Dissertation

Master in Civil Engineering – Building Construction

Composite heat-insulating materials based on natural raw materials and mineral binders

Bialosau Aliaksandr

Leiria, *September of 2017*

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Dissertation developed under the supervision of Doctor Bakatovich Aliaksandr, professor at the building-engineering department of the Polotsk State University and Doctor Florindo Gaspar, professor at the School of Technology and Management of the Polytechnic Institute of Leiria.

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RESUMO

O aumento dos custos no aquecimento da habitação torna necessário ter especial cuidado na seleção de materiais modernos de alta resistência à transferência de calor. O sistema de isolamento térmico corretamente aplicado em comparação com o que é feito de forma não adequada, permitirá ao proprietário reduzir os custos de aquecimento em 3 a 4 vezes. O uso de isolamento térmico insuficiente e ineficaz ou a colocação incorreta conduz inevitavelmente a uma deterioração do conforto térmico.

A procura e a criação de materiais de isolamento térmico efetivos com base em matérias-primas baratas continua a ser um desafio. Ao mesmo tempo, o critério de economizar combustível e recursos energéticos na produção de materiais de isolamento térmico é de grande importância. Dependendo da composição das substâncias das quais os materiais de isolamento térmico são feitos, sob certas condições, eles podem atuar sobre as superfícies isoladas, o ambiente, e o corpo humano ou animal.

Os materiais de isolamento ecologicamente limpos e modernos de matérias-primas vegetais estão cada vez mais difundidos. Na maioria das vezes, esses materiais são feitos de fibras de linho, cânhamo ou madeira, aglomerados com componentes de ligação seguros. Os materiais de isolamento naturais são feitos sob a forma de esteiras, placas e rolos, o que torna o material universal em termos de opções de aplicação.

O objetivo deste trabalho foi determinar a possibilidade de usar musgo *sphagnum* como agregado em painéis de isolamento térmico. Para realizar este estudo, foram desenvolvidas diversas composições para placas de isolamento térmico à base de musgo *sphagnum*. As placas foram testadas quanto à condutividade térmica. Além disso, para testar a resistência do material a 10% de deformação, foram preparados cubos.

Palavras-chave: isolamento, musgo, sphagnum, matérias-primas, resíduos agrícolas, condutividade térmica.

ABSTRACT

The growth of tariffs for the heat supply of the dwelling makes it necessary to take special care in selecting modern high-performance heat-insulating materials. Correctly mounted heat insulation system in comparison with what is done unprofessionally, can allow the owner to reduce heating costs by 3-4 times. The use of insufficient, ineffective thermal insulation or its incorrect placement inevitably leads to deterioration in the microclimate of the premises.

The search and creation of effective heat-insulating materials on the basis of cheap raw materials continues to be a chalenge. At the same time, the criterion of saving fuel and energy resources in the production of heat-insulating materials is of great importance. Depending on the composition of the substances from which the thermal insulation materials are made, under certain conditions they can act on the insulated surfaces, the environment, and the human or animal body.

Increasingly widespread are modern ecologically clean insulation from vegetable raw materials. Most often, these materials are made from fibers of flax, hemp or wood, fastened with safe binding components. Natural insulators are made in the form of mats, plates and rolls, which makes the material universal in terms of application options.

The purpose of this research work was to determine the possibility of using sphagnum moss as a heat-insulating aggregate. To accomplish the task, compositions for heat-insulating boards based on sphagnum moss were developed. The plates were tested for thermal conductivity. Also, to test the material for strength at 10% deformation, cubes were made.

Keywords: insulation, moss, sphagnum, raw materials, agricultural waste, thermal conductivity.

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1. INTRODUCTION

1.1 General

After populating wet habitats, mosses have long since firmly established their specials place in nature and have preserved it till now. The history of mosses is hundreds of millions years old. Representatives of this group of plants are closest in structure and life cycle to the plants - the first inhabitants of the land, appeared on earth in the middle of the Paleozoic era. Bryophytes - a large group of higher perennial plants, very different in external structure. Throughout the world there are about 25 thousand species. Among the higher plants, according to the number of species, mosses occupy the second place after flowering plants. The mosses have no real vascular tissue and no real roots. Water and mineral salts are absorbed by the entire surface of the moss body [1].

The most famous representatives of mosses are Kukushkin flax and sphagnum [2]. Sphagnum genus includes about 350 species growing mainly in the Northern Hemisphere [3]. Sphagnum is widespread from the mountains of the tropics to the Arctic and subarctic zones. The Sphagnum genus is particularly widely represented in the temperate latitudes of the Northern Hemisphere, where the vegetation forms in large areas of the upper marshes. The wetland of the West Siberian Plain is estimated at about 100 million hectares, which has the largest peat bogs in the world, including the Big Vasyuganskoye, which occupies a significant part of the Ob-Irtysh watershed and has an area of about 5.4 million hectares. By area it is the largest marsh in the world. The basis of the marsh cover is formed by oligotrophic sphagnum associations. The identifiers of these communities are sphagnum mosses. Very often mosses form a continuous sphagnum carpet and also act as dominants [4].

In tropical regions, moss grows mainly in mountainous areas and forests, i.e., where the increased humidity of air prevails. Sometimes the soil covered with mosses also occurs in arid territory, since the plant has the ability to temporarily stop its life activity in the dry period, and with the appearance of moisture, renew it. In the main, mosses predominate in the temperate and subarctic belts of the northern hemisphere [5].

One of the features of the structure of sphagnum is the presence in all vegetative organs of aquiferous hyaline cells, being elastic and hollow, designed to absorb moisture from the environment. It is precisely this morphological-anatomical structure of sphagnum mosses that determines their water-physical properties both during life and after withering [6].

For sphagnum moss, the following features are characteristic: lamellar protonema, absence of rhizoids in adult plants, unlimited growth of the main shoot, which has a peculiar branching: the lateral branches branch out in different directions [3].

In each bundle, there are two types of branches - separated and dangling. The first bear more well-developed leaves, have blunt tops and promote the close closure of the growing plants and the exchange of water between them; The latter have smaller, slightly separated leaves, almost filiform apexes, and, closely pressing against the stem, help it to draw water from the base of the plant to the apex. At the top of the main shoot, the branches are short, collected in a dense head, not divided into individual bundles. In the leaves of these branches the most active photosynthesis is carried out, since the lowered branches are usually strongly shaded due to the dense growth of the sphagnum stalk next to each other. The main shoot constantly grows upwards at a speed of about 1-3 cm per year and, approximately, with the same speed dies off at the bottom, forming peat [3].

Sphagnum can reproduce both spores and vegetatively. The sporophyte explodes in dry warm weather, and spores are carried by the wind at different distances, because they have different sizes, 20-50 microns. Another mechanism for the transfer of spores is - a stream of water or spray from rain drops. In the latter case, the transfer distance does not exceed ten centimeters. Large spores have a greater supply of nutrients and, therefore, better chances to wait for suitable conditions. According to the results of the experiments, 15-30% of the sphagnum spores retained their ability to develop after 13 years of storage in the refrigerator, and it is the ability of the spore bank in the environment to explain that almost all marshy, nutrient-poor areas of the northern forests colonized the sphagnum. Reproduction by spores is the main one for the resettlement of sphagnum over long distances, and - new or damaged areas from fire or economic activities. To form a plant from a spore, it is necessary that it falls on a suitable soil-moist peat. Another mechanism of sphagnum distribution - vegetative, with parts of the stem or branches, is effective at short distances [2].

The properties of the moss of sphagnum include: ecological compatibility, medicinal (bactericidal) properties, durability, aging of temperature extremes, non-susceptibility to decay, low thermal conductivity, heat retention, hygroscopicity.

Considering given set of positive qualities, the use of moss for plate heat insulation material is very perspective. Today, the niche of heat-insulating materials that have bactericidal properties is not occupied and there is a real need for such a heater, especially for buildings with increased hygiene requirements for premises.

1.2 Objectives

The aim of the thesis is to obtain a plate heat-insulating material with high physical and mechanical properties, possessing biocidal properties on the basis of natural plant material and crop production waste.

To describe the current situation in the world thermal insulation area, a literature review of existing environmentally friendly insulating materials based on natural raw materials with various manufactured forms and properties was conducted.

In the first experimental stage, a microscopic analysis of the structure of the material used as the main filler in the heat insulating material was carried out. At this stage, the goal was to search for factors that cause high insulation properties of the material used.

At the second stage of the study, the goal was to determine the physico-mechanical characteristics of the resulting thermal insulation materials, such as the thermal conductivity, compressive strength at 10% deformation, and flexural strength.

1.3 Structure

Present research work consists of 5 chapters. Chapter 1 contains the introduction, objectives and structure of the work done.

Chapter 2 is a study of the world practice of manufacturing and use of thermal insulation materials based on natural raw materials. Also in this chapter, the experience of using sphagnum moss in various spheres of human activity, the methods for the correct collection and drying of sphagnum are described.

Chapter 3 describes the main materials, techniques and equipment used in research work. This chapter shows a part of the experimental work, namely the microstructural study of the main filler and the analysis of the results obtained.

The main experimental work is set forth in Chapter 4. In this part, a quantitative selection of the composition of one and two-component heat-insulating material, manufactured in the subsequent in the form of plates, is carried out. Further, insulating board tests were carried out, and heat conductivity parameters were obtained. Based on the selected compositions, cubes were also made to determine the compressive strength and bending strength characteristics.

Chapter 5 outlines the conclusions on the work done and the results obtained, suggestions for further research on this topic.

2. USE OF PLANT RAW MATERIAL IN THE PRODUCTION OF HEAT-INSULATING MATERIALS

2.1 Thermal insulation materials based on natural plant aggregates

Modern ecologically clean insulations from vegetable raw materials are increasingly widespread. Most often, these materials are made from fibers of flax, hemp or wood, fastened with safe binding components. Natural heaters are made in the form of mats, plates and rolls, which makes the material universal in terms of application options. These materials are used for insulation of walls, roofs, floors, ceilings, internal partitions [7].

One of the known environmentally friendly thermal insulation materials is "Geokar" (Fig. 2.1), used for the construction of energy-efficient and ecological houses. This unique material consists of 60% peat [8].

Figure 2.1. - General view of the Geokar block

Ten years of experience using Geokar shows that the material perfectly insulates the walls, eliminating the causes that lead to condensation and mold. In addition, thanks to peat, the air in the apartment is disinfected. Walls from peat blocks reduce five times the level of penetrating radiation, they perfectly "breathe" and create the effect of a wooden house. The surface of the peat blocks is well plastered.

Today, we built five- and nine-storey buildings in Vologda, where one of the first acquired on Bezhetsky experimental plant production line of "Geokar".The durability of the 5-storey houses built in Tver is also guaranteed by another important feature of Geokar. At the freezing point of the peat blocks, frost forms, but not ice, as when other insulations are used. Hoarfrost is an excellent additional natural heat insulator, which increases its effectiveness with increasing frost. Ice, on the contrary, destroys the wall and lets the heat out.

As a result of the application of «Geokar» in the construction of a 150-apartment building in Tver, 3 times less heat is used for heating than in a similar house built using standard technology. At a price, «Geokar» competes only with expanded polystyrene, but in terms of the amount of characteristics associated with the ecology of the dwelling, «Geokar» surpasses the artificial insulator [9].

Any region that has peat reserves has the opportunity to establish the production of such blocks directly at the site of peat deposits. Plant for the production of «Geokar» can be placed in any premises with a positive temperature. The technology of production of the material is as follows: peat, water, filler (wood sawdust, straw or flax seed) are used for the basis, peat is sieved, mixed with water, then rubbed on a special mill, where it is brought to the state of peat binder. Then the filler is added, and the blocks «Geokar» are formed from the finished mass. The material does not require burning - it can be dried even in natural conditions, however, to speed up the process, forced drying is carried out. It is possible to produce hollow blocks for the warming of the capital walls, solid blocks for interior and inter-apartment partitions [10].

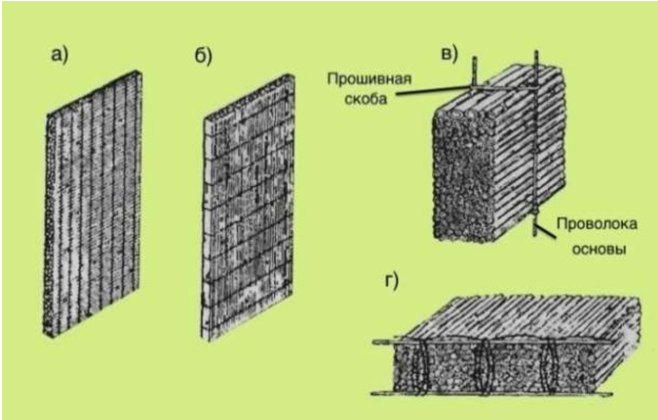
The insulation material «Geokar» has many advantages: a low thermal conductivity (0.047 - 0.08 W / m • ° C), the durability - the guaranteed life of blocks - not less than 75 years old, has a bactericidal action and environmentally friendly (since the base of the blocks is peat, which is a natural antiseptic), reduces the level of ionizing radiation to 5 times, fine absorbent gases and odors (1 kg peat able to absorb up to 50 grams of ammonia), and does not decay under attack of rodents and insects, hard heat-insulating material with a compressive strength of 1.1-1.2 MPa (in low-rise building with up to 2 floors, blocks can be used for the construction of load-bearing walls), it is easy to process and adjust.

The material «Geokar» also has a number of shortcomings. The production of «Geokar» is a fire hazard. Without additional processing, the material is flammable and spontaneously supports combustion, even without access to oxygen. If the material is not treated correctly, the material is prone to self-ignition under pressure. The extraction of peat is a very costly production. These negative factors restrain producers from expanding their assortment [11].

