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Use of Activated Mineral Powders to Improve the Strength of Asphalt Concrete Pavements

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Abstract: This study investigates the scientific and practical aspects of improving the performance of asphalt concrete pavements through the use of activated mineral powders. Particular attention is given to the role of mineral fillers in asphalt mixtures, as well as to the mechanisms of their mechanical and chemical activation and the resulting physicomechanical transformations. The findings indicate that activated mineral powders significantly enhance compressive strength, shear resistance, moisture stability, and temperature resistance of asphalt concrete. These improvements are attributed to increased surface activity, enhanced adhesion between bitumen and mineral particles, and the formation of a denser microstructure. Furthermore, under the continental climatic conditions of Uzbekistan, the application of activated mineral powders contributes to extending pavement service life and reducing overall maintenance and lifecycle costs.

Keywords: Activated Mineral Powder, Asphalt Concrete, Bitumen, Dispersity, Adhesion, Deformation, Compressive Strength, Water Resistance, Pavement, Structural Reinforcement

Introduction

In modern road construction, increasing the durability and exploitation reliability of asphalt concrete pavements is a primary objective. Among the components of asphalt mixtures, mineral powder plays a crucial role in forming the internal structure and ensuring the stability of the material [1].Mineral powder, together with bitumen, forms asphalt mastic, which determines the strength, elasticity, and resistance of asphalt concrete to external loads [2], [3]. Despite its relatively small content (5–12%), it has a significant impact on the performance of the mixture.However, traditional mineral powders often exhibit insufficient surface activity, which negatively affects adhesion with bitumen and reduces resistance to moisture damage [4,5]. To overcome these limitations, modern research focuses on the activation of mineral powders, which enhances their physical and chemical properties. Recent advancements in material science have introduced the concept of mineral powder activation, which aims to enhance its surface properties and reactivity [6,7]. Activated powders exhibit improved interaction with bitumen, leading to better adhesion and a more stable microstructure.

Methodology

Activated mineral powders were obtained through combined mechanical and chemical activation processes aimed at improving their physicochemical properties. Mechanical activation was carried out using high-energy grinding, which increased the specific surface area, dispersity, and surface energy of mineral particles. Chemical activation involved coating the particles with a modifying agent composed of bitumen and gossypol resin in a 1:1 ratio, applied at a rate of 1.5–2.5% by weight of mineral powder. This treatment enhanced hydrophobicity, reduced moisture susceptibility, and improved adhesion between the mineral filler and bitumen. The activated powder demonstrated improved compatibility with the binder, ensuring more uniform distribution within the asphalt mixture.

Asphalt concrete samples were prepared using both conventional and activated mineral powders under controlled laboratory conditions. Standard mixing temperatures (150–170°C) and compaction procedures were applied. The specimens were tested according to GOST and O‘z DSt requirements. Key performance indicators, including compressive strength, shear resistance, water resistance, porosity, and rutting depth, were measured and compared to evaluate the effectiveness of the activated mineral powders.

Results and Discussion

Activation of mineral powder is aimed at improving its surface properties, increasing dispersity, and enhancing its interaction with bitumen. The modifier consists of a 1:1 ratio of bitumen and gossypol resin.The activating mixture is applied at a rate of 1.5% to 2.5% by weight of the mineral powder.Mineral powder prepared using this approach demonstrates enhanced compatibility with bitumen, ensuring uniform mixing. Moreover, this method minimizes dust formation during transportation and handling, while also preventing moisture absorption and agglomeration when stored under open environmental conditions.The application of activating agents facilitates the coating of mineral powder particles with bitumen, leading to the formation of chemisorption bonds between the filler and the binder at the interface of solid and liquid phases. When cement dust is treated with bitumen of varying viscosity through activation techniques, a carbonate-based mineral powder is produced, which significantly improves the overall performance of the mixture.Asphalt concrete mixtures incorporating such activated mineral powders exhibit superior structural quality. According to technical specifications, mineral powders must meet specific particle size distribution requirements. In particular, the fraction passing through a 0.071 mm sieve is considered the finest and most active component. Under standard conditions, only a negligible portion of the material remains on the sieve, and this coarser fraction can also be effectively utilized as a filler in asphalt mixtures.The incorporation of activated mineral powders in asphalt concrete production contributes to reduced bitumen consumption, while simultaneously decreasing thermal expansion and enhancing the mechanical strength of the binder. Furthermore, it prevents segregation of fine particles within the mixture and reduces material losses during handling and placement processes[8,9,10]

- **Mechanical activation** involves high-energy grinding, which increases the specific surface area of particles and expands the contact area with bitumen.
- **Chemical activation** involves the use of surface-active agents, which impart hydrophobic properties to mineral powder and improve resistance to moisture.

