

Activated mineral powders for asphalt concrete mixture

D A Kuznetsov, E A Lukash

Belgorod State Technological University named after V.G. Shukhov, 46, Kostyukova St., Belgorod, 308012, Russia

E-mail: roads-bstu@yandex.ru

Abstract. Possibilities of activation of disperse mineral powders from the technogenic raw materials of KMA by ultraviolet irradiation are considered in this article. The optimum time of ultraviolet exposure for each material is determined during which the concentration of exchange centers is increased, the rate of rehydration is slowed down and the moisture absorption is significantly reduced. It is shown that both physical and mechanical characteristics, as well as durability of asphalt concrete prepared on the basis of modified mineral powders are significantly increased.

1. Introduction

Asphalt concrete is a composite material commonly used in road construction. However, this traditional material does not always fully ensure the required reliability and durability of road structures. In this regard, there is an acute problem caused by the need to improve existing materials and technologies, taking into account modern requirements and new tasks. One of the ways to solve this problem is to control both technological and construction-technical properties of composites by increasing the structure-forming ability of dispersed components, i.e. mineral powders, which are the main elements of the structure at the micro- and meso-levels.

When using mineral powders, their surface properties come to the forefront, which may differ significantly from the volume characteristics. For such materials, it is necessary to know the nature and state of the surface, which plays an important role in the processes of structure formation and, consequently, affects both physical and mechanical characteristics of the composite material. It is becoming very topical because of the emerging need for the production of mineral powders from local raw materials and industrial wastes [1].

Analysis of the surface state of dispersed materials and mechanisms of contact interactions in filled composite construction materials allows us to outline the ways aimed at modifying mineral powders in order to strengthen their adhesion to the binder and increase the structure-forming role, one of which is ultraviolet (UV) irradiation. According to the research work [2], it is indicated that under the influence of ultraviolet irradiation there is a change in the state of the surface of silica, resulting in the formation of free valences, which play the role of new active adsorption centers [3]. This fact was proved by several researchers [4,5].

In addition, it has been established [6] that active adsorption centers have a significant effect on the interaction of mineral materials with the organic binder. The author concluded that the necessary condition for ensuring strong adhesive contacts between the organic binder and mineral materials is the presence on the surface of the last active sites capable of adsorbing virtually all organic



compounds contained in the bitumen.

2. Materials and methods

The aim of this work was to study the effect of ultraviolet radiation on the properties of mineral powders and asphalt concrete based on them. In this study, the following mineral powders with a specific surface of about 350 m²/kg were used: quartzite sandstone of Lebedinsky Mining and Processing Plant of Kursk Magnetic Anomaly, wastes of wet magnetic separation of ferrous quartzites (WMS), slag of Oskol Electrometallurgical Plant (OEMK) and sand of Nizhneolshan deposit. The source of UV radiation was quartz lamp Q-139. Thin-layered mineral powder was placed at a distance of 0.3 m from the quartz lamp and was irradiated in the process of its mixing.

3. Results and discussion

Analysis of the results presented in Table 1 showed that the dependence of the concentration of exchange centers on the time of irradiation for all materials is extreme at the irradiation time range of 10-12 minutes for quartzite sand, 12-15 minutes for WMS wastes, 7-10 minutes for sand and 15 minutes for OEMK slag. It should be noted that the exchange capacity of all mineral powders under study at the optimum irradiation time increases by more than 100% compared to the initial materials. This occurs due to the partial dehydration of the surface of mineral materials, which leads to an increase in the number of isolated hydroxyl groups and reactivity increase [7].

Table 1. Dependence of the exchange capacity of mineral powders on UV irradiation time

Mineral powder	Exchange capacity, $\mu\text{Eq/g}$ at the time of irradiation, min.							
	0	3	5	7	10	12	15	20
Quartzite sand	14.1	19.0	23.7	27.0	29.8	30.2	29.1	26.9
WMS waste	15.2	19.6	22.9	25.9	28.5	29.5	29.4	27.2
Quartz sand	9.8	13.7	18.4	20.8	20.9	19.5	18.3	16.3
OEMK slag	6.4	8.6	9.9	11.0	12.1	12.6	12.8	12.3

To check the positive effect of UV irradiation of dispersed materials on the enhancement of their adhesion to the organic binder, the adhesion of bitumen at the optimum processing time was determined by the weight method and the obtained values were compared with the values of exchange capacity and moisture absorption.

