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INNOVATIVE APPLICATION OF ASPHALT CONCRETE MODIFIERS AND FOUNDATION REINFORCEMENT TECHNOLOGY IN CHALLENGING SOIL ENVIRONMENTS

Abstract. This article highlights innovative applications of asphalt concrete modifiers and foundation reinforcement technologies in challenging soil environments. We discuss the problem of reduced lifespan of asphalt concrete pavements on roads, bridges, and airports and attribute this to increased vehicle traffic and dynamic loads. It is known that the service life of asphalt concrete pavements of roads, bridges and airports has been reduced by 2–3 times in the past few decades; more than 90% of the material, labor and energy resources allocated to the road industry are not spent on new construction instead of spending it on the repair and reconstruction of old asphalt concrete pavements. This situation hampered the development of the paved road network. This situation is exacerbated by the continued increase in the carrying capacity and intensity of vehicular traffic, which results in a significant increase in dynamic loads on road surfaces. This article takes an in-depth look at the modification of rubber and rubber compounds using various additives, including multi-walled carbon nanotubes (MWCNTs), to improve their properties. It discusses how multi-walled carbon nanotubes can be used as modifiers in different elastomer matrices to improve strength and heat resistance. This article presents experimental studies of rubber composites modified with different concentrations of carbon nanotubes, focusing on their physical, mechanical and thermal properties. The use of carbon nanotube (CNT)-modified rubber for asphalt concrete has been particularly explored and advantages such as enhanced durability, noise reduction, and environmental friendliness have been noted. The performance of rubber-modified asphalt is affected by factors such as rubber-asphalt ratio and rubber particle size.

In addition, the reconstruction of ground structures has become an urgent issue in recent years. Today, climate change, rapid urbanization and the aging and obsolescence of previous generation buildings have put the reconstruction of ground structures on the agenda. Economic development, social progress and the emergence of new technologies have also provided the possibility for the reconstruction of ground structures in this complex soil environment. The article provides specific solutions to this problem.

In summary, this paper proposes solutions for foundation reinforcement and pavement structural reconstruction in difficult soil conditions, highlighting the promise of carbon nanotube-modified asphalt in these applications.

Key words: pavement reconstruction, foundation, asphalt concrete, carbon nanotubes, nanomodification technologies, modifying additives, polymer, polymer additive, asphaltenes, road construction, survivability, strength and deformation performance criteria.

Шао Мейюй, Барабаш Марія. ІННОВАЦІЙНЕ ЗАСТОСУВАННЯ МОДИФІКАТОРІВ АСФАЛЬТОБЕТОНУ ТА ТЕХНОЛОГІЇ ЗМІЦНЕННЯ ФУНДАМЕНТУ В СКЛАДНИХ ГРУНТОВИХ СЕРЕДОВИЩАХ

Анотація. Ця стаття висвітлює інноваційне застосування модифікаторів асфальтобетону та технологій зміцнення фундаменту в складних ґрунтових середовищах. Ми обговорюємо проблему скорочення терміну експлуатації асфальтобетонних покриттів на дорогах, мостах, аеропортах і пов'язуємо це зі збільшенням автомобільного руху та динамічними навантаженнями. Відомо, що термін служби асфальтобетонних покриттів доріг, мостів і аеропортів за останні кілька десятиліть скоротився в 2–3 рази; більше 90% матеріально-трудових та енергетичних ресурсів, що виділяються на дорожню галузь, спрямовуються не на нове будівництво, а на ремонт та реконструкцію старих асфальтобетонних покриттів. Така ситуація гальмувала розвиток мережі доріг з твердим покриттям. Ситуація ускладнюється постійним зростанням вантажопідйомності та інтенсивності автотранспорту, що призводить до значного зростання динамічних навантажень на дорожнє покриття. У цій статті детально розглядається модифікація каучуку та гумових сумішей за допомогою різних добавок, у тому числі багатостінних вуглецевих нанотрубок (MWCNT), для покращення їхніх властивостей. У ньому обговорюється, як багатопарові вуглецеві нанотрубки можна використовувати як модифікатори в різних еластомерних матрицях для підвищення міцності та термостійкості. У цій статті представлені експериментальні дослідження гумових композитів, модифікованих різними концентраціями вуглецевих нанотрубок, зосереджені на їхніх фізичних, механічних і термічних властивостях. Використання гуми, модифікованої вуглецевими нанотрубками (CNT) для асфальтобетону, було особливо досліджено, і були відзначені такі переваги, як підвищена довговічність, зниження шуму та екологічність. На характеристики модифікованого гумою асфальту впливають такі фактори, як співвідношення гума-асфальт і розмір частинок гуми.

