficient. The most appropriate energy by-product appears to be the use of fluid fly ash from the Olomouc thermal power station. The measured values of the specimen properties, using this ash, show a very good relationship between the physical mechanical and thermal technical properties.

VI. CONCLUSION

In conclusion we can state that the use of energy by-products in the structure of hemp filler materials is possible.

When using these products, although there is a slight decrease in strength properties, but on the other hand, it improves thermal and technical properties of the materials. This is very beneficial especially for applications such as thermal-insulation filling material applicable for vertical and horizontal structures not only in the construction of new buildings, but also in rehabilitation interventions on the ceiling and floor layers. For a comprehensive assessment of the appropriateness or inappropriateness of using energy by-products in the structure of filling materials we need to proceed further to extensive testing of the properties of the resulting materials. The most important aspect is the durability characteristics of the materials, such as hardness or resistance in various environments. Furthermore, for use as a thermal and sound insulating filling material it is necessary to test the required properties further.

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