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Improving The Service Life of Road Concrete Under The Effect of Mineral and Chemical Additives

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Abstract: In the Republic of Uzbekistan, the construction of modern toll roads and highways represents a key infrastructure component that ensures the efficient functioning of transport networks globally. While asphalt and concrete materials traditionally used in road construction have proven somewhat effective, they face challenges related to long-term strength, durability, and environmental impact. This study analyzes composite materials that are fundamentally transforming road and highway construction practices and highlights their potential to overcome existing issues. It evaluates the operational efficiency of complex modified materials in road construction, emphasizing how mineral and chemical additives enhance concrete and pavement strength, resistance to deformation, cold, and aggressive environments. The findings indicate that employing these materials can extend infrastructure service life, reduce maintenance costs, and support environmental sustainability.

Аннотация: В Республике Узбекистан строительство современных платных дорог и автомагистралей является ключевым элементом инфраструктуры, обеспечивающим эффективное функционирование транспортных сетей на глобальном уровне. Хотя традиционно используемые в дорожном строительстве материалы, такие как асфальт и бетон, доказали свою относительную эффективность, они сталкиваются с проблемами, связанными с долгосрочной прочностью, долговечностью и воздействием на окружающую среду. В данном исследовании анализируются композиционные материалы, которые фундаментально трансформируют практику строительства дорог и автомагистралей, и подчеркивается их потенциал для решения существующих проблем. Оценивается эксплуатационная эффективность комплексных модифицированных материалов в дорожном строительстве, с акцентом на то, как минеральные и химические добавки повышают прочность бетона и дорожного покрытия, устойчивость к деформации, холодам и агрессивным воздействиям. Результаты показывают, что использование этих материалов может продлить срок службы инфраструктуры, сократить расходы на обслуживание и способствовать экологической устойчивости.

Annotatsiya: O‘zbekiston Respublikasida zamonaviy pullik avtomobil yo‘llari va magistral yo‘llar qurilishi transport tarmoqlarining global miqyosda samarali faoliyat ko‘rsatishini ta’minlovchi infratuzilmaning muhim tarkibiy qismi hisoblanadi. An’anaviy yo‘l qurilishida ishlatiladigan asfalt va beton materiallari o‘z samarasini nisbatan ko‘rsatgan bo‘lsa-da, ular uzoq muddatli mustahkamlik, chidamlilik va atrof-muhitga ta’sir bilan bog‘liq muammolarga duch keladi. Ushbu tadqiqot yo‘l va magistral yo‘llar qurilish amaliyotini tubdan o‘zgartirayotgan kompozit materiallarni tahlil qiladi va ularning mavjud muammolarni hal qilishdagi potentsialini yoritib beradi. Tadqiqotda yo‘l qurilishida kompleks modifikatsiyalangan materiallarning ekspluatatsion samaradorligi baholanadi, xususan, mineral va kimyoviy qo‘shimchalar beton va yo‘l qoplamasining mustahkamligini, deformatsiyaga, sovuqqa va agressiv muhitlarga chidamliligini qanday oshirishini ko‘rsatadi. Tadqiqot natijalari ushbu materiallardan foydalanish yo‘l infratuzilmasining xizmat muddatini uzaytirish, ta’mirlash xarajatlarini kamaytirish va ekologik barqarorlikni ta’minlash imkonini berishini ko‘rsatadi.

Introduction

Improving the quality of concrete materials in road construction is crucial for ensuring the long-term performance and durability of pavements. Modern construction conditions and climate change significantly

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affect concrete performance, especially due to factors that contribute to damage during freezing and thawing cycles. In recent years, there has been growing demand for high-quality concrete mixtures in road construction, as their improvement can extend pavement service life and reduce operational costs. The development of new construction technologies and materials, including concretes incorporating complex additives, represents an innovation for the industry, increasing the competitiveness of Uzbekistan's construction sector and prolonging structural lifespan. Considering the country's dry and hot climate, this study aims to develop recommendations for enhancing the operational, physical, and mechanical properties of concrete for cement-concrete roads using locally available mineral and chemical additives. The construction of roads and highways plays a vital role in the development of Uzbekistan's infrastructure, serving as a key factor in economic activity, transport logistics, and interregional social connectivity. Traditional road construction materials—namely asphalt and concrete—have been widely used for decades due to their strength and multifunctionality. However, the country faces challenges such as limited natural resources, environmental impacts, and increasing costs associated with the operation and maintenance of pavements [1]. Therefore, the search for innovative and composite materials that enhance the operational durability of road concrete has emerged as a pressing scientific and practical task. In recent years, a new generation of concrete incorporating mineral and chemical complex additives has been developed for road construction under Uzbek conditions. These additives serve to improve the physical and mechanical properties of concrete, increasing the strength of pavements, resistance to deformation, and durability under cold and wet conditions.

