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Evaluating the Effectiveness of Producing the Activated Mineral Powders from Technogenic Raw Materials for Asphalt Mixtures

Anna Trautvain*, Valentina Yadykina, Anatoly Gridchin and Christina Pashkova

Belgorod Shukhov State Technological University, Russia, 308012, Belgorod, Kostyukova str.,46

Abstract

The article describes the grinding efficiency of siliceous raw materials in various grinding units with respect to the alteration of their surface area and the concentration of active sites on the surface. The influence of mechanical activation of dispersed materials on the physical and mechanical characteristics of asphalt concrete has been evaluated. The proportional relationship between the number of active adsorption sites on the surface of milled mineral powders and the intensity of their interaction with bitumen, strength and water resistance of asphalt concrete has been determined, which allows to recommend this index as an integral characteristic evaluation of reactivity of materials to mechanical activation.

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Keywords: Mineral powders, mill, surface area, activity, modification, anthropogenic raw materials, physical and mechanical properties, asphalt concrete

1. Introduction

Development of the Russian economy is accompanied by an increase in transport and requires a qualitative improvement of the transport complex, the important part of which are roads. The largest consumer of road transport is the agro-industrial complex, the share of traffic of which accounts for over 82.4% of cargo, which is why the organic part of the economic development of the country are the steps to the substantial increase in the volume of

* Corresponding author. Tel./fax: +7(4722)54-90-44.
E-mail address: trautvain@bk.ru

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road construction. The solution to this problem depends on the implementation of scientific and technological progress, scientific management, new high-performance machines and mechanisms, extensive use of local building materials and industrial wastes. Improving the quality of road construction materials, especially in asphalt concrete pavements is an important condition for improving the efficiency of road construction. One of the important components of asphalt concrete is a mineral powder, which is nowadays mainly produced by grinding limestone or dolomite, containing no more than 5% impurities of clay. Currently, the most important task is to use local materials as mineral aggregates and fillers for the production of asphalt concrete. However, the available raw materials often do not meet the regulatory requirements, which forces us to use various technologies of its treatment to improve the quality of the finished product.

2. The analysis of publications

There are numerous technological and scientific research works [1-8] of mechano-chemical effects. Moreover, in [9] the possibility of a fairly active interaction of acidic mineral materials surface (due to the presence of active adsorption sites on it) with the molecules of organic substances, contained in an organic binder, has been substantiated. However, there are no clearly established criteria for the targeted application of mechanical and chemical technologies in the industry yet. In some cases, the practical use of mechanical activation in production is rather a natural consequence of the evolution of the dispersion process than the conscious inclusion of it into the flow chart. This is because the dispersion process leads to the same technological results, as does the mechano-chemical activation, occurring in the same grinding process. Moreover, the methods of measuring the quality of mixing and dispersion, in contrast to the methods measuring activity, have been well developed and have become commonplace.

Mechanical activation of raw materials in the mills is a common process. However, the mechanical and physical processes, occurring in such devices, are still a subject of numerous studies [10-15]. Most of these works are focused on optimizing the grinding process - a process in which the aim is to maximize the specific surface of the solid substance with the minimum energy consumption. The studies devoted to machines for the mechanical activation are significantly much fewer.

Based on the above, it was of interest to study the effect of changes of a mineral powder's characteristics, which occur during its grinding in various grinding units.

The work was performed as a part of competition in 2014 projects oriented basic research on interdisciplinary topics, conducted jointly by the Russian Foundation for Basic Research (RFBR) and the Government of the Belgorod region under contract number 14-41-08027 NC / 14, as well as the state task of Ministry of Education and Science of the Russian Federation №1950.

3. Purpose and problem statement

The purpose of work is to determine the nature of the influence of mechanical activation in different grinding units on the reactivity of dispersed silica-containing materials.

To achieve this goal the following tasks were set:

- to investigate the interaction of mechanically activated mineral powders with bitumen and to develop the effective asphalt compositions using them;
- to assess the influence of mechanical activation of dispersed materials on the physical and mechanical properties of asphalt concrete.

