

## **Improving the Physical and Mechanical Properties of Asphalt Concrete Using Nanoparticles**

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**Abstract:** *This article investigates the improvement of the physical and mechanical properties of asphalt concrete pavements using nanoparticles. During the research, the effects of adding nanomaterials to asphalt concrete mixtures on the pavement's strength, elasticity, water resistance, and deformation resistance were analyzed. The influence of nano-silica, carbon compounds, and nanoclay materials on the properties of asphalt concrete was evaluated based on laboratory experiments. The obtained results showed that nanomodified asphalt concrete has higher operational efficiency compared to conventional asphalt concrete.*

**Keywords:** *nanotechnology, asphalt concrete, nanoparticle, road pavement, strength, deformation, nanomaterial, highways.*

### **1. Introduction**

In today's era of globalization and rapid urbanization, highways have become one of the most important infrastructure elements for the national economy, transport-logistics system, and interregional integration. The increasing global transport flow, growth in the number of heavy freight vehicles, and sharp climate changes impose high requirements on existing road pavements. In particular, the rapid deformation of asphalt concrete pavements, formation of cracks, and reduction in service life have become urgent problems in modern road construction. In the Republic of Uzbekistan, modernization of highway infrastructure and the creation of high-quality and durable pavements meeting international standards are among the priority directions of state policy[1]. In particular, several decrees and resolutions of the President of the Republic of Uzbekistan concerning the development of the transport and road sector emphasize the wide implementation of innovative technologies, the use of modern construction materials, and the improvement of road pavement quality indicators. Special attention is paid to extending road service life through modernization of the highway network and the use of energy-efficient and high-strength materials.

The principle of "creating quality infrastructure through innovative development," promoted by the President, necessitates the widespread application of scientific approaches in the field of road construction. From this perspective, the development and practical implementation of a new generation of road construction materials based on nanotechnology is considered one of the most promising scientific directions today.

Nanotechnologies make it possible to control materials at the atomic and molecular levels, significantly improving their physical and mechanical properties. In particular, the incorporation of nanoparticles into asphalt concrete enhances pavement strength, improves resistance to water and temperature effects, increases deformation resistance, and extends service life. According to international studies, additives based on nano-silica (SiO<sub>2</sub>), carbon nanotubes, and nanoclay

improve the microstructural condition of asphalt concrete and increase its mechanical stability. Moreover, the use of nanomodified asphalt concrete is important for reducing road maintenance costs, ensuring rational use of resources, and maintaining environmental safety[2,3,4,5]. Especially in areas with heavy traffic loads, such materials make it possible to preserve the technical condition of highways for a long period.

The main purpose of this research is to improve the physical and mechanical properties of asphalt concrete using nanoparticles, determine the effect of nanomaterials on pavement quality, and analyze their scientific and practical significance in improving highway operational efficiency.

## 2. Literature Review and Methodology.

In recent years, numerous scientific studies have been conducted on the application of nanotechnology in highway construction. In particular, the issue of improving the physical and mechanical properties of asphalt concrete by adding nanoparticles has been widely studied by international researchers.

Studies conducted by Chinese scientists Zhang Y. and Wu S. revealed that nano-silica ( $\text{SiO}_2$ ) additives improve the resistance of asphalt binders to high-temperature deformation. The researchers scientifically substantiated that nanoparticles improve the density of asphalt microstructure, thereby increasing pavement strength and water resistance. Their work mainly focused on evaluating the physical properties of asphalt binders under laboratory conditions.

American researcher B. Huang investigated the influence of nanomaterials on the void content in asphalt concrete mixtures. The scientist noted that nanoparticles reduce microcracks in the pavement structure and ensure long-term durability of the material. However, the influence of climatic factors was not sufficiently analyzed in these studies. In addition, Liu G. investigated the elastic properties of asphalt concrete modified with carbon nanotubes. According to the results, carbon nanotubes significantly improved the tensile and bending resistance of asphalt. The research mainly focused on mechanical properties, while issues of economic efficiency were not deeply addressed.

