Thermo-mechanical properties of perlite composite

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Abstract.
Currently, perlite is used in the insulation of facades, roofs, ceilings, based on perlite, heat-insulating plasters, masonry mortars and even adhesive compositions are produced. However, practically not used as a monolithic-structural material. Expanding the production of heat-insulating perlite materials for various purposes inevitably will be allow to reduce heat loss and high cost of fuel. Perlite materials can improve the physical properties of existing structures. A significant advantage of the use of perlite as a heater is a reduction in fire hazard and an increase in the fire resistance of building structures.
The article presents the results of a study of the monolithic heat-insulating material based on expanded perlite of deposit «Fogosh» (Zakarpatski region, Ukraine) and liquid silicate sodium glass. The basic thermal, mechanical properties and structures of this material and compliance with the standard are investigated. In this article describe complex of properties new thermal insulation material that have: ρ=219 kg/m3, λ= 0,087 W/(m K), σ_c=9,1 MPa.
It is established that the investigated perlite composite according to its strength and thermal conductivity characteristics can be recommended as thermal insulation and structural material for thermal power equipment isolation.

Keywords: Expanded perlite, Composite of perlite, Liquid glass, Thermal Insulation, Water absorption, Thermal conductivity

1 Introduction

Perlite is widely used as loose-fill insulation, especially in masonry construction, because of the following qualities that make it desirable: low toxicity. According to the Perlite Institute, «No test result or information indicates that perlite poses any health risk» Other insulators, such as asbestos, vermiculite (which may contain asbestos), and fiberglass are more hazardous; chemical inertness, meaning it will not corrode piping, electrical or communications conduits. Perlite has a pH of around 7, which is similar to fresh water; pliability.

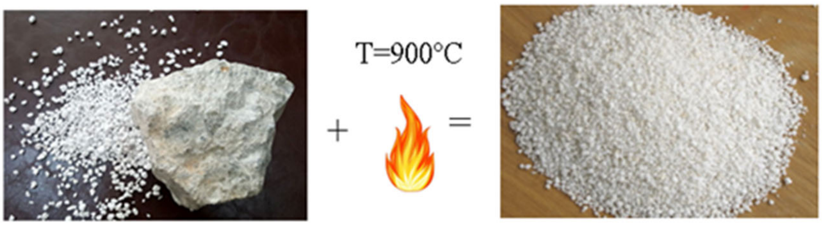


Fig. 1. Perlite ore and expanded perlite. Perlite has a bulk density around 1100 kg/m^3, while typical expanded perlite has a bulk density of about 30–150 kg/m^3

Rapidly heating perlite ore (Fig.1) to temperatures of about 900°C (1,700°F) so ends the volcanic glass causing entrapped water molecules in the rock to turn to steam and expand the particles like popcorn.

The leader in the production of expanded perlite and its products is the USA, where about 7 million m^3 of this product is produced every year. Until 2005, the leadership in this area belonged to Greece, and major manufacturers in the market are Japan and China too.

Since 1960, the Fogosh perlite deposit (Transcarpathian region) has been operating in Ukraine, with reserves of 13,4 million tonnes. The Transcarpathian deposit is known not only in Ukraine but also far beyond its borders. In Ukraine, perlite is mainly used as backfill in pure form and about 30% in the production of dry cement mortar or gypsum binder by «Knauf Gypsum», «SMS-Knauf» (Moldova), «Henkel», «Artel». The analysis of foreign and domestic experience in the use of expanded perlite shows that in addition to the traditional spheres of application of this material, known both in Ukraine and abroad, new directions have emerged and are under development [1–5].

In particular, syntactic foams filled with metal matrix perlite (MMSF) are widely explored as new materials. They have great potential in energy absorption products [1], and since MMSFs are durable, lightweight, and flame retardant, they can be used as structural materials, such as lightweight cores for panels and pipes.

These foams are a good substitute for conventional metal foams because they have a low density (0,75-1,1 g/cm^3) and high energy absorption efficiency [6-8].

2 Literature review

In the course of the research, scientific articles of such scientists as G.M. Samadova, Ur. Usmanova, S.V. Bukharov [1-3], whose works investigated the thermal insulation properties of materials based on perlite. In the last decade in the world have been developed and passed all the necessary environmental and fire tests such thermal insulation materials on the basis of perlite, such as lignoperlite, epsoperlite, thermoperlite and perlitodiatomite [2-5, 10]. The vast majority of patented monolithic composites are filled with perlite based on mineral powdered binders [12-16]. There is a rather limited volume of published works devoted to the study of monolithic thermal insulation materials based on perlite with other types of binders, and there is practically no information on the study of perlite from Ukrainian deposits, which have their unique chemical composition and properties.