4. Investigation of reactivity of mineral powders at grinding

The mineral powders for building materials are typically obtained by grinding, and only a small percentage of raw materials can be used in its original form, therefore it is of considerable interest to obtain the most reactive fillers at grinding these materials in different mills.

One of the main parameters, affecting the efficiency of grinding and differing mills from each other, is a method

of exposure of the material to the grinding media: crush (compression), break (bending), splitting (equivalent to stretching), abrasion and impact.

Therefore, it can be assumed that the principle of grinding materials in various mills may affect the fineness of grinding, particle size distribution, shape and roughness of particles' surface, concentration of active sites and the amount of the amorphous phase of produced mineral powders (Fig. 1).

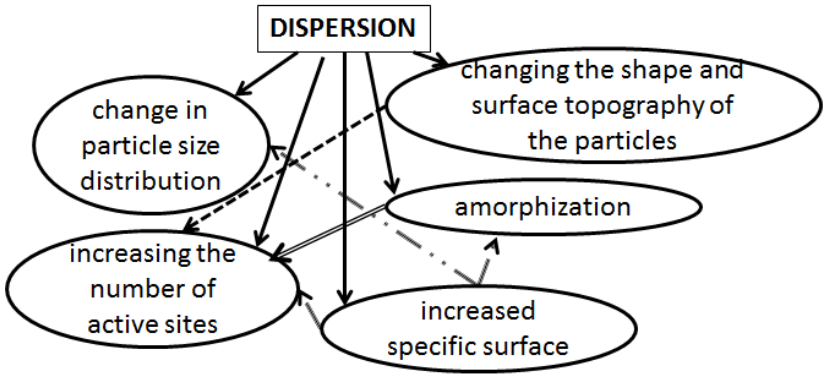

Fig. 1. Basic parameters, characterizing the reactivity of powders at grinding

Essentially, grinding is the formation of new surfaces. Various solid materials, depending on their physical properties, while being ground in the similar conditions with the same amount of energy consumption, give products characterized by various degrees of reactivity and dispersibility.

As the object of research, we have used dispersed technogenic raw materials of Kursk Magnetic Anomaly (KMA) from quartz sandstone and the waste of wet magnetic separation of ferruginous quartz sandstone (WMS). For comparison there were taken quartz sand and screenings of granite crushing. The particle size of the dispersed raw material did not exceed 1.25 mm. The grinding process was carried out in seven grinding units: four laboratory mills (ball mill, planetary ball mill, vibration mill, vibration attritor) and three industrial mills (ball mill, counter jet mill, centrifugal grinding-mixing unit (CGMU)).

When carrying out this work, a number of up-to-date research methods were used. The specific surface area was investigated by the device of «Tovarov» and by method of the Brunauer-Emmett-Teller. The particle size analysis of the particles' distribution was carried out by a Microsizer laser particle analyzer. The activity of the materials' surface was characterized by the number of Bronsted acid sites, which were determined by titration.

The activating ability of grinding units was assessed by changes of the concentration of acid Bronsted sites on the surface because, according to the up-to-date research in the field of surface chemistry and building materials science, they have the most significant influence on the interaction with the binders.

Studies, carried out by using a Microsizer laser particle analyzer, showed that powders milled in a planetary ball mill, ball mill, vibratory mill and centrifugal grinding-mixing unit, have rather a wide range of particle distribution, and the observed highs and lows were recorded in the areas similar to each other. As for the fine-ground fillers milled in a vibratory attritor, they show a high content of particles in the range of 18.2 to 75 microns, and as for those milled in a counter jet mill – in the range from 1.64 to 12.2 microns.

Thus, the materials crushed in a counter jet mill and in a vibration attritor, which implement basically only one modality on the grinding bodies' effect on the material (impact or abrasion respectively), are characterized by rather a narrow particle size range.