The results obtained (Table 2) show that all mineral powders activated at the optimum processing time provide much better bitumen adhesion compared to the nonactivated powders. A surface area of mineral powders from quartzite sandstone (94%) and WMS wastes (90%) is significantly covered with bitumen, and oppositely to that, an insignificant surface area of mineral powder from OEMK slag (58%) is covered with bitumen. The adhesion of bitumen to quartz sand is by 25% less than to quartzite sand, despite the same chemical and mineralogical composition, as well as the lowest moisture absorption (0.51%), which is associated with a smaller number of active adsorption centers located on the surface of quartz sand. It should be noted that for the same percentage increase in the exchange capacity after UV irradiation (on average by 100%) for all materials, the same percentage increase in adhesion (31-32%) is observed. The exception would be the OEMK slag as its adhesion to bitumen has increased by 24% due to the increased moisture absorption.

Table 2. UV irradiation influence of mineral powders on their adhesion to bitumen

Mineral powder	Exchange capacity, $\mu\text{Eq/g}$		Adhesion, %		Moisture absorption, %	
	before activation	after activation	before activation	after activation	before activation	after activation
Quartzite sand	14.1	30.2	62	94	1.29	0.63
WMS waste	15.2	29.5	58	90	1.41	0.76
Quartz sand	9.8	20.9	38	69	1.69	0.51
OEMK slag	6.5	12.8	34	58	2.96	1.92

Moisture absorption of untreated quartz sand is 30% higher than that of quartzite sand. This is confirmed by the results obtained with the help of IR spectroscopy of different states of adsorbed water and its fragments on the surface of two varieties of quartz [5]. Apparently, the adsorption of water does not occur on isolated hydroxyl groups; however it occurs on previously adsorbed water molecules, the number of which is much higher on the sand surface.

The established character of the change in the adsorption capacity and hydrophobization of dispersed materials as a result of UV treatment should be related to the bitumen capacity of mineral powders.

Table 3. Influence of UV irradiation of fillers on bitumen capacity

Mineral powder	Bitumen capacity, $\text{g}/100 \text{ cm}^3$	
	Initial mineral powder	Activated mineral powder
Quartzite sand	55,2	47,6
WMS waste	56,8	49,4
Quartz sand	59,7	52,9
OEMK slag	67,5	61,4

Basing on the results of the studies (Table 3), the bitumen content of mineral powders activated at the optimal UV exposure time is reduced by 9-13.8%, which is explained by the hydrophobization of the filler surface as a result of the treatment. At the same time, the mineral powder activated by mineral quartzite sand (47.6 g) has the lowest bitumen capacity; the highest bitumen capacity refers to mineral powder from OEMK slag (61.4 g). Based on the obtained data, it can be assumed that the optimal bitumen content in the mixtures on activated mineral powders would be less compared to the mixtures on the unmodified powders.

To study the effect of UV treatment of mineral powders on the physical and mechanical characteristics of asphalt concrete, samples from an asphalt concrete mixture of type G were produced and tested using standard techniques, which is due to the influence of the properties of the dispersed material on the composite quality. It should be noted that depending on the type of the mineral powder used, as well as taking into account its activation, the content of bitumen was individually selected for each mixture. This allowed us to establish that the use of the modified mineral powders in the composition of asphalt concrete mixtures makes it possible to reduce the consumption of bitumen by 8-10%.

The physical and mechanical characteristics of asphalt concrete prepared on ultraviolet-treated mineral powders significantly increase (Table 4). A significant strength increase during the

compression within the range of +20°C and +50°C is observed. Thus, at a temperature of +20°C, the maximum increase in strength is observed in the samples with the activated mineral powder from quartzite sandstone (30.6%); for WMS waste, it is 28.9%; for mineral powders from quartz sand and OEMK slag, it is 25.9% and 23.8% respectively.