Method Of Research

The dry and hot climate negatively affects concrete work technology and the long-term durability of cement-concrete pavements on roads. This impact is manifested in changes to the properties of the pavement concrete, the formation of various cracks, and an increase in the degree of deformation. Ignoring the characteristics of a dry-hot climate can lead to a significant deterioration, and even failure, of cement-concrete pavements.Studies on the causes of failure in several cement-concrete road pavements have shown that during repairs, concreting was carried out in the dry and hot season, resulting in concrete with physical and mechanical properties significantly below standard [2]. The dry-hot climate creates serious challenges for concrete works, including:

- An increase in the temperature of the concrete mixture, which raises its water demand;
- A sharp reduction in the workability of the concrete mixture during transportation;
- Rapid moisture loss in newly placed concrete, causing a reduction of up to 50% in the compressive strength over the first month and deterioration of other physical and mechanical properties;
- The formation of cracks in curing concrete due to increased plastic shrinkage, significantly reducing the long-term durability of reinforced concrete structures;
- Uneven temperature distribution in cement-concrete pavements under solar radiation, leading to thermal stress and crack formation;
- Additional difficulties in performing concrete works, which require excessive expenditures.

Improving the quality of concrete used in road construction is one of the key directions of modern scientific and technological development. The sharp increase in traffic flows, the growing complexity of climatic conditions, and the demand for extending the service life of pavements necessitate the use of additives in concrete compositions. In particular, complex additives make it possible to simultaneously enhance several important technological and physical-mechanical properties. Scientific research indicates that the effectiveness of complex additives is based on the synergistic interaction of the substances that constitute them. For example, when a superplasticizer and microsilica are applied together, the cement hydration process is controlled, resulting in a denser and more homogeneous cement stone. This increases the concrete strength by 20–30% and raises its water impermeability to the W8–W10 range. At the same time, the reduction of voids in the concrete mixture can increase frost resistance from F200 to F400–F500. Complex additives not only enhance the strength and density of concrete but also improve its long-term operational properties. For instance, air-entraining additives create fine air bubbles within the concrete, preventing internal pressure during freeze–thaw cycles. As a result, common cracking and spalling in road concrete are significantly reduced.Mineral additives (metakaolin, microsilica, fly ash, slag, silica fume) form

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secondary hydration products that fill the voids in the cement gel, thereby increasing the concrete's resistance to aggressive environments. Scientific and theoretical studies also indicate that the use of complex additives ensures the microstructural stability of concrete. According to the theory of dispersed systems, additives strengthen interparticle bonding, while according to crystal formation theory, they stabilize the crystalline phases of cement stone. Such an approach can extend the service life of concrete by 1.5–2 times [3].

Materials Used

Table 1.

Names of the materials	**, fraction)**	**Manufacturer**
Portland cement	**CEM I 42.5 N**	**"HUAXIN CEMENT JIZZAKH"**
Sand	**-**	**OOO «Zarxal sand».**
Gravel	**5-20 Fraction**	**OOO «Zarxal sand»..**
Crushed stone	**20–40 Fraction**	**"Sayxan" LLC Stone crushing plant Quarry**
Metakaolin admixture	**Metaver I**	**OOO "ALES POLIIZOL"**
uperplasticizer admixture	**Master Glenium 115**	**Arment Construction Chemicals**

Reactive metakaolin is employed as an additive in combination with superplasticizer and wollastonite. Metakaolin (MK) is a mineral pozzolanic additive that significantly enhances the properties of hydraulic cement mixtures, concrete, and similar products. MK mixtures are easily workable and provide a smooth plastic consistency, improving convenience during construction. With kaolin ore deposits available in Kazakhstan, the production of this additive is considered promising. The unique feature of MK is its ability to bind substantial amounts of free lime in the form of stable crystalline hydrates.Elemental analysis was performed on various sample particles. Figures 1 and 2 present the spectral results of this analysis [4]. The additive is dominated by SiO_2 and Al_2O_3, with contents of 52–54% and 40–43%, respectively. Additionally, small amounts (0.1–2%) of Fe_2O_3, TiO_2, CaO, MgO, Na_2O, and K_2O were detected. The high silicon dioxide content demonstrates the high chemical reactivity of metakaolin.

