Effective Heat-Insulating Solutions

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Abstract. The paper presents the results of the study devoted to the reduction of perlite wastesin size in a vortex jet mill, as well as their reduction features. The bonding compositions were obtained at various ratios of cement and perlitesand wastes in a vortex jet mill at different reduction modes. Peculiarities of reduction processes were studied and technological and physical-mechanical properties of obtained bonding compositions were defined. The electron microscopy made it possible to study microstructures of cement stones received from taggedPortland cement and bonding compositions in a vortex jet mill. It was established that the open pores of cement bonding compositions prepared using perlite aggregates are always filled with new growths at various stages of collective growth. The microstructure of bonding compositions has dense structure due to rationally selectedcontent, use of effective mineral aggregates, i.e. perlite wastes thus creating additional substrates for the formation of an internal microstructure of a composite, mechanochemical activation of raw mix allowing obtaining composites with prescribed properties.

1. Introduction
At present, the improvement of energy efficiency is the main priority of the energy policy of Russia. The design of an energy efficient house first of all considers the issue ofheat losses through building envelops, and only then the optimization of engineering systems, reduction of lighting costs and introduction of alternative power supply sources. Heat-insulating materials with heat conductivity being its core feature, play a crucial role in ensuringthe bestmicroclimate conditions. Currently, there is an urgent need to create heat-insulating solutions with enhanced heat-shielding performance. The purpose of this study was to reduce the density of heat-insulating solutions thus creatingefficient composite bonding agents [1-5].

2. Materials and methods
Cement CEM I 42.5H of JSC Belgorodsky Cement, expanded perlite sand M75 of JSC Oskolsnab (StaryOskol), and its production wastes– M25 polystyrene foam microspheres of LLC Teploekoservice were used for the study with the following functional additives: ASCO 93, MELMENT F 10, VINNAPAS LL 4042H. The study was based on standard tests complying with GOST10180-2012, GOST 310.4-81, GOST 7076-99 standards.

3. Main part
The content of bonding compositions (Table 1) was studied to establish the rational composition of low-density dry construction mix. The bondingcompositions were obtained in a vortex jet mill via one
to three times diversion with various content of perlite sand wastes: 5; 7.5 and 10%. For comparison, the finished Portland cement was studied at the corresponding diversion through a jet vortex mill.

Table 1 shows composition, standard consistency, setting time and stress-strain properties of bonding agents.

It is found that the standard consistency and the setting time of bonding agents depending on their composition and preparation method vary over a wide range, which, undoubtedly, will influence the formation of microstructures and their stress-strain properties.

**Table 1.** Compositions of bonding agents

| No. of composition | Standard consistency, % | Setting time, min. | Density, g/cm³ | Compression strength $R_{cm}$, MPa |
|--------------------|-------------------------|--------------------|----------------|-----------------------------------|
|                    |                         | start              |                | in 3 days                          | in 28 days                         |
| 1                  | 29                      | 169                | 2.3            | 40.1                              | 43.1                               |
| 2                  | 32                      | 124                | 2.1            | 46.3                              | 47.2                               |
| 3                  | 34                      | 101                | 2.1            | 45.5                              | 49.0                               |
| 4                  | 42                      | 78                 | 2.1            | 48.4                              | 50.1                               |
| 5                  | 51                      | 252                | 1.8            | 13.6                              | 25.8                               |
| 6                  | 41                      | 172                | 2.0            | 41.9                              | 55.6                               |
| 7                  | 44                      | 157                | 2.0            | 34.8                              | 38.1                               |
| 8                  | 45                      | 146                | 2.0            | 42.2                              | 52.0                               |
| 9                  | 63                      | 177                | 1.7            | 6.9                               | 13.2                               |
| 10                 | 44                      | 169                | 1.9            | 31.9                              | 38.0                               |
| 11                 | 45                      | 153                | 2.0            | 20.0                              | 41.8                               |
| 12                 | 46                      | 137                | 2.0            | 23.4                              | 31.6                               |
| 13                 | 65                      | 150                | 1.6            | 5.8                               | 13.2                               |
| 14                 | 45                      | 120                | 1.8            | 23.8                              | 45.5                               |
| 15                 | 46                      | 113                | 2.0            | 15.3                              | 53.3                               |
| 16                 | 47                      | 101                | 2.0            | 21.8                              | 47.8                               |

