E3S Web of Conferences 161, 01037 (2020) https://doi.org/10.1051/e3sconf/202016101037
ICEPP-2020

TECHNOLOGY FOR PRODUCING PEAT HEAT-INSULATING BOARDS USING ORGANOSILICON POLYMERS

Lyudmila Voropai[1,*], *Anton* Sinitsyn[1], *Galina* Tikhanovskaya[1], and *Olga* Yukhtarova[1]

[1]Vologda State University, Lenina Street 15, Vologda, 160000, Russia

Abstract.

1 Introduction

One of the strategic forward routes of the Vologda Oblast is the development of technologies for producing new types of composite building materials based on natural raw materials. The Vologda Oblast is rich in peat reserves, having 2381 deposits. The area of peat bogs is 1 million 376 thousand ha, the average content of peat soils is 8.8%, and in some areas it reaches 30-45%.

It is known that peat has been used as a heat-insulating material from olden times. However, this material isn't chemically and biologically stable and the processes of its decomposition begin under the influence of moisture. To prevent peat destruction, it is "encapsulated", that is, enveloped with other materials that are hydrophobic. This increases its mechanical strength without increasing its thermal conductivity. High-molecular-weight compounds (HMWC) containing fluorine atoms in molecules and atomic groups of silicon (silicon polymers) instead of carbon chain are used for these purposes.

The performed patent and literature search shows that nowadays production of heat-insulating materials (HIM) uses peat mixtures that include, in addition to peat, inorganic natural additives and industrial wastes possessing binding properties (gypsum, Portland cement, cement dust), and high-molecular-weight organic substances of natural, synthetic and artificial origin (sawdust, flour; liquid and solid polymers: polystyrene, polypropylene, polyvinylacetate, polyethylene), silicofluoric and organic polymers.

The main component of HIM production is peat, which acts as a heat insulator. Taking into account the significant reserves of peat (both low-lying and high-lying) within the territory of Russia and the Vologda Oblast, its availability, environmental friendliness, and low thermal conductivity, this raw material appears to be promising for HIM production.

The second component for production of composite HIM are binders of organic and inorganic origin. Over the last years, there has been a tendency to partially replace inorganic binders by organic high-molecular-weight compounds: polystyrene, expanded bead polystyrene, phenol-formaldehyde resins, silane-siloxane compounds. These components provide quick setting of HIM. However, they are toxic substances that are prone to spontaneous combustion at high temperatures and lose their hydrophobic properties in humid environment and therefore do not prevent the destruction of peat particles, which reduces the HIM quality and limits their use [1-2].

It was established that despite a vast variety of HMWC and polymers produced by industry, only some of them can be used as additives and binding base for production of heat-insulating building materials, the properties of which must meet the established requirements.

The criteria for selection of polymers for production of building insulation materials have been developed as a result of long-lasting practice. They must be inert, resistant to oxidizing agents, durable, have high adhesive properties and provide a firm binding between polymer and other components of mixture, be low toxic or non-toxic, and resistant to light, water, frost, fire, and biodegradation.

Organosilicon compounds (OSC) possess such properties, as they are able to penetrate deeply into the pores of organic and inorganic components of mixtures in the molten state. They provide stronger enveloping and adhesion of particles of heat-insulating mixtures (HIM) with formation of single agglomerates. During operation these agglomerates are characterized by high inertness to chemical and physical changes in the environment, including interactions with water, that is, they must be hydrophobic. It was established that OSC after heat treatment form a developed porous structure and have low thermal conductivity, low specific density while maintaining the strength characteristics of composite.

It is also known that adhesion and cohesion characteristics of individual OSCs and their mixtures vary widely. For example, equal amounts (10%) of solution of polymethylphenylsiloxane (PMPS) with molecular weight of 4500 and polymethylsilosane (PMS) individually have significantly less enveloping and strengthening effects in comparison with that of their

* Corresponding author: karpov_denis_85@mail.ru

mixtures with the following composition: 1.3 PBW of PMPS: 2 PBW of PMS.