In studies [16-20] it was demonstrated that powders milled in a planetary ball mill, ball mill, vibratory mill and centrifugal grinding-mixing unit, have rather a wide range of particle distribution. Materials, ground in a counter-jet mill and vibrating attritor, which mostly implement only one type of impact of the grinding media on the material (impact and abrasion respectively) are characterized by rather a narrow particle size range.

It has been found out that the grinding of silica raw stuff occurs in different ways. The highest grindability is shown by WMS waste and quartz sandstone ground in a centrifugal grinding-mixing unit and in a planetary ball mill and the lowest grindability is demonstrated by quartz sand and granite, ground in a vibratory ball mill and in an attritor.

The analysis of milling equipment has shown that the highest activating ability is possessed by planetary ball mill and jet mill, which implement the principle of impact crushing. As a result of grinding in these mills, the concentration of proton-donor sites increases in the range from 4.4 to 2.1 times. The lowest activating ability is shown by vibrating attritor and ball mill. The increase of activity when grinding materials in them amounts to 2.4-1.6 times. As for the test materials, the highest concentration of active sites on the surface is shown by WMS waste ground in a planetary ball mill (79 mc-eqv/g), and the minimum concentration is observed when milling quartz sand in a vibratory attritor (23 mc-eqv/g).

The intensity of the interaction between mineral materials and organic binder is an essential element of structure formation in asphalt concrete.

The effectiveness of using the mechanically activated mineral powders in asphalt mixtures was evaluated on the basis of physical and mechanical properties of asphalt concrete samples, in which a decisive influence on the composite's quality is conditioned by the characteristics of dispersed materials.

It was found out that the quality of asphalt concrete made of activated mineral powders improves significantly. The highest growth of the asphalt concrete performance was observed when using mineral powder made of WMS waste, ground in a planetary ball mill, as the activity increase of the freshly ground filler is the highest compared with the non-activated powder and amounts to 71%.

By an example of silica-containing materials of different origins, ground in a planetary ball mill (Fig. 2), and WMS waste, ground in various mills (Fig. 3), there were constructed the graphs of the alteration of the compressive strength of asphalt concrete samples at different temperatures, compared with the same performance of the composites based on mineral powders in a stable state.

Figure 2 shows that the durability of asphalt concrete samples at 20 and 50 °C increases from 20 to 43%. Moreover, the greatest increase was observed when using wet magnetic separation waste and quartz sandstone as mineral powder, further (in descending order) there go fillers in the following sequence: quartz sand, granite. Despite the fact that the use of mechanically activated fillers in asphalt mixtures has led to a significant increase of strength characteristics of the composite at temperatures of 20 and 50 °C, its mechanical strength at 0 °C was reduced in the range from 5 to 7%.

Thus, the use of activated powders made of metamorphic rocks, such as quartz sandstone and WMS waste, the surface of which has a high reactivity to the bitumen, results in a significant improvement in mechanical strength of asphalt concrete compared to samples of composite containing fillers of granite and silica sand. Previously it was found out that on the surface of the latter materials there are significantly fewer acidic proton-donor sites, which have a significant influence on the interaction with organic binder.

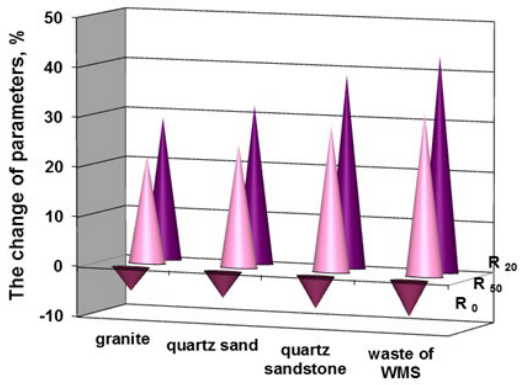

Fig. 2. Alteration of compressive strength of asphalt concrete samples on mineral powders, ground in a planetary ball mill, at 0, 50