On the basis of the above, it is possible to formulate the task of the study, which is to determine the optimal composition, the method of formation of monolithic materials filled with perlite and to establish the relationship between composition, method of manufacture and physical and mechanical properties.

3 Research methodology

Experiments on the development of the optimal composition of the material were carried out using a second-order simplex lattice plan (Shaffe). The standard physical and mechanical parameters for thermal insulation materials according to DSTU 17177-94 were determined as initial values: Y1 - material density, ρ, kg / m^3; Y2 - strain compression strength [$\sigma_{st.}$], MPa; Y3 is the coefficient of thermal conductivity. Variation factors in the experiment were (in terms of 1 m^3 of finished material): X1 - the amount of filler in a completely dry state, kg; X2 is the amount of binder,% of X1; X3 is the amount of plasticizer,% of X1. The optimal composition was considered that, in which the minimum density and thermal conductivity were reached with satisfactory values of physical and mechanical properties. The optimization problem can be formulated as follows: it is necessary to find in the range of permissible values of factors Ω those values for which the initial parameters take the minimum or maximum values.

Studies of compressive strength and bending were performed by known methods of study of building materials. According to the experimental data of the destructive force, calculated the ultimate compressive strength of formula (1) and the flexural strength of formula (2):

$$\sigma_c = \frac{P_{max}}{S}, \quad (1)$$

where P – is the destructive force, kg; S – is the sample area, cm^2.

$$\sigma_A = \frac{3P_{max}*l}{2b*h^2}, \quad (2)$$

where P – is the destructive force, Pa; l – is the distance between the supports, cm; b, h – is the width and thickness of the specimen, cm.

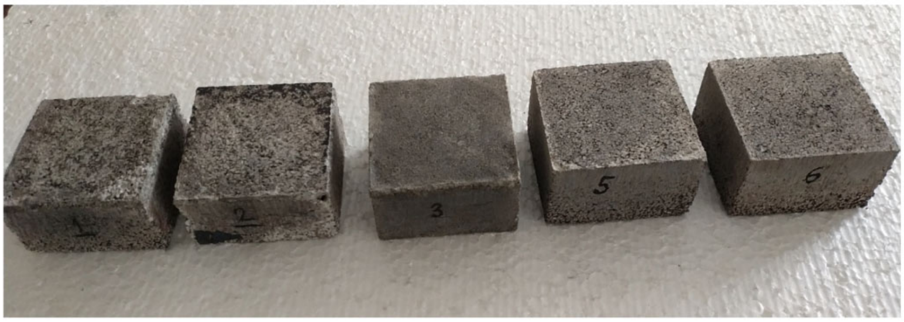
Surveys of the state of the surface were carried out using an optical digital microscope LEICA DMS300. The microstructure of thermoperlite specimens was examined using a SEM Hitachi TM3000 scanning electron microscope.

4 Results

For the preparation of the compositions were used: perlite fraction of 1,8…2,2 mm, which was obtained with using laboratory sieves, liquid silicate sodium glass DSTU 13078-81 and plasticizer. The components were added in the following order: firstly, the plasticizer was mixed and then the binder was gradually mixed mechanically with perlite. The samples were formed in the metal forms (they are shown in Fig.2), further, the compositions were compressed and sintered in the temperature range from 600 to 800 °C for 1-2 hours.

The samples were examined for water absorption of the material (according to DSTU 14457) is to measure the mass of water absorbed by the sample of dry material, partially immersed in water for a given time [10].

The sample was placed in a tub on a mesh stand and fixed with a mesh load. Then it was poured into the bath water at a temperature of 22 ºC , so that the water level was higher than the loader by 20…40 mm. After 24 hours after pouring water, the sample was transferred to a stand and weighed on a dry pallet after 30 seconds. The mass of water leaking from the sample during weighing into the pallet was included in the mass of the water-saturated sample.



a)

b)

Fig. 2. General view of molds (a) and specimens of sintered thermal perlite (b).

As a result of mathematical planning, optimal composition ratios were obtained for 5 compositions whose properties were investigated empirically. The average values of the specific density of the different compositions are shown in table 2.

