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EXPERIMENTAL STUDIES OF ECOLOGICALLY-CLEAN THERMAL INSULATION NON-AUTOCLAVE COMPOSITES BASED ON FLAX SHIVE AND DIFFERENT KINDS OF LIME CONTAINING BINDERS

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The main object of the this paper is to study the effect of the mix proportions with flax shive as filling agent in composite system on selected physico-mechanical properties of the light weight composites in influence of new kind of lime-silica binder. The article presents eco-friendly composite thermal insulation materials designed as an alternative to traditional cement-lime binders. When adapted to local raw material resources of a particular region the structural materials can prove to be a promising material for eco-friendly timber frame housing construction in the Republic of Belarus, which is to some extent a revival of the millennial experience in the use of crop waste when constructing low-rise buildings.

Introduction

The phenomen of global warning and its impact on the environmental has called attention to the use of more environmentally friendly processes and the use of agriculture waste as a biomass resource to ensure environmental, social and economical sustainability [2]. Flax shive (hurds) are considered the waste product remaining after cellulose fiber removal from flax straw.

As was shown in [2; 3] the yield of shives is 2,5 tons for every one ton of fiber produced.

The large amount of agri-based biomass produced highlights the need for positioning a material conventionally deemed a waste product of agricultural production as a co-product [3].

As was shown in [3] sustainable development can only be possible when constructions uses renewable natural materials or materials recycled from constructions wastes. Natural materials such as hemp, flax and sisal have been identified as attractive raw materials for lightweight composite manufacturing in many areas of the wored. They are cheap, abundant, renewable, hon-structural element and have good specific proporties do to their low deusities. This vegetable material has also low environmental impact.

Natural fibres such as hemp, flax (linen) and sisal have been identified as attractive candidates for the composites production.

Trend in modern research and development of environmental friendly composite materials are focused on “green approach” what is connected with moving from the limited and non-renewable finite material to easialy renewable raw materials are materials of plant origin. The use of natural fibers as well as waste from processing of plants as reinforcement of composite materials is one of the most important targets in recent materiale research [3; 4].

In context of challenging environmental and a global energy crisis, bio-based materials are attracting increasing levels of research interest, from both academia and industry, because of their numerous advantages: renewable resource usage, low cost, biodegradability, and so on.

As shown in [4] the properties of flax, hemp fiber depend on the chemical composition. The blast fibers contain more amount of cellulose compared to the hurds (shives). Contrary, content of hemicellulose and legnin as a morning substances are higher in hurds (shive) [1] (table 1).

Table 1

Chemical composion of flax [1]

Component	Flax, [%]	
	fiber	shive (hurds)
Cellulose	65,0	44,2
Hemicellulose	16,0	30,3
Pectin	3,0	
Lignin	2,5	24,4
Proteins	3,0 (proteins only)	
Fats and waxes	1,5	
Ash (minerals)	1,0	
Water	8	

As was noted in [2] only 5 % of flax shive (hurds) is used to preparation of building materials, mainly in production of thermal insulation composites do to their porous structure. For recent thermal insulation materials is used fibrous part of flax stem. Building industry is focussing on the fibers and hurds that originate in the stem of the plant.

While individual products vary in the choice of source material, natural fibre insulation is commonly divided from co-products of other processes, and hence generally has a low environmental impact [3; 4].

Natural fibre insulation is typically processed to form rigid of semi-rigid rolls or loose insulation materials (table 2) for a variety of uses in construction. Typically, natural fibre insulation has to be treated with a fire retardant, often ammonium salt or sodium borax, although the latter may be phased out by forthcoming European legislation. Non-toxic salts ave usually added as a evolution to ensure good dispersial.

Table 2

Properties of natural fibre insulation materials [1]

Material	Typical thermal conductivity, [w/mK]	Commonly available format
Natural Wood fibre	0,038...0,050	Boards, semi-rigid boards and batts
Paper (cellulose)	0,035...0,040	Loose batts, semi-rigid batts
Hemp	0,038...0,040	Semi-rigid slabs, batts
Wovl	0,038...0,040	Semi-rigid boards, rools
Flax(linen)	0,038...0,040	Semi-rigid boards, rools
Cork	0,038...0,070	Boards, granulated

The lightweight composites were developed by using only hemp and flax fibers. The most of the researches are currently focused to the use of the woody core part of the hemp or flax (shives or hurds) as waste material from flax fiber separation process.