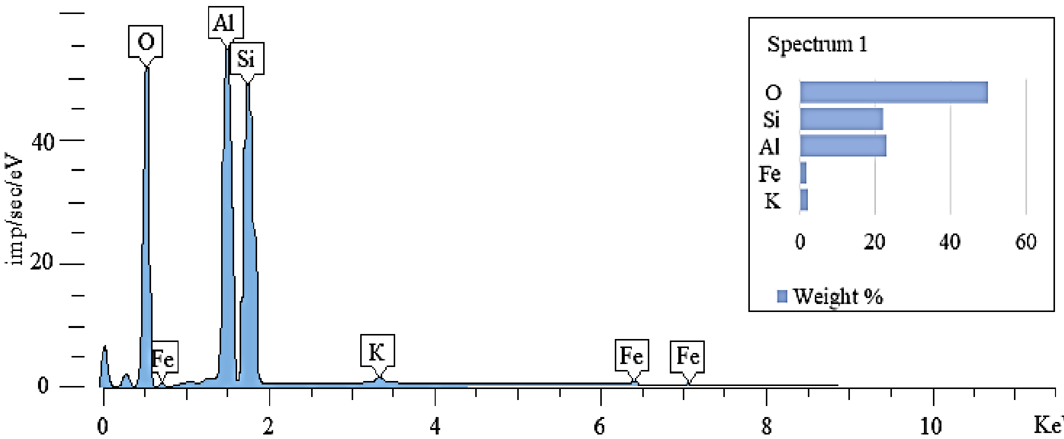

FIGURE 1. Elemental analysis of metakaolin

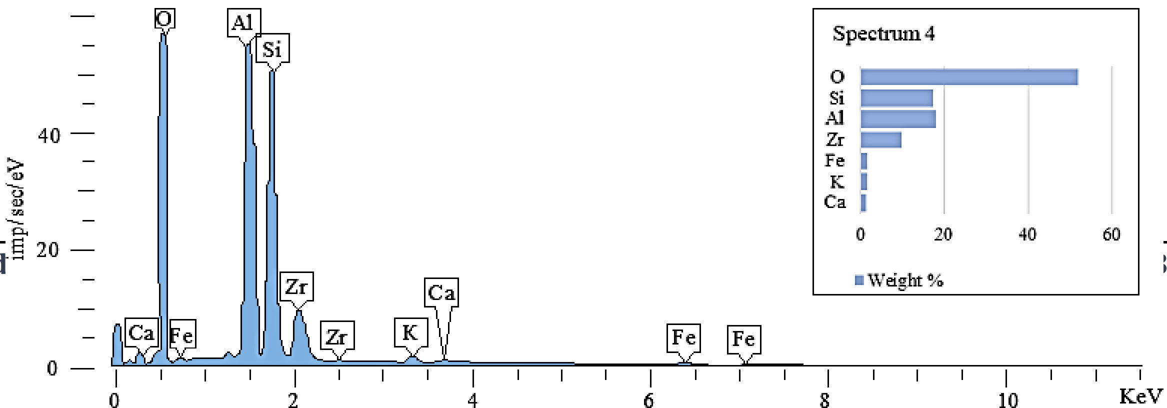

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FIGURE 2. Elemental analysis of metakaolin

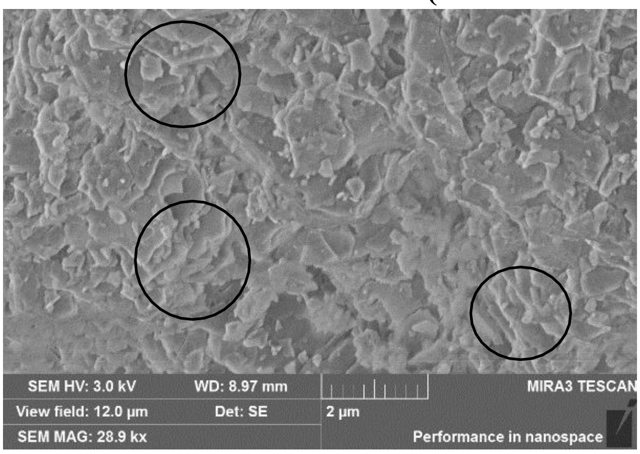
The main physical properties of metakaolin are presented
Physical properties of metakaolin

TABLE 2.

