Modification of bitumen for road construction

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Abstract. To increase reliability and durability of road surfaces, asphalt concrete based on modified bitumens is actively used. Experts’ research shows that in modified bitumen extracted from road surfaces after 10 years of operation there are no significant changes in viscosity. The purpose of this study is to improve the properties of bitumen and asphalt concrete based on it by modifying road bitumen with carbon nanotubes. Bitumen was modified with carbon nanotubes obtained by deposition from the gas phase in the laboratory of Vladimir State University. The selection of the optimal amount of the introduced modifier was performed, modified bitumen was prepared, its properties were determined, and a comparative analysis of the properties of asphalt concrete made on modified and non-modified bitumen was carried out. Due to the introduction of carbon nanotubes into the heated bitumen, the strength and elasticity of the resulting asphalt concrete are significantly increased. The test results showed an improvement in all quality indicators of asphalt concrete by 7-9%, which allows us to say that the resulting composite has increased strength characteristics.

1. Introduction
Highways make one of the basic elements of the economy of any nation. For Russia, which has the largest territory in the world, the development of road infrastructure is of key importance. However, it is in Russia, due to seasonal temperature differences that can be up to 70 degrees or more and the constantly increasing traffic load, where there are serious problems with the adequacy of the existing road network. These problems are largely caused by the use of binders for asphalt concrete that do not meet the strict requirements imposed on them during operation.

The most effective way to improve the quality of binders for road asphalt mixes is their modification, which significantly increases the adhesion, strength and deformation characteristics of asphalt concrete, and thus the road surface as a whole.

One of the most well-known methods of modifying bitumen is the use of a modifier based on rubber crumb obtained from used rubber of automobile tires [1]. A rubber crumb based modifier can be used to improve the performance properties of a hot asphalt mixture and act as an alternative to polymer modifiers. In addition, the use of rubber crumb in the composition of asphalt concrete makes it possible to recycle production wastes.

Along with adding rubber crumbs to bitumen, they can also be added to mineral materials during their mixing (dry process), during mixing from 1 to 5% of the rubber crumbs with other components, a modified asphalt-concrete mixture is obtained [2].

Having analyzed the results of studies [2, 3], one can conclude that with an increase of rubber crumbs ratio in the mixture, the stability of asphalt concrete increases at extreme temperatures. It also significantly increases the abrasion resistance of the coating.

Another common method of modifying bitumen and waste disposal at the same time is the use of palm oil fuel ash in the modification of bitumen for the production of hot asphalt mix and warm asphalt concrete mix [4]. Research data show that mixtures prepared on bitumen modified by applying palm oil fuel ash have a 30% higher resistance to rut formation compared to standard mixtures.
Russia has a developed petrochemical industry, so the country annually has 300-400 thousand tons of polyethylene terephthalate waste, and the problem of its recycling is quite urgent, primarily due to the high cost [4,5].

However, in our opinion, the task of modifying binders for road asphalt concrete coatings can be most effectively solved with nanostructures of high-molecular polymer compounds.

A promising direction is the modification with the introduction of inorganic binders of the carbon nanoscale structures in bitumen. It was found that the introduction of carbon nanoscale structures into asphalt concrete increases the range of its operational capabilities by 10-30% [6,7].

Among the most effective nanoscale structures there are carbon nanostructures [8], which are a hollow nanofibers in the form of a filamentous structure of carbon atoms.

The object of the research is viscous road bitumen.

The goal of the research is to develop high-strength asphalt concrete compositions based on modified bitumen with nanoadditives.

Research objectives: first, identification of the optimum amount of nanoparticles introduced into the primary bitumen; second, comparative analysis of changes in the strength indicators of asphalt concrete based on bitumen modified with nanoparticles and traditional asphalt concrete.

Modifying organic binders with nanostructures of synthetic and natural origin improve their strength indicators, which in turn makes it possible to improve the quality of structural materials [9].

The fact is that modified bitumen has a larger operating temperature range, for example, the difference between the brittleness and softening temperatures of modified bitumen is about 100°C, while conventional bitumen – only about 60°C.

Asphalt concrete prepared with modified bitumen is highly resistant to deformation due to a higher degree of elasticity of such bitumen. It should also be noted that the modified bitumen greatly slows down the aging process of asphalt concrete. Expert studies show that modified bitumens extracted from road surfaces after 10 years of operation do not have significant changes in viscosity [4, 5]. The purpose of the study at this stage is to develop new compositions of modified bitumens by introducing organic carbon nanotubes into the composition.

The materials shown in figure 1 are additives whose final function is to improve the quality of the roadbed.

Figure 1 shows the classification of bitumen modifiers.