The properties of "biocomposites" depend on chemical composition (table 3) and structure of flax material, matrix properties as well as good adhesion in the flax shives – matrix interface.

Table 3

Properties of natural fiber [1]

Fiber	Density, [kg/m^3]	Elongation, [%]	Tensile strength, [MPa]	Young's modulus [GPa]
Cotton	1,5...1,6	7,0...8,0	287...597	5,5...12,6
Jute	1,3	1,5...1,8	393...773	26,5
Flax	–	2,7...3,2	345...1035	27,6
Hemp	–	1,6	690	–
Sisal	1,5	2,0...2,5	511...635	9,4...22,0
E-glass	2,5	2,5	2000...3500	70,0

The object of this work is study the effect of the mix compositions with flax shive (hurds) as filling agent in composites system on selected physico-mechanical properties of the lightweight composities in influence of new kind of lime-silica binder.

The results of measured parameters (density, compressive strength, thermal conductivity coefficient, shrinkage strains) of developed composites are presented in dependence on a hardening time.

1. The methodology of the research

1.1 The main criteria for the selection of mineral binders compositions and organic fiber fillers of plant origin

The aim of the conducted researches was to obtain composite materials that meet the following criteria:

1) ecological compatibility;

2) development of strength under natural conditions;

3) possibility of high repeatability during construction in local conditions without the using of specific, less-common equipment;

4) use of renewable and (or) the available components of the mixture;

5) minimal negative environmental impact of the entire lifecycle (LCA according to DIN ISO 14040 [5]) of the obtained material in comparison with traditional materials (with a high content of cement or autoclave hardening);

6) high thermal insulation properties with possibility to obtain R-value of enclosure structure up to 50 sm thick which is equal to 3,2 m^{2}C/W (according to the requirements of technical code of common practice 45-2.04-43-2006 [6]);

7) using of the materials with low possibility of an alternative using or industrial wastes in the compositions;
8) durability;
9) active hydroregulation;
10) fire safety corresponding to regional standards;
11) satisfactory sound insulation and acoustic comfort;
12) frost-resistance;
13) suitable technological properties: adhesion, workability, etc..;
14) no less than 1,5 times smaller payback period in local conditions compared to traditional materials.

Chemical production waste, slags, ashes, non-technological clays, associated rocks, waste of glass processing, waste of metals and alloys machining, waste of ceramic industry, waste of silicate manufacturing are the most promising materials in terms of the possibility of their use in the building composite materials. The use of these materials in construction can be carried out in two directions:

1) *passive* (waste utilization, change in physical properties with very little impact on the chemical processes of hardening);

2) *active* (participating in chemical processes as a reactive component or a binder with a significant change in the physico-mechanical properties, imparting special properties).

The first direction allows to use at least half of the capacity of materials or resources invested in them in very rare cases, therefore the principal modern direction is just using them as active ingredients, such as binders.

In this paper sludge of water cleaning generated during grinding and polishing the glass on one of the local businesses was used according to the active scheme. Cement binders were used in minimally required amount in certain compositions for the primary fixing of the structure and shrinkage decrease during hardening.

Organic fibrous fillers of plant origin (flax shive, rye straw, wheat straw) were used according to the passive scheme.

Flax shive is practically unusable waste of flax fiber production with a low possibility of an alternative use (only as fuel).

Produced part of straw is directly chopped in the fields and scattered as an organic fertilizer. Most of the straw in rolls or bales is delivered to the farms from the fields, where it is stored in haystacks and further used for the cattle feeding or as a bedding. In practice, due to the high volume of production, up to 30…45 % of the straw is not used and it rots in haystacks in the open fields or in the territories of livestock complexes. In practice up to 30…45 % of the straw is not used and it rots in haystacks in the open fields or in the territories of livestock complexes. This is due to the high volume of production. Such storage leads to rotting of a straw and its germination after the winter season. As a result a significant portion of the straw becomes unfit for use and it can not be used.

1.2 Experimental program

Based on results of previous study experimental optimal compositions was selected and program was developed (table 4).