The literature analysis shows that composite mixtures based on wood, cement, gypsum and HMWC are widely used for HIM production [3-5]. The mixture consists of methyl phenylsiloxane oligomer (K-9, K-47, K-42) and vinyl polymer (PVB) in a 1:1 weight ratio to which polymethylsilazane organosilic resin (MSN-7) is added and put in a solid wood-peat mixture. In this case, the mass ratio between the components is maintained: double mixture of K-9 and PVB is 30%; organosilicon resin MSN-7 is 70%. The high-molecular-weight mixture has good antiseptic properties; it protects the material from destruction by ultraviolet radiation, hydrophobizes the surface, increases the resistance of materials to fire, temperature changes, and humidity. It is also used for wood restoration. According to the HIM manufacturing technique, high-molecular-weight compounds are added to composite consisting of wood, cement and gypsum, thoroughly mixed and heat treated. After such treatment, one obtains a heat-insulating composite with high strength characteristics and gas permeability, but with high thermal conductivity. It is known that addition of peat to the initial mixture helps to reduce the thermal conductivity. However, the resulting composite is highly toxic when used in wet conditions, which is its significant drawback.

In this regard, the aim of this work is to develop a new composition of the heat-insulating mixture based on peat, sawdust, gypsum and a mixture of organosilicon polymers and oligomers for the production of heat-insulating materials with improved heat-insulating and environmental characteristics.

To achieve this goal, the following tasks were solved:
1. To experimentally determine the composition of heat-insulating mixture, which provides high mechanical strength of composite, low thermal conductivity and specific gravity.
2. To produce samples of heat-insulating material from the specified mixture in laboratory conditions, and to select the temperature regime for structure formation of material.
3. To determine the main characteristics of the obtained laboratory samples of HIM: mechanical compressive strength, density, thermal conductivity, toxicity.

2 Materials and methods

The object of research is a new composition of the composite mixture, providing production of HIM with improved properties. The subject of the study is the technology for obtaining new types of composite construction materials.

During the experiment, the modern methods of analysis were used: gravimetric, titrometric, ionometric.

Drying of the finished mixture was carried out in a muffle furnace SNOL-7-2/1100. The heat conductivity coefficient was determined by the stationary heat flux method in accordance with the Russian State Standard GOST 7076-99 [6]. The toxicity was determined by biotesting using the Paramecium caudatum and Tetrahymena pyriformis ciliates using the BioLaT device [7]. Setting rates were determined using the Vicat apparatus.

The patent search shows that low-lying peat is mainly used in production of heat-insulating boards. Low-lying peat, unlike high-lying peat, is characterized by a high content of mineral substances, which are similar in composition to Portland cement minerals. This provides higher adhesion to other components of mixture, for example to sawdust and contributes to a quick hardening process under normal conditions. In addition, low-lying peat has lower hygroscopicity and water absorption compared to that of high-lying peat. However, these factors do not exclude the possibility of using high-lying peat for HIM production, if organic binders are introduced into the HIM composition, which simultaneously function as hydrophobic substances and have high binding properties.

Despite the large reserves of high-lying peat, it is unclaimed in industry. So, alternatively to the known existing mixtures for HIM production, in this work we used high-lying peat from peat bogs in the Vologda Oblast of the Totemsky District with the 10-15% degree of decomposition and the initial moisture content of 18-25%. The model samples belong to sphagnum-sedge peat according to their species composition.

The chemical characteristics of high-lying peat (ash content, organic matter content) were determined by combustion in laboratory conditions in accordance with standard procedures of the Russian State Standard GOST 27784-88 [8] and the Russian State Standard GOST 26213-91 [9]. Samples were calcined in a muffle furnace at a temperature of 350-400 °C. The resulting solid precipitate was weighed on analytical balance and the ash content was calculated according to the following expression (1):

$$A = ((m - m_1)/m_2)\cdot 100,\ \%, \qquad (1)$$

where A is the ash content, %; m is the mass of crucible with ash residue, g; m_1 is the mass of the empty crucible, g; m_2 is the mass of dry soil, g.

The content of organic substances was determined from ash-content according to formula (2):

$$X = (100 - A), \qquad (1)$$

where A is the ash content, %.

3 Results

To obtain reliable results, the ash-content and the content of organic substances were determined for six peat samples taken from one field. The chemical characteristics of peat from Totemsky District of the Vologda region are presented in Table 1.

The performed analysis shows that peat is poorly decomposed and therefore can perform a reinforcing function.