Крім того, останнім часом актуальним питанням стала реконструкція наземних споруд. Сьогодні зміна клімату, швидка урбанізація, старіння та застарілість будівель попереднього покоління поставили на порядок денний реконструкцію наземних споруд. Економічний розвиток, соціальний прогрес і поява нових технологій також забезпечили можливість для реконструкції наземних споруд у цьому складному ґрунтовому середовищі. У статті наведені конкретні рішення цієї проблеми.

Підводячи підсумок, у цьому документі пропонуються рішення для зміцнення фундаменту та реконструкції конструкції тротуарів у складних ґрунтових умовах, підкреслюючи перспективність модифікованого вуглецевими нанотрубками асфальту для цих застосувань.

Ключові слова: реконструкція тротуарів, фундамент, асфальтобетон, вуглецеві нанотрубки, технології наномодифікації, модифікуючі добавки, полімер, полімерна добавка, асфальтени, будівництво доріг, критерії показників живучості, міцності та деформації.

Introduction. The reliability of the reconstructed building is guaranteed by the joint operation of the "base-foundation-ground structure" system. Failures in structural operation result from complete or partial failure of the reliability of various elements of the system.

The causes of foundation failure include both natural factors and man-made factors, as well as deviations from the scope allowed by normative documents during survey, design, construction and operation. The main causes of foundation failure are [1]:

- Overflow processes and fluctuations in groundwater levels caused by changes in hydrogeological conditions in the area where the building is located, water in the atmosphere and emergency and systemic leaks from utilities;
- Manifestations of karst deformation;
- The strength and deformation properties of the soil decrease after getting wet, and the soil expands and frost heaves;

- Excavation works, soil buoyancy, etc. in or near buildings;

- Laying communication lines;
- Increased load on the base, especially if eccentricity occurs during use;
- Vibration or dynamic effects from road and rail transport, metro lines, equipment installed in buildings and nearby industrial plants.

When rebuilding a foundation, it is impossible to develop a standard reinforcement plan. Reinforcement plans should be adopted one by one based on the load of the foundation, the existence of basements and other underground structures, engineering geology and hydrogeological conditions, etc.

It should be noted that various projects to strengthen the foundation and change the design of the foundation will not necessarily cause foundation deformation and settlement.

Improving the load-bearing capacity of foundations and foundations during reconstruction can be achieved by:

- Reinforcing and changing the design or dimensions of foundations;
- Reinforcement of subgrade soil through grouting;
- Machinery Seal;
- Strengthen;

If a reinforced concrete structure undergoes (is occurring) deformation due to settlement of the base soil, and its water sources are not removed, all methods of strengthening the structure, including the foundation, are ineffective. While soil sinking (settlement) continues, additional deepening, widening of base slabs, elimination of faults and deformations, and reinforcing or raising the bulk of damaged foundations will not prevent further building deformation.

Against the above background, this article focuses on discussing and introducing the reconstruction and calculation methods of the structure based on this.

Purpose. Discuss the problem of reconstruction of pavement structure and foundation reinforcement under difficult soil conditions, with using suitable dosage of carbon nanotube-modified rubber.

Discussion. Before assessing the nature of the damage (deformation) of the reinforced concrete structure, selecting reinforcement methods and making a general prediction of the operational suitability of the entire facility for restoration, engineering work should first be carried out to eliminate the causes of soil subsidence at the base of the foundation and then under the soil. After the sinking and building foundation subsidence were stabilized, reinforcement of the structure began.

Before starting foundation and structural reinforcement works, it is necessary to carry out long-term monitoring of crack opening conditions using beacons of various systems, and to organize and conduct geodetic monitoring of foundation settlement throughout the preparation and construction of the reinforcement works.