Table 4

Designation and general description thermal insulating and structural composites (own research)

Sample	Kind of composite	Approximate composition	The expected dry density in the wall structure, ρ [kg/m^3]
FRA-1ALS	Fiber reinforced thermal insulating composite with organic fibrous fillers of plant origin and blended lime – aluma – silica binder	Hydraulic lime, non-hudraulic (unslaked) lime, metakaolin or clay suspension, Ca-, Si-containing water treatment wastes (fine or crushed quartz sand), flax shive, straw, mineralizer, alkali	550…1000
FRA-2LS	Fiber reinforced thermal insulating composite with organic fibrous fillers of plant origin and blended lime- silica binder	Hydraulic lime, non-hudraulic (unslaked) lime, Ca-, Si-containing water treatment wastes (fine or crushed quartz sand), flax shive, straw, mineralizer	550…1000
FRA-3CLS	Fiber reinforced non-autoclaved composite with blended cement-lime-silica binder and organic filler of plant origin	Hydraulic lime, non-hudraulic (unslaked) lime, metakaolin or clay suspension, cement CEMI-42.5R, Ca-, Si-containing water treatment wastes (fine or crushed quartz sand) flax shive, straw, mineralizer, gazifier	350…550
FRA-4LS	Fiber reinforced non-autoclaved composite with lime- silica binder and organic filler of plant origin	Hydraulic lime, non-hudraulic (unslaked) lime, Ca-, Si-containing water treatment wastes (fine or crushed quartz sand) flax shive, straw, mineralizer, gazifier	350…550

Three kind of thermal insulation and construction material for externall wall was investigated. As shown in table 4 all type of experimental specimen includes composite materials with a predominant content of lime, flax shive and active filles (two types M and G) that meet the criteria listed in paragraph introduction, at the stage of review and previous preparation of experimental studies. Designation of prepared composites based on varios composion and proportions of components is show in table 4, 5.

The next kind of binders was used in experimental research lima-aluma-silica binder, lime-silica binder and lime-cement-silica binder.

Table 5

Approximate composion of thermal insulating and structural composites in own research

N	Sample	Component								
		hudraulic lime	non-hudraulic (unslaked) lime	metakaolin or clay syspension	quartz sand	flax shive, straw	mineralizer	alkali	gazifier	cement
1	FRA-1ALS	+	+	+	+	+	+	+	–	–
2	FRA-2LS	+	+	–	+	+	+	–	–	–
3	FRA-3CLS	+	+	+	+	+	+	+	+	+
4	FRA-4LS	+	+	–	+	+	+	–	+	–

Samples FRA-(1...4)XX

Preparatory operations

Before mixing non-hydraulic lime (quick lime) was slaked by water. Amount of water was corresponded to the lime mass. The straw was cuted to 2...7 cm length fractions in straw cutter. Flax shive was preliminary was separated and sifted through vibrating sieve with the mesh up to 5 mm. Flax shive and straw was mixed in the ratio 3:5, washed by the water and soaked in 30 % liquid glass for 2 to 4 hours. Water was changed 3...4 times. Then the mixture was squeezed and pached.

1.3 Research methods

The density, thermal conductivity coefficient, compressive strength and water absorbtion were measured on composite after 28...40 days of hardened. Density was determined in accordance with standard STB EN 12390-7 and GOST 12730.0, GOST 12730.1. The thermal conductivity coefficient of composite samples, as one of the main parameter of heat transport was measured by the device ISOMET 104 in accordance Standard of the Republic of Belarus STB 1618.

Compressive strength of all initial materials (binders) and composites was determined using the testing machine CONTROLS (Italy) accordance National Standards GOST 10180, GOST 310.1, GOST 310.4.

Water absorbtion was specified in accordance with standard STB EN 12087/A1. Compressive strength of the all composites was tested on standard cube specimens 100×100×100 mm. Composive and flexural (bending) strength of binder materials was tested on standard beam specimens 40×40×160 mm.

Dry density of the all composite materials was tested used the specimens of regular geometric shape accordance with national standards.

Shrinkage strain of the all composite material was calculated from the measurement results of beam specimen tests 40×40×160 mm and 50×50×200 mm in accordance with Standard of the Republic of Belarus STB 1570. Standard beam specimens (40×40×160 mm and 50×50×200 mm) and standard cube (100×100×100 mm) were made in steel molds which were covered with film immediately after remolding to prevent drying.

Possible variability intervals of the components' mass ratio were not preset and were chosen anew after each experiment. The optimal value was determined by the parallel production of least 2 series (no mo then 6 specimens in each) of prototypes under the same conditions.

