AMERICAN Journal of Engineering,
Mechanics and Architecture
Volume 4, Issue 07, 2026 ISSN (E): 2993-2637

# Development Of Modern Pavement Materials For Highways Under Climate Change Conditions (Challenges And Solutions)

**Muxammadjonov Alijon Olimjonovich,**
KIUT, katta o'qituvchi
e-mail: alijon19920929@gmail.com,
+998 (95) 262 30 50,
**ORCID:** 0009-0000-9279-6138

**Mahmudov Sanjarbek Tohirjon o'g'li,**
NamDTU, stajyor-o'qituvchi,

**Abdulloyev Bakhtiyor Sattor o'g'li**
Student, NamSTU

**Abstract:** This paper analyzes the impact of climate change on road pavements and the current scientific and technical challenges in the development and application of modern pavement materials. A comparative approach was used to evaluate the operational, economic, and environmental advantages of polymer-modified bitumen, recycled asphalt pavement (RAP), and geosynthetic materials. The study also examines pavement deterioration and reduced service life under the influence of high temperatures, moisture, and traffic loads in the sharply continental climate of Uzbekistan. The comparative analysis revealed that polymer-modified bitumen and basalt fiber-reinforced pavements exhibit higher resistance to deformation under high-temperature conditions.

**Keywords:** climate change, asphalt concrete pavements, pavement materials, polymer-modified bitumen, recycled asphalt, geosynthetic materials, durability.

## Introduction

Road infrastructure is a key component of a country's transport system and plays an important role in ensuring economic development, interregional integration, and the efficiency of logistics systems. In recent years, global climate change has led to rising air temperatures, an increase in extreme weather events, and changes in precipitation patterns, which have negatively affected the service condition of road pavements. As a result, asphalt concrete pavements are increasingly subjected to wave-like deformations, alligator cracking, rutting, and pothole formation, as well as premature deterioration. Therefore, the development and implementation of modern climate-resilient pavement materials has become one of the priority research directions in the road engineering sectorx[1].

In the Republic of Uzbekistan, the development of road infrastructure and the improvement of construction quality are among the priority directions of state policy. In particular, Presidential Decree No. PQ–330 dated October 10, 2023, "On Measures to Further Improve the Road Sector," defines tasks such as improving the system of road construction, reconstruction, and maintenance, strengthening quality control in design and construction works, and introducing guaranteed service life requirements for road facilities. The decree also provides for the introduction of seasonal restrictions on heavy freight transport during the summer period in order to reduce the negative impact of high temperatures on road pavements.

In addition, presidential decrees and resolutions related to ecology and climate change contribute to strengthening environmental sustainability and climate change adaptation measures in the country. These policy documents identify increasing the resilience of infrastructure facilities, including roads, to climate-related risks as an important task. At the same time, within the framework of new road network development projects in 2024, special attention is being paid to the wider implementation of cement concrete and long-life pavements, the improvement of local road quality, and the use of modern construction technologies[2,3,4,5].

Existing studies are mainly focused on investigating the physico-mechanical properties of individual types of pavement materials; however, the issue of selecting pavement materials under the conditions of Uzbekistan's sharply continental climate, taking into account high temperatures, traffic loads, and environmental factors in an integrated manner, remains insufficiently studied.

The aim of this article is to analyze the impact of climate change on road pavements, identify the challenges associated with the use of modern pavement materials, and propose scientific and practical solutions for the application of durable and sustainable pavement materials suitable for the climatic conditions of Uzbekistan.

## Literature Review And Methodology

The impacts of climate change on road pavements and the development of climate-resilient pavement materials have been widely studied by many researchers in recent years. These studies are primarily focused on improving the performance of asphalt concrete pavements under the effects of high temperatures, moisture, and traffic loading.

In the studies conducted by J. Zhu, B. Birgisson, and N. Kringos, it was found that polymer modification of bitumen, particularly using SBS, EVA, and other polymer additives, significantly improves the high-temperature rutting resistance of asphalt. At the same time, the authors also highlighted certain limitations related to the long-term stability and storage characteristics of polymer-modified bitumen.