In order to determine the cause of settlement deformation of the foundation of an existing facility, it is necessary to carry out ancillary engineering and geological surveys at its site to determine

the source of standing water and to determine the actual physical and mechanical (deformation and strength) properties of the soil, which are used to calculate the foundation and Base. The size of the water spread zone in the foundation should be determined, for this purpose the spacing of controlled excavations should not exceed 10–15 meters.

Given the significant heterogeneity and variability (in space and time) of the natural composition of built-up areas, the formation and development of adverse engineering geological and hydrogeological processes resulting from specific anthropogenic influences are insufficiently studied for housing in built-up areas. Buildings and structures are unique and highly responsible and should therefore be based on basic principles that ensure hydrogeological reliability and safety [2]: At all stages of the life cycle, the groundwater level (GWL) should be within established limits.

Floods have adverse effects on the soil of the foundations of buildings and structures, resulting in uneven precipitation, soil subsidence, changes in strength properties, and a decrease in the soil bearing capacity of the foundations of buildings and structures. These changes can trigger new landslides and karst erosion processes, or trigger old ones, leading to accidents, collapses and the inability to continue functioning of buildings and structures. For clays, when flooded, the adhesion force decreases by a factor of 2–2.5; the angle of internal friction decreases by a factor of 10–15%; and the modulus of deformation E decreases by a factor of 2–3.5.

Groundwater has both direct and indirect effects on the foundations of buildings and structures. According to the literature [5; 6], the indirect or direct impact of groundwater on building foundation soil can lead to building deformation and accidents in 80% of cases.

Determination of the physical, mechanical and strength properties of the soil should be carried out under the influence of loads actually acting at the soil sampling depth. It should be assumed before the survey that an actual stress state exists in the foundation, including stresses resulting from the soil's own weight and stresses distributed through the thickness from external loads,

which stresses are transferred to the foundations of the object in question and to the foundations of adjacent adjacent buildings. In other words, the following conditions hold true throughout the thickness of the foundation

$$\sigma_2 = \sigma_{2g} + \sigma_{gp}$$

where, σ_2 – the determined actual compressive stress sum under the combined action of soil weight and external load;

σ_{2g} – the compressive stress caused by the soil's own weight;

σ_{gp} – Compressive load resulting from external loads transferred from the building to the base.

The calculated characteristics of the soil should be determined according to the data of laboratory or stamping tests, taking into account the loading and unloading zones, including natural humidity and wetting (water saturation).

In workshops where corrosive liquids and solutions seep into the ground, determine whether the foundation structure has waterproofing and chemical protection measures. Asphalt concrete surfaces are often used in these workshops. And hydraulic plates are used to reinforce the ground.

Hydraulic slabs shall be bowl-shaped with concrete properties W6. It functions as a slab foundation and is a sealed basin that does not allow moisture to penetrate from the ground into the building and vice versa.

When choosing how to reinforce foundations and foundations, the following should be taken into consideration if the building experiences unacceptable deformations that affect its normal operation, as well as increased loads on the foundations during reconstruction:

a) The nature of ground structure deformation (growth, attenuation, stability, frequency of occurrence – seasonality, regularity, emergency, single or multiple times, random or long-term, etc.);

b) Type of ground structure deformation (such as deformation growth, attenuation, stability, frequency of occurrence decay, stability, frequency of occurrence – seasonal, regular, urgent, single or multiple times, random, long-term, etc.);

c) Determine the type of construction based on the nature of the technical workmanship and

the potential for water accumulation in the sub-soil, including

Process buildings with frequent spills of water or aqueous liquids in certain areas or throughout the area;

Also included are processes without regular bottling of water or aqueous liquids, buildings with water supply networks and domestic premises;

Additionally, no water distribution network and fixtures are installed except for external drainage and stormwater drainage systems, and the external water distribution network is located at a distance that exceeds 1.5 times the depth of the settlement layer beneath the facility;

d) There are (no) external permanent or possible (emergency) immersion sources in the foundation soil (reservoirs, cooling towers, pools, sedimentation tanks, etc.); there are (no) external permanent or possible (emergency) sources near the reinforcement facilities (reconstruction). Whether there are external permanent or possible (emergency) sources of foundation soil immersion (reservoirs, cooling towers, pools, sedimentation tanks, etc.) near the immersion sources and reinforcement facilities (reconstructed structures) [3];

e) The technical and technological nature of the reconstructed building (see item "b") and water-carrying equipment networks, devices and equipment;

f) Continuous water leakage caused by failure of water-containing pipe networks and facilities such as water supply, sewage, heating, rainwater and domestic sewage discharge outlets;

g) Groundwater level rise (permanent, seasonal);

h) Annual flood flow in the development area;

i) Due to the lack of necessary vertical planning in built-up areas, the natural runoff conditions of atmosphere and melt water are damaged;

j) Uncontrolled watering of green areas [4].

