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COMPOSITE BASED ON FOAM LIME MORTAR WITH FLAX FIBERS FOR USE IN THE BUILDING INDUSTRY

KOMPOZYT NA BAZIE SPIENIONEJ ZAPRAWY WAPIENNEJ Z WŁÓKNAMI LNIANYMI DO ZASTOSOWANIA W BUDOWNICTWIE

Abstract: Building industry as an important branch of the economy of each country consumes significant amounts of energy and emits greenhouse gases into the environment (CO_2). These negative effects which affect on the environment have a contribution to make many of the restrictions recorded in the documents of sustainable development in the construction industry. The most significant are: environmentally friendly building products, energy efficiency of buildings, organized management of construction wastes including demolition materials. However, in relation to a building and its surroundings can be distinguished: reduction of impurities emissions resulting from the combustion of the heating facility, reduction of the energy demand for heating, possibility of disposal of waste and effluents.

These considerations leads to the exploration and initiation of new construction materials and technologies, and in the final stage for the implementation of low-energy and passive buildings.

This paper presents the results of preliminary studies of new composite material based on foam lime mortar, packed with natural flax fibers and additives and admixtures. The paper presents the physico-mechanical characteristics of the composite (strength parameters, absorption, coefficient of thermal conductivity, etc.) of different composition mix output. It is expected that the composite will be applied in the implementation of low-energy and passive building as parts fulfilling the structural and insulation function. The proposed material solution from natural ingredients meets the requirements of sustainable development in the construction industry.

Studies are carried out under a cross-border grant from the Technical University in Brest and the material as the original solution is submitted to the Polish Patent Office.

Keywords: flax, organic fibers, lime binder, sustainable development

Introduction

Although ecological building is a relatively new phenomenon, it is growing rapidly in the construction sector. Regulations on the reduction of greenhouse gas emissions

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(CO_2) and waste production accelerate the development of sustainable construction. Public awareness of the conventional energy sources depletion and the negative effects of environmental impact contribute further to the progress in the field of construction. For this reason, natural, eco-friendly materials are still being sought since they are recyclable and can also be used in the construction industry as a construction material. In addition, and at the same time fulfilling the function of thermal insulation in accordance with the specifications of the heat transfer coefficient [1, 2].

In France and the United Kingdom, a study was carried out on a composite consisting of cut pieces of hemp stalks and lime binder [3]. In Slovakia, in turn, a composite containing hemp was tested, for thermal loads effects on the mechanical properties [6]. Apart from hemp, other fibers were also used in tests. In Brazil for instance, sisal fiber was added to concrete blocks [4]. More importantly, the largest use of natural composites has been observed in France where about 2,000 houses have been built from eco-friendly materials.

In Poland, however, especially in agricultural regions for instance, in Lublin surroundings, an alternative is flax-plant, once popular in cultivation, yet forgotten due to low profitability which mainly depends on the garment industry. Linen products (oil, straw) are widely used in construction industry, for example in the manufacture of flaxboards, linoleum, flax-seed oil [7].

The purpose of this article is to present a proposal for a composite material with a natural composition with flax applied to the low buildings, and to develop proposals of technological solutions. The material was tested for physico-mechanical and thermal properties, test results and analysis are presented in the further part of the article.

Own research and used materials

The laboratory tests included the execution of composites based on lime binder involving fiber and straw from flax. The material properties were modified by adding additives and admixtures. Flax was obtained from a farm in the province of Lublin. Processing flax (containing straw and fiber inside) consisted of cutting it into lengths of about 25 mm (Fig. 1). The diameter of flax straw was about 1–1.5 mm. A flax fiber itself was also used which was sliced into three fractions, the length of 10 mm, 15 mm and 20 mm (Fig. 2). During the preparation of flax straw, its high water absorption was found, which could affect the destruction of the thermal properties of a finished composite. It was noted that flax straw swelled quickly, and after an hour of soaking in water, its weight increased twice. In order to reduce the absorption of straw hydrophobization, natural impregnation (flax-seed oil) was applied.

Furthermore, hydrated lime and in some cases, lime with the addition of Portland cement CEM I 42,5R were used as a binder. Lime as a natural binder is an ecological product, hence affects positively a microclimate in the building, as well as the health of residents.