Physical and mechanical parameters of samples molded on the basis of Portland cement and bonding agent in 3 and 28 days demonstrate the steady increase of their strength after being stored in normal conditions. Nevertheless, if in case with non-triggered Portland cement the strength of samples from three-day treatment to 28 days makes not more than 8%, the strength of hydrated bonding agent has its own peculiarities. Compositions of bonding agents No. 5, 9-16 have low compression strength relative at the age of 3 days. However, by the 28th day the strength of No. 6, 8, 11, 14, 15, 16 reaches parameters similar to, and in certain cases exceeding the strength of non-triggered Portland cement. It was established through experiments that compositions No. 6, 8 and 15 are the most efficient of all obtained bonding agents with strength equal to 55.6 MPa, 52.0 MPa, 53.3 MPa respectively, which exceeds strength characteristics of initial Portland cement by 20-23%.

Thus, features of material composition of bonding agents and their activation in a jet vortex mill have favorable impact on the compression strength by increasing this indicator up to 23%.

The standard consistency and setting times of bonding agents (Table 1) were defined in compliance with the requirements of GOST 310.3-76 “Methods for determination of standard consistency, times of setting and soundness”.

The obtained results of influence of various compositions of perlite wastes, their preparation conditions in a jet vortex mill on standard consistency of bonding agents showed that the standard consistency increases with greater content of perlite wastes. The comparison of standard consistency of initial Portland cement with cements triggered in a mill from 1 to 3 times indicated that its
value increases from 10 to 44% due to increase of specific surface, which, in turn, leads to increased water demand of Portland cement.

It is noted that the standard consistency of commercial Portland cement in comparison with bonding agents with various content of perlite wastes: 5; 7.5 and 10% increases from 29 to 65%, which exceeds the standard consistency of Portland cement by 2.2 times thus justifying high water demand of compositions.

The standard consistency of bonding agents with 95% ratio of Portland cement – 5% perlite and bonding agents at a similar ratio activated in a mill from 1 to 3 times decreases from 11 to 19% with the reduction of the number of passages from 3 to 1 (Table 1).

The analysis of standard consistency of bonding agents with 92.5% ratio of Portland cement – 7.5% perlite and similar bonding agents that passed through a mill from 3 to 1 times foster the decrease in standard consistency from 21 to 27%.

The standard consistency of bonding agents with 90% ratio of Portland cement – 10% perlite and bonding agents at a similar ratio activated in a mill from 1 to 3 times decreases from 21 to 28% with further reduction in the number of passages from 3 to 1.

Thus, in the preparation of bonding agents with various content of perlite wastes it is noted that with the increase in the number of passages through a mill the standard consistency increases, which is caused by the increase in specific surface of composition and its enhanced reaction capacity.

Table 1 shows the setting time of bonding agents (compositions 1-16). It was found that the setting time of samples on the basis of Portland cement activated in a jet vortex mill from 1 to 3 passages decreases: the initial setting time decreases from 27 to 54% and the final setting from 27 to 38%. The obtained results correspond to currently available theoretical data. In case of bonding compositions not activated in a vortex jet mill with 5% perlite concentration, the initial setting time when compared to plain Portland cement, increases by 49%, and with the increase in perlite concentration of up to 7.5% and 10% it is reduced from 4% to 12%, while the final setting of these compositions increases from 50% to 60%. The increase in the number of passages through a vortex jet mill accelerates the initial setting time of bonding compositions with different concentration of perlite, which ensures reactivation of cement hydration within systems. Early setting start is typical for compositions with 12% perlite content, which demonstrates enhanced hydraulic activity of synthesized compositions. The analysis of factual findings to determine the setting time of bonding compositions provides enough reasons to make an assumption on exceptionally complex interactions within the considered systems, which, will obviously define finite physical-mechanical properties of a composite and ensure the formation of its microstructure.

Any milling facility forms the structure of a mill feed material and its certain shape to be further reflected in a composite bonding agent and in a produced composite.