In all such cases, it is very difficult to strengthen the foundations by structural means, and therefore it is worth using a coating made of modified asphalt concrete modification of rubber using carbon nanotubes.

The above results have guiding significance for the reconstruction of ground structures, which

of course also includes infrastructure such as roads and pavements. Next we will introduce the modification of rubber using carbon nanotubes. The research results are of great significance to the modification of asphalt concrete.

The performance characteristics of modified rubber are shown in Tables 1 and 2.

Table 1
Physical and mechanical properties of the sample

Technical specifications	Modified rubber using CNTs			
	1	2	3	D
Concentration of carbon nanotubes (weight percent)	0	0.5	1.0	
Conditioned tensile strength, MPa	9.02	104	102	14
Elongation at break, %	142	185	208	38
Wear resistance, cm ³ /W	255	105	96	58
Wear energy, J/mm ³	144	391	361	165
Aging, 1000 C, 24 hours, percentage	15	4.1	8.1	27

Table 2
Sample thermal analysis results

Index	SBC composition with different carbon nanotube contents (weight %)	
	0	0.5
T5%, 0 C	307	355

When the CNT content is 0.1 wt.%, the physical and mechanical properties are improved by 2–4 times (sample No. 2). The composites with 0.1 wt.% CNT content had the highest condition strength and the largest relative elongation. Composites of this composition have the highest bond energy in the polymer matrix. As the carbon nanotube content further increases to 5.0 wt.%, the physical and mechanical properties decrease, i.e. the bond energy in the polymer matrix gradually weakens.

When the carbon nanotube content in the composite increases from 0.1 wt.% to 2.0 wt.%, the strength of the composite increases significantly. As the filling degree further increases, the reinforcement effect decreases, while the viscosity of the paste increases, and the physical and mechanical properties decreased.

For spheres, the introduction of multi-walled carbon nanotubes affects all studied properties: as the concentration of carbon nanotubes increases in the

studied interval, the fracture strain of the nanocomposite decreases and the tensile strength and hardness increase. It is worth noting that these dependencies are not linear, so optimal CNT concentration values can be found based on consumer characteristics.

An effective mechanism for improving the strength of polymer-multiwall carbon nanotube composites is the crystallization of the composites. The degree of crystallinity varies depending on the concentration of carbon nanotubes. In the case of very low concentrations of carbon nanotubes, the degree of crystallinity may not be sufficient due to the small number of "crystalline centers"; in the case of high concentrations of nanotubes, these centers may "interfere" with each other: the "peripheral" molecules. The number increases, as evidenced by the increase in the half-width of the X-ray reflection. Fabrication of the composite involves synthesizing multi-walled carbon nanotubes of diameter D in a growth catalyst gas mixture, adding nanotubes at a mass concentration N to the polymer, and pressing at the polymer melting temperature. Then, in order to determine the concentration of N, additional composite samples with different nanotube concentrations were made, and the relationship between the infrared absorbance of the composite of a given nanotube diameter D and polymer and the mass concentration of nanotubes in the composite was measured, thus Determine the nanotube concentration N corresponding to the maximum infrared absorption rate in the nanotube hybridization frequency region sp³. In this case, multi-walled carbon nanotubes with diameter D = 20÷25 nm were used, with a N concentration of 0.25±0.05 wt.%, and diene rubber as polymer.