The aggregates used in small quantities include sand fraction of 0–1 mm and powdered limestone. In order to accelerate the binding of the lime binder, a pozzolanic admixture in the form of microsilica (Woerosil U-P) was applied to the mixture. In addition, such an admixture causes the tight fill of voids in the mix, and improves its

Fig. 1. Chopped straw with fiber inside used in the study

Fig. 2. Cut flax fiber used in the study

workability. Another admixtures include sodium bicarbonate ($NaHCO_3$) and citric acid ($C_6H_8O_7$). These compounds react together in the presence of water, which results in the emission of large amounts of carbon dioxide that accelerates the carbonation of lime. It is worth mentioning that even Ancient Romans added young fig wine to lime, which led to the fermentation and the consequent emission of considerable amounts of CO_2 that contributes to faster bonding of lime [5].

In order to improve the thermal properties of the final product, composites containing foam, which was obtained by the mechanical mixing foaming agent with water, were also made. Foam introduced into the mix causes the closure of air bubbles in the bulk and increases the volume of the finished product, which leads directly to the decrease in the density of the composite. Moreover, the structure of cutted capillary pores facilitates the distribution of ready-mix in shuttering.

Four composites, differing in composition, were executed (K1, K2, K3, K4) (Table 1). In the composites K1 and K2, flax straw was impregnated by using flax-seed oil, while in the others, flax components did not hydrophobize. In the case of K3 and K4, cement was used in the amount of 30 % and 25 % by volume of the lime. The quantity of pozzolanic admixture was 5 % by the weight of lime.

Table 1

The components included in the various composites

Components / Composites	Water	Lime	Cement	Sand	Lime powder	Micro-silica	Flax straw	Flax fiber	Foam
K1	X	X	—	X	—	—	X	—	—
K2	X	X	—	X	—	X	X	—	—
K3	X	X	X	X	—	—	X	—	X
K4	X	X	X	X	X	X	X	X	X

After mixing all components, samples were formed by light, hand-held tamping successive layers. After disassembling samples that maturated at air-dry conditions, tests on physical-mechanical and thermal properties of K1 and K2 composites were held after 90 days of maturation, and of K3 and K4 after 28 days.

The basic physical and mechanical properties of the material, such as bulk density, tightness, porosity, water absorption and compressive strength, were examined. All the tests were performed on cubic samples with the dimension of 10 × 10 × 10 cm. Thermal conductivity coefficient was measured on the basis of thermal parameters in Heat Flow Meter (HFM) instrument, on samples having the dimension of 25 × 25 × 5 cm. For each test, an outcome was defined as the arithmetic mean of the three samples. In order to evaluate the microstructure of the composite, a material was viewed by using a Scanning Electron Microscope (SEM).

Analysis of the results

Results of physical parameters are shown in Table 2. Bulk density values of composites are in the range from 0.44 to 1.29 kg/m^3, with the lowest values obtained by K3 and K4. This is caused by the presence of foam in the mixture, whose application minimizes the use of other ingredients. Bulk density differs by 20 % between K1 and K2 which is caused by the use of a larger amount of sand in the composite K1. The differences in bulk density between the composites indicate that there is a wide range of options to modify the material, depending on the application (construction, construction and insulation, insulation).

Table 2

Examples of the physical properties of tested composites

Composites / Physical properties	K1	K2	K3	K4
Bulk density [kg/dm^3]	1.29	1.05	0.5	0.44
Tightness [%]	50.5	48.3	23.0	17.5
Porosity [%]	49.5	51.7	77.0	82.5
Mass absorption [%]	28.0	39.0	67.0	77.0

While analyzing the results of the porosity test, it was observed that the examined composites can be divided into two groups. Hence K3 and K4 composites obtained higher porosity of about 60 % in comparison with K1 and K2. The differences in these values are due to the foam used in K3 and K4 which forms a structure of closed pores filled with air. The high porosity of K3 and K4 is equivalent to the low tightness of these composites.

Composites, as a result of relatively high porosity in the case of conventional building materials (such as concrete, brick), and the presence of straw and flax fibers show absorption of 35 % for K1 and K2, and 70 % for K3 and K4. During a binding process, samples in which flax component was impreganted (K1 and K2) obtained the solid mass in air-dry conditions in three times longer period than K3 and K4. It was found that the hydrophobization of flax straw (K1 and K2) accelerates the process of lime binding in relation to samples in which impregnation was not applied (K3 and K4).