Physical characteristics	Indicator
Density	2.6 kg/cm^3
Particle distribution d50 d95	3.4-4.5 mk 12-18 mk
Specific surface area (Blaine)	23000 cm^2/g
Specific surface area (BET)	18 m^2/g
Color	Cream

Studies were conducted on the microstructure of MK. Figure 3 presents photographs of the MK microstructure obtained using a Tescan MIRA3 scanning microscope. As shown in the images, the sample exhibits a layered structure. The layered microstructure imparts plasticity to these base materials. The bright areas on the right side indicate the presence of heavier elements relative to the main matrix [5]. X-ray spectral analysis results revealed that zirconium, along with other elements, is also present in these bright regions.

Figure 3. Microstructure of metakaolin (view field: 12.0 μm)



In addition to metakaolin, a superplasticizer additive based on polycarboxylate ether, MasterGlenium 115, was used. The plasticizing additive improves the workability of the concrete mixture, reduces water

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content, saves cement (without compromising concrete strength), and increases adhesion. TABLE 3 presents the main properties of the MasterGlenium 115 additive [6,7].

Properties of the Master Glenium 115 superplasticizer admixture

TABLE 3.

Property	**Indicator**
Color	**Light brown color**
Density,	**1.05-1.09**
Chloride content, %	**<0,1**
Alkali content %	**<3**

Another important aspect of using complex additives in road construction is economic efficiency. Incorporating additives into the concrete mixture allows for a reduction in cement consumption, which lowers the cost of construction materials. Additionally, the extended service life of pavements significantly reduces maintenance and reconstruction expenses. The use of complex additives in road concrete is a scientifically justified, highly effective, and promising approach. These additives enhance concrete strength, water impermeability, frost resistance, and long-term durability. At the same time, they extend the operational lifespan of road structures, ensuring both economic and environmental efficiency. Future research should focus on developing environmentally friendly and cost-effective complex additives based on local raw materials. By incorporating chemical additives into the concrete mixture, the properties of concrete can be controlled: setting can be accelerated or retarded, workability and plasticity improved, the curing process optimized, and both strength and frost resistance increased [8].

Results And Discussion

According to the experimental results, the incorporation of activated metakaolin into the concrete mixture, particularly in combination with a plasticizing additive, leads to a substantial improvement in compressive strength. Specifically, when metakaolin is introduced at a dosage of 15% by weight of cement together with a superplasticizer, the compressive strength of concrete increases from 40.45 MPa to 54.7 MPa. This corresponds to a 35% increase in strength compared to the control mixture without mineral and chemical additives. The positive effect of metakaolin can be attributed to its high pozzolanic activity and its role as a finely dispersed filler, which contributes to the densification of the cement matrix. The addition of metakaolin accelerates the formation of secondary calcium silicate hydrates (C–S–H), leading to a denser microstructure and reduced capillary porosity. As a result, the strength development process is significantly enhanced, with the strength index increasing by approximately 40% relative to the initial reference value. Furthermore, the pre-treatment of mixing water using an electrolyzer has a pronounced effect on the mechanical properties of concrete. The use of electrolytically activated water increases the compressive strength by up to 1.5 times compared to the control sample prepared with ordinary water. This effect is explained by the increased reactivity of activated water, which improves cement hydration kinetics and promotes more uniform distribution of hydration products. Consequently, the application of such pre-activated water is considered essential for the production of high-strength and high-performance concrete. The combined use of metakaolin, a superplasticizer, and electrolytically activated water demonstrates a synergistic effect, resulting in superior strength characteristics compared to the use of each component individually. The study confirms that metakaolin exhibits maximum efficiency when applied alongside chemical plasticizers and activated mixing water. It should be noted that previous studies reported strength increases of approximately 30% when dispersed fillers such as metakaolin were used independently at dosages of up to 30% of the cement weight. In contrast, the present research employs wollastonite in combination with metakaolin and a superplasticizer, achieving an overall strength increase of up to 50% compared to the initial control composition [9,10]. This significant improvement is primarily attributed to enhanced adhesion between the cement stone and reinforcing components, a marked reduction in the

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porosity of the cement matrix, and the effective micro-reinforcement of concrete due to the fibrous structure of wollastonite. As a result, the proposed composite modification approach provides a promising pathway for developing high-strength and durable concrete with improved microstructural characteristics and enhanced эксплуатацион (service) performance.

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