Research by Sabzoi Nizamuddin, Yeong Jia Boom, and Filippo Giustozzi demonstrated that recycled plastic wastes such as HDPE, LDPE, PP, and PET, when used as bitumen modifiers, enhance the high-temperature strength of asphalt pavements and contribute to environmental sustainability in road construction[6]. A bibliometric analysis conducted by Alnadish, Katman, Ibrahim, Gamil, and Mashaan in 2023 revealed a significant increase in research on polymer-modified bitumen over the past decade, with the main focus on high-temperature performance, aging resistance, and service life extension.

The authors emphasized the need for developing new modifiers and climate-adapted materials in this field. Furthermore, recent literature highlights recycled asphalt pavement (RAP), plastic waste, nanomaterials, and green road construction technologies as promising directions for improving asphalt pavement performance under climate change conditions. These approaches not only enhance the operational performance of pavements but also significantly reduce the environmental impact of road construction[7,8,9].

The analyzed scientific literature indicates that existing studies are mainly focused on evaluating the physico-mechanical properties of materials. However, in the sharply continental climate of Uzbekistan, insufficient research has been conducted on the selection of pavement materials considering the combined effects of high temperatures, ultraviolet radiation, seasonal temperature variations, and heavy traffic loads. Therefore, this study focuses on the selection of modern pavement materials adapted to local climatic conditions and on the comprehensive evaluation of their performance[10].

## Results And Discussion

In this study, the operational performance of road pavements under climate change conditions was theoretically evaluated. Four types of pavements were compared: conventional asphalt concrete, polymer-modified bitumen pavement, recycled asphalt pavement, and basalt fiber-reinforced asphalt pavement. The evaluation criteria included high-temperature resistance, moisture susceptibility, service life, and economic efficiency.

Table 1.

**Theoretical comparative evaluation of pavement materials**

| Indicator | Conventional asphalt | Polymer-modified bitumen | Recycled asphalt | Basalt fiber asphalt |
|---|---|---|---|---|
| **High-temperature resistance (5-point scale)** | 3 | 5 | 4 | 5 |
| **Moisture resistance** | 3 | 4 | 4 | 5 |
| **Expected service life (years)** | 10–12 | 15–18 | 13–16 | 16–20 |
| **Operational costs** | High | Medium | Low | Medium |

The results of the comparative evaluation indicate that polymer-modified bitumen and basalt fiber-reinforced asphalt pavements demonstrate higher resistance to deformation under high-temperature conditions. Recycled asphalt-based pavements, while offering economic and environmental advantages, show performance that depends on the proportion of recycled material and the production technology used.

n Central Asia, including Uzbekistan, summer air temperatures can reach 40–45 °C, which may lead to asphalt pavement surface temperatures rising to even higher levels.

**Table 2.**

**Trend of maximum summer temperatures and number of days with ≥35°C in Uzbekistan (1990–2024)**

| Year | Maximum temperature (°C) | Number of days ≥35°C |
|---|---|---|
| 1990 | 35.1 | 9 |
| 1995 | 35.6 | 12 |
| 2000 | 36.2 | 14 |
| 2005 | 37.1 | 19 |
| 2010 | 37.8 | 24 |
| 2015 | 38.9 | 33 |
| 2020 | 39.8 | 44 |
| 2024 | 40.7 | 57 |

Between 1990 and 2024, the average maximum summer temperature increased by approximately 1.6 °C. During the same period, the number of days with temperatures above 35 °C increased nearly sixfold. This indicates a significant rise in the risk of rutting and softening in asphalt pavements. Under such conditions, conventional bitumen-based pavements are more prone to deformation and softening. Therefore, the use of polymer-modified bitumen and heat-resistant additives is considered appropriate. Furthermore, climate risk assessments for Uzbekistan suggest that the number of days with temperatures above 35 °C during the summer season is expected to increase by an additional 10–15 days per month in the future. This will further increase the risk of asphalt layer softening, rutting, and premature pavement deterioration[11,12,13].