![Additives](image)

**Figure 1.** Classification of modifiers

2. Experiments
In this research, bitumen was modified with carbon nanotubes produced by deposition from the gas phase in the laboratory of Vladimir State University. The effectiveness of the modification depends on the resulting structure.

In some cases [10-12] agglomeration of CNT results in weakening of their influence on the strength characteristics of building composites. The method of preparation of modified bitumen, proposed in this study, allows you to eliminate this phenomenon.
Our task was to determine the optimal concentration of CNT to achieve maximum strength, which is reached to the point of formation of agglomerates [12], which degrade quality indicators.

The research was carried out on bitumen, the brand of which is the most widely used in road enterprises of the Vladimir region.

The technological scheme of preparation of nanomodified bitumen in the laboratory conditions included the following processes:
1. Preparation of a suspension by means of ultrasonic dispersion of carbon tubes in an organic solvent medium at a temperature of 70°C within 2 minutes.
2. Loading the initial bitumen heated to a temperature of 160 – 165°C into a laboratory mixer for sample preparation during bitumen modification.
3. Introduction of a pre-dosed amount of carbon nanotubes into the heated bitumen.
4. Thorough mixing of bitumen with carbon nanotubes for 2 – 2.5 hours with simultaneous heating to a temperature of 180°C to obtain a homogeneous state.

Table 1 shows the composition of the modified binder.

| Sample | Sample № | % component content |
|--------|----------|---------------------|
|        |          | BND 60/90 bitumen | carbon nanotube, % |
| Base   | Without marking | 100 | - |
| Modified | 1       | 95.0 | 4.5 |
|        | 2       | 95.5 | 3.75 |
|        | 3       | 95.5 | 3.5 |
|        | 4       | 95.5 | 3.0 |
|        | 5       | 95.5 | 2.0 |
|        | 6       | 94.0 | 1.0 |

The technological scheme for preparing asphalt concrete based on nanomodified bitumen in the laboratory included the following processes:
1. Identifying the composition of asphalt concrete mix and its preparation on CNT modified and non-modified bitumen.
2. Forming samples and testing them.

3. Results and discussion

Due to the introduction of carbon nanotubes into the heated bitumen, the strength and elasticity of the resulting asphalt concrete are significantly increased. At the same time, an important condition for the durability and strength of asphalt concrete is provided – this is the adhesion of bitumen to the surface of quartz sand. Since the adhesion of bitumen to the surface of such sand is insufficient, the nanotubes, which have particularly high adhesive properties, will fully ensure reliable adhesion of bitumen to the sand.

The process of strengthening the asphalt coating with carbon nanotubes is carried out as follows [10]. The basis is an asphalt concrete mix prepared in accordance with the current regulations. For our research we used asphalt concrete produced for covering roads with high and medium traffic intensity. The main component is bitumen, so improving the physimechanical and chemical properties of bitumen was the most important task in its modification. Thus, nanotubes introduced into the bitumen during the preparation of asphalt concrete mix strengthen it, turning it into a composite material with increased strength characteristics.

The results of tests on the strength of asphalt concrete produced with bitumen modified with carbon nanotubes are illustrated in figures 2 and 3.
Various studies show that the optimal amount of CNT injected into bitumen is 3-6% [5, 6, 16-21], however, the introduction of such amount of modifiers in some cases does not result in complete dissolution in the mass of bitumen, and thus it requires an increase in temperature and mixing time. This, in turn, can accelerate the aging process of bitumen and increase the cost of materials. In addition, an excessive amount of the modifier introduced can cause its aggregation in the mass of bitumen, which also affects the quality of the binder [21-25].

**Figure 2.** Strength at 20 °C of asphalt concrete samples with CNT modified and non-modified bitumen

**Figure 3.** Strength at 20 °C of asphalt concrete samples with CNT modified and non-modified bitumen
In this research, we introduced a modifier in the amount of 2% of the bitumen mass, and even this proportion made it possible to increase strength characteristics by an average of 7%.

Thus, it can be claimed that to improve the performance properties of asphalt concrete nanomaterials can be used, since the resulting composite has increased strength characteristics. This will prevent cracking and increase the durability of the road surface, and thus reduce the cost of additional technological operations (adding CNT to the bitumen). It is worth noting that this technology is a near-term perspective rather than a long shot, as it is already possible to produce such carbon nanotubes on an industrial scale.

Conclusions
1. It is proved that carbon nanotubes can be used as modifiers of road bitumen.
2. The technology of suspension preparation by means of ultrasonic dispersion of carbon tubes in an organic solvent medium in a mass of petroleum bitumen has been developed.
3. The introduction of carbon nanotubes in the amount of 2% into the road bitumen allowed obtaining an organic binder with improved performance properties.
4. The developed composition and technology contribute to improving the strength characteristics of road surfaces by 7-9%.

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