In a humid environment at a temperature of 50-60 °C, a process of partial hydrolysis and destruction of components of high-lying peat occurs with formation of

Table 1. Chemical characteristics of the high-lying peat of the Totemsky District.

Sample No.	Field	Peat type	Peat kind	Moisture, W,%	Ash-content, %	Content of organic substances, %	pH
1	Totemsky	High-lying	Sphagnum	17.87	4.12	95.88	5.4
2				17.94	4.09	95.91	5.3
3				17.94	4.08	95.92	5.4
4				17.89	4.11	95.89	5.4
5				17.91	4.09	95.91	5.4
6				17.92	4.12	95.88	5.3

resinous components that envelop the particles of aggregates: sawdust, gypsum.

Unlike the existing methods for obtaining the mixture, the initial peat was pre-moistened by treating the peat with steam at a temperature of 95-105 °C to a humidity of 80%. The amount of water introduced into peat when moistened with steam is sufficient for the primary setting processes of gypsum and eliminates the side processes of leaching and decomposition of humic substances, which prevents the corrosion destruction of building materials. For full setting, an additional portion of water must be added to HIM, the content of which should not exceed 5% of the total mass of HIM. After wetting, some part of peat was ground in a ball mill, another part was left without grinding, and at the same time two groups of mixtures with dispersed peat and peat with a preserved natural structure were prepared.

At the next stage, the treated peat was mixed with sawdust, the moisture content of which is 30-35%, and gypsum was added. Then it was mixed thoroughly and a small amount of water not exceeding 5% by weight of gypsum was added to the mixture. With constant stirring, a three-component composition consisting of polymers K-9; PVB; MSN-7 was added to the mixture. The compositions of the initial composite mixture for the production of HIM are presented in Table 2.

After mixing, the mixture is molded in cubes of 10x10x10 cm. Then it is subjected to heat treatment with a gradual increase in temperature up to 105 °C for 2 hours to form a more ordered structure and to prevent shrinkage, warping, and cracking. After the specified period of time, the temperature is raised to 160-200 °C and the cubes are matured at this temperature interval for 90-120 minutes. After cooling, the samples are tested in laboratory conditions to determine the average density, compressive strength, thermal conductivity, and toxicity. The results of studies are presented in table 3.

The analysis of results shows that upon the application of dispersing high-lying peat while maintaining the initial mixture composition, the compressive strength, the average density of the composite material, and the thermal conductivity coefficient increase.

The results of compressive strength measurements are presented in **fig. 1**.

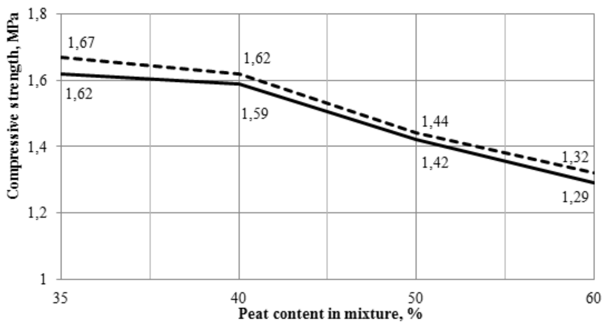

Fig. 1. Relationship between compressive strength and the degree of peat dispersing.

The dashed line in fig. 1 presents the dispersed peat, while solid line is used for peat with a preserved natural structure. The obtained data indicate that with decreasing peat content, the compressive strength increases. Maximum strength is typical for samples with peat content of 35%.in the composite mixture

The established dependence between the average HIM density and the degree of peat dispersion and the chemical composition of the initial mixture is presented in **fig. 2**.

Table 2. The composition of the initial composite mixture for HIM production.