In subsequent studies, currently underway, a mixture is also secured by adding impregnating admixture and a mature material is secured by surface hydrophobization in order to reduce the absorption of the composite. This analysis shows that a hydrophobized flax component should be used by contractors, which translates into improving physical and mechanical properties (rapid growth of strength, reduced absorption, improved thermal insulation properties).

Strength tests showed that the compressive strength changed in the range from 0.45 MPa to 0.65 MPa (Fig. 3). The mechanism of the destruction of all the samples proceeded slowly and caused a large plastic deformation. Such a phenomenon is consequent upon the presence of straw, and flax fibers which together with a binder,contained in the matrix, increase the cohesion of the material. This feature affects the safety of the structure in case of emergency, which translates into the comfort of a used building, made of a tested material. Samples of the lime binder or cement-lime binder without fibers deteriorate dramatically due to large discontinuity in the structure.

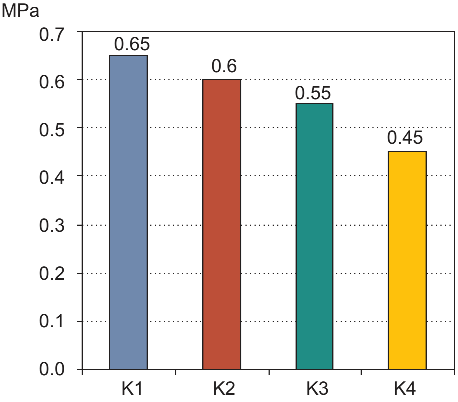

Fig. 3. The compressive strength of test samplesy

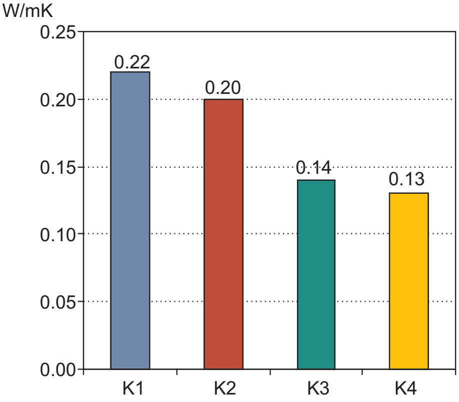

Fig. 4. The thermal conductivity of composites

In Fig. 5, the sample after reaching about 15 mm deflection is shown. After the research, the breakthrough of the sample was made, which showed the arrangement of the fibers in the matrix (Fig. 6).

The analysis of the results allowed to observe the relationship of the strength of the material and density. If composite K1 obtains the highest strength which is also characterized by the highest bulk density, the quantity of the sand is also the highest compared with other composites. More importantly, the lowest strength and density reached K4, in which foam was applied. A percentage difference in strength between K1 and K4 is about 30 %. Composite K4 has approximately three times lower bulk density than K1. It was concluded that by adjusting the composition of the mixture, strength properties of a composite can be increased, simultaneously trying to reduce the density of the material.

Measured values of λ coefficient of tested composites are shown in Fig. 4. Composite K3 and K4, despite lower content of fiber and straw in the volume of

Fig. 5. Compressive strength test

Fig. 6. Breakthrough of flax straw composite

material in comparison with K1 and K2, showed higher thermal resistance due to the large amount of air voids that resulted from the application of foam. The λ coefficient for K3 and K4 amounted respectively to 0.14 and 0.13 W/mK. The wall of this material would meet current thermal requirements for a traditional building (U-value ≤ 0.3 W/m^{2}K) with a thickness of 45 cm. Composites K1 and K2, althgouh having the highest bulk density, the thermal conductivity is relatively low (about 0.2 W/mK). It was noted that the increase of the amount of straw and flax fibers and the use of foam result in lowering of the thermal conductivity coefficient.

In Figs. 7 and 8 the fiber and the structure of mortar K3 composite were shown respectively with the use of a SEM. Moreover, relatively little energy was used, approximately of 100x-5000x due to the combustible nature of the individual natural fibers.