In the heat insulation industry, the reed has also found its use due to its wide distribution and positive properties. The chemical composition of reeds differs little from wood and contains about 41% of cellulose, 29% of lignin, about 21% of pentosans. Thus, reeds are suitable for manufacturing various types of products, usually produced from wood, including building materials [12].

The main types of building materials and products from reed can be divided into five groups: reed materials, reed-concrete products, reed-chaff and reed-shaving products on mineral binders, reed-wool materials and products, reed-chaff materials and products on synthetic binders [12].

Reed materials (Fig. 2.2) include plates, mats, beams and fascia from whole reed stalks.



а) with a transverse arrangement of stems;
б) with longitudinal arrangement of stalks;
в) a version of the firmware of products with the help of wire braces;
г) the version of the firmware of products with a continuous seam
Figure 2.2. - Reed materials

Reed plates are used in low-rise housing and agricultural construction for sound and heat insulation in the construction of walls, partitions, coatings and ceilings. For protection against decay, the plates are impregnated with a 5% solution of ferrous sulfate. To reduce the air permeability of cane walls, their surface is plastered [13].

There are a number of advantages of reed materials such as: thermal conductivity (depending on the degree of compaction and raw type) ranges from 0.058 to 0.093 W / (m • ° C), low hygroscopicity (against external moisture protected thin layer of a kind of self lacquer with great silica content), resistant to decay (in normal operating conditions, the structure of the material is not exposed to contamination by fungi household), fire resistant (under the direct influence of fire the reeds does not come on, but only undergoes charring on surface and to a depth of 1-2 cm, and a layer formed by this fly ash contains up to 80% silica preventing flame propagation), low sound conductivity and high sound absorption [14].

Also, reed materials have some disadvantages: susceptibility to putrefaction at high humidity, flammability and fear of rodents. To eliminate the disadvantages, antiseptics are added to the starting material, and plaster is protected from the fire [15].

For the production of reed slabs, presses of various designs are used. On the consumption of raw materials, plates with a longitudinal arrangement of the stems are more economical. The production of cane slabs is carried out in several stages. The belt conveyor feeds plant stems from the loading site of the plant to a pendulum (circular) saw cutting the stems to a certain length. The cut stems are fed into the pre-pressing device, and then into a vertical chamber for final pressing, punching of the compressed packet with wire and filing of the sides. The continuous reed board, coming out of the press, is cut into plates of the required dimensions [16].

Another natural and environmentally friendly thermal insulation material is the «Kamka» (Fig. 2.3) insulation, which is a sewing mat from organic raw materials - the sea herb of Zostera growing in the Black Sea. The bulk of the leaves are grass with a small number of stems from 20 to 100 cm long. Zostera has a brown-green color, humidity in the air-dry state is 15%. The chemical structure of zosters on many parameters, such as the content of cellulose, coincides with the chemistry timber [17].

Figure 2.3. - General view of the Kamka plate

The «Kamka» material has a number of advantages. A high percentage of sorption humidification of the material contributes to the maintenance of the optimal humidity for the person in the room, the high iodine content in the sea grass and the constant saturation of the air in the room have a beneficial effect on the functioning of the thyroid gland. The material is longevous, because the chemical structure of sea grass in many ways coincides with the chemistry of wood, but unlike wood, the Zoster is absolutely not prone to rotting, as well as destruction of rodents and insects. The high content of calcium salts and consequently, increased osmotic pressure creates an unacceptable habitat for the above parasites. On ignition, a seaweed insulant belongs to a group of flammable combustible materials. The coefficient of useful combustion is practically zero. When smoldering, toxic substances hazardous to human health are not released [18].

However, along with the advantages of the «Kamka» material, there are also negative aspects. The first disadvantage can be attributed to the low efficiency, because this material refers to insulators with an average thermal conductivity, therefore for a reliable protection against cold will have to create a fairly thick layer. At a density of 86 kg / m^3, the thermal conductivity is 0.085-0.088 W / m • ° C. The next negative factor is the low mechanical strength, the mats of this material are very easily torn, as a result of which they immediately turn into rubbish. Another and not less important disadvantage is the loss of stability of the material to combustion over time, during drying. It should also be noted the need for a moisture barrier layer [18].

2.2 Vegetable heat-insulating materials based on agricultural waste

A significant segment in the production of the agro-industrial complex of the Republic of Belarus is plant growing, including the cultivation of grain crops. According to the statistical yearbook on the territory of the Republic of Belarus in 2016, the sown areas of grain crops amounted to about 2.3 million hectares [19]. As a result, large amounts of agricultural waste are generated. An example of such material is straw, which is used in various spheres of human activity.

Wide use of straw as raw material for thermal insulation materials is due to a number of advantages of this material: availability and low price of the material (blocks can be formed from any cereal crops), low thermal conductivity (lower than wood), construction of a house made of straw blocks is carried out in a short time, since do not need a mortar for placing and construction equipment, ecological cleanliness.

One of the options for using straw as a raw material for an insulator is the production of straw material in the form of mats, slabs or blocks. Thatchboard is used as an ecological insulation, for filling walls in frame construction, as a material for partitions [20].

Over time, in the thatchboard, under certain conditions, mice or insects can be planted. With a straw moisture content of more than 20%, the material begins to rot. To solve these problems, the blocks are pressed with a density of at least 250 kg / m^3 [21].

Post-production processing of thatchboard takes place after the installation of products. As a finish, plaster can be used with a clay mixture or other vapor-permeable mixtures. The plaster is applied to one or two sides of the thatchboard and protects perfectly from the effects of fungi, fire, rodents and mechanical damage. The thickness of the wall of strawboards is 120 mm, plastered on both sides with clay plaster in terms of thermal conductivity parameters is equivalent to 500 mm of brick and 200 mm of wooden enclosure. To reduce thermal conductivity, use a warm clay plaster, which significantly increases the resistance to heat transfer of the wall with straw [22].

Straw plates (Fig. 2.4) are more technological and versatile materials than straw mats. Plates are produced in the USA, Europe and other countries of the world. The raw material for such articles can also be sorghum, a chaff of technical hemp or flax, cane and coconut fibers [22].

Figure 2.4. - General view of the straw plate

The production of straw plates consists of five stages. At the initial stage, the collection and delivery of raw materials, grinding with additional processing and then pressing are carried out. Then there is a coating on the plate in the form of paper or lamellae. When the lamella is applied, the production line is equipped with additional units and aggregates that provide a more dense mass of finely divided raw material with addition of a stable adhesive on the loose base layer, additionally on both sides. After laminated in the form of a film or veneer. The production of drying and packaging of finished boards is completed [23].

Plates should always be in a dry condition, and straw should not contain more than 12% moisture. To reduce the absorption of moisture from the air, the slabs are pasted on either side with cardboard or asphalt paper. Drying of moistened straw lasts a long time - in normal conditions it takes more than a month for the plate to reach its original weight. The average thermal conductivity of the material is 0.09 W/(m · ° C). The density depends on the degree of pressing, equal to 260-360 kg / m³ for the first grade and 200-300 kg/m³ for the second one [24].

Advantage of straw plates is wide application in construction and decoration of premises, ecology and durability, simplicity of installation and processing. Straw slabs are ready for finishing, which shortens the commissioning of the facilities [23].

Absolutely harmless for humans and animals is a heat-insulating material made from hemp (Fig. 2.5), 85% consisting of natural fibers. To increase the fire resistance of the material, manufacturers add fire retardant (soda) in an amount of 3 - 5% of the total mass of raw materials. Hemp fibers are fastened with fine polyester fibers (10%). The insulation is produced in the form of plates or coils with a thickness of 3 to 18 cm [25].

Figure 2.5. - General view of the hemp plate

The following characteristics can be attributed to the advantages of hemp insulation: high thermal insulation properties (thermal conductivity coefficient is 0,038-0,04 W/(m·°C)), effective soundproofing ability, ecological and completely safe insulation (in the process of growing hemp does not need pesticide treatment , the absence of harmful effects on nature and human health during production, operation and disposal, contributes to reducing CO2 emissions), ease of installation (thanks to the elasticity of the material is easy to mount it), resistant to mold, putrefaction and exposure to insects, and creates "breathing" structures [26].

The disadvantages of heat-insulating material of hemp fibers include exposure to combustion and moisture absorption, accordingly requires additional material and water-repellent impregnation of refractory solutions, need vapor barrier device. The same disadvantage is the high cost of hemp insulation.

There are several types of insulation based on flax, differing in the type of raw materials and structure used. The enterprises produce ribbon felt under the trademark «Euroflax», consisting of 100% of flax fibers, obtained as a result of the production of fibers of various lengths. Initially, the yarns are sorted by means of a carding machine. Long fibers go to making felt, and the remnants of short filaments are used in the production of tow. «Euroflax» (Fig. 2.6) is not susceptible to rotting, and the insulation can be laid at negative temperatures [27].

Figure 2.6. - General view of Euroflax

Flax tow (Fig. 2.7) also applies to a variety of linen insulation. Thanks to the tow the process of building a wooden frame is greatly accelerated, since the laying of the insulation is done quite easily and quickly. Tow is considered to be one of the most popular interventure insulations, but the material is also widely used for insulation of windows and door openings. The tow used as additional insulation when sealing joints between individual sheets of the main insulation. The downside of flax tow is that the insulation is attractive for birds, who tend to equip themselves with nests of soft linen fibers. The advantages of the material include low cost [27].

Figure 2.7. - General view of the flax tow

The insulation flax-jute (Fig. 2.8) represents the combined material consisting of two types of raw materials: flax and jute. Most often these components are a part of a insulation in an equal proportion, but certain manufacturers produce material where the first or second component prevails. Flax-jute combines all positive properties of the materials which are a part of a insulation. Besides, material has big durability in comparison with other analogs, and also possesses high elasticity [28].

Figure 2.8. - General view of the flax-jute

Material lnovatin (Fig. 2.9) is made on the carding machine on needle-cutting technology. A layer of cathonin from flax is sewn with a cotton or nylon thread. The insulation has a lower density than felt [28].

Figure 2.9. - General view of the lnovatin

Flax thermo plates (Fig. 2.10) are an insulator that allows you to sheathe the walls of houses, insulate roofs and horizontal surfaces. The material is suitable for the thermal insulation of frame structures, since it allows the walls to "breathe". The use of linen insulation in the form of slabs in log houses allows to achieve an optimal microclimate and promotes natural circulation of air masses [29].

Figure 2.10. - General view of the flax thermo plates

In general it is possible to refer the antiseptic properties interfering formation of a mold and fungi on walls, lack of allergic reactions to advantages of linen insulations. When soaking the materials do not lose heat-insulating properties, are not electrified, provide a high sound absorption and a thermal capacity, ease of installation (does not pour, does not raise dust), do not allow to be formed to condensate on walls (are capable to hold moisture and to return it outside even in winter time), environmental friendliness [30].

Linen materials show high heat-insulating properties, possessing heat conductivity coefficient ranging from 0,038 to 0,054 W/m·°C, vapor permeability of 0,4 mg/m·h·Pa. Density of such material is 30-32 kg/m³, sound absorption coefficient - 0,98. It is used in the range of operational temperatures up to +160 °C and has durability of 60 years [29].

However along with advantages linen insulations possess also a number of shortcomings: high price of linen plates, narrow range of application, thin fiber of a heater can rupture at a tension, demand impregnation by water-repellent solutions when using in baths and saunas. Packings with a insulation from flax are recommended to be stored in the dry closed place for protection against a rain, a wind, snow and blows. On the street material needs to be stored on a pallet and should not contact the ground. Packing with a heater should be opened just before installation [30].

Bark of a cork oak traditionally is raw materials for wine bottle plugs and different hand-made articles. Rather recently cork waste started applying for production of effective heat-insulating materials. Using a technical cork in the form of plates (Fig. 2.11) for warming of buildings, it is possible to considerably reduce heatlosses, and also to protect the room from penetration of extraneous noises [27].

Figure 2.11. - General view of the cork plates

There are three kinds of a insulation on the basis of a cork which are most often used in construction as thermal insulation: the granulated cork in rolls 2 or 4 mm thick; rubber-cork in the form of tapes 2 and 3 mm thick, and also sheets 5, 8 and 10 mm thick with an area of 0,5 and 1 m^2; the agglomerated cork (cork agglomerate) which is produced in form of plates from 10 to 320 mm thick [44]. Plates or rolls make of the crushed bark of a cork oak which is glue together with the help of organic binders [27].

Cork material is applied for warming of the walls, floors, underground parts of buildings, thermal insulation of overlappings, roof, and temperature seams fillings [27]. Heat conductivity of a cork heater is equal 0,04 ± 0,1 W/m· °C, density makes 245 ± 5 kg/m³, strength - to 3 MPa, water absorption no more than 13%, material hardens at low temperatures, but under the influence of heat again gains elasticity [29].

The microstructure of cork bark represents consistently connected hard capsules having a form of the irregular polygon. The closest analogue of this structure will be honeycomb. Each capsule has a complex structure, consisting of several layers. Outside the capsules are covered with two layers of fiber, giving it a structure. Then follows a hollow chamber filled with a gas mixture close to atmospheric air (the difference is only in the significantly reduced content of carbon dioxide). Next is a drop of wood tar - suberin, which is the main component of the whole cork material. The core of the capsule also consists of celluloses that impart internal hardness to it [31].

The cork insulation possesses high elasticity and resistance to deformations (for this reason the cork is also used as a substrate for some kinds of floor coverings), noise-absorbing, environmental friendliness [32].

The disadvantages of this material include high cost, since the ratio of the cost to the level of energy saving, the agglomerate clearly loses to modern polymer and mineral wool heaters, as well as insufficient moisture resistance (when the moisture enters the granules begin to swell and deform, so in most cases an additional hydro- or vapor barrier is required) [33].