Sample No.	The initial mixture composition					
	Non-dispersed peat, %	Dispersed peat, %	Sawdust, %	Gypsum, %	Water, %	Three-component polymer, %
1	35	-	25	20	5	15
2	40	-	25	15	5	15
3	50	-	20	10	5	15
4	60	-	15	5	5	15
5	-	35	25	20	5	15
6	-	40	25	15	5	15
7	-	50	20	10	5	15
8	-	60	15	5	5	15

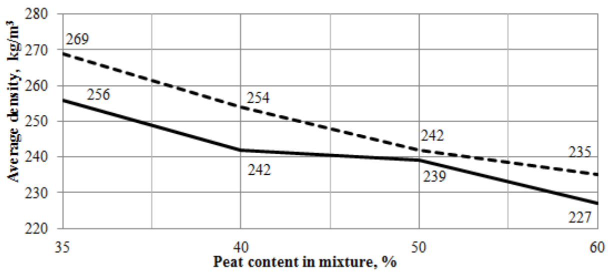

Fig. 2. Relationship between the average HIM density, the degree of peat dispersion and the chemical composition of the initial mixture.

The dashed line in **fig. 2** presents the dispersed peat, while solid line is used for peat with a preserved natural structure. The analysis of results shows that with an increase in the degree of dispersion, an increase in the average density of samples is observed from 1.24 to 5%, depending on the chemical composition of the composite mixture. With an increase in peat content from 35 to 60%, the average density of samples decreases from 269 to 235 kg/m^3 for dispersed peat, from 256 to 227 kg/m^3 for peat with a preserved natural structure. The minimum average density is typical for samples containing 60% of peat in the initial composite mixture.

Under laboratory conditions, the thermal conductivity was determined using the stationary heat flux method. The measured values are presented in **fig. 3**.

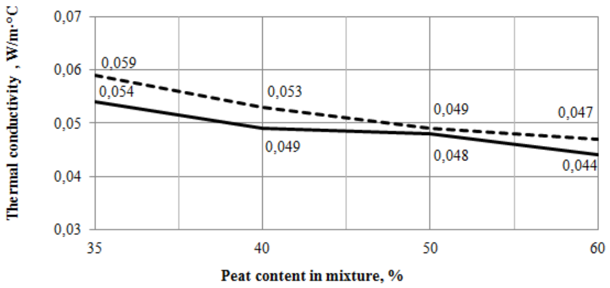

Fig. 3. Relationship between the thermal conductivity and the degree of peat dispersion.

The dashed line in **fig. 3** presents the dispersed peat, while solid line is used for peat with a preserved natural structure. The results indicate that the minimum thermal conductivity of 0.044 (W/m·°C) is typical for samples containing peat without dispersion. With an increase in peat content from 35 to 60%, the thermal conductivity coefficient decreases from 0.059 to 0.047 (W/m·°C) for dispersed peat and from 0.054 to 0.044 (W/m·°C) for peat with a preserved natural structure.

Thus, a composite based on peat with a preserved natural structure, is characterized by other consumer characteristics: lower thermal conductivity, average density, and mechanical strength, which is a drawback. With an increase in peat content from 35 to 60%, a decrease in the average density of composite and thermal conductivity is observed and it is a common pattern. However, tests of samples to determine compressive strength indicate a decrease in this important indicator with an increase of peat content in mixture, which therefore reduces the quality of HIM.

4 Discussion

It was experimentally established that the qualitative characteristics of heat-insulating materials depend on the content of sawdust. With an increase in the content of sawdust from 15 to 25%, the compressive strength, the average material density, and the thermal conductivity increase.

An increase in the gypsum content from 5 to 20% contributes to an increase in compressive strength from 1.29 to 1.62 MPa for peat with a preserved natural structure and from 1.32 to 1.67 MPa for dispersed peat. But this also increases the average material density, as well as the thermal conductivity, which reduces the composite quality.

The optimal amount of the introduced three-component polymer was established in laboratory conditions using the model samples, which should be 15% by weight of the initial mixture. When the resin content is reduced to 10%, cracking occurs during compression, i.e., the brittleness increases. With a decrease in resin content, the brittleness increases for all samples.

When the resin content exceeds 15%, a glassy layer forms on the surface during heat treatment, and it makes the material airtight. So, in a humid environment, when the temperature decreases, condensation forms on the surface of insulating boards.

Thus, the analysis of experimental data indicates that the preliminary mechanical treatment of peat and the chemical composition of initial mixture affects the quality of HIM. Grinding of peat contributes to an increase in mechanical strength, but at the same time, the thermal conductivity and average density increase, which is a drawback. An increase in peat content in the composite reduces mechanical strength, thermal conductivity and average density.