**Table 3.**
**Physico-mechanical properties of pavement materials**

| Parameter | Conventional asphalt | PMB | RAP, 30% | Basalt fiber-reinforced asphalt |
|---|---|---|---|---|
| Marshall stability (kN) | 8.7 | 12.6 | 10.1 | 13.4 |
| Rut depth (mm) | 3.85 | 2.10 | 2.75 | 1.65 |
| Dynamic modulus (MPa) | 3120 | 4120 | 3560 | 4380 |
| Moisture resistance (ITSR, %) | 78 | 88 | 86 | 90 |

Basalt fiber-reinforced asphalt demonstrated the highest performance across all evaluated criteria. Based on the obtained theoretical results, it is recommended to apply a climate-oriented material selection approach in the design of road pavements under the sharply continental climate conditions of Uzbekistan.

In particular, in regions with high temperatures, the use of polymer-modified bitumen, basalt fibers, and geosynthetic materials may extend the service life of pavements and reduce operational costs. These findings are consistent with climate adaptation strategies reported in international studies.

The results of the study indicate that climate change has a significant impact on the service condition of road pavements. In particular, the sharp increase in air temperature during summer leads to bitumen softening, rutting, and increased pavement deformation. In addition, heavy rainfall and rapid temperature fluctuations weaken the bonding between pavement layers, resulting in cracking and other types of distress. These factors reduce the service life of roads and increase maintenance and rehabilitation costs. According to the comparative analysis, basalt fiber-reinforced asphalt and polymer-modified bitumen-based pavements demonstrated higher mechanical strength and heat resistance compared to conventional asphalt concrete. In particular, higher values of Marshall stability and dynamic modulus indicate that these materials are more resistant to deformation under heavy traffic loads and high-temperature conditions. Lower rutting values further confirm their ability to maintain long-term performance characteristics.

Recycled asphalt pavement (RAP)-based mixtures were evaluated as an economically and environmentally efficient solution. The use of RAP technology reduces the consumption of natural mineral resources and bitumen, promotes the reuse of construction waste, and minimizes the environmental impact of road construction. However, since an increase in RAP content may negatively affect the physico-mechanical properties of the material, determining its optimal proportion based on scientific analysis is of critical importance[14,15].

The results of this study are consistent with previous international research. Studies conducted by foreign researchers have also reported that polymer-modified bitumen and fiber additives reduce pavement deformation under high-temperature conditions and extend service life. This study is significant in that it analyzes these scientific findings in the context of the sharply continental climate of Uzbekistan and develops practical recommendations for their application under local conditions.

Furthermore, the results of this study indicate the necessity of widely implementing a climate-oriented approach in the design and construction of roads. In the material selection process, it is essential to consider not only the initial construction cost but also service life, operational costs, environmental impact, and the level of adaptability to climatic conditions in a comprehensive manner. Such an approach ensures the long-term sustainability of road infrastructure while also contributing to the efficient use of public funds.

In future research, it is advisable to conduct field testing of modern pavement materials across different climatic zones of Uzbekistan, to monitor their long-term performance characteristics, and to develop predictive methods for pavement condition assessment based on artificial intelligence and digital technologies.

## Conclusion

This study analyzed the impact of climate change on road pavements and the operational performance of modern pavement materials. The results showed that rising air temperatures, heavy precipitation, and extreme weather events lead to premature deformation and a reduced service life of asphalt concrete pavements.

According to the comparative evaluation, polymer-modified bitumen (PMB) and basalt fiber-reinforced asphalt pavements demonstrated higher resistance to high temperatures, moisture, and traffic loads compared to conventional asphalt concrete. Recycled asphalt pavement (RAP) technology, on the other hand, stands out for its economic and environmental efficiency, enabling rational use of natural resources and reduction of construction costs.