Process of manufacture of a cork insulation is not labor-consuming. Impregnated plates (white agglomerate) are received by molding and pressing of cork grain to which add binding substances (organic glues, gelatin, coal-tar and pitches). The insulation in the form of plates is made 1000×500 mm in size and from 10 to 120 mm thick. Expanded cork plates (black agglomerate) are made of grains of bark of cork oak without binding additives by heat treatment at a temperature of 250-300°C. Under the influence of temperature there is an allocation of the resinous substances. Due to the expansion of the air and water vapor contained in the pores during heating, the cork volume increases to 30% (i.e., a swelling process takes place). The blocks thus obtained are cut to slabs. Expansion slabs are usually made in the size of 1000×500 mm with a thickness of 10-320 mm [33].

American researchers have developed a new wall material, made from pressed rice straw and glue. The blocks, called "Stak Block", resemble the larger "LEGO" blocks, differ by three times the best insulating properties than conventional sandwich panels, but are easier to handle than bales of straw used in the construction of "green" buildings. The block "Stak Block" with dimensions of 0.3×0.3×0.6 m has a density of 240 kg / m³. Like bales of straw, the blocks are stacked on a concrete foundation and are covered on the outside with waterproof panels. From the inside, the blocks can be gypsum plasterboard or plywood. The estimated cost of one Stak Block is about $ 8 [34].

Another example of the use of rice production waste is the "Kuntan" (Fig. 2.12) insulation based on rice husks. Japanese thermal insulation material "Kuntan" is produced in the form of plates using 100% natural materials (vegetable fibers): cadmium abelmosus, paper mulberry (brussonetia) and expanded rice husks. Expanded rice husk is a high-temperature and high-pressure processed ordinary rice husk having a significantly increased moisture absorbing capacity. The wood of brussoneti is steamed, then it is grinded, beaten, dried. In the boiling solution with wood, a powder is added from the carbonized rice husk rich in silica. As a result, a layer of gruel appears on the surface, then mixed with pure water and a special glue. The resulting mixture poured into the mesh screen, and then falls under the press. After molding, the plate drying process takes place [34].

Figure 2.12. - General view of the Kuntan plate

Due to the porous structure of the material is lightweight, does not shrink, it can be easily attached. Installation does not require special costs - both material and physical, the material is joined almost without seams, without forming gaps between the plates. After the load is removed, the plates return to their original shape [35].

Plates demonstrate excellent thermal insulation properties, are intended for interior decoration and warming of premises, the coefficient of heat conductivity is 0.055 W/(m•°C). When the walls are insulated from the inside, energy is not spent on heating the walls, which allows to significantly reduce the energy consumption for heating in winter and cooling in the summer. The plate does not burn and does not melt, the smoke appears before the flame. When the source of fire is eliminated, the material immediately ceases to smolder, smoke is not released, the plate is not deformed.

The newest thermal insulation material is a insulation made of coconut fiber (Fig. 2.13). Processed coconut fibers are considered to be among the most durable and durable. The material is used in the insulation of frame exterior walls, internal partitions, floors and interfloor overlappings [36]. Roll material and slabs of coconut fiber are immune to mold and rot. Coconut insulation comes to Europe from Sri Lanka, Indonesia and Malaysia. The production of coconut fiber is limited by the complexity of the process. First, the fibers are separated from the shell of immature coconuts and soaked for several months. As a result, the pectin contained in the fibers is destroyed. Then the raw material is knocked out until the fiber remains resistant to rotting, used for the production of mats and plates [37].

Figure 2.13. - General view of the coconut plate

The coconut insulation consists of 85% coconut fiber and 15% of the hypoallergenic binder component. Plates have a low thermal conductivity of 0.038-0.042 W/m•°C, with a vapor permeability of 0.59 and a density of 30 kg / m³. The material has a long service life of 85 years [38].

Despite certain advantages of the examined materials, there are drawbacks to vegetable raw materials. For a number of insulated heaters, despite the use of plant filler, environmental safety is highly questionable, since synthetic binders are used as a gluing component. Many insulation belongs to the group of combustible materials. At the same time, a number of heat-insulating materials on a plant basis have rather low physical and mechanical parameters, including the coefficient of thermal conductivity and the compressive strength and bending strength. The above factors significantly reduce the scope of application of insulations based on plant raw materials in the construction of buildings and structures. Thus, the development of a heat-insulating material that satisfies the above-listed parameters seems to be a very urgent task. At the stage of analytical review of the literature, it can be assumed that the use as a filler moss sphagnum as a natural material will provide an effective insulation with biocidal properties.

2.3 Experience with moss sphagnum

Sphagnum moss is used in various branches of human life: construction, medicine, beekeeping, livestock, horticulture, floristry, in assessing the ecological situation.

It has been known for many centuries about the enormous usefulness of sphagnum moss in folk medicine as a medicinal plant. There is evidence that sphagnum was used as a dressing was used from the XI century, and possibly earlier. Use of sphagnum for wound dressing allows its high hygroscopicity. Moss absorbs a huge amount of blood, pus and other liquids, but unlike cotton wool, sphagnum also has antibacterial properties. The disinfecting and antifungal properties of sphagnum are caused by substances that make up the composition [1]. Modern medicine comes to the conclusion that sphagnum is a more effective means than, for example, cotton wool, and therefore, the production of sphagnum-gauze swabs is resumed [39]. The main active substances of plants of the sphagnum genus are phenolic compounds (mainly phenolic carboxylic acids) and polysaccharides. In the 90s of the last century a number of funds were developed on the basis of sphagnum mosses used in surgical dentistry and female hygiene. The use of sphagnum in these agents is based on its high hygroscopicity, bactericidal properties, and ease of disposal after use [40].

During the Great Patriotic War, sphagnum mosses, in conditions of shortage of dressings, were used in military hospitals as sphagnum-gauze dressings to heal wounds, especially purulent, which saved many lives. The stem contains hollow cells, designed specifically for the accumulation of water. Their wall is permeated with holes through which moisture enters the cell. Therefore, the stalk of sphagnum well absorb water, blood, and pus, while it does not lose elasticity, and the wound remains dry. Such properties of the moss allowed less frequent change of the dressing, which accelerated the healing process, shortening the duration of the hydration phase of the wound, which is especially important in the front conditions, with overload of the medical staff. The percentage of complications also decreased significantly due to the content in sphagnum of many complex organic compounds that prevent suppuration.

The bactericidal properties of sphagnum are used to try to find applications in our days, recommending the use of moss in the manufacture of ointments and powders for external use. As a food supplement for people with physical exhaustion or hypovitaminosis, a powder of lyophilized sphagnum is recommended [41].

Moss sphagnum also found its application in beekeeping and cattle breeding. From the pressed dry sphagnum make a insulation for hives for the winter, so that the bees do not freeze. And in order to maintain a constant level of humidity inside the hive, moss, previously dried in air at room temperature, is used. Moss, placed in the base of the hive, takes away excess moisture and at the same time further disinfects the space, which helps to avoid various diseases in bees. With increased dryness of the air, the moss will begin to give moisture, which will make it impossible to honey in bee's cells.

Moss sphagnum is also used as a litter for pets in cages. Sphagnum perfectly absorbs odors, which allows it to be used as a filler for domestic animal toilets. Sphagnum can be used as litter not only for pets, but for cattle. In this case, the sphagnum, left after use, mixed with manure, will be an effective fertilizer [42].

Moss proved to be extremely useful in horticulture and floristics. Sphagnum is used for rooting cuttings of houseplants, as well as suburban bushes or bushes. Pre-moss is wetted or taken wet sphagnum from nature, finely torn and mixed with the ground. After that, cuttings are planted in this moistened soil. Experiments show that the amount of decaying roots with such growing will be less than in any other method.

Dry moss cover plants for the winter. Moss perfectly preserves heat and allows plants not to freeze in winter. In addition, sphagnum produces such a mineral as peat, which is an excellent fertilizer [42].

A new trend in designer plants for decorative wall finishing is the device of coatings from moss by the mixture method. Green graffiti is not costly, does not require coordination, easily tolerates a warm season and can survive through the winter [43].

Methods of environmental assessment, based on bioindication and biomonitoring research, are gaining in popularity. Are the most accurate for assessing the state of the environment and predicting its changes. Biomonitoring of atmospheric air pollution with chemical elements using mosses has been one of the most promising, effective, simple and less costly methods for assessing changes and controlling air quality in the past decade [44].

The use of gas analyzers and the conduct of research at stationary stations for solving atmospheric monitoring problems are not always rational; since requires installation of a large number of stationary automatic posts, as well as a one-time sampling at a high frequency (6 times per day). In this case, the use of biological indicators is the most optimal way to solve the problem [44].

The moss-biomonitor method has been used regularly in the Scandinavian countries for the last 30 years to monitor atmospheric deposition of metals in very large areas, and recently this technology has found wide application in Western Europe [45].

Also, sphagnum mosses are widely used in environmental studies as test objects, sensitive to anthropogenic impacts, changing their characteristics or accumulating elements coming from the environment. At the same time, the concentration of substances in mosses is much higher than in herbaceous vegetation [39].

Currently, the development of new materials from sphagnum is underway. It has been established that cyclic mechanochemical treatment of pyrolytic amorphous carbon from sphagnum moss under specific conditions of mechanoactivation results in formation of nanofiber carbon material [46]. In complex processing of sphagnum moss, carbon multiwalled nanotubes with a diameter of 10 to 70 nanometers with low ash content are formed. It is possible to predict the high efficiency of the use of the obtained carbon nanotubes as modifiers of interphase boundaries in composite materials, and also as a promising carbon agent for the synthesis of metal carbides and energy-intensive anode material for lithium-polymer batteries [47].

Because of its low thermal conductivity, sphagnum moss is used as an insulating material for warming the crowns of wooden houses. Builders, dismantling old wooden houses, note perfectly the state of the wood in the places where the moss was. The preservation of wood is due to the beneficial bactericidal properties of sphagnum containing sphagnol, a substance that prevents the development of putrefactive processes. This fact is confirmed by archaeological finds. So, on the mossy marsh in Austria found the remains of a road from logs, laid by the Romans. Nowadays, builders constantly use sphagnum moss as a insulation for the construction of wooden houses, baths and saunas. For baths and saunas, sphagnum moss is very suitable, as the plant is able to withstand temperature changes, moisture and condensation [48]. Unfortunately, until now the construction industry cannot offer a thermal insulation material based on sphagnum in the form of slabs, which would make it possible to use moss not only in log construction.

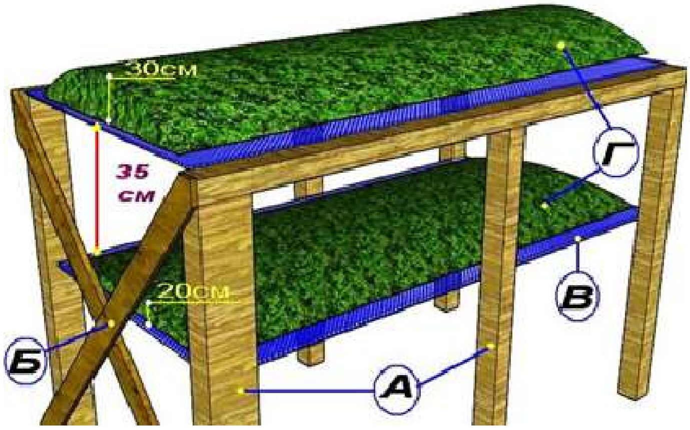
2.4 Technology of drying and storage of moss

When collecting moss, several simple rules should be followed, allowing plants to resume quickly. To collect moss is better not to choose a marshy area, the most suitable place for collecting moss is near the trees, where the moss is the least watery. You can collect sphagnum in two ways: completely removing the plant together with the roots (this is how much larger it is, but it takes a lot of thorough cleaning) or by cutting the upper surface with a knife. The sphagnum moss is collected and stacked in bundles. Procurement of sphagnum is carried out mainly manually at the sites as clean as possible from other plants. The moss is collected selectively, with strips of width 20-30 cm and with the same intervals between them, left untouched, which allows the moss to gradually recover in the collection areas. Re-harvesting in this area is possible only after 7-10 years. For medicinal purposes, the whole living part of the sphagnum is used and harvested. The preparation is carried out from May to September in dry, sunny weather [49].

Drying of moss is an important process for its further use, because improper handling of raw material can lead to loss of positive properties. When moss is collected in a wooded area, moss is often hanged down on small bushes without leaves or on small (up to 1.5 m) dead wood or pine trees. In this case, the moss is dried two to three weeks. Another way to dry the moss is a mop of moss. Sphagnum is dried, folding into small stumps, like hay. This method of drying does not give a qualitative drying of the material, and there is a possibility of mold formation inside the mash as a result of poor blowing. Drying moss on the hangers, is the most suitable way of preparing raw materials. Moss, hung on hanging, well blown, retains its elasticity. Hanging from barrels, small trees leaving knots no longer than 20 cm, it is desirable to take the middle part of deadwood coniferous trees, since the branches of dry spruce are strong and have a kind of "mesh" of dried lapnika, which increases the area for laying moss [50].

Hanged, placed under a canopy, covering moss from rain, fog and sun. If it is not possible to procure the right amount of deadwood trunks with branches, you can make a rack (rack) of old boards, bars (Fig. 2.14). Between these knocked-in supports pull ropes (only non-synthetic origin, because on such ropes moss is poorly kept because of the slippery surface of ropes) or pull the net (you can use the old, small-mesh fishing net).

Lay the moss with a collar, the thickness of the layer at the top point of the coarse of the first tier, should not exceed 30-35 cm, on the second tier the thickness of the layer of moss laid should be no more than 20-25 cm. The distance between the tiers is 30-40 cm. Such a racking device will provide qualitative drying of moss due to air flow between layers [50].