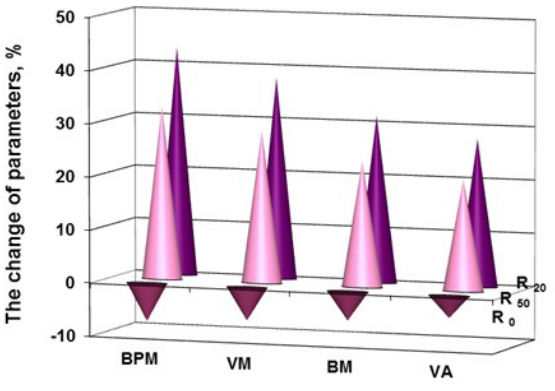

Fig. 3. Alteration of compressive strength of asphalt concrete samples on WMS waste mineral powder, ground in various mills, at

and 20 ºC

0, 50 and 20 ºC

The obtained results (Fig. 3) clearly rank mills in the order of their effectiveness decrease: planetary ball mill, vibration mill, ball mill and vibrating attritor. It is known that the grinding of material in a planetary ball mill is carried out under the influence of shock loads; in a vibrating mill grains of material 1-2 mm of size are partly crushed, but mainly, as well as in a simple ball mill, attrited between grinding bodies. The method of grinding in a ball mill and in a vibratory attritor is identical - abrasive effect on the treated material.

As it was noted earlier, an important condition for asphalt concrete production is to obtain coverage, resistant to shear deformations in summer, due to the mechanical strength of asphalt concrete at elevated temperatures. The degree of strength alteration depending on the temperature fluctuations is characterized by the coefficient of thermal stability.

By an example of siliceous materials of different origins, ground in a planetary ball mill (Fig. 4), and WMS waste, ground in various mills (Fig. 5) there were graphed the alterations of water resistance, water resistance at prolonged water saturation and heat resistance of asphalt concrete in comparison with the composite based on mineral powders in a stable condition.

From the graphs (fig. 4-5) it is seen that the heat resistance of asphalt samples based on mechanically activated mineral powders alters more rapidly than the water resistance and water resistance after prolonged water saturation. The use of freshly ground fillers instead of stable-condition mineral powders in asphalt concrete, leads to substantial increase of its heat resistance in the range from 38% (when using silica sand) to 72% (using waste of WMS).

The water resistance of organic-mineral composite based on WMS waste and quartzitic sandstone mineral powders, ground in a planetary ball mill, is the highest and amounts to 0.98 and 0.95, respectively. The values of this parameter when using fillers in stable condition do not exceed 0.81.

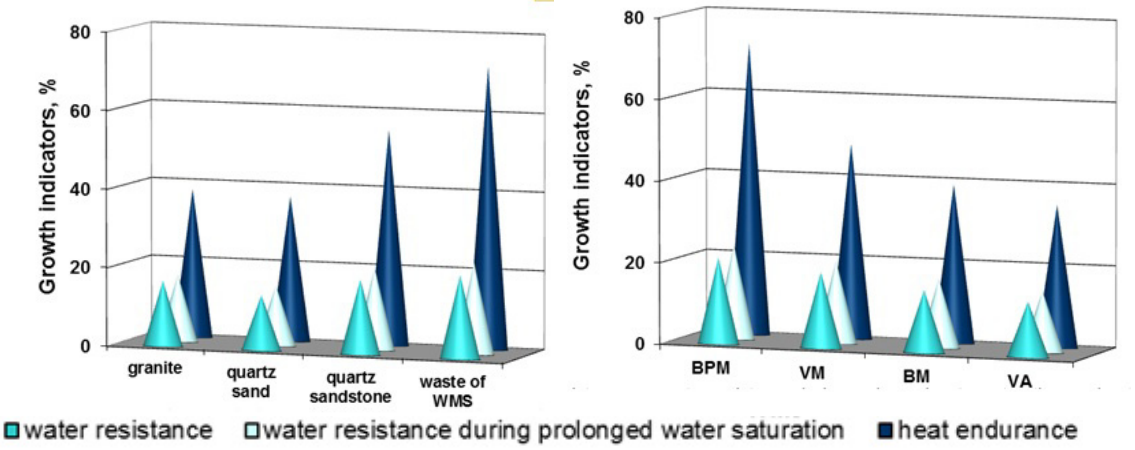

Fig. 4. Alteration of the coefficients of water resistance, water resistance with prolonged water saturation and heat resistance of asphalt concrete samples on mineral powders, ground in a planetary ball mill