Table 1. The average values of the specific density of the different compositions.

compositions	1	2	3	4	5
ρ, kg/m^3	188	204	219	326	458

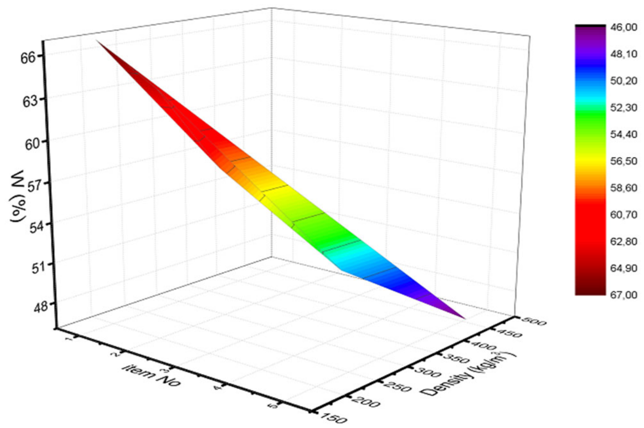


Fig. 3. Dependence of change of water absorption coefficient for different compositions on specific density.

On a Fig.3 shows the results of measuring water absorption by weight. Comparing the results, that were reported in [10], it can be observed that water absorption decreased on average by 20%. This is due to the decrease in the number of open pores, possibly due to pressing and sintering at temperatures up to 800 °C, but the adsorption of water by perlite is still quite high and the material absorbs a lot of water up to 68%. Therefore, for products where possible contact with water, the material requires hydrophobization of the surface layer, which will significantly reduce the water absorption.

So in Fig. 4 it can be seen visually that the number of surface pores increases with the decrease in the amount of binder from composition №5 to №1. Inclusions of dark color are particles of graphite powder, which was used as a non-stick layer in metallic forms.

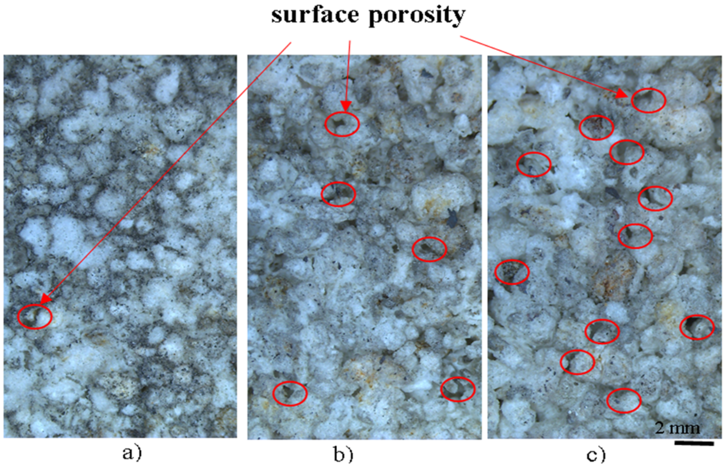


Fig. 4. Surface porosity of compositions: a - №5; b - №3; c - №1, x 3.2

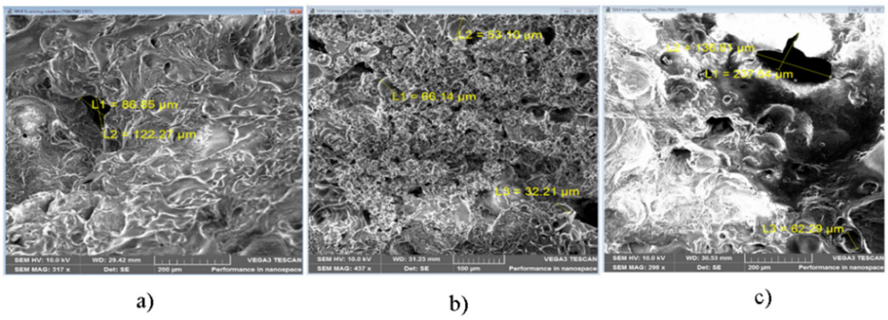


Fig. 5. SEM microstructure of the fracture surface of thermoperlite compositions: a-№5; b-№3; c-№1

The results of electron microscopy are shown in Fig. 5, it can be seen that all the composite samples have a uniform structure and evenly distributed perlite particles in the matrix.

However, cavities are observed in compositions №1 and №3, as shown in Fig.5 (b, c). Obviously, this was due to insufficient binder being insufficient to completely wet the filler, as a result of cavities of up to 400 μm in size. Accordingly, such cavity dimensions are stress concentrators and significantly weaken the matrix, which correlates well with the results of the mechanical characteristics study [11]. In sample №3, the pores on the border of the filler matrix are smaller and more evenly distributed across the cross section of the sample. Sample №5 contains the least amount of defects due to its high liquid glass content and extrusion. Further studies are needed to establish a relationship between seal pressure and pore number.

According to the results of the strength study (Fig. 6), with increasing binder content, the composite strength is almost linearly increased, which provides the matrix and the formation of strong interphrase bonds between the matrix and the filler. All compositions have sufficient strength not only as thermal insulation lining material but also as structural material. In particular, the composition №5 withstands the load corresponding to the strength of the brick brand M-150.