The crystal phase of a cement stone obtained on the basis of activated composite bonding agent (1 passage through a mill) is presented (Figure 1a) by plate-like and hexagonal prism crystal blocks intergrown in twinning position as a result of geometric selection of growing crystals. Besides, the cement stone is also characterized by new growths representing crystals and crystalline aggregates – druses within certain stages of geometric selection of growing crystals under confined conditions. The figure shows the logging of cement stone pores with hydrated compounds and their reduction, which is critical for grouting of a stone and synthesis of its strength. The same microphotography clearly illustrates the growth of certain prismatic crystals of secondary Portlandite in the direction perpendicular to the initial surface of pore walls, which makes it possible to trace prismatic crystals formed as a result of geometric selection of growing crystals.
The microstructure of cement stones obtained from synthesized bonding agents of 5-16 compositions was studied via electron microscopy (Table 1, microstructure of 1b composition). The microstructure of certain blocks and block-like and cross-bedding structure of a cement stone was also revealed. It was found that the flakes of hydrated calcium silicate have grown together in many places throughout the entire volume, which indicates the process of secondary recrystallization caused by a silicate component, i.e. perlite sand wastes. Perlite grain-plates are observed throughout the entire volume. Active clogging of pores presented as mesh structures throughout the cleavage is registered. This process has nonuniform stages, which is caused by various mineral compositions of initial clinker grains of Portland cement and perlite wastes introduced into bonding compositions.

Electron microscopy of bonding compositions prepared using perlite aggregates showed that the first open space is filled with new growths being at various stages of collective growth and presented by single crystals or their druses. Besides, the growth of certain crystals was identified in fully overgrown pores. Mineral aggregates or perlite wastes are essential for the formation of such new growths.

The analysis of bonding agent microstructures testifies compact intergrown structure formed due to rationally selected composition, use of efficient mineral aggregates (perlite wastes) thus creating additional substrates for internal microstructure of a composite, additional activation of the raw mix allowing obtaining composites with prescribed properties.

Finally, the study of microstructures of bonding compositions and Portland cement activated in a jet vortex mill confirmed earlier obtained physical-mechanical characteristics of these bonding agents.

To ensure their further optimization the compositions were studied using the modifying additives.

The best indicators of composite bonding agents were obtained through the following dosage of additives: Melment F10 0.53% – 68.9 MPa; ASCO 93 0.04% – 58.0 MPa and 4042H 1.30% – 49.0 MPa, which determined their application in heat-insulating solutions.

The composition of low-density heat-insulating solution was developed using the obtained composite bonding agent (CB) and expanded perlite sand (PS). It was experimentally proved that it is efficient to use the ratio of CB:PS = 1:1.1.

The development of efficient compositions of dry mixes and the study of the influence of certain components building solutions obtained on their basis in technological and physical-mechanical properties were made by mathematical planning of an experiment. The best minimum consistency values (0.9 g/cm³) at the maximum strength (2.3 MPa) were obtained in the following dosage of functional additives: Melment F10 – 0.85%; ASCO 93 – 0.05%; Vinnapas 4042H – 1.1%.

Various microspheres were used to ensure further optimization of dry heat-insulating mixes. It was found that the introduction of polystyrene foam microspheres allows reducing the consistency by 82%.
Hence, this led to the production of heat-insulating solutions with consistency of 240 - 260 kg/m³, compression strength of 1.3 – 1.43 MPa, heat conductivity of 0.051 – 0.059 W/(m·°C), freeze-thaw resistance of 80-100 cycles [6-20].

4. Conclusions
The study resulted in the production of low-density heat-insulating solution with high thermal and operating performance. It was established that the proposed low-density heat-insulating solution equals or betters domestic and foreign analogs in some parameters. The developed low-density heat-insulating solution will make it possible to reduce thickness of outer thermal insulation of building walls, and therefore, to increase energy efficiency of building structures, to improve fracture resistance and durability, as well as considerably reduce building construction and operation costs.