А - support racks; Б - jibs for stability of the rack;
В - a place for laying moss; Г- moss
Figure 2.14. - Drying moss on the hangers

Sphagnum dries long enough, but artificial drying is not recommended, because in this case the moss will dry unevenly. The degree of drying depends on the further purpose of the moss. When used for medical purposes, the moss is completely dried (to crunch, brittle) [42].

Live sphagnum is stored in plastic bags in the refrigerator or freezer. Dry moss should be stored in a glass or tin container. In large quantities, dry moss is stored in canvas or cotton bags, in a ventilated room [51].

Taking into account the experience of using moss for warming gaps between wreaths in log buildings, the task of obtaining a highly efficient moss-based thermal insulation material can have a successful implementation. The main requirement for the collection and drying of moss should be the preservation of the structure of the material, which is an important condition for the production on the basis of sphagnum rigid plate warmer. To ensure the ecological purity of not only the filler of moss, but also all thermal insulation material, it is necessary to use a safe binder. Such a binder component can be a sodium liquid glass, which additionally ensures the incombustibility of the insulation in case of fire in the building.

2.5 Chapter summary

1. Heat-insulating materials based on natural plant raw materials, such as peat, reeds, cane, and algae have rather high thermal characteristics. However, additional material costs and technological operations are required to ensure non-flammability and water resistance of products.

2. Substantial results have been achieved in the manufacture of thermal insulation materials based on plant waste agricultural production. According to their thermo-technical characteristics, materials from crop waste are close to those of artificial organic insulants.

3. The experience of using sphagnum moss in various spheres of human activity has been known since the XI century. The most effective moss is used in medicine and as biomonitors for environmental assessment. In construction moss sphagnum is used only as a insulation for buildings made of wood.

4. An important aspect of the use of natural plant material is the renewability of raw materials. The correct collection of moss allows to accelerate the process of growth and recovery. In order to obtain moss with the necessary properties and the possibility of further use, it is necessary to adhere to certain technological rules during drying and storage.

5. The use of sphagnum moss as the main component of aggregate for an effective environmentally sound insulation material is a very urgent task taking into account the needs of the modern construction market. Increasing the ecological culture of consumers forces builders to seek and offer customers thermal insulation materials that ensure the ecological safety of buildings. Development on the basis of moss of an ecologically clean insulation with bactericidal properties in the form of plates allows to satisfy the growing demand for such material.

3. CHARACTERISTICS OF MATERIALS AND METHODS OF RESEARCH. MICROSCOPIC ANALYSIS OF THE MOSS STRUCTURE

3.1 Characteristics of used materials

3.1.1 Source materials

As the main aggregate in the manufacture of insulation plates used moss sphagnum, which is a natural plant material growing in vast areas of temperate latitudes. Moss sphagnum is a fibrous plant with a length of 50-100 mm. After collection, the moss is wet. At the preparation stage the moss was processed in a drying chamber at a temperature of 40-50°C for 6-8 hours, and then cut into a length of no more than 20 mm. The material composition of the moss shown in Table 3.1

Table. 3.1 - The chemicals in the composition of sphagnum moss

№	Composition of moss	
	Chemicals	Quantity, %
1	Carbohydrates	70-80
2	Proteins	0,5 - 3
3	Fats	2
4	Wax	1
5	Gum	3
6	Pigments	3
7	Acids	4

The second filler was rye straw or reed ordinary. Straw and reed were used in combination with moss to give rigidity to the finished heat-insulating material and eliminate shrinkage deformations during the drying of plates. Stems of straw and reed were cut into pieces in the form of tubes 15-20 mm in length.

Straw is a dry stalk of rye left after threshing. For research, rye straw was used, grown on the sown areas of the Joint Stock Company (JSC) "Dunilovichi-agro" of Postavy district, the JSC "Banon" of the Polotsk district. Dry cane was taken from swampy areas of the Polotsk district.

Tables 3.2 and 3.3 show the main chemical substances contained in rye straw and reed ordinary.

Table 3.2 - The chemicals in the composition of rye straw

№	Composition of rye straw	
	Chemicals	Quantity, %
1	Cellulose	40 - 49
2	Hemicellulose	18 – 18,5
3	Lignin	23
4	Pentosans	27 – 28
5	Chemicals extracts by dichloroethane	2 – 2,6
6	Silica	3,1 – 4,1
7	Hygroscopic water	rest

Table 3.3 - The chemicals in the composition of reed ordinary

№	Composition of reed ordinary	
	Chemicals	Quantity, %
1	Sugars	13
2	Starch	50
3	Fats	1
4	Raw protein	2,5
5	Cellulose	36
6	Protein	3 - 5

In the manufacture of heat-insulating boards, sodium liquid glass was used as a binder, manufactured at JSC "Domanovsky Industrial and Commercial Combine" and meeting the requirements of GOST 13078 [19]. Liquid glass is a thick liquid of yellow-green color without mechanical impurities and impurities. The silicate module is 2.8-3.2, the pH is 11-12, the viscosity corresponds to 0.0194 n·s/m, the density is in the range 1.4-1.47 g/cm^3.

3.1.2 Methods of research

The main physical and mechanical properties of heat insulation boards - density, compressive strength at 10% deformation were determined in accordance with GOST 17177 "Heat-insulating building materials and products. Methods of testing "[52].

The thermal conductivity of the test materials was measured according to STB 1618 -2006 "Construction materials and products. Methods for determining the thermal conductivity for a stationary thermal regime "[53].

Thermophysical properties of heat-insulating boards were investigated with the help of the "ITP-MG4 100" device (Figure 3.1). The stationary device determines the thermal conductivity and thermal resistance of materials at an average sample temperature of + 15°C to + 43°C.

Figure 3.1. - General view of the device «ITP-MG4 100»

Microscopic analysis of the moss structure was performed using a "Crocus 5MP MCX100" binocular biological microscope (Figure 3.2). The principle of operation of an optical microscope is to refract light at the time it passes through the glass. Light is reflected from the mirror surface, passes through the object under consideration and enters the lens. A beam of light rays entering a microscope is first converted into a parallel stream, then it is refracted in the eyepiece. Then the information about the object of research enters the visual analyzer of the person.

Also, the microstructure of sphagnum moss was examined using an optical metallographic microscope "Altami MET 5C" (Fig. 3.3). The microscope makes it possible to work in reflected light using light field and polarization methods, and is also designed to investigate transparent and translucent objects in transmitted light in a bright field. The principle of operation of the microscope "Altami MET 5C" is based on the fact that the light incident on the object under investigation is reflected from it, allowing analysis of the structural components and control of the microstructure of the surface (flatness and roughness). At the stage of preparation of the sample, a moss sample (leaf, longitudinal section of the stalk 0.5 mm thick, transverse section of the stem 0.2 mm in diameter) was placed on a transparent silicate slide glass with a size of 26×76 mm. The object under study was moistened with a pipette with distilled water and covered with 18×18 mm. Then the sample was placed on a stage.

Figure 3.2. - General view of the microscope «Crocus 5MP MCX100»

Figure 3.3. - General view of the microscope «Altami MET 5C»

When studying the structure of dried sphagnum moss, the X-ray tomograph "Sky-Scan1174v2" was used (Fig. 3.4).

Figure 3.4 - General view of the scanner «SkyScan1174v2»

The scanner works using a non-destructive method of visualization of the three-dimensional internal microstructure of objects using X-ray radiation, which is an analogue of medical tomography, but having a much higher spatial resolution. A micro-focus X-ray tube illuminates the object, and the X-ray camera receives its enlarged shadow projections. Based on hundreds of projections collected at different angles as the object rotates, the computer reconstructs a set of virtual sections of the object. The operator can view various sections at any angle, obtain numerical characteristics of the three-dimensional internal microstructure throughout the volume or the selected area. Also, the tomograph allows you to create realistic three-dimensional models of micro-structure for virtual movement within the object of investigation.

3.2 Study of the microstructure of the sphagnum moss leaf

3.2.1 Investigation of the microstructure of the sphagnum moss leaf

To determine the factors responsible for the thermal insulation properties of moss, optical microscopy of moss leaves was carried out on a microscope called "Crocus 5MP MCX100". As a result, images of the sheet structure were obtained (Figures 3.5, 3.6). In Figure 3.5, a frame is selected with a frame, enlarged in Figure 3.6.

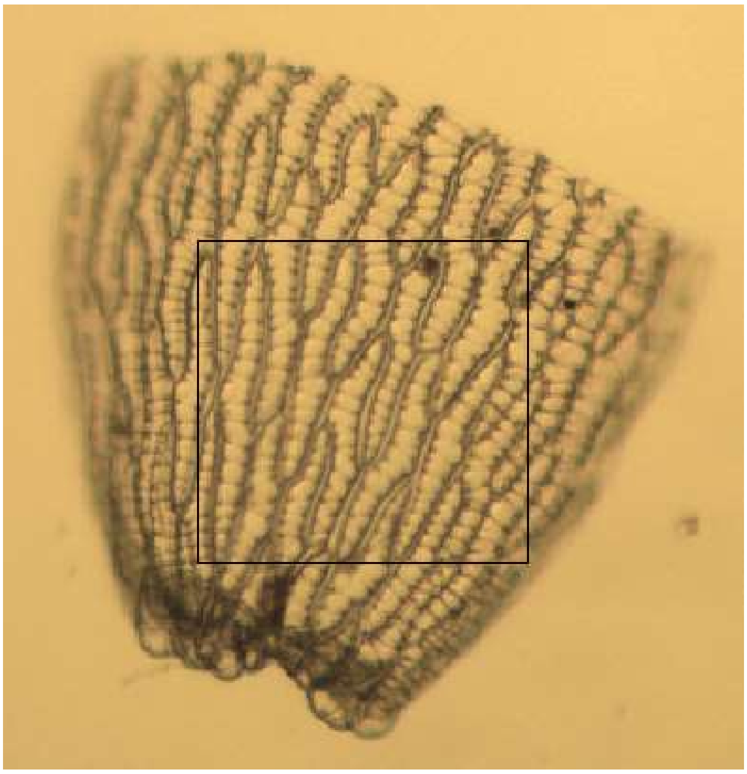


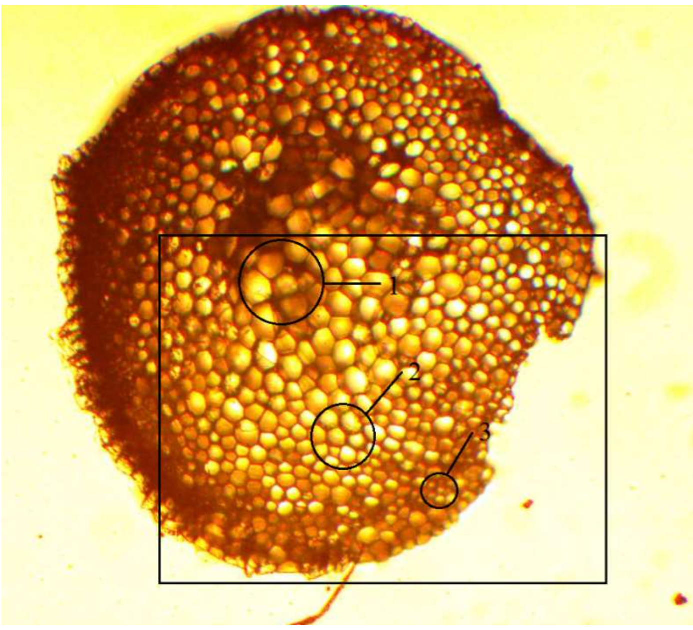
Figure 3.5. - Microstructure of the sphagnum moss leaf, 10x magnification

The study of the structure of the sphagnum moss leaf (Figures 3.5, 3.6) made it possible to determine two distinct types of cells. The first - narrow chlorophyll-bearing assimilating cells, connected by ends and form a network structure. In chlorophyllon cells, photosynthesis occurs, and the movement of organic substances takes place throughout the cell structure. The second type of cells include wide dead hyaline aquifers with spiral thickenings, located between the living ones (Figure 3.6). Dead cells are closed hollow shells-capillaries, with a length of 60 to 90 μm. In this case, the thickness of the moss leaf corresponds to one layer of cells. The multiple presence of hollow shells in the microstructure of the sphagnum determines the thermal insulation properties of the moss leaves. Similarly, dead cells with pore openings (Figure 3.6) draw in and condense water vapor from the surrounding air. By the principle of capillarity, water is actively absorbed from the moist atmosphere into the cell and is firmly retained there due to the hygroscopic properties of the hyaline. Thus, sphagnum moss can absorb a volume of water 20 times larger than its own. This property of moss to absorb water from moist air and give if necessary helps maintain a favorable moisture regime in the premises. Aquifers of sphagnum moss occupy about 65% of the surface area of the leaf.

1 - live chlorophyll-bearing cells;
2 - tracheids with spiral thickenings of the membrane; 3 - pores in tracheids
Figure 3.6. - Microstructure of moss sphagnum leaf, 40x magnification

3.2.2 Investigation of the microstructure of the stalk of moss sphagnum

An optical microscope "Altami MET 5C" was used to study the stalk of sphagnum moss. During the study, images of transverse and longitudinal sections of the moss stalk were obtained (Figs. 3.7-3.12).



1 - parenchymal cells, the core; 2- tracheids, aquifers;
3 - the outer bark

Figure 3.7. - Transverse section of the stalk of sphagnum moss, 10x magnification

Using the light field method, optical microscopy in transparent light made it possible to establish that in the cross section of the moss stalk there are three regions forming a cellular structure. The cross section of the stem resembles the structure of honeycombs of hexagonal and indeterminate form. In the center of the section is a core of parenchymal cells measuring 20 - 45 μm (Fig. 3.9) performing conductive and storage functions. The core is surrounded by a basic layer of dead hollow hyaline cells measuring 10-20 μm in cross-section, forming capillaries. Gialline and parenchymal cells are connected by thin septa with a thickness of less than 0.5 μm.