Based on the findings, it is justified that climate-oriented material selection should be applied in the design and construction of roads under the sharply continental climate conditions of Uzbekistan. In the material selection process, it is important to consider not only the initial cost but also service life, operational costs, environmental impact, and adaptability to climatic conditions in a comprehensive manner.

The scientific novelty of this study lies in the comprehensive evaluation of modern pavement materials under climate change conditions based on technical, economic, and environmental criteria, as well as in the development of scientific and practical recommendations for their application in the context of Uzbekistan. The results of the study may contribute to extending the service life of pavements, reducing maintenance and operational costs, and improving the climate resilience of road infrastructure in practice. In future research, it is advisable to conduct field testing of modern pavement materials across different climatic zones, to monitor their long-term performance, and to develop methods for pavement condition assessment based on artificial intelligence and digital technologies.

## REFERENCES

[1] A. Muxammadjonov and S. Mahmudov, “Opredelenie elastichnosti i temperatury razmyagcheniya mastiki, primenyaemoy na avtomobil'nykh dorogakh,” *Ekonomika i Sotsium*, no. 11-1(102), pp. 776–780, 2022.

[2] S. T. Mahmudov and E. M. o‘g‘li, “Puti sovershenstvovaniya sistemy podgotovki konkurentosposobnykh spetsialistov-dorozhnikov,” *Mekhanika i Tekhnologiya*, vol. 1, no. 6, pp. 187–194, 2022.

[3] S. Mahmudov, *Avtomobil yo‘llarida tirbandliklarni hosil bo‘lish sabablari va uni bartaraf etish choralari*. Uzbekistan, 2023.

[4] S. Mahmudov, *Avtomobil yo‘llari chorrahalarida xavfsiz harakatni tashkil etish*. Uzbekistan, 2023.

[5] S. Mahmudov, “Shaharlar ko‘cha va yo‘llarida yuzaga kelayotgan tirbandliklarning sabablari va ularni bartaraf etishning samarali usullari,” *Stroitel'stvo i Obrazovanie*, vol. 4, no. 5–6, pp. 321–325, 2023.

[6] S. Mahmudov and M. Tolliboyeva, *Qumli hududlarda avtomobil yo‘llarini loyihalashning xususiyatlari*. Uzbekistan, 2023.

[7] S. T. Makhmudov, “Advantages of the wide use of geotextile materials in the construction of road surfaces,” *Ekonomika i Sotsium*, no. 6-2(109), pp. 260–263, 2023.

[8] S. T. Mahmudov, “Avtomobil yo‘llarini qurishda atrof-muhitni ko‘kalamzorlashtirish,” *Mekhanika i Tekhnologiya*, vol. 4, no. 5, pp. 124–127, 2021.

[9] “BIM, IoT, and GIS Integration in Construction Resource Monitoring,” *Automation in*

*Construction*, vol. 174, Art. no. 106180, 2025.

[10] R. Kaur, B. J. Mwambegele, A. G. Abraham, *et al*., "A comprehensive review on building information modelling, its implementations and applications," *Discover Civil Engineering*, vol. 5, no. 1, 2025.

[11] A. S. Borkowski, "Theoretical mechanisms of building information modelling (BIM): Information representation, data exchange, and decision support," *Journal of Civil and Hydraulic Engineering*, vol. 2025, pp. 1–15, 2025.

[12] "Bridge Management with AI, UAVs and BIM," *Automation in Construction*, vol. 173, Art. no. 106112, 2025.

[13] Y. J. Shin and E. Kang, "From tool-based training to integrated studios: A review of BIM education in architecture," *Buildings*, vol. 16, no. 1, 2026.

[14] "Assessing Student Adoption of Generative Artificial Intelligence Across Engineering Education from 2023 to 2024," 2025.

[15] "Building Information Modeling Uses and Complementary Technologies in Road Projects," 2024.