Table 4. Physical and mechanical characteristics of asphalt concrete

Name of indicator	GOST requirements	Mineral powder							
		Quartzite sand		WMS waste		Sand		OEMK slag	
		init.	modif.	init.	modif.	init.	modif.	init.	modif.
Water saturation, %	1.50 – 4.00	1.67	1.51	1.69	1.54	2.20	2.05	2.60	2.46
Compressive strength, MPa:									
- at 20 °C	>2.20	4.90	6.40	4.83	6.23	4.63	5.83	4.50	5.57
- at 50 °C	>1.20	3.10	3.90	2.93	3.63	2.70	3.34	2.40	2.87
- at 0 °C	<12.0	11.20	10.80	11.33	10.87	11.47	11.0	11.67	11.43
							3		
Water resistance	>0.85	0.92	0.96	0.91	0.96	0.88	0.93	0.85	0.90
Water resistance for long-term water saturation	>0.75	0.83	0.88	0.82	0.87	0.76	0.81	0.75	0.82

A decrease in water saturation indexes, as well as an increase in water resistance of asphalt concrete samples, indicates that the bitumen films on the surface of mineral material are highly resistant to peeling when exposed to aggressive media. This prevents deep penetration of water into the pores and capillaries of the material, as well as the diffusion of water into the bitumen film, which is dangerous because the sorbed water molecules can easily migrate over the surfaces, which leads to the material destruction.

Attention should be paid to the change in the compressive strength of asphalt concrete at a temperature of +50°C, which characterizes the operability of asphalt concrete in the summer period when the surfacing temperature has the maximum value and the viscosity of the bitumen is minimal. Thus, at a test temperature of +50°C, the maximum strength increase is observed in the samples with activated mineral powder from quartzite sandstone (25.8%); for WMS waste, it is 23.9%; for mineral powders from quartz sand and OEMK slag, it is 23.3% and 19.5% respectively.

The aforesaid can be attributed to asphalt concrete tests for compressive strength at 0 °C. Basing on these results, it is possible to estimate how the asphalt concrete would behave when the bitumen is transformed from an elastic-plastic to a solid state during which such property as brittleness of bitumen is observed.

4. Summary

Thus, based on the results of the conducted studies, it can be concluded that UV irradiation with the optimal exposure parameters positively affects the properties of mineral powders, which significantly improves the physical and mechanical characteristics, as well as durability of asphalt concrete.

5. Acknowledgments

The article was prepared in the framework of the development program of the University and on the basis of Belgorod State Technological University named after V.G. Shukhov, using the equipment of High Technology Center at BSTU named after V.G. Shukhov.

References

- [1] Kuznetsov D, Visotskaya M, Agamijan B 2014 *Regulation of the properties of asphalt concrete pavement by the use of porous mineral powders. Geo-Hubei 2014 international conference on sustainable infrastructure: Design, Analysis, and Asphalt Material Characterization for road and airfield pavements* (Yichang, Hubei: China) pp. 224-228
- [2] Kiselev V F, Krylov O V 1978 *Adsorption processes on the surface of semiconductors and dielectrics* (Nauka, Moscow)
- [3] Rane N J 2007 *Hydrocarbon Conversion over Brønsted and Lewis Acidic Zeolites*. (Eindhoven University of Technology)
- [4] Gladkikh Yu P, Yadikina V V, Zavrazhina V I 1989 Influence of UV-irradiation on the physicochemical activity of quartz sand and the processes of cement-sand concrete formation. *Colloid Journal*. **51** (3) 445-450
- [5] Yadykina V V, Gridchin A M, Lukash E A 2009 *Increasing of concretes efficiency by modifying of extenders surface. Internationale Baustofftagung* (Bauhaus-Universität Weimar).. – pp. 17.
- [6] Yadykina V V 2009 *Managing the processes of formation and the quality of construction composites given the state of the surface of the particulate material: monograph* (Publishing House of the DIA)
- [7] Ayler R K 1982 *Chemistry of silica: World*