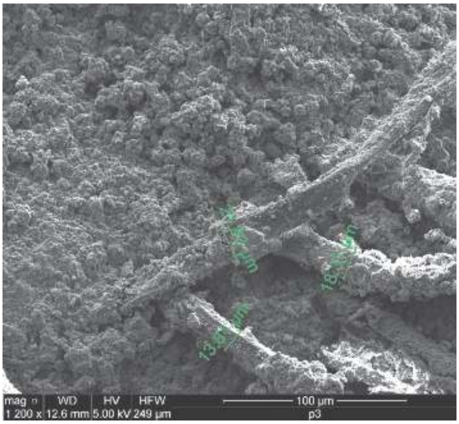

Fig. 7. Flax fiber

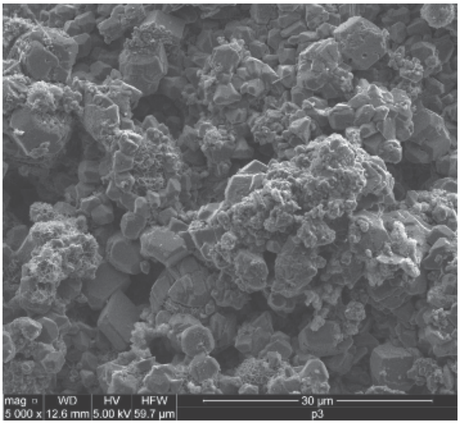

Fig. 8. The structure of mortar with foaming component

On the basis of the material structure analysis, it was observed that there occurred very good adhesion of flax fibers into the lime-cement matrix, which was consequent upon the rough surface of a fiber. In addition, in comparison with steel fibers used in conventional structural reinforced concrete, flax fibers exhibit high plasticity. This property is beneficial for the cohesion of material, which is due to better "matching" flax micro-reinforcement to the discontinuity of the composite structure, as opposed to steel fibers. Figure 8 shows the porous nature of the material and the calcium carbonate crystals in surroundings of partially hydrated cement grains. Calcite appears in the form of flat cubic tiles, which shows the final stage of carbonation of calcium hydroxide. Studies were performed by using scanning electron microscopy in the laboratory of the Faculty of Civil Engineering and Architecture of Lublin University of Technology.

Possible applications of composites

The target application of the composite is the construction of walls. The components in the form of blocks, fill timber frame (Fig. 9) and monolithic wall (Fig. 10) are taken into consideration. As described in the previous section, the lowest obtained value of thermal conductivity was 0.13 W/mK. Table 3 presents the achievable U-values for a wall in different configurations of insulation and composite thicknesses.

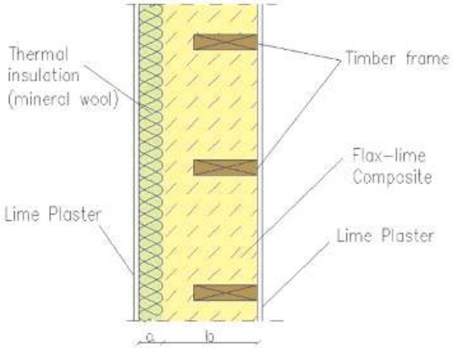

Fig. 9. Frame construction filled with the flax-lime composite and insulated with mineral wool

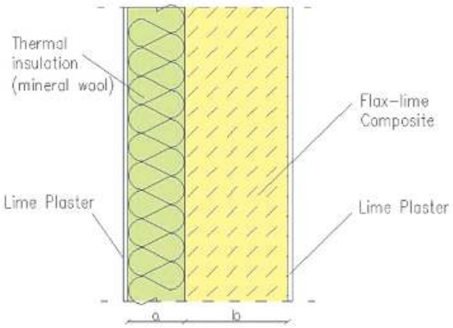

Fig. 10. TMonolithic wall made of the flax-lime composite and insulated with mineral wool

Results 1–4 in Table 3 are related to the thermal requirements of the walls of conventional buildings, where the U-value ≤ 0.3 W/m^{2}K. Options 5–8 are intended for a passive and low-energy construction, where the required heat transfer coefficient is 0.15 W/m^{2}K, while recommended amounts to U ≤ 0.10 W/m^{2}K. Due to the ecological character of the composite, mineral wool was deliberately used instead of foamed polystyrene as a thermal insulation. To meet the standard thermal requirements it is possible to eliminate completely the additional insulation by using a 45 cm thick wall made of flax-lime composite. In the case of a passive house, the additional insulation is necessary. Further studies aim at decreasing the obtained value of thermal conduction coefficient, in order to minimize the thickness of the mineral wool.