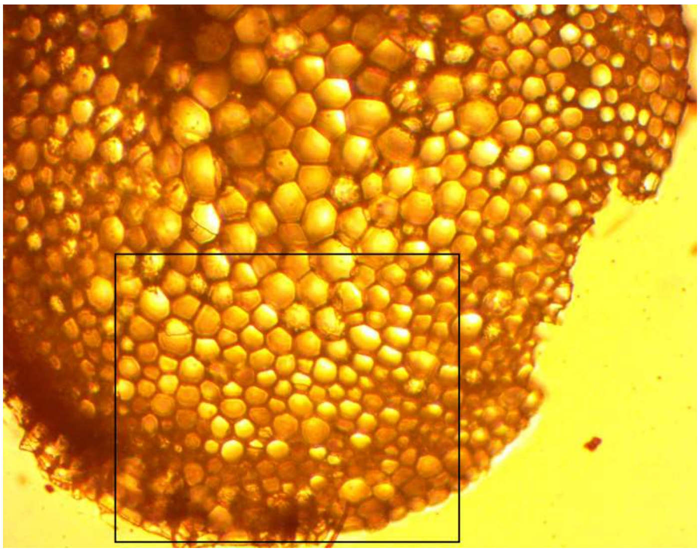


Figure 3.8. - Transverse section of the stalk of sphagnum moss, 20x magnification

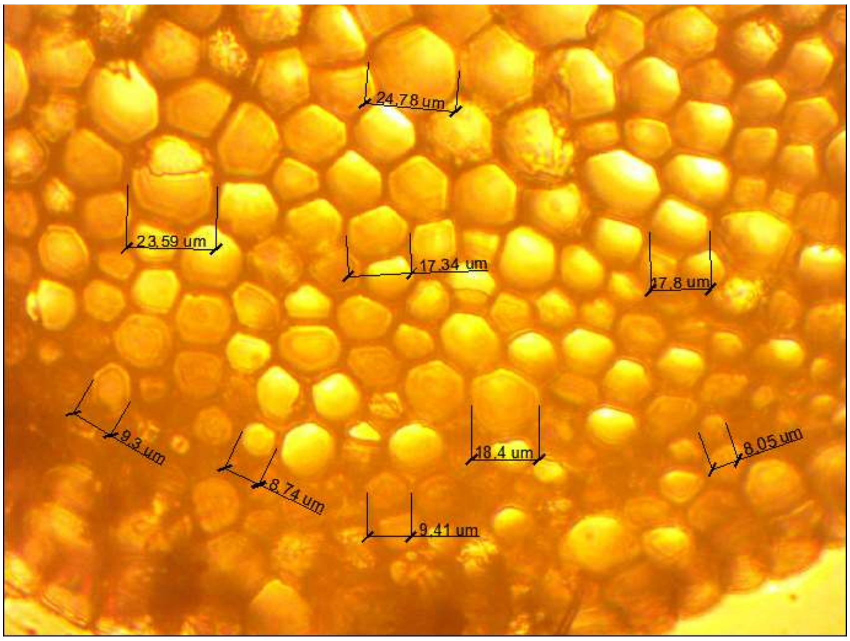


Figure 3.9. - Transverse section of the stalk of sphagnum moss, 40x magnification

The outer region (Figures 3.7, 3) is also represented by hyaline cells. These cells differ in a smaller diameter in the cross section from 6 to 10 μm and thicker partitions from 0.5 to 1.5 μm. Thus, in the region of the outer layer, the most rigid and strong cellular-capillary structure is formed.

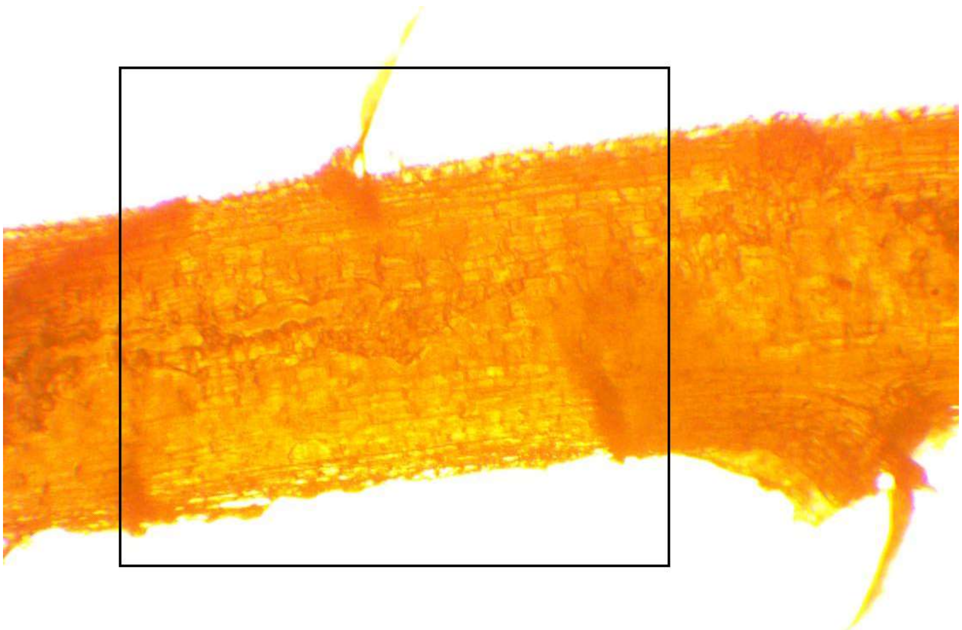
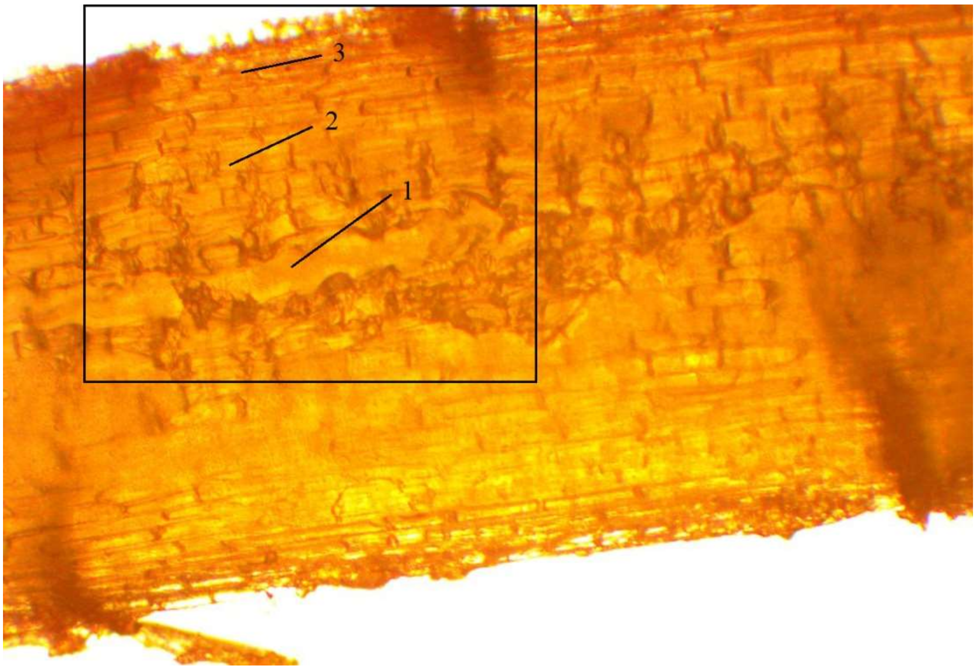


Figure 3.10. - Longitudinal section of the stalk of sphagnum moss, 5x magnification



1 - parenchymal cells, the core; 2- tracheids, aquifers;
3 - the outer bark
Figure 3.11. - Longitudinal section of the stalk of sphagnum moss, 10x magnification

In the process of microscopic research of the longitudinal section of the sphagnum moss trunk (Figure 3.10 - 3.12), it is noted that the stalk structure is formed from capillary vessels having thin transverse partitions along the length. Each capillary consists of successively located member cells in the form of a cylindrical cell 50-65 µm in length. The transverse partitions in the core are located at a greater distance from 60 to 80 µm.

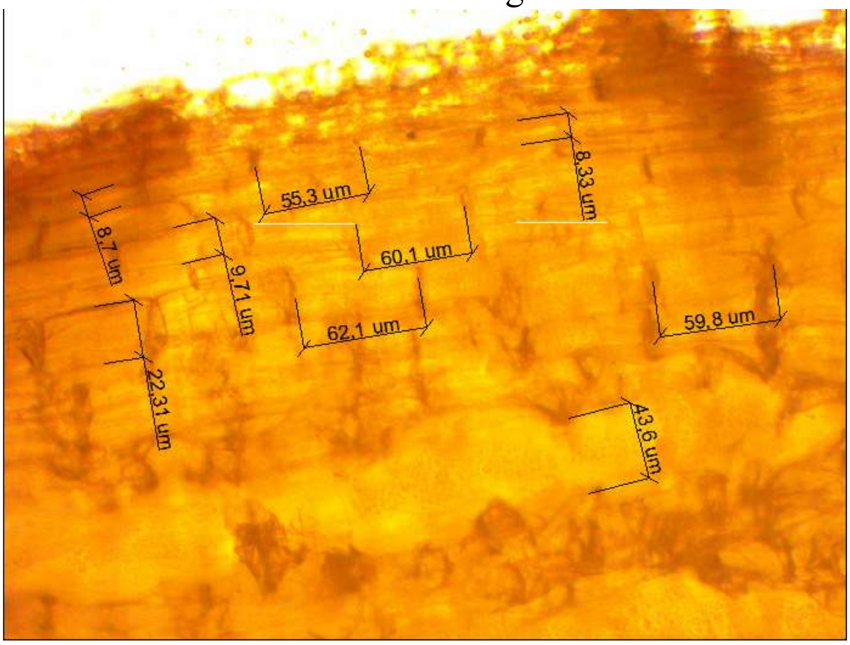


Figure 3.12. - Longitudinal section of the stalk of sphagnum moss, 20x magnification

The structure of dry sphagnum moss was studied using the X-ray tomograph "Sky-Scan1174v2". The result of scanning is shown in Figure 3.13.

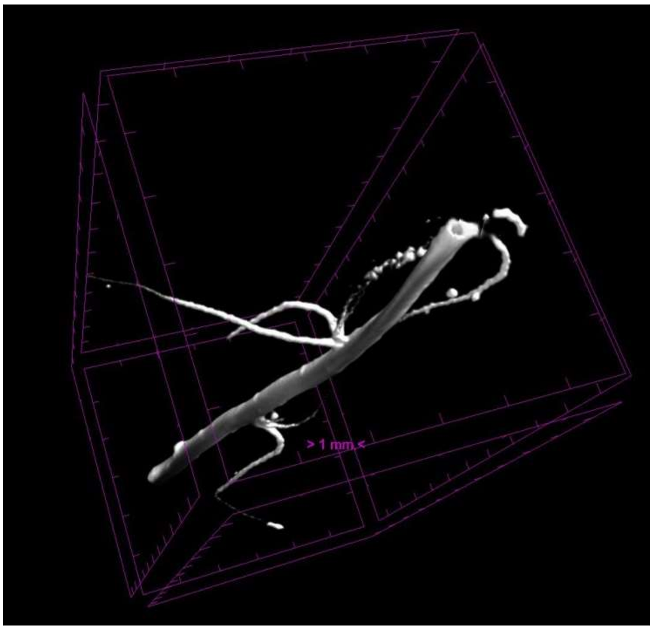


Figure 3.13. - 3D scan image of the stem of sphagnum moss

The image clearly shows that the dry trunk of the sphagnum is hollow inside and in shape has the form of a hollow cylinder-tube. The resulting image of the structure of the moss stem is explained by the fact that the density of the structure of the sphagnum moss varies along the width of the cross section and increases when approaching the outer boundary of the stem. Reducing the volume of cells and thickening of the partitions create a denser structure in the form of a denser shell. In the dry state, the structure of the parenchymal cell region is a spatial structure of the finest transparent partitions. For this reason, the tomograph determines the inner central region as a void, and the structure of the stem as a whole in the form of a tube. The performed tomography of the sample made it possible to obtain an intuitive spatial image of the fragment of the moss stalk with the possibility of evaluating the shape and external dimensions of the moss stem.

3.3 Chapter Summary

1. The use of optical microscopy and the X-ray tomograph allowed to fully assess the microstructure of the moss.

2. According to the results of the research, it was established that thin-walled shells remaining after the cells in both leaves and stems form a microcellular structure of dry moss that provides high thermal insulation properties of plant material.

3. The cell sizes determined by optical microscopy equal to 6-45×60-125 μm, with the thickness of partitions 0.5-1.5 μm indicate that the moss structure is similar to the structure of expanded polystyrene, which explains the thermal insulation properties of the natural plant material.

4. The use of moss as a filler insulation will allow to regulate the humidity regime in the premises, which will help maintain a favorable microclimate.

4. INVESTIGATION OF PHYSICAL-MECHANICAL CHARACTERISTICS OF THERMAL INSULATION MATERIALS ON VEGETABLE RAW MATERIALS

4.1 Study of the thermal insulation properties of moss-based materials

To obtain heat-insulating materials on the basis of plant raw materials, complex studies were carried out on the selection of compositions, including the preparation of an aggregate of a certain fraction, and the basic physico-mechanical characteristics of the samples were studied.