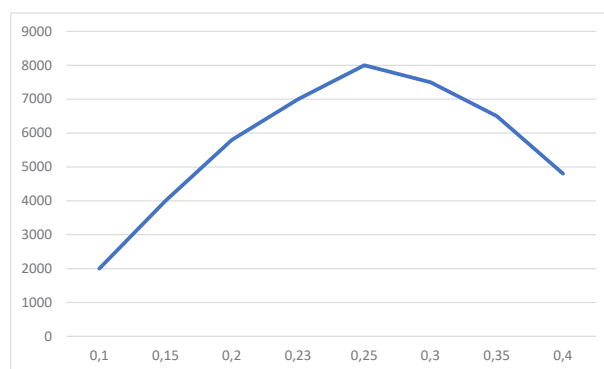


Fig. 1. Relationship between infrared spectrum and carbon nanotube concentration

Figure 1 shows the experiment of infrared absorption in the hybrid sp^3 bond region of carbon nanotubes at a frequency of 1370 cm^{-1} and the mass concentration of multi-walled carbon nanotubes with a diameter of 20 nm in a rubber-multiwalled carbon nanotube composite (icon) relationship, and its one-dimensional Gaussian curve approximation (a straight line).

It is clear that carbon nanotubes are a more efficient filler, thanks first to their form factor. The ratio of the largest dimension (length) of CNTs to the smallest dimension (diameter) is 103 times. At the same time, the specific surface of CNT is $200\text{ m}^2/\text{g}$, while this value for carbon black is $100\text{ m}^2/\text{g}$ [7].

The relaxation mechanism of CNT dispersion and the molecular colloidal organization model of the rubber structure [8] are based on the heterogeneity of the Newtonian flow of elastomers and the forced adhesion of the minimally mobile polymer parts. The dispersion of carbon nanotubes begins with their association with elastomer segments, which glue together in the shear stress region, causing excessive strain of the elastomer chains and stretching of the agglomerates into carbon rubber particles. The segregation of carbon nanotube particles is due to reduced segment mobility of the bonded elastomer, causing the particles to shrink and harden with each glass transition cycle. The overly stressed matrix chains are not as strong as the particles and will break into large free radicals at the boundary with the glass segment, thus initiating the cross-linking process and further strengthening the particles and elastic transition layer. Tightly cross-linked transition layers combine carbon rubber particles into chain structures, thus strengthening the matrix, while loose transition layers expand in matrix segments and may collapse under the rolling conditions of the rubber compound [9, 10, 11].

It can be seen that elastomer strengthening is not an isolated phenomenon at the interface boundary, but a complex colloid-chemical process that forms the interface region and vulcanization structure in the carbon-rubber nodes of the rubber network structure. The deformation of the rubber begins with the repositioning of the mesh nodes, overcoming their physical interaction within the chain structure and with the matrix, while at the same time reducing its functional-

ity due to breakage of the overstressed chains. During the final stages of fracture, the nodes also deform, which helps dissipate overstress at the interface boundary and further increases rubber strength. Occlusion rubber plays an important role in increasing the ability of mesh nodes to deform, while polar modifiers reduce this ability.

Strengthen interface boundaries and seal transition layers in rubber mesh nodes, thereby reducing their deformability [12]. Reducing the unsaturation of the rubber through hydrogenation redistributes the cross-linking process from the interface boundaries to the entire volume of the particle, thereby increasing the thickness of the transition layer and the functionality of the nodes, and increasing the strength of the rubber by 30%.

It should also be noted that when carbon nanotubes are introduced directly into the elastomer matrix as a modifying additive, all necessary fillers such as carbon black and gas silicon must be added first [13].

Therefore, the combination of recipes and technical methods that control the functionality, strength and deformability of the mesh nodes, the interfacial interactions within the mesh nodes, and the thickness and density of the transition layers form the basis for reinforcement, allowing targeted Change rubber properties [14].

According to the experimental correlations obtained, carbon nanotubes introduced at 0.1–0.25% by weight have the highest values for the physical and mechanical properties of the rubber composites. With the further introduction of carbon nanotubes, the conditional strength and relative elongation at break decreased. This is due to the bonds in the elastomer component being broken.

Results. Through theoretical and experimental studies, we have developed a series of solutions for the reinforcement of foundations and the reconstruction of pavement structures in difficult soil conditions. In addition, the mechanism of carbon nanotube modified asphalt was demonstrated, and ultimately we believe that carbon nanotubes introduced at a weight percentage of 0.1%–0.25% have the highest physical and mechanical property values of the rubber composite. The research results are of great significance to the construction of road pavements, especially high-quality construction.

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