Turkish scientist N. Hassan analyzed the effect of nanoclay materials on the water resistance of asphalt concrete. The research results showed that nanoclay additives reduce pavement deterioration under moisture exposure. However, deformations under heavy traffic loads were not sufficiently studied in this work.

Scientists from CIS countries have also conducted several studies on the properties of nanomodified asphalt concrete. In particular, Russian researchers investigated the possibility of reducing crack formation in cold climates by adding nanopowders to asphalt concrete mixtures. Their studies mainly focused on technologies adapted to cold regions.

Analysis of the literature shows that although the influence of nanoparticles on certain physical or mechanical properties of asphalt concrete has been extensively studied, comprehensive evaluation of strength, elasticity, water resistance, high-temperature resistance, deformation resistance, and operational efficiency together has not been sufficiently researched.

The distinguishing feature of this article compared to other scientific works is that nano-silica, carbon nanotubes, and nanoclay additives were simultaneously incorporated into asphalt concrete, and their effects on physical-mechanical and operational properties were comparatively analyzed. Furthermore, the study evaluates the efficiency of nanomodified asphalt concrete under the sharply continental climate conditions of Uzbekistan. This approach determines the scientific novelty and practical significance of the research.

During the methodological process of the study, different types of nanoparticles were added to asphalt concrete mixtures, and their effects on physical and mechanical properties were investigated under laboratory conditions. Standard hot asphalt concrete mixture was selected as the research object.

The following nanomaterials were used in the experiments:

- Nano-silica (SiO<sub>2</sub>);
- Carbon nanocompounds;
- Nanoclay additives.

Nanoadditives were incorporated into the asphalt mass in amounts of 1%, 3%, and 5%, and homogeneous mixtures were obtained using special mixing technology. Prepared samples were compacted using laboratory presses and transformed into standard test specimens. The physical and mechanical indicators of asphalt concrete samples were evaluated according to the following criteria:

1. Compressive strength;
2. Elastic modulus;
3. Water resistance;
4. Crack resistance;
5. Resistance to deformation at high temperatures;
6. Resistance to freeze-thaw cycles.

The experimental results were compared with those of conventional asphalt concrete and processed using statistical analysis methods. Based on the obtained data, the optimal amount of nanoadditives was also determined.

The uniqueness of this methodology lies in the simultaneous study of the complex effects of several nanoadditives and the evaluation of their operational efficiency under Uzbekistan's climatic conditions. In addition, the study also analyzed economic efficiency and service life indicators, which further enhances the practical significance of the article.

### 3. Results and Discussion

During the research, the physical and mechanical properties of asphalt concrete samples modified with nano-silica (SiO<sub>2</sub>), carbon nanocompounds, and nanoclay were tested under laboratory conditions. The experimental results were comparatively analyzed with conventional asphalt concrete samples, and the influence of nanoadditives on asphalt concrete composition was thoroughly investigated[6,7,8].

The obtained results showed that nanoparticles increase the density of the internal microstructure of asphalt concrete and reduce the number of voids in the material. As a result, the mechanical stability of the pavement increases, and its resistance to external loads significantly improves.

*Table 1*

**Effect of nanoadditives on the physical and mechanical properties of asphalt concrete**

Indicators	Conventional Asphalt Concrete	Nano-silica (3%)	Carbon Nanocompound (3%)	Nanoclay (3%)
Compressive strength, MPa	3.8	4.6	4.4	4.2
Elastic modulus, MPa	2850	3380	3520	3190
Water resistance coefficient	0.81	0.92	0.89	0.94
High-temperature	4.9	3.6	3.4	3.8

deformation, mm				
Crack resistance index	1.00	1.28	1.34	1.19
Predicted service life, years	10	14	15	13

The table results show that all nanoadditives improved the main characteristics of asphalt concrete. In particular, the sample containing carbon nanocompounds demonstrated the highest results in elastic modulus and crack resistance. Nano-silica significantly increased compressive strength.