Composite materials' composition (table 4) was optimized through a conducting the experiment with mean values of variable parameters. For this purpose two parameters were changed simultaneously compared to the initial composition.

For each of the following materials were made at least two optimization cycles.

2. Results and brief discussion

Selected properties of hardened composite materials based on flax shive with various compositions of mixes were compared.

In table 6, density, thermal conductivity coefficient, shrinkage strains and compressive strength of 28 days hardened composites are given.

According to the measurements, dry density values of composites were in range of 375...770 kg/m^3.

The obtained composite FRA-1ALS is characterized by high density and thus the highest value of thermal conductivity coefficient among all the composites, which can be up to 0.21 W/m°C under operating conditions B of Technical Code of Common Practice TCP 45-2.04-43-2006 [6]. However the given composite is also characterized by the highest compression strength $f_{c,28}$ which means that this construction material can bear complementary loading in addition to its own weight. The shrinkage strains of given composite FRA-1ALS was the lowest among all composites.

Fig. 1. Samples of lime-silicate heat insulating fiber-reinforced concrete with organic fiber fillers of vegetable origin

Fig. 2. Surface samples from the lime-silicate heat insulating fiber-reinforced concrete with a density of 800...900 kg/m^3

Fig. 3. Surface samples from the lime-silicate heat insulating fiber-reinforced concrete with a density of 600...700 kg/m^3

Table 6

Result of experimental studies of thermal and nonstructural wall composites

N	Sample seria	Density, ρ [kg/m^3]	Thermal conductivity coefficient in dry state, λ W/m°C	Compressive strength, $f_{c,28}$ N/mm^2	Shrinkage strain [mm/m] binder/composite	Thickness of the wall, d_N for R = 3,2 m^{2}C/W, [mm]	Approximate mass for insulation of 1 m^2 of the wall, kg
1	FRA-1ALS	770	0.21	1.2...2.2	3/7.0	640	490
2	FRA-2LS	650	0.15	0.5...0.8	4/8.0	480	312
3	FRA-3CLS	375	0.10	0.3...0.6	3/9.0	320	120
4	FRA-4LS	435	0.11	0.15...0.4	4/14.0	355	155

Notes: 1. Range for the tested specimen in sample seria.
2. Value d_N without additional thermal insulation.