In the main experimental studies, a composite aggregate was used, which is a mixture of sphagnum moss with reed or rye straw. The sodium liquid glass was used as a binder. The use of moss, as an aggregate, is due to antiseptic properties and experience of use in thermal insulation purposes. Liquid sodium glass provides the heat-insulating material with incombustibility, binds the aggregate, is an antiseptic and prevents the formation of fungi.

In the preliminary stage of the studies, the cut moss with a fraction of 1-2 cm was used as a filler for the preparation of a heat-insulating material. Molding of slabs measuring 250×250×30 mm was made at a pressure of 0.02 MPa. The samples were kept in the form for 5-6 hours, and then they were removed and dried for 6-7 hours in a chamber at a temperature of 40-50°C. The heat-conductivity and density were determined on the plate samples obtained (Figure 4.1).

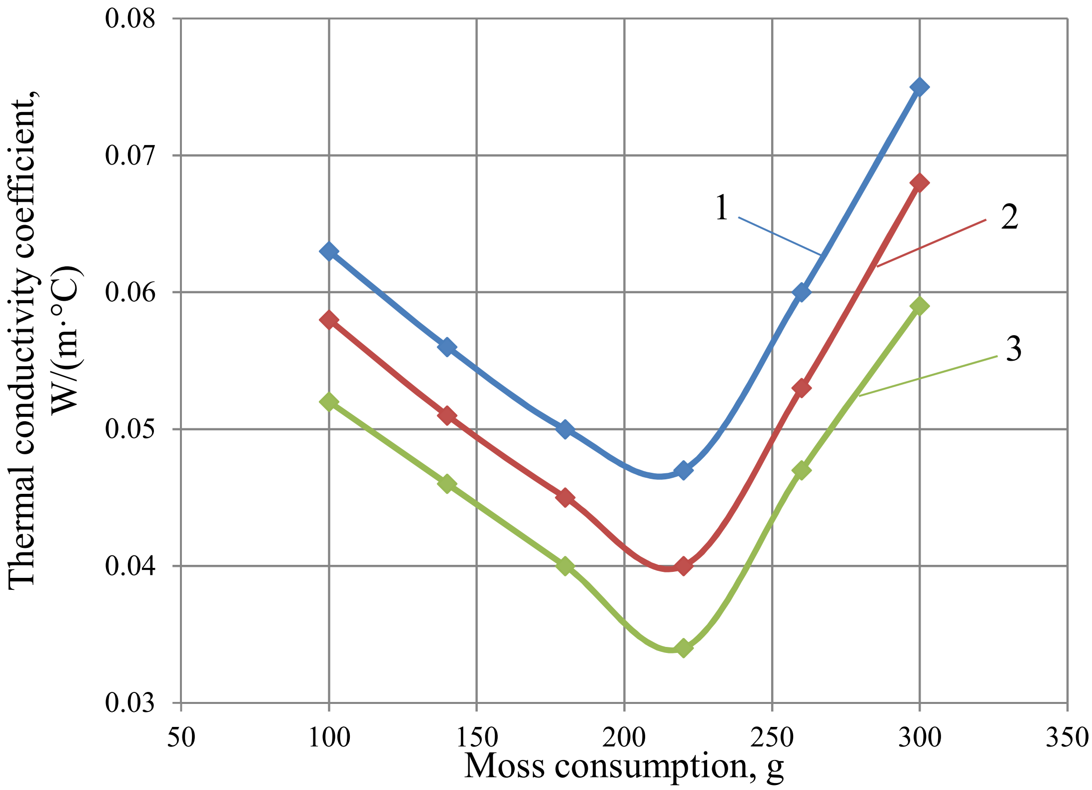
Figure 4.1. - Thermal insulation plates based on moss

The results of testing the moss-based thermal insulation material are presented in Table 4.1.

Table 4.1 - Physical and mechanical characteristics of moss-based plates

№ of composition	Sample mass, g	Components consumption on plate, g			Density, kg/m³	Thermal conductivity coefficient, W/(m·°C)	Sample dimensions, sм
		moss	liquid glass	water			
1	531	300	400	175	300	0,075	24,4×24,4×3
2	499	260	400	160	285	0,06	24,4×24,4×3
3	464	220	400	145	265	0,047	24,4×24,3×3
4	437	180	400	130	250	0,05	24,3×24,3×3
5	396	140	400	115	225	0,056	24,3×24,2×3
6	352	100	400	100	200	0,063	24,2×24,2×3
7	439	300	300	175	255	0,068	24,4×24,3×3
8	410	260	300	160	235	0,053	24,3×24,3×3
9	377	220	300	145	215	0,04	24,3×24,2×3
10	349	180	300	130	200	0,045	24,2×24,2×3
11	316	140	300	115	180	0,051	24,2×24,2×3
12	280	100	300	100	160	0,058	24,2×24,1×3
13	346	300	200	175	205	0,059	24,3×24,3×3
14	320	260	200	160	185	0,047	24,3×24,3×3
15	289	220	200	145	170	0,034	24,3×24,2×2
16	261	180	200	130	155	0,04	24,2×24,2×3
17	236	140	200	115	140	0,046	24,2×24,1×3
18	208	100	200	100	120	0,052	24,1×24,1×3

The obtained dependences (Fig. 4.2) allow to establish that for a fixed amount of binder (for example, 300 g), an increase in aggregate consumption by 120 g (compositions 9 and 12) leads to an increase in density by 26% and a reduction in the thermal conductivity by 31%. However, with a further increase in aggregate consumption from 220 to 300 g (compositions 9 and 7), the thermal conductivity coefficient increases by 42% from 0.04 to 0.068 W/(m·°C). An increase in the mass of the liquid glass also leads to an increase in the heat conductivity index. Thus, when comparing the characteristics of compositions 3 and 9, it can be noted that the addition of 100 g of binder causes an increase in the thermal conductivity by 15% and a density of 19% at an equal filler consumption, and when composites 3 and 15 are compared, the thermal conductivity increased by 28% and density by 37%.



1 - compositions 1 - 6, consumption of liquid glass 400 g;
2 - compositions 7 - 12, consumption of liquid glass 300 g;
3 - compositions 13 - 18, consumption of liquid glass 200 g
Figure 4.2. - Dependence of the coefficient of thermal conductivity of plates on moss consumption

Thus, an increase in both moss consumption and liquid glass increases the thermal conductivity and plate density. The obtained dependences are explained by the fact that at an increased consumption of liquid glass, the layers of the binder begin to act as bridges of cold. On the layers of the binder, covering the particles of the aggregate, heat begins to be transferred. At a low density of insulation, a loose structure of the aggregate is formed, passing through itself warm air streams. At a moss consumption of 220 g, it is possible to achieve an optimum densified structure that blocks the free movement of air heat flows through the insulation, which ensures the preservation of the maximum integrity of the cellular microstructure. Further increase in the density of the heat-insulating material leads to crushing and densification of the cellular microstructure, which causes destruction of the cell walls. As a result, in spite of the absence of through-flow of air through the structure, heat losses on the material of the aggregate. The best results on thermal conductivity are fixed on compositions 3, 9, 15 at different consumption of binder, which is due to the formation of an optimal structural system of moss that blocks the passage of through air flows through the insulation. In this case, the internal cellular microstructure of the trunks and leaves of moss remains as intact as possible.

After heat treatment of heat-insulating plates, the presence of considerable shrinkage deformations along the length and width by 7-8 mm is noted, which is about 6% of the dimensions of the molding. When mixed with liquid glass due to hygroscopicity of moss, water enters dead cells, which leads to their swelling and increase in volume. Thus, the size of cut moss fragments increases, which has a significant coefficient of linear expansion in the wet state. During drying, the water evaporates from the dead hyaline cells, and the moss decreases in size, which leads to the appearance of shrinkage deformations.

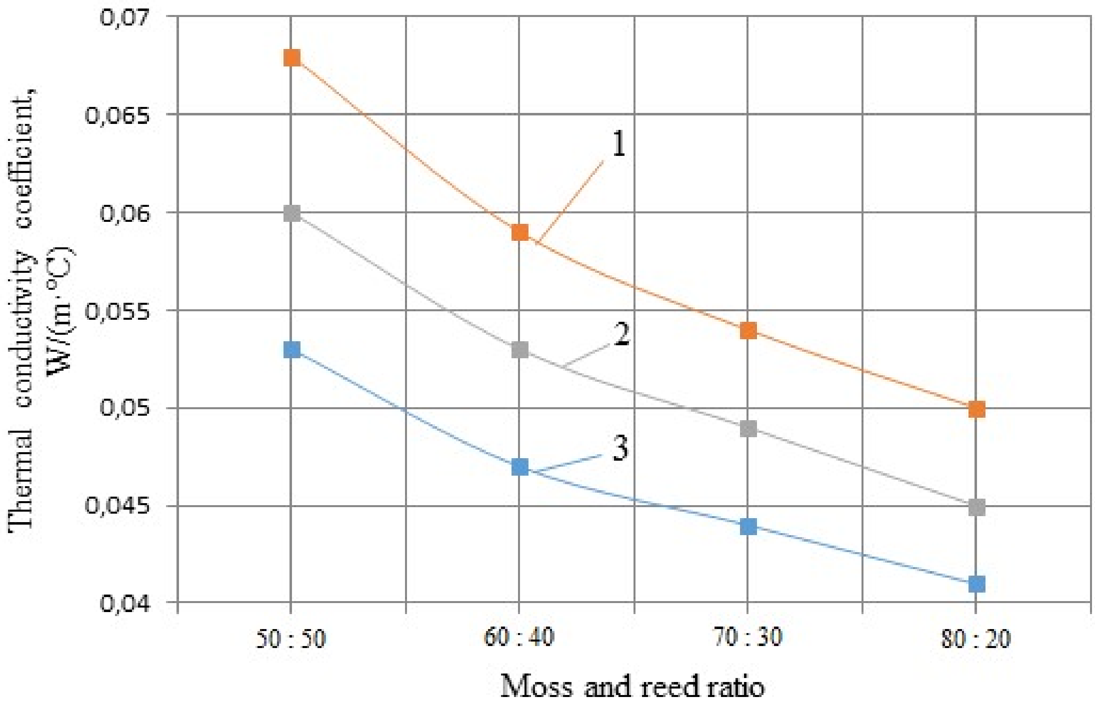
In the second stage of the research, in order to make the heat-insulating material more rigid and reduce shrinkage, an additional component was introduced into the aggregate – reed ordinary in the form of cut pipes 1-2 cm in length. When trying to crush the reed stalk into parts less than 1 cm long, the material lost its cylindrical shape and collapsed into segments. The use of reed tubes longer than 2 cm is not advisable from the position of forming the necessary rigid coherent structural system. In the composition of a complex aggregate, the reed tubes should create a framework of strong and interconnected crushed particles of cylindrical shape. Thus, the obtained frame from the reed tubes in the bulk of the moss will allow us to perceive the compressive forces and reduce the shrinkage deformations. For the total mass of the complex aggregate, the mass of moss in single-component compositions 3, 9 and 15 (Table 4.1) with the lowest coefficients of thermal conductivity is adopted. Reed was introduced in an amount of 20-50% of the total mass of the aggregate.

The results of tests of moss-and-reed insulation material are presented in Table 4.2.

Table 4.2 - Physical and mechanical characteristics of plates based on sphagnum moss and reed ordinary

№ of composition	Sample mass, g	Components consumption on plate, g				Density, kg/m³	Thermal conductivity coefficient, W/(m·°C)	moss : reed ratio, %	Sample dimensions, sм
		moss	reed	liquid glass	water				
1	426	110	110	400	100	228	0,068	50:50	25×24,9×3
2	426	132	88	400	115	231	0,059	60:40	24,8×24,8×3
3	425	154	66	400	130	234	0,054	70:30	24,6×24,6×3
4	423	176	44	400	145	235	0,05	80:20	24,5×24,4×3
5	359	110	110	300	75	194	0,06	50:50	24,9×24,8×3
6	358	132	88	300	90	195	0,053	60:40	24,8×24,7×3
7	359	154	66	300	105	198	0,049	70:30	24,6×24,5×3
8	357	176	44	300	130	200	0,045	80:20	24,4×24,4×3
9	293	110	110	200	75	160	0,053	50:50	24,7×24,7×3
10	294	132	88	200	90	163	0,047	60:40	24,7×24,6×3
11	295	154	66	200	105	165	0,044	70:30	24,5×24,3×3
12	294	176	44	200	130	166	0,041	80:20	24,3×24,3×3

When considering the compositions (Table 4.2) with an equal amount of binder, it is established that an increase in the consumption of crushed reed leads to an increase in the thermal conductivity of the plates (Fig. 4.3). The introduction of reed in an amount of 50% of the total mass of the aggregate (composition 5) causes an increase in the coefficient of thermal conductivity relative to the composition index 8 by 33% from 0.045 to 0.06 W/(m•°C). Also, an increase in the heat conductivity is observed with an increase in the amount of binder. For example, for compositions 3 and 11 with an equal component consumption, an increase in the mass of the liquid glass by 200 g (composition 3) led to an increase in the thermal conductivity index by 23%. In general, it should be noted that the heat conductivity of materials on a two-component basis (Table 4.2) is higher than that of single-component compositions (Table 4.1) with an equal consumption of the components of the mixture. Composition 12 with the largest amount of moss in the aggregate at a density of 166 kg / m³ has a coefficient of thermal conductivity of 0.041 W/(m·°C), which is 21% more than that of a single-component material with the same amount of binder (composition 15, Table 4.1).