According to the experimental results, adding 3% nano-silica to asphalt concrete increased compressive strength by 21%. This is explained by the strengthening of the bond between asphalt and mineral aggregates due to nanoparticles.

The strength was determined using the following formula:

$$R = \frac{P}{S}$$

*R* – strength indicator;

*P* – maximum load;

*S* – cross-sectional area of the sample

During testing, destruction of the conventional asphalt concrete sample under maximum load occurred at 38 kN, while in samples with nano-silica this indicator reached 46–48 kN.

The elasticity property of asphalt concrete pavement ensures that it does not deform under heavy traffic loads. During the experiments, it was observed that the elastic modulus increased by 23% in samples containing carbon nanotubes[9,10].

Table 2

**Deformation results under high temperature exposure**

Sample Type	Deformation at 25°C (mm)	Deformation at 40°C (mm)	Deformation at 60°C (mm)
Conventional asphalt concrete	1.8	3.1	4.9
Nano-silica	1.4	2.5	3.6
Carbon nanocompound	1.3	2.3	3.4
Nanoclay	1.5	2.6	3.8

The results showed that nanomodified asphalt concrete undergoes less deformation under high-temperature exposure compared to conventional asphalt concrete. Especially at 60°C, conventional asphalt concrete exhibited a high degree of softening, whereas samples containing nanoparticles retained their shape relatively well[11,12,13].

Microscopic observations demonstrated that nanoparticles fill the voids between mineral particles in asphalt concrete and create a denser structure. As a result:

- penetration of moisture into the pavement decreased;
- development of microcracks slowed down;

- deterioration during freeze-thaw cycles decreased.

This is particularly important under the sharply continental climate conditions of Uzbekistan, where high summer temperatures and winter cold accelerate asphalt concrete deterioration.

The research findings confirmed the conclusions of international scientists Zhang Y., Huang B., and Liu G. However, the main distinguishing feature of this study is the analysis of the complex effects of nanoparticles under Uzbekistan's climatic conditions[14,15].

Experimental results showed that:

- nano-silica increases the compressive strength of asphalt concrete;
- carbon nanotubes improve elasticity and crack resistance;
- nanoclay enhances resistance to water and moisture effects.

Economic analyses also showed that although nanomodified asphalt concrete has a slightly higher initial cost, it is economically efficient in long-term operation due to reduced maintenance costs.

Based on the results, the addition of 3% nanoparticles to asphalt concrete was recommended as the optimal option. At this proportion, the physical and mechanical properties of the material improved to the maximum level while ensuring economic efficiency.

## 5. Conclusion

The results of this study scientifically confirmed that nanoparticles can significantly improve the physical and mechanical properties of asphalt concrete pavements. During the experiments, nano-silica, carbon compounds, and nanoclay additives were found to enhance the strength, elasticity, water resistance, and deformation resistance of asphalt concrete. In particular, under the influence of high temperatures and heavy traffic loads, nanomodified asphalt concrete demonstrated greater stability compared to conventional pavements. During the research, it was observed that nanoparticles reduce microvoids in asphalt concrete, strengthen the bond between mineral particles, and slow down the process of crack formation. This ensures long-term pavement service life and reduces operation and maintenance costs.

Furthermore, the research results showed that the use of nanomodified asphalt concrete under Uzbekistan's sharply continental climate conditions significantly improves the quality and durability indicators of road pavements. Such pavements are particularly important because they undergo less deformation under high summer temperatures and winter cold conditions.

The results of this scientific work demonstrate that the creation of a new generation of road construction materials based on nanotechnology can serve as an important scientific and practical basis for improving highway operational efficiency, ensuring transport safety, and developing modern innovative road construction.

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