Table 3

Configurations of wall layers thickness and the corresponding value of "U" (alternative solutions)

Option	a) Mineral wool $\lambda = 0.042$ W/mK	b) Flax-lime composite $\lambda = 0.13$ W/mK	U-value [W/m^{2}K]
1	10 cm	20 cm	0.26
2	8 cm	30 cm	0.24
3	5 cm	40 cm	0.23
4	—	45 cm	0.29
5	20 cm	40 cm	0.13
6	20 cm	45 cm	0.12
7	25 cm	40 cm	0.11
8	30 cm	40 cm	0.10

Conclusion

The pilot study demonstrated the applicability of flax of composites. This natural ingredient can be the future of green building in Poland. The binder is mostly a natural product – which is lime. It is planned to reduce gradually the amount of cement to the zero level in the composite to increase the ecological nature of the product. This material is completely biodegradable and after demolition it can be used again for building. Also the foam-forming component is made of a blend of natural ingredients, harmless to humans and the environment; in contrast to the aluminium powder and the process of autoclaving in the case of aerated concrete.

The article shows that the reduction of CO_2, produced in the process of building, can be influenced by using natural materials, locally available, to implement various elements of the building, where the quality of use is not inferior to materials commonly used.

Studies continue to search for the most optimal formula which gives the best strength and thermal results, according to the principles of sustainable development in the construction industry. The pilot study is simultaneously carried out, with the possible uses of additives that significantly accelerate the binding process of lime binder, which results in a rapid increase of strength of the material.

The research is carried out on the basis of cross-border grant with Brest State Technical University.

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KOMPOZYT NA BAZIE SPIENIONEJ ZAPRAWY WAPIENNEJ Z WŁÓKNAMI LNIANYMI DO ZASTOSOWANIA W BUDOWNICTWIE

Wydział Budownictwa i Architektury
Politechnika Lubelska

Abstrakt: Budownictwo jako ważna gałąź gospodarki każdego kraju zużywa znaczące ilości energii i emituje do otoczenia gazy cieplarniane (CO_2). Te negatywne skutki wpływające na środowisko były przyczynkiem do wprowadzenia wielu ograniczeń zapisanych w dokumentach zrównoważonego rozwoju w budownictwie. Do najważniejszych można zaliczyć: wyroby budowlane przyjazne środowisku, efektywność energetyczna obiektów budowlanych, zorganizowane zarządzanie odpadami budowlanymi w tym rozbiórkowymi. Natomiast w odniesieniu do obiektu budowlanego i jego otoczenia można wyróżnić: obniżenie emisji zanieczyszczeń powstałych ze spalania przy ogrzewaniu obiektu, redukcję zapotrzebowania na energię do ogrzewania, możliwość utylizacji odpadów i ścieków.

Powyższe uwarunkowania prowadzą do poszukiwania i wprowadzenia nowych rozwiązań materiałowych i technologicznych, a w końcowym etapie do realizacji budynków niskoenergetycznych i pasywnych.

W artykule przedstawiono wyniki badań pilotażowych nowego materiału kompozytowego opracowanego na bazie spienionej zaprawy wapiennej, z wypełnieniem naturalnych włókien lnianych oraz z dodatkami i domieszkami. W opracowaniu przedstawiono cechy fizykomechaniczne kompozytu (wytrzymałość, nasiąkliwość, współczynnik przewodzenia ciepła itd.) o różnym składzie mieszanki wyjściowej. Przewiduje się, że kompozyt będzie miał zastosowanie przy realizacji budynków niskoenergetycznych i pasywnych jako elementy spełniające funkcję konstrukcyjną i izolacyjną. Zaproponowane rozwiązanie materiałowe z naturalnych składników spełnia wymogi zrównoważonego rozwoju w budownictwie.

Badania realizowane są w ramach grantu transgranicznego z Uniwersytetem Technicznym w Brześciu, a materiał jako oryginalne rozwiązanie zgłoszono do Urzędu Patentowego RP.

Słowa kluczowe: len, włókna organiczne, spoiwo wapienne, zrównoważony rozwój