1 - compositions 1 - 4, consumption of liquid glass 400 g;
2 - compositions 5 - 8, consumption of liquid glass 300 g;
3 - compositions 9 - 12, consumption of liquid glass 200 g

Figure 4.3. - Dependence of the change in the coefficient of thermal conductivity on the ratio of moss and reed in the aggregate mixture

Reed has a high bulk density - 270 kg/m³. As a result, the amount of crushed reed introduced in most of the compositions does not ensure the formation of a bound rigid framework necessary to eliminate shrinkage deformations of the plates. In addition, a part of the shredded cane stalks in the form of tubes is split into segments during the forming of the material, which reduces the volume occupied by the particles in the plate and leads to the decomposition of the moss structure. The uneven distribution of crushed reed along the insulation layer is also noted. As a result, air heat fluxes in the material structure are formed and move freely, which leads to an increase in the thermal conductivity coefficient and a decrease in the thermal resistance. The smallest coefficient of thermal conductivity of plates on a two-component basis is equal to 0.041 W/(m·°C) is established in composition 12 at a density of 166 kg/m³ with a mixing ratio of 80:20.

To eliminate the shrinkage of plates was possible only in the composition 1 with the maximum amount of binder at a ratio of moss and reed 50:50. In the other compositions, on the basis of a mixture of moss and reed, the shrinkage deformations decreased by 3-5 mm compared to moss plates.

Also, as a second component of the aggregate, rye straw was used as a 1-2 cm fraction. The results of tests of a heat-insulating material based on a mixture of moss and straw are presented in Table 4.3.

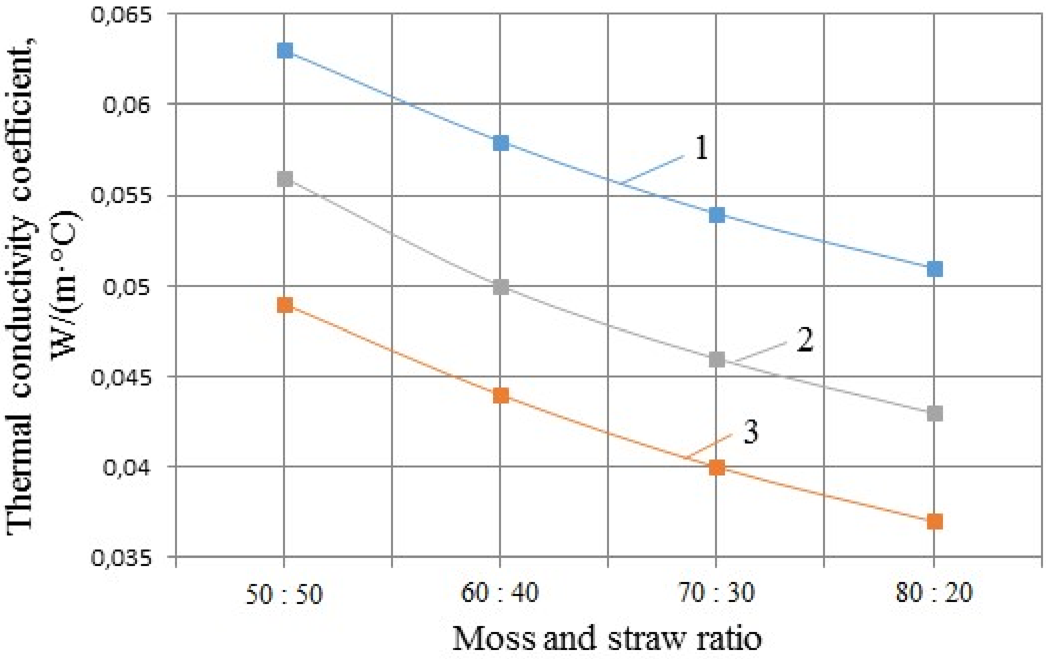
During the analysis of the obtained data, it was established that the changes in the heat conductivity index from the ratio of the components in the aggregate mix and the amount of binder (Figure 4.4) are similar to those of the insulator based on a mixture of moss and reed (Figure 4.3). Thus, in compositions 5 and 8 (Table 4.3), with an equal mass of liquid glass, an increase in the amount of straw in the composition leads to an increase in the thermal conductivity by 30% from 0.043 W/(m•°C) to 0.056 W/(m•°C). At the same time, adding 200 g of binder with an equal ratio of the components in the aggregate mixture in compositions 2 and 10 increases the density of the plates by 45% from 156 kg/m³ to 226 kg/m³, and the coefficient of thermal conductivity up to 0.058 W/(m•°C) by 32%. Also, insignificant deterioration of the thermal insulation properties of the material with respect to compositions with a single-component aggregate (Table 4.1) and an improvement in performance compared to plates based on the composition of moss and reed (Table 4.2) was also established. For example, with a maximum amount of moss and a binder consumption of 200 g (composition 12), the coefficient of thermal conductivity is 0.037 W/(m·°C), which is 9% higher than the value of composition 15 (Table 4.1) based on moss and 11% lower of the composition index 12 (Table 4.2) from a mixture of moss and reed. When comparing cane and rye straw as components in a complex aggregate, it should be noted that the bulk density of straw is 125 kg/m³, which is 2.16 times less than the reed value corresponding to 270 kg/m³. With equal masses of components, the straw takes up 2 times more volume in the aggregate mixture. When forming plates based on a mixture of moss and straw, a rigid bound frame of crushed stems of straw is formed, filling the void space with a dense structure of moss, which prevents the free movement of air flows through the structure of the insulation. The resulting structural system provides a low coefficient of thermal conductivity, high strength and the absence of shrinkage deformations during drying. Also, straw has a thermal conductivity of 0.05 W/(m·°C), which is 23% less than the cane index of 0.065 W/(m·°C). The microstructure of straw and reed is similar, but the reed has a high density due to the presence of thicker partitions due to the reduction in the cross-sectional dimensions of the cells. The destruction of hollow cylindrical particles of reed into segments during the formation of slabs prevents the formation of internal local air voids in the particles, which also reduces the thermal conductivity. Crushed stems of straw at all technological stages of production of thermal insulation plate retain their cylindrical shape and properties. After molding, air cavities in the tubes along the ends are closed by compacted moss and air circulation through the voids does not occur. In addition, there is no destruction of the cellular structure of straw capillaries, since there are no deformations of the tubes of crushed stems during the molding of the insulation, which also contributes to an increase in resistance to heat transfer.

When using a mixture of moss and straw, significant changes in the reduction of shrinkage deformations were observed. The shrinkage of the plates during the drying in the longitudinal direction was noted in compositions with the least amount of straw and binder in the compositions 8, 11, and 12 and was 2-3 mm from the dimensions during molding. On the plates of the remaining compositions shrinkage deformations are not fixed. The lowest coefficient of thermal conductivity is equal to 0.044 W/(m·°C) with the absence of shrinkage of the slab set in composition 10 (Table 4.3). A decrease in the density of the material was also observed in comparison with the plates based on the mixture of moss and reed, which is explained by the preservation of the original dimensions of the plates with the same weight of components after drying. Thus, the density of composition 8 (Table 4.3) was 191 kg/m³, which is 9 kg/m³ less than the composition index 8 (Table 4.2).

The larger volume of straw relative to the reed space, the preservation of the geometry of crushed stems as hollow tube cylinders, made it possible to create in the moss structure a uniformly distributed coherent framework of straw, which perceives compressive forces under load and prevents the appearance of shrinkage deformations. Also, due to the larger volume of straw filled in the composite aggregate, the moss is compacted to a structure similar to that of 3, 4, 9, 10, 15, 16 (Table 4.1). The factors resulted in the absence of shrinkage deformations of heat-insulating plates during drying.

Table 4.3 - Physical and mechanical characteristics of plates based on moss sphagnum and rye straw

№ of composition	Sample mass, g	Components consumption on plate, g				Density, kg/m³	Thermal conductivity coefficient, W/(m·°C)	moss : straw ratio, %	Sample dimensions, sм
		moss	straw	liquid glass	water				
1	423	110	110	400	100	225	0,063	50:50	25×25×3
2	425	132	88	400	115	226	0,058	60:40	25×25×3
3	426	154	66	400	130	227	0,054	70:30	25×25×3
4	424	176	44	400	145	226	0,051	80:20	25×25×3
5	358	110	110	300	75	191	0,056	50:50	25×25×3
6	359	132	88	300	90	192	0,05	60:40	25×25×3
7	357	154	66	300	105	190	0,046	70:30	25×25×3
8	358	176	44	300	130	191	0,043	80:20	24,8×24,8×3
9	294	110	110	200	75	157	0,049	50:50	25×25×3
10	292	132	88	200	90	156	0,044	60:40	25×25×3
11	290	154	66	200	105	155	0,04	70:30	24,8×24,8×3
12	293	176	44	200	130	156	0,037	80:20	24,7×24,6×3



1 - compositions 1 - 4, consumption of liquid glass 400 g;
2 - compositions 5 - 8, consumption of liquid glass 300 g;
3 - compositions 9 - 12, consumption of liquid glass 200 g
Figure 4.4. - Dependence of the change in the coefficient of thermal conductivity on the ratio of moss and straw in the aggregate mixture

4.2 Investigation of strength properties of materials based on moss

4.2.1 Determination of strength at 10% deformation

Tests for strength at 10% deformation, were performed on samples sized cubes 100×100×100 mm. Samples were kept in the forms for 5-6 hours, followed by drying for 6-7 hours. Compositions for the preparation of the sample-cubes correspond to the compositions of heat-insulating plates (Tables 4.1-4.3).

The results of testing samples with a moss filler for strength at 10% deformation are given in Table 3.4.

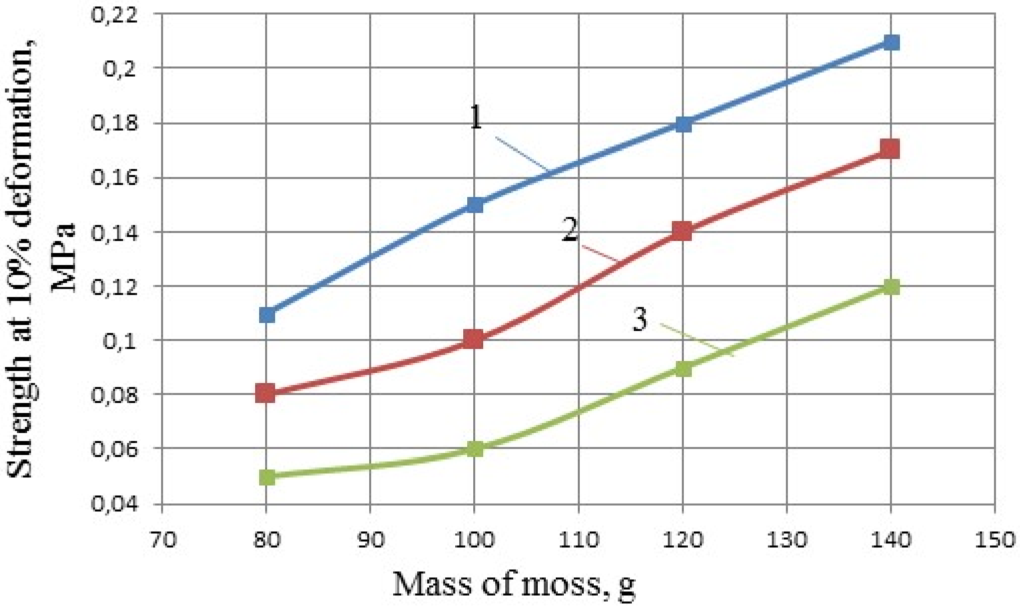
Table 4.4 - Compressive strength of specimens with moss aggregate

№ of composition	Components consumption, g		Strength at 10% deformation, MPa
	moss	liquid glass	
1	140	220	0,21
2	120	220	0,18

3	100	220	0,15
4	80	220	0,11
5	140	160	0,17
6	120	160	0,14
7	100	160	0,1
8	80	160	0,08
9	140	100	0,12
10	120	100	0,09
11	100	100	0,06
12	80	100	0,05

Analysis of the obtained data showed that an increase in the amount of aggregate increases the strength of the material at 10% deformation (Table 4.4). For example, in compositions 1 and 4 with an equal amount of a binder, increasing the aggregate consumption increases the strength of the material at a 10% deformation of 1.9 times from 0.11 MPa to 0.21 MPa. A similar dependence is observed with a change in the consumption of the binder (Table 4.4). Thus, with an equal amount of aggregate (compositions 2 and 10), with an increase in the consumption of liquid glass by 120 g, the strength of Composition 2 increases by a factor of 2 times.

According to the established dependencies (Figure 4.5), the increase in aggregate consumption provides an increase in strength by 0.07-0.1 MPa with a fixed amount of binder. A change in the binder consumption from 100 to 220 g increases the strength index by 0.06-0.09 MPa on samples with the same moss consumption.



1 - compositions 1 - 4, consumption of liquid glass 400 g;
2 - compositions 5 - 8, consumption of liquid glass 300 g;
3 - compositions 9 - 12, consumption of liquid glass 200 g
Figure 4.5. - Dependence of the change in the strength of the samples at 10% deformation on the mass of moss

In the second stage of the research, samples were prepared on the basis of composite aggregates from mixtures of moss and reed, as well as moss and straw (Figure 4.6). The results of testing the samples for strength at 10% deformation are presented in Tables 4.5 and 4.6 respectively.