Fig. 5. Alteration of the coefficients of water resistance, water resistance with prolonged water saturation and heat resistance of asphalt concrete samples on WMS waste mineral powders, ground in various mills

It should be emphasized that the alteration of water resistance with prolonged water saturation, unlike the alteration of water resistance, is more intense. Thus, the increase of this parameter varies from 15 to 23%. The powders ground in a planetary ball mill and in a vibratory mill were especially effective. On the base of freshly ground quartz sandstone and WMS waste there was received asphalt concrete, the water resistance with prolonged water saturation of the samples of which is of the highest value – 0.93 and 0.89 respectively, compared with the composite, prepared on the base of mechanically activated granite and quartz sand filler – 0.82 and 0.7 (ground in a planetary ball mill). As follows from the above said, the asphalt concrete prepared with the use of freshly ground mineral powders from WMS waste and quartz sandstone, ground in planetary ball mills and vibratory mills, has the

highest thermal stability, water resistance and water resistance at prolonged water saturation, as compared to the composite, with the use of granite or quartz sand as mineral powder, ground in a simple ball mill or in a vibration attritor. Such results are conditioned by the intensity of interaction in the system "bitumen - mineral powder."

Thus, our studies give us reason to believe that mechanical activation may contribute to the successful use of mineral powder from non-traditional silica-containing materials in composition of asphalt concrete.

There was determined the proportional relationship between strength and water resistance indices of asphalt concrete and concentration of active sites on the surface of all tested materials, ground in various mills (Fig. 6). The correlation coefficients between the compressive strength at 20 °C, water-resistance, and the number of active Bronsted adsorption sites amount to 0.976 and 0.982, respectively.

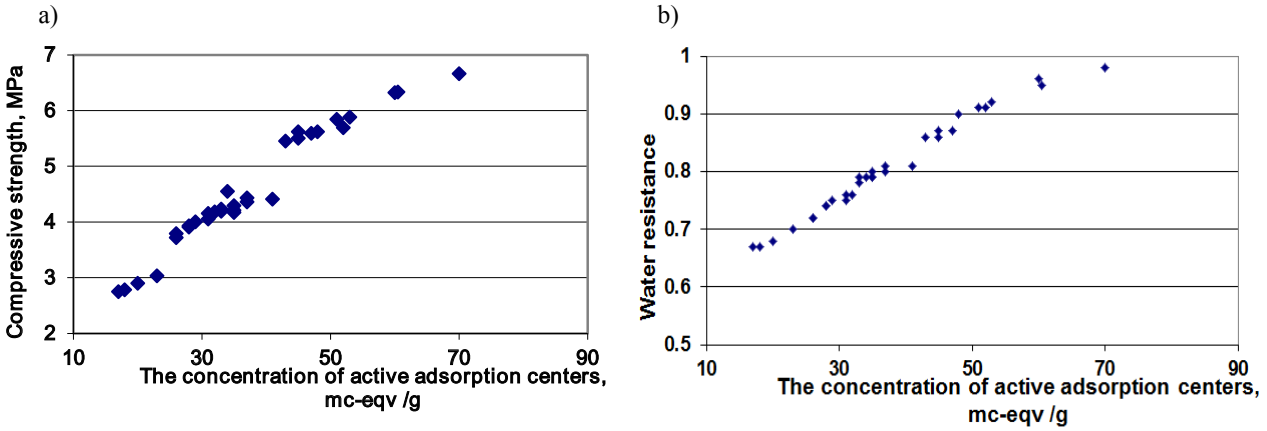

Fig. 6. The dependence of compressive strength at 20 °C (a) and water-resistance (b) on the concentration of active sites on the surface of mineral powders

Thus, we can say that the number of adsorption sites on the surface of disperse materials is an integral characteristic of their reactivity at mechanical activation. Moreover, the identifying of this index does not require complex hardware and a lot of time.