References
[1] Zagorodnuk L.H. 2014 Composite bonding agents on the basis of organo-mineral modifier for dry mixes Bulletin of BSTU named after V.G. Shukhov vol. 5 pp. 25-31.
[2] Ilyinskaya G.G. 2012 Application of KMA wastes in the production of dry construction mixes Bulletin of BSTU named after V.G. Shukhov vol. 4 pp. 15-19.
[3] Shkarin A.V. 2012 Production of composite bonding agents in various grinding units Bulletin of BSTU named after V.G. Shukhov: Proceedings of the International Scientific Conference vol. 4 pp. 53-57.
[4] Shkarin A.V. 2012 Production of composite bonding agents in various grinding units Bulletin of BSTU named after V.G. Shukhov, Proceedings of the International Scientific Conference vol. 9 pp. 89-92.
[5] http://dv.sartpp.ru/news.php?ID=206
[6] Zagorodnuk L.H., Lesovik V.S., Shkarin A.V., Belikov D.A., Kuprina A.A. 2013 Creating Effective Insulation Solutions Taking into Account the Law of Affinity Structures in Construction Materials World Applied Sciences Journal vol. 24 (11) pp. 1496-1502.
[7] Lesovik V.S., Zagorodnuk L.H., Chulkova I.L. 2014 Law of Affinity Structures in Materials Science Fundamental Research vol. 3 pp. 267-271.
[8] Lesovik V.S., Zagorodnuk L.H., Belikov D.A., Shchyokin A.Yu., Kuprina A.A. 2014 Effective dry mixes for repair and recovery works Construction Materials vol. 7 pp. 82-85.
[9] Zagorodnuk L.H., Lesovik V.S., Belikov D.A. 2014 The issue of design of dry repair mixes taking into account the law of affinity Bulletin of the Central Regional Office of the Russian Academy of Architecture and Construction Sciences Issue 18 pp. 112-119.
[10] Zagorodnuk L.H., Lesovik V.S. 2014 Gaynutdinov R., Features of construction solutions hardening on the basis of dry materials Bulletin of the Central Regional Office of the Russian Academy of Architecture and Construction Sciences pp. 93-98.
[11] Lesovik V.S., Zagorodnuk L.H., Tolmacheva M.M., Smolikov A.A., Shekina A.Y., Shakarna M.H.I. 2014 Structure-formation of contact layers of composite materials Life Science Journal vol. 11(12p) pp. 948-953.
[12] Kuprina A.A., Lesovik V.S., Zagorodnyk L.H., Elistratkin M.Y. 2014 Anisotropy of Materials Properties of Natural and Man-Triggered Origin Research Journal of Applied Sciences vol. 9 pp. 816-819.
[13] Lesovik V.S., Chulkova I.L., Zagorodnuk L.H., Volodchenko A.A., Popov D.Y., 2014 The Role of the Law of Affinity Structures in the Construction Material Science by Performance of the Restoration Works Research Journal of Applied Sciences vol. 9(12) pp. 1100-1105.
[14] Volodchenko A.A., Lesovik V.S., Zagorodnuk L.H., Volodchenko A.N., Kuprina A.A. 2015 The control of building composite structure formation through the use of multifunctional modifiers Research Journal of Applied Sciences vol. 10(12) pp. 931-936.
[15] Volodchenko A.A., Lesovik V.S., Zagorodnuk L.H., Volodchenko A.N., Prasolova E.O. 2015 Influence Of The Inorganic Modifier Structure On Structural Composite Properties
[16] Ilyinskaya G.G., Lesovik V.S., Zagorodnuk L.H., Kolomatsky A.S. 2012 Application of KMA wastes in the production of dry construction mixes *Bulletin of BSTU named after V.G. Shukhov* vol. 4 pp. 15-19.

[17] Zagorodnuk L.H., Lesovik V.S. 2014 Increase in production efficiency of dry construction mixes. *Belgorod: BSTU publishing house* p. 548.

[18] http://dv.sartpp.ru/news.php?ID=206

[19] Belov N.V., 1978 *Chemistry and crystal chemistry of calcium silicates. V All-Union Meeting on Cement Chemistry*: abstracts. M pp. 23-29.

[20] Zagorodnuk, L.H. 2015 Increase in efficiency of dry construction mixes taking into account characteristics of a basic surface: doctoral thesis.: 05.23.05 ZagorodnukLilia Hasanovna. – *Belgorod* p. 532.