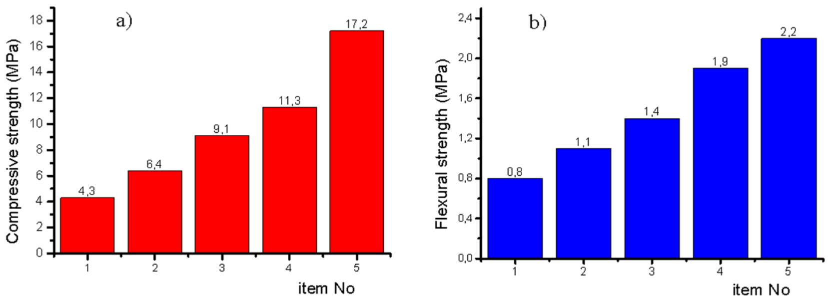


Fig. 6. Dependence of change of compressive strength (a) and flexural strength (b) for different compositions.

Determination of thermal conductivity was carried out by the method of simulation. The sample is placed between the heater and the cooling medium, as shown in Fig 7.

The heat flow from the heater II through the test samples and the discharge flows through the refrigerator III with water. The refrigerator is a container with spiral grooves, which creates the circulation of cooling water, which provides the same temperature on the cooled surfaces of the samples. To reduce heat loss through the face surfaces of the specimens into the environment, a heat-insulating casing I extruded with expanded polystyrene is provided.

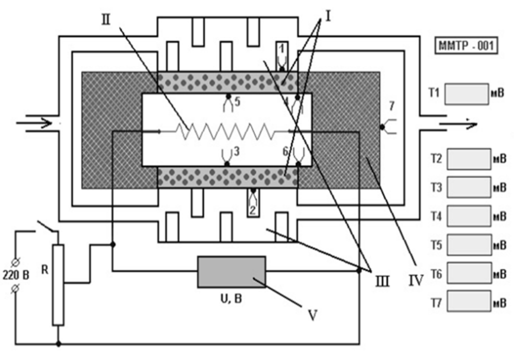


Fig. 7. Experimental setup for determining thermal conductivity (1,2,3,4,5,6,7 - thermocouple junctions)

Hot junctions 1 and 2 thermocouples are located on the outer surface (cooled), hot junctions 3 to 6 thermocouples are located on the inner surface (heated) of the sample, hot junction 7 thermocouple is installed on the outer surface of the insulating casing and is used to determine thermal losses through the torque the surface of the samples.

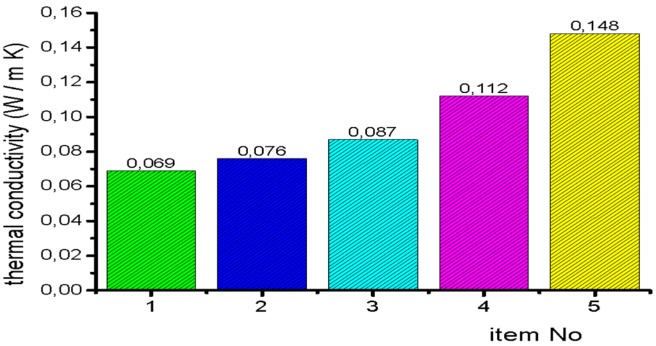


Fig. 8. The dependence of the change in the thermal conductivity coefficient for different compositions

According to research results, the coefficient of thermal conductivity increases with the increase in the composition of the proportion of liquid glass, which is logical because not only is the decrease in the amount of perlite in the composition which provides low thermal conductivity, but also the decrease in the number of internal air pores, which is consistent with the increase in the specific density of the samples. The obtained thermophysical properties of the compositions are provided with the appropriate composition of the components, the method of molding and the sintering mode.

5 Conclusions

The article focuses on the development of the optimum composition of a new composite material based on perlite for the manufacture of thermal insulation structures. According to the results of mathematical planning, the optimal ratios were determined for 5 compositions based on perlite and binder liquid glass. However, not all samples have been tested for water absorption and therefore require additional hydrophobization measures for use in industrial and residential construction. Specifically, specimens 4 and 5 have a density 326…458 kg/m^3 and relatively thermal conductivity 0,112…0,148 W/(m K); specimens 1 and 2 have water absorption more than 50% and not very high compressive and flexural strength. Monolithic material number 3 has the most optimal complex of properties: ρ=219 kg/m^3, λ= 0,087 W/(m K), σ_c=9,1 MPa. Consequently, that material can be recommended as insulation material for the isolation of power and heating technological equipment with temperatures up to plus 970 K. Further studies of other characteristics of the material, namely vapor permeability, durability, frost resistance, porosity, porosity, porosity, are planned strengths and other.

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