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Abstract. The paper presents the results of the study devoted tothe 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 withheat 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. Thestudy 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 cementwas 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 consistencyand the setting timeof bonding agentsdepending 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/cm^3	Compression strength$R_{сж}$, MPa	
		start	start		in3days	in 28 days
1	29	169	271	2.3	40.1	43.1
2	32	124	199	2.1	46.3	47.2
3	34	101	185	2.1	45.5	49.0
4	42	78	169	2.1	48.4	50.1
5	51	252	378	1.8	13.6	25.8
6	41	172	267	2.0	41.9	55.6
7	44	157	260	2.0	34.8	38.1
8	45	146	244	2.0	42.2	52.0
9	63	177	434	1.7	6.9	13.2
10	44	169	278	1.9	31.9	38.0
11	45	153	251	2.0	20.0	41.8
12	46	137	243	2.0	23.4	31.6
13	65	150	406	1.6	5.8	13.2
14	45	120	275	1.8	23.8	45.5
15	46	113	168	2.0	15.3	53.3
16	47	101	140	2.0	21.8	47.8

Physical and mechanical parameters of samples moldedon the basis ofPortland cementand bonding agentsin 3 and 28 daysdemonstrate the steady increase of their strength after being stored in normal conditions.Nevertheless, if in case with non-triggeredPortland cementthe strength of samples from three-day treatment to 28 daysmakes not more than 8%, the strength of hydrated bonding agentshas its own peculiarities. Compositions of bonding agents No. 5, 9-16 have low compressionstrength ratio 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 agentswith strength equal to 55.6 MPa, 52.0 MPa, 53.3 MPa respectively, which exceeds strength characteristics of initial finishedPortland cementby 20-23%.

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

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

The obtained results ofinfluence of various compositions of perlite wastes, their preparation conditions in a jet vortex mill on standard consistencyof bonding agentsshowed that the standard consistencyincreases withgreater contentofperlite wastes. The comparison ofstandard consistencyof initial Portland cementwith cements triggered in a mill from 1 to 3 times indicated that its valueincreases 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 commercialPortland cementin comparison with bonding agents with various content of perlite wastes: 5; 7.5 and 10% increases from 29 to 65%, which exceeds the standard consistencyof Portland cementby 2.2 times thus justifying high water demandof compositions.

The standard consistencyof 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 agentsthat passed through a mill from 3 to 1 times foster the decrease instandard consistencyfrom 21 to 27%.

The standard consistencyof bonding agentswith 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 passagesfrom 3 to 1.

Thus, in the preparation of bonding agents with various content of perlite wastesit is notedthat with the increase in the number of passagesthrough a mill the standard consistencyincreases, 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 ofPortland cementactivated in a jet vortex mill from 1 to 3 passagesdecreases: the initial setting time decreases from 27 to 54% and the final setting from 27 to 38%. The obtained results correspond to currently available theoreticaldata. In case of bondingcompositions not activated in a vortex jet mill with 5%perlite concentration, the initial setting time when compared toplain Portland cement, increases by 49%, and with the increase in perliteconcentrationof up to 7.5% and 10% it is reduced from 4% to 12%, while thefinal setting of these compositions increases from 50% to 60%.Theincrease in the number of passagesthrough a vortex jet mill accelerates the initial setting time of bonding compositions with different concentration of perlite, whichensuresactivation of cement hydration within systems. Early setting startis typical forcompositions 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 shapeto 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 positionas a result of geometric selection of growing crystals. Besides, the cement stone is also characterized by new growths representing crystals and crystalline aggregates – druseswithin certain stages of geometric selection of growing crystals under confined conditions. The figure shows thecloggingof acement stone poreswith 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 Portlanditein 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.

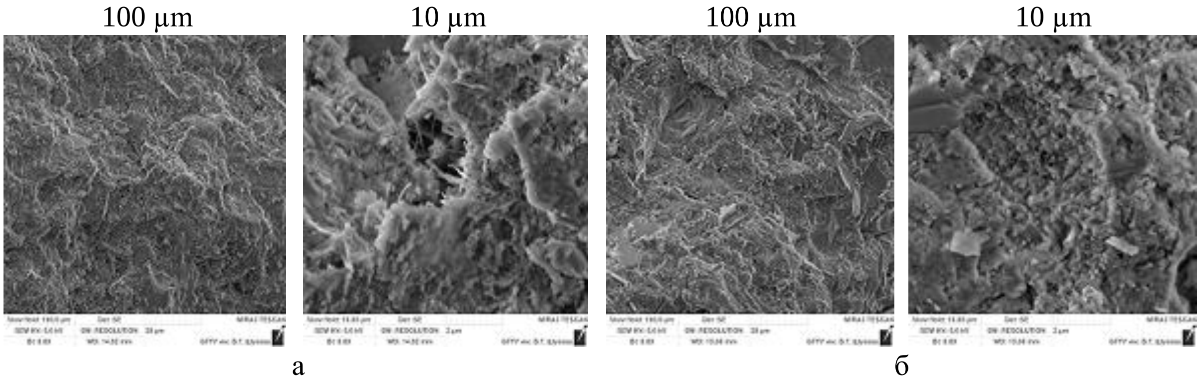

Figure 1:a) microstructure of a cement stone from Portland cementtagged in a vortex jet mill (1 pass) in 28 days; b) microstructure of a cement stone from a bonding agent with composition 6 in 28 days

The microstructure of cement stones obtained from synthesized bondingagentsof 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 wasfound that theflakes of hydrated calcium silicate have grown togetherin many places throughout the entire volume, which indicates the process of secondary recrystallization caused by a silicate component, i.e. perlite sand wastes. Perlitegrain-plates are observed through the entire volume. Active clogging of porespresented as mesh structures throughout thecleavage is registered. This process has nonuniform stages, whichis caused by various mineral compositions of initial clinker grains of Portland cementand perlitewastes introduced into bonding compositions.

Electron microscopy of bonding compositions prepared usingperliteaggregates 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, thegrowth of certaincrystalswas identified in fully overgrown pores. Mineral aggregates orperlitewastesare essential for the formation of such new growths.

The analysis of bondingagent microstructurestestifies compactintergrown structure formed due to rationally selectedcomposition, use of efficient mineral aggregates(perlitewastes) thus creating additional substrates for internal microstructure of a composite, additional activation of the raw mix allowing obtaining composites with prescribed properties.

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

To ensure their further optimization the compositionswere studied using the modifying additives.

The best indicators of composite bonding agents were obtainedthrough 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 developedusing the obtained composite bonding agent(CB) and expandedperlitesand (PS). It was experimentally proved that it is efficient to use the ratio of CB:PS =1:11.

The development of efficient compositions of dry mixes and the study of the influence of certain components building solutions obtained on their basison technological and physical-mechanical properties were madevia mathematical planning of an experiment. The best minimum consistency values (0.9 g/cm^3) at the maximum strength (2.3 MPa)were obtainedin the following dosage of functional additives: Melment F10 – 0.85%; ASCO 93 – 0.05%; Vinnapas 4042H – 1.1%.

Various microsphereswere used to ensure further optimization of dry heat-insulating mixes. It wasfound that the introduction of polystyrene foam microspheres allows reducing theconsistency by 82%.

Hence, this led to the production of heat-insulating solutions with consistency of 240 - 260 kg/m^3, 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 inthe production of low-density heat-insulating solution with high thermal and operating performance. It was established that the proposedlow-density heat-insulating solution equals or betters domestic and foreign analogs in some parameters. The developedlow-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 asto considerably reducebuilding construction and operation costs.

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