5. Conclusions

It has been determined that mechanically activated mineral powder significantly improves the quality of asphalt concrete: compressive strength at 20 ° C in the range from 19 to 43% and at 50 °C - from 14 to 39%, water resistance - 14 - 21%, heat resistance - 19 - 72%. The best physical and mechanical properties were demonstrated by the composites on mineral powders of metamorphic origin (quartz sandstone and WMS waste), the lowest - when using granite and quartz sand as a filler. Mills in the order of decrease of their effectiveness for mechanical activation of mineral powder in asphalt concrete production can be ranked in the following order: planetary ball mill, vibration mill, ball mill, vibrating attritor

It has been proved that mineral powders' tendency to rapid deactivation in the air reduces the strength characteristics of asphalt concrete samples based on various mineral powders during their storage after grinding.

The formulas of high-quality asphalt concrete on freshly ground quartz sandstone and WMS waste mineral powders, milled in a ball mill, planetary ball mill and vibratory mill, physical and mechanical characteristics of which are higher than those using traditional limestone mineral powder, have been offered.

There was determined a proportional relationship of strength and water resistance of asphalt concrete with concentration of active sites on the surface of all tested materials ground in various mills. The correlation coefficients between the compressive strength at 20 °C, water resistance and the number of active Bronsted adsorption sites amount to 0.976 and 0.982, respectively.

References

[1] Yalamaç, E, Akkurt, S. Additive and Intensive Grinding Effects on the Synthesis of Cordierite (2006) Ceramics International, 32(7), pp. 825-832.

[2] Tamborenea, S., Mazzoni, A.D., Aglietti, E.F. Mechanochemical Activation of Minerals on the Cordierite Synthesis (2004) Thermochimica Acta, 411(2), pp. 219-224.

[3] Filio, J.M., Sugiyama, K., Saito, F., Waseda, Y.A. Study on Talc Ground by Tumbling and Planetary Ball Mills (1994) Powder Technology, 78(2), pp. 121-127.

[4] Lomovskiy, O.I., Boldyrev, V.V. Mekhanokhimiya v reshenii ekologicheskikh zadach [Mechanochemistry in solving environmental problems] (2006) Ekologiya. Seriya analiticheskikh obzorov mirovoy literatury, 79, pp. 1-22.

[5] Yadykina, V.V. Vzaimosvyaz' donorno-aktseptornykh svoystv poverkhnosti mineral'nykh materialov s ikh reaktsionnoy sposobnost'yu pri formirovanii organo-mineral'nykh kompozitov [The relationship of donor-acceptor properties of the surface of mineral materials with their reactivity in the formation of organo-mineral composites] (2004) Izvestiya vysshikh uchebnykh zavedeniy. Stroitel'stvo, 4, pp. 46-50.

[6] Korostovenko, V.V., Korostovenko, L.P., Strekalova, T.A., Strekalova, V.A. Izbiratel'noe raskrytie i strukturno-khimicheskie izmeneniya mineralov pri impul'snom vozdeystvii [Selective Disclosure and structural and chemical changes in minerals with pulsed action] (2013) Mezhdunarodnyy zhurnal eksperimental'nogo obrazovaniya, 4-2, pp. 73-76.

[7] Yusupov, T.S., Gusev, G.M., Kirillova, E.A., Korneva, T.A., Pal'chik, N.A., Pantyukova, L.P., Razvorotneva, L.I., Tsimbalist, V.G., Shumskaya, L.G. Establishment of laws of changes in structural and chemical properties and reactivity of minerals in the process of fine grinding of ores: a report on the research work No. 96-05-65933, Russian Foundation for Basic Research (2011) Establishment of laws of changes in structural and chemical properties and reactivity of minerals in the process of fine grinding of ores: a report on the research work No. 96-05-65933, Russian Foundation for Basic Research, 125 p.