The relationship between the qualitative characteristics of peat and the heat treatment characteristics was established experimentally. A sharp increase in temperature to 105 °C causes an increase in internal stress of the composite structure and subsequent cracking. Therefore, it is recommended to carry out a slow temperature increase to 105 °C for two hours, followed by heating to 160-200 °C and heat treatment at the indicated temperature range for 2 hours. By raising the temperature to 160-200 °C, a more homogeneous structure is formed with greater compressive strength, and lower thermal conductivity. Without heat treatment, samples were obtained with lower mechanical strength in different directions, but with higher thermal conductivity.

At the last stage of the study, toxicity thresholds were determined for the obtained samples. The samples were kept in distilled water for one month. After exposure, the aqueous solution was placed in Biolat cuvettes and toxicity was determined. The results show that all the obtained samples are non-toxic.

 https://doi.org/10.1051/e3sconf/202016101037

5 Conclusions

Thus, based on the experimental data, the following conclusions can be drawn:
1. HIM model samples based on peat, sawdust, gypsum, and a mixture of organosilicon polymers and oligomers were obtained in laboratory conditions.
2. The optimal composition of HIM was experimentally selected, and it ensures consumer properties of the composite that meet the requirements of the Russian State Standard GOST.
3. The relationship between the consumer properties of peat and the degree of its grinding (dispersion) is established. With an increase in the degree of peat dispersion, prismatic strength increases, but the thermal conductivity increases.
4. Replacing an organic binder with a mixture containing organosilicon compounds helps to improve the HIM quality.

Thus, the new composition for HIM production, subject to the technological conditions for its processing, allows one to obtain a new environmentally friendly, moisture-resistant HIM composite with indicators corresponding to those of the Russian State Standard GOST.

References

[1] V.I. Suvorov, N.L. Soloviev, K.L. Shakhmatov, Thermal insulation mass, Applicant and patent holder, Patent 2333173 Russian Federation, MPK S 04 V 26/00, Tver State Technical University, 2006129082/03; declared 10.08.2006, publ. 10.09.2008, bull. no. 5.
[2] N.O. Kopanitsa, A.I. Kudyakov, M.A. Kalashnikov, Thermal insulation composition for the production of building materials based on peat, Applicant and patent holder,Patent 2393128 Russian Federation, MPK$^{(51)}$ S 04 V 26/00, TGASU, 2008101233/03; declared 20.07.2009; publ. 27.07.2009, bull. no. 18.
[3] N.O. Kopanitsa, A.I. Kudyakov, M.A. Kalashnikov, Peat-wood composition for producing construction insulating materials, Applicant and patent holder, Patent. 2307813 Russian Federation, MPK$^{(51)}$ S 04V 38/00, TGASU, 2005130585/03; declared 03.10.2005; publ. 10.10.2007, bull. no. 28.
[4] O.A. Medvedev, L.B. Khoroshavin, V.S. Rudnov, et al., Peat-polymer mixture for producing heat-insulating products with increased fire resistance, Applicant and patent holder, Patent 2513801 Russian Federation, MPK$^{(51)}$ S 04 V 26/00, All-Russian Research Institute for Civil Defense and Emergencies EMERCOM of Russia, 2012147661/03; declared 09.11.2012; publ. 20.04.2014, bull. no. 11.
[5] A.I. Kudyakov, L.A. Anikanova, L.N. Pimenova, et al., Heat-insulating composite material, Applicant and patent holder, Patent2409529 Russian Federation, MPK$^{(51)}$ S 04 V 28/14, TGASU, 2009122275/03; declared 10.06.2009; publ. 20.01.2011, bull. no. 2.
[6] The Russian State Standard GOST 7076-99, Method for determination of thermal conductivity and thermal resistance under stationary thermal conditions, Standards Publishing House (2000).
[7] O.V. Lisovitskaya, V.A. Terekhova, Phytotesting: basic approaches, problems of the laboratory method and modern solutions, Reports on ecological soil science, **3**, 1-18 (2010).
[8] The Russian State Standard GOST 27784-88, Soils, Method for determination the ash content of peat and peat soil horizons, Standards Publishing House (1988).
[9] The Russian State Standard GOST 26213-91, Soil, Methods for determination of organic matter, Standards Publishing House (1992).