Figure 4.6. - General view of a sample-cube based on moss and straw

Table 4.5 - Compressive strength of samples based on moss and reed

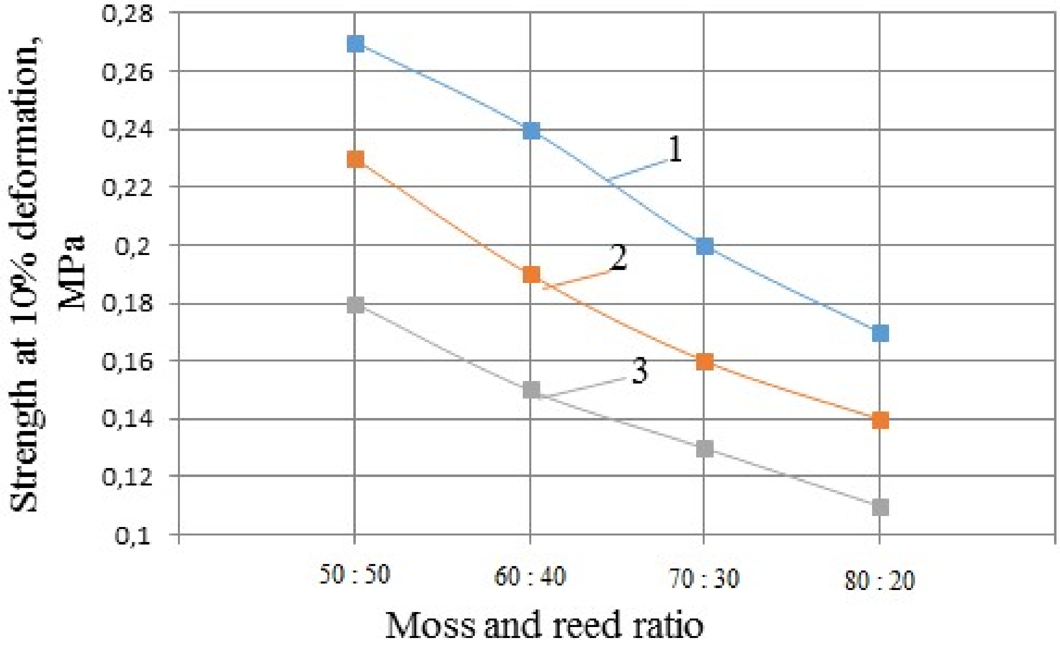
№ of composition	Components consumption, g			moss : straw ratio, %	Strength at 10% deformation, MPa
	moss	reed	liquid glass		
1	60	60	220	50:50	0,27
2	72	48	220	60:40	0,24
3	84	36	220	70:30	0,20
4	96	24	220	80:20	0,17
5	60	60	160	50:50	0,23
6	72	48	160	60:40	0,19
7	84	36	160	70:30	0,16
8	96	24	160	80:20	0,14
9	60	60	100	50:50	0,18
10	72	48	100	60:40	0,15
11	84	36	100	70:30	0,13
12	96	24	100	80:20	0,11

Table 4.6 - Compressive strength of samples based on moss and straw

№ of composition	Components consumption, g			moss : straw ratio, %	Strength at 10% deformation, MPa
	мох	солома	liquid glass		
1	60	60	220	50:50	0,32
2	72	48	220	60:40	0,29
3	84	36	220	70:30	0,25
4	96	24	220	80:20	0,22
5	60	60	160	50:50	0,28
6	72	48	160	60:40	0,24
7	84	36	160	70:30	0,21
8	96	24	160	80:20	0,19
9	60	60	100	50:50	0,23
10	72	48	100	60:40	0,20
11	84	36	100	70:30	0,18
12	96	24	100	80:20	0,16

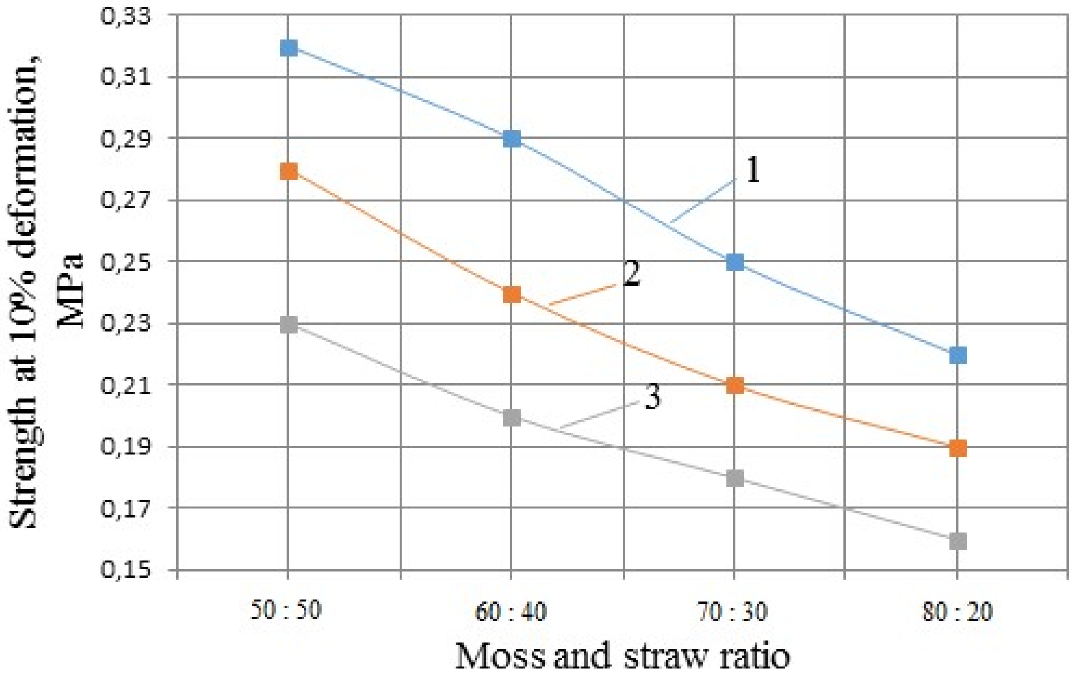
Analysis of the results of research when replacing the part of the moss with reed or straw as part of the aggregate showed an increase in strength at 10% deformation compared to samples on a single-component aggregate. Thus, the strength at 10% deformation of composition 1 (Table 4.6) based on moss and straw is 0.32 MPa, which is 52% higher than the one-component composition 1 (Table 4.4). The greatest strength of the sample cubes on a two-component aggregate from a mixture of moss and reed is 0.27 MPa (composition 1, Table 4.5), which is 29% higher than the one-component composition and 19% lower than the value of composition 1 (Table 4.6).

It should also be noted that with an equal amount of binder, increasing the amount of crushed reed or straw in the total mass of the aggregate leads to an increase in the strength of the samples (Figure 4.7, Figure 4.8). When comparing compositions 8 and 7 on the basis of moss and straw (Table 4.6), an increase in the strength index by 0.03 MPa is observed. With a further increase in the proportion of straw in the aggregate, the strength index is increased by 41%. A similar dependence is observed with an increase in the binder consumption with an equal amount and the ratio of the filler components in the composition of the mixture. When the compositions 10 and 2 are compared on the basis of moss and reed (Table 4.5), the strength index increases by 40% from 0.15 MPa to 0.21 MPa, respectively.



1 - compositions 1 - 4, consumption of liquid glass 400 g;
2 - compositions 5 - 8, consumption of liquid glass 300 g;
3 - compositions 9 - 12, consumption of liquid glass 200 g

Figure 4.7. - Dependence of the change in the strength of the samples at 10% deformation on the ratio of moss and reed in the aggregate mixture



1 - compositions 1 - 4, consumption of liquid glass 400 g;
2 - compositions 5 - 8, consumption of liquid glass 300 g;
3 - compositions 9 - 12, consumption of liquid glass 200 g

Figure 4.8. - Dependence of the change in the strength of the specimens at 10% deformation on the ratio of moss and straw in the aggregate mixture

The obtained data make it possible to establish that for all compositions the strength of samples from a mixture of moss and straw is greater than for moss and reed samples. For example, when the strength of the composition 3 (Table 4.6) is equal to 0.25 MPa and composition 3 (Table 4.5) is compared with 0.2 MPa at 0.2%, an increase of 25% is observed. The rigid coherent structured framework created by crushed straw is intended not only to eliminate shrinkage deformations, but also to absorb external loads, which is facilitated by the shape of the straw particles stored in the form of hollow cylinders preserved after pressing the samples. Thus, the greater strength at 10% deformation, obtained from materials on a two-component aggregate of moss and straw, is explained.

It should be noted that on the samples-cubes from the mixture of moss and reed, the same drawbacks as for the plates on a single-component aggregate are fixed: loose moss fibrous structure, absence of a coherent carcass of reeds, shrinkage deformations after drying. The smaller volume of cane compared to straw at the same mass, the destruction of cane pipes during molding, the less dense structure of the samples and the absence of a coherent framework are factors that cause less strength relative to the material from the mixture of moss and straw. On samples from a mixture of moss and straw (Table 4.6), these negative factors are absent, which as a result allows achieving higher strength characteristics.

4.2.2 Determination of flexural strength

Sampling to determine the flexural strength was made by cutting the finished plates with a circular saw (Figure 4.9). In the studies, slabs were used for single- and two-component aggregates with the same compositions by mass (composition 3 of Table 4.1, composition 1 of Table 4.2, composition 1 of Table 4.3). The tests were carried out on beam samples with a size of 250×40×30 mm (Figure 4.10).

Figure 4.9. - Manufacturing of beam samples for bending strength test

Figure 4.10. - General view of testing of beam samples for bending strength

Table 4.7 - Bending strength of beam samples based on moss

№ of composition	Components consumption, g		Bending strength, MPa
	moss	liquid glass	
1	220	400	0,07
2	220	400	0,08
3	220	400	0,08
4	220	400	0,09

Table 4.8 - Bending strength of beam samples based on moss and reed

№ of composition	Components consumption, g			moss : reed ratio, %	Bending strength, MPa
	moss	reed	liquid glass		
1	110	110	400	50:50	0,14
2	110	110	400	50:50	0,14
3	110	110	400	50:50	0,13
4	110	110	400	50:50	0,15

Table 4.9 - Bending strength of beam samples based on moss and straw

№ of composition	Components consumption, g			moss : straw ratio, %	Bending strength, MPa
	moss	straw	liquid glass		
1	110	110	400	50:50	0,27
2	110	110	400	50:50	0,26
3	110	110	400	50:50	0,24
4	110	110	400	50:50	0,25

The results of experimental research showed a significant increase in the flexural strength of the insulation on a composite basis of moss and straw in comparison with the one-component composition and composition of the mixture of moss and reed. Thus, the average bending strength of compositions of moss and straw is 0.26 MPa, which is 1.9 times greater than that of composite composition based on moss and reed, and 3.2 times higher than the values of samples on a single-component basis.

A significant increase in flexural strength when introducing crushed straw indicates that the evolving frame system of straw tubes takes a larger tensile and compressive forces occurring during bending of insulation.

Thus, the spatial frame system of straw tubes with the filling of voidspace with compressed moss is the most optimal structure of the insulation, which provides high physical and mechanical parameters of the heat-insulating material.

4.3 Chapter Summary

1. Thermal insulation plates on a single-component basis from moss sphagnum have a low coefficient of thermal conductivity of 0.034-0.04 W/(m·°C). However, the material has drawbacks in the form of shrinkage deformations and low strength characteristics.

2. The change in the consumption of aggregate and sodium liquid glass has a significant effect on the properties of the thermal insulation material. The increase in the consumption of binder and aggregate positively affects the strength characteristics of the resulting thermal insulation materials, but it negatively affects the thermal conductivity, causing an increase in the index.

3. In order to eliminate the drawbacks inherent in the material, on a single-component aggregate, the cane ordinary or rye straw was introduced. The tests carried out showed that the addition of reed pipes has a negligible effect on the thermophysical characteristics of the heat-insulating material. The presence of straw in the composition with moss increases the strength at 10% deformation by 1.5 to 3 times, the flexural strength by 2 to 3.2, and allows to eliminate shrinkage deformations with an insignificant increase in the thermal conductivity coefficient.

4. The optimal compositions obtained in the course of the research, taking into account the physico-mechanical characteristics and the absence of shrinkage deformations, are two-component compositions 7 and 10 based on sphagnum moss and rye straw, providing a coefficient of thermal conductivity of the plates of 0.044-0.046 W/(m·°C) at a density 156-190 kg/m^3 and strength at 10% deformation of 0.2-0.21 MPa.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

5.1 Conclusions

1. The obtained data of optical microscopy of sphagnum moss indicate the presence of a cellular structure with a cell size of 9-20 × 60-90 μm and a moss stem of 6-45 × 50-80 μm with a thickness of 0.5-1.5 μm in the parameters superior to the microstructure foam polystyrene, which explains the high thermal insulation properties of a moss-based insulation.

2. The increase in the consumption of aggregate and sodium liquid glass leads to an increase in the density of insulating materials containing moss in 1.3 - 1.4 times, an increase in the compressive strength at 10% deformation of 1.9 - 4.2 times and an increase in the coefficient of thermal conductivity of 1 , 4 - 1.7 times.

3. High physical and mechanical characteristics of the thermal insulation material are due to the formation of a spatial frame system from straw tubes with the filling of a void space with compacted moss, as well as a fine mesh microstructure of moss and rye straw.

4. The developed new thermal insulation material based on vegetable raw materials of natural origin and agricultural production provides, at a density of 156-190 kg/m^3, no shrinkage deformations during drying, a coefficient of thermal conductivity of 0.04-0.046 W/(m·°C) and strength at 10 % of the deformation corresponding to 0.2-0.22 MPa.

5. With the use of natural plant raw materials and agricultural production waste, an ecologically safe effective rigid plate insulation is obtained, which has a biocidal property and has no analogues in the construction market for thermal insulation materials.

5.2 Future developments

For further research, we propose to expand the quantitative selection of the compositions to obtain the most optimal proportions and properties.

It is also possible to consider other complex fillers of heat-insulating material, providing the properties of heat conductivity and safety for human health.

In further research, it is proposed to search for solutions to increase the strength properties of the resulting plate material without loss of thermal insulation properties.

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