[8] Shangina, N.N. Prediction of physical and mechanical properties of concrete in view of the donor-acceptor properties of the surface of the fillers and aggregates: synopsis, Sankt-Peterburg (1998) Prediction of physical and mechanical properties of concrete in view of the donor-acceptor properties of the surface of the fillers and aggregates: synopsis, Sankt-Peterburg, 45 p.

[9] Yadykina, V.V. Management of processes of formation and the quality of construction of composites with the state of the surface of particulate materials: monograph, M.: ASV(2009) Management of processes of formation and the quality of construction of composites with the state of the surface of particulate materials: monograph, M.: ASV, 374 p.

[10] Lesovik, R.V. Aktivatsiya napolniteley kompozitsionnykh vyazhushchikh [Activation of fillers composite binders] (2009) Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. Shukhova, 1, pp. 87-89.

[11] Strokova, V.V., Zhernovskiy, I.V., Lyutenko, A.O., Lebedev, M.S. Analiz organomineral'nykh kompozitov s uchetom genezisa i razmernykh urovney mineral'nogo syr'ya [The analysis of organic composites with the genesis and dimensional levels of minerals] (2009) Vestnik Belgorodskogo gosudarstvennogo tekhnologicheskogo universiteta im. V.G. Shukhova, 2, pp. 28-32.

[12] Dushkin, A.V. Potential of Mechanochemical Technology in Organic Synthesis and Synthesis of New Materials (2004) Chemistry for Sustainable Development, 12, pp. 251-273.

[13] Lu, J., Gao, L., Guo, J. Preparation and Phase Transition of Superfine Boehmite Powders with Different Crystallinity (2001) Journal of Materials Science Letters, 20(20), pp. 1873-1875.

[14] Mendelovici, E. Selective Mechanochemical Reactions on Dry Grinding Structurally Different Silicates (2001) Journal of Materials Science Letters, 20(1), pp. 81-83.

[15] Zhang, D.L. Processing of Advanced Materials Using High-Energy Mechanical Milling (2004) Progress in Materials Science, 49(3-4), pp. 537-560.

[16] Trautvain, A.I., Yadykina, V.V., Gridchin, A.M. Osobennosti mekhanoaktivirovannykh mineral'nykh poroshkov [Features mechanically activated mineral powders] (2011) Stroitel'nye materialy, 11, pp. 32-34.

[17] Yadykina, V.V., Trautvain, A.I., Gridchin, A.M. Analiz regressivnykh zavisimostey vliyaniya prirody materialov i rezhimov ikh izmel'cheniya na svoystva asfal'tobetona [Analysis of the influence of the nature regressive dependency materials and modes of grinding on the properties of asphalt concrete] (2014) Nauka i tekhnika v dorozhnoy otrasli, 4, pp. 26-29.

[18] Trautvain, A.I., Yadykina, V.V., Gridchin, A.M., Verbkin, V.I. Upravlenie protsessom vzaimodeystviya v sisteme «organicheskoe vyazhushchee - mineral'nyy napolnitel'» [Managing the process of interaction in the "organic binder - mineral filler"] (2014) Izvestiya vysshikh uchebnykh zavedeniy. Stroitel'stvo,4, pp. 45-51.

[19] Trautvain, A.I., Yadykina, V.V., Gridchin, A.M. Preparation of the silica-reactive filler material (2013) Middle-East Journal of Scientific Research, 18 (10), pp. 1499-1504.

[20] Yadykina, V.V., Akimov, A.E., Trautvain, A.I. The theoretical basis for the use of microwave processing of bitumen for high-quality asphalt production (2014) Advances in Natural and Applied Sciences, 8(4), pp. 291-295.