Mechanical activation is a physico-mechanical process aimed at improving the structural and surface properties of mineral powders through intensive grinding and high-energy mechanical treatment This process is widely applied in material science and road construction engineering, particularly in the modification of mineral fillers used in asphalt concrete compositions During mechanical activation, mineral particles are subjected to strong mechanical forces such as impact, compression, friction, and shear stress in high-energy milling equipment. As a result, significant structural changes occur at micro- and nano-scale levels One of the key effects of mechanical activation is the partial destruction of the crystal lattice of minerals . This leads to the formation of defects, dislocations, and microcracks on the particle surface . Consequently, the specific surface area of the mineral powder increases significantly, which enhances its surface energy and chemical reactivityStudies show that the use of activated mineral powder significantly enhances the structural strength of asphalt concrete [11]. Effect of Activated Mineral Powder on Asphalt Concrete

Properties.Experimental results demonstrate that asphalt concrete prepared with activated mineral powder exhibits significantly improved performance compared to conventional mixtures.

- Compressive strength increases by approximately 15–25%
- Shear resistance improves
- Water resistance increases
- Porosity decreases
- Rutting depth is reduced

These improvements are explained by a denser microstructure and stronger internal bonding within the material.The resistance of asphalt concrete to deformation, especially rutting at high temperatures, is largely determined by the quality of the mastic phase [12].

Table 1. Comparison of the properties of asphalt concrete based on conventional and activated mineral powder

No	Property	Unit	Conventional Powder	Activated Powder	Change (%)
1	Compressive strength (20°C)	MPa	3.8	4.7	+23.8
2	Shear resistance	MPa	0.42	0.53	+25.7
3	Water resistance coefficient	-	0.82	0.91	+11.1
4	Porosity	%	4.8	3.9	−18.55
5	Rut depth	mm	6.5	4.9	−24.6

The increase in compressive strength and shear resistance is associated with improved adhesion between bitumen and mineral particles [13]. Activated powders enhance the formation of a dense and homogeneous microstructure, which improves load distribution.Reduced porosity leads to lower water absorption and increased resistance to moisture damage [14]. This is particularly important for long-term pavement durability.Additionally, rutting resistance improves significantly due to increased structural stiffness and elasticity, especially under high temperature conditions [15]. In regions with sharply continental climates, asphalt pavements are subjected to extreme temperature variations. These conditions lead to internal stresses, cracking, and deformation.The use of activated mineral powders improves thermal stability, reduces crack propagation, and enhances resistance to environmental effect. This makes the technology especially effective for Central Asian conditions.Water resistance is a critical parameter for asphalt concrete performance. The use of hydrated lime or activated mineral powder significantly increases the water resistance coefficient, due to improved adhesion between bitumen and mineral particles.The mechanical behavior of asphalt concrete is based on the interaction between mastic and aggregates. A stronger and more elastic mastic results in better load resistance and durability.The climate of Uzbekistan sharply continental climate, characterized by high summer temperatures and cold winters, has a significant impact on pavement performance. Temperature fluctuations lead to internal stresses and microcrack development[16]. The use of activated mineral powder increases microstructural density, reduces porosity, and slows crack propagation.

Standards and Economic Efficiency

Compliance with established technical standards is a critical requirement in the design and production of asphalt concrete mixtures. International and national standards define the quality parameters of asphalt mixtures, including strength, durability, water resistance, and deformation stability. In this context, the properties of mineral powder play a decisive role, as they directly influence the structure and performance of asphalt mastic.The use of activated mineral powders significantly facilitates compliance with these standards. Due to their enhanced surface activity and improved adhesion with bitumen, activated powders contribute to the formation of a dense and homogeneous microstructure. This results in improved mechanical properties, including higher compressive strength, increased shear resistance, and enhanced moisture stability, all of which are key parameters specified in regulatory documents.From an economic perspective, the implementation of activated mineral powder technology offers substantial long-term benefits. Although the initial production costs may slightly increase due to the activation process, this is compensated by a reduction in bitumen consumption and improved mixture efficiency. Furthermore, the enhanced durability of asphalt concrete leads to a significant decrease in maintenance frequency and repair costs over the pavement lifecycle.Standards define requirements for asphalt concrete mixtures, where the quality of mineral powder plays a crucial role. The use of activated powder facilitates compliance with these standards and improves pavement quality.From an economic perspective, although the use of activated mineral powder may slightly increase initial costs, it significantly reduces maintenance frequency and overall exploitation costs due to extended service life.

Conclusion

In conclusion, this research establishes that the implementation of activated mineral powder technology represents a promising and sustainable direction for modern road engineering. It provides a robust framework for meeting international technical standards while effectively addressing the challenges of regional climatic extremes.The expanded analysis confirms that activated mineral powders are an effective solution for improving asphalt concrete performance. Their use enhances mechanical properties, durability, and resistance to environmental factors. This technology represents a promising direction for modern road construction, particularly in regions with challenging climatic conditions.

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