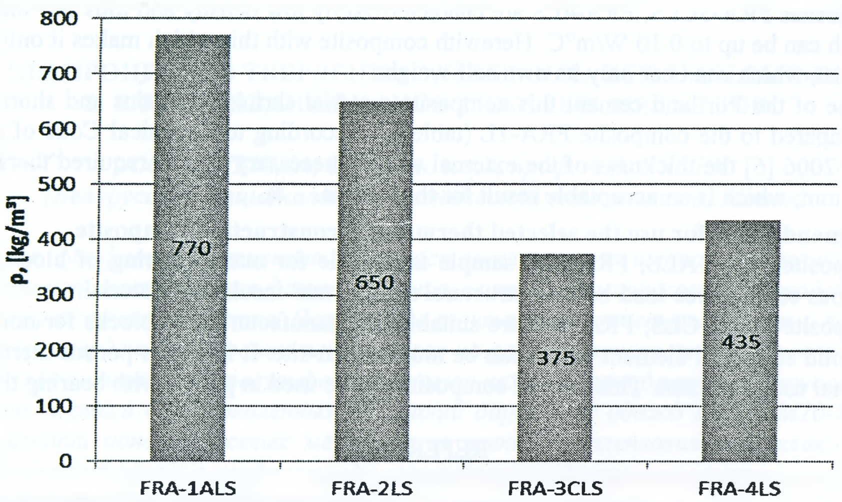

Fig. 4. Density of composites in dry conditions

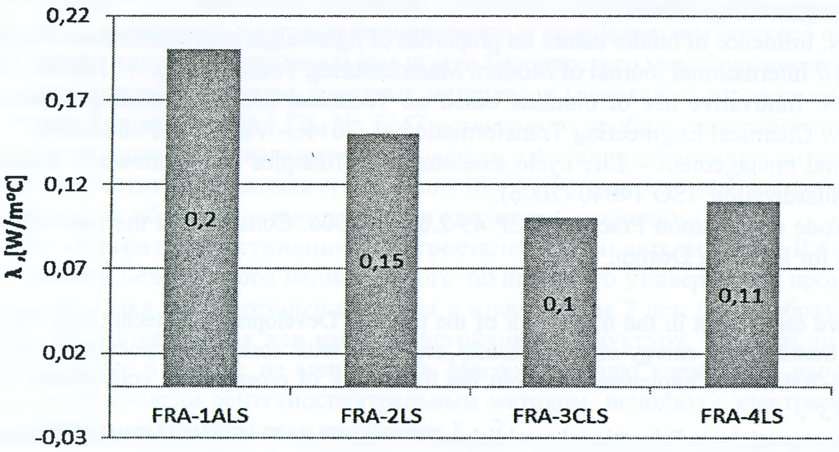

Fig. 5. Values of the thermal conductivity coefficient λ

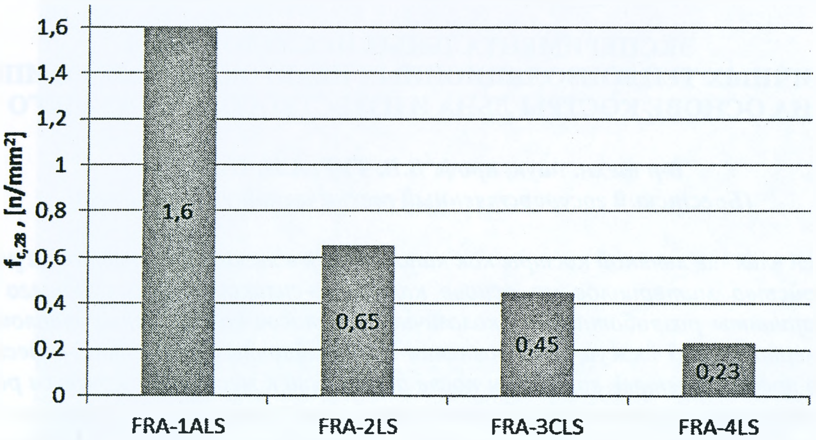

Fig. 6. Compressive strength at 28 days

According to requirements of Technical Code of Common Practice TCP 45-2.04-43-2006 [6] the thickness of the wall d_N, necessary for the required thermal resistance can reach 480…640 mm, which is not an acceptable result for criteria. However, this composition can be used in sandwich constructions with a separate external thermal-insulating layer increasing the temperature resistance of premises due to the its own greater heat capacity.

The composites FRA-3CLS, FRA-4LS are characterized by low density and thus low thermal conductivity coefficient, which can be up to 0,10 W/m°C. Herewith composite with this which makes it only a heat-insulating composite material, which can bear only its own self-weight.

Due to use of the Portland cement this composite material shrinkage strains and shorter strength development time compared to the composite FRA-1L (table 6). According to Technical Code of Common Practice TCP 45-2.04-43-2006 [6] the thickness of the external wall d_N necessary for the required thermal resistance can reach 320…360 mm, which is an acceptable result for the criteria.

3 Recommendations for use the selected thermal and construction composite

The composite FRA-1ALS, FRA-2LS sample is suitable for manufacturing of blocks for load-bearing walss. It is a porous cement-free load-bearing structural and thermal-insulating material.

The composite FRA-3CLS, FRA-4LS are suitable for manufacturing of blocks for non-load-bearing external walls or solid structural element which can be moulded on-site. It is a high-porous thermal insulating material with minimal use of cement. This kind of composite can be used in panels with bearing timber frames.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ЭКОЛОГИЧНЫХ ТЕПЛОИЗОЛЯЦИОННЫХ НЕАВТОКЛАВНЫХ КОМПОЗИТОВ НА ОСНОВЕ КОСТРЫ ЛЬНА И ИЗВЕСТКОВОГО ВЯЖУЩЕГО

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Исследуется влияние льняной костры как наполнителя в легких композитах на различные физико-механические свойства материалов на основе кальциево-силикатного связующего вещества. Рассматриваются варианты разработанных экологичных составов композитных теплоизоляционных материалов на альтернативных вяжущих в сравнении с традиционными цементно-известковыми. Сделан вывод о том, что представленные варианты после адаптации к местным сырьевым ресурсам конкретного региона могут быть перспективным материалом для экологичного каркасного домостроения в условиях Республики Беларусь, что в определённой степени является возрождением тысячелетнего опыта применения отходов растениеводства при строительстве малоэтажных зданий.