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DEVELOPMENT OF A TECHNOLOGICAL LINE FOR THE PRODUCTION OF POLYMER-BITUMEN COMPOSITIONS

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Abstract. This study presents the development and technological substantiation of a process line for producing polymer–bitumen composite materials intended for road construction applications. The proposed system integrates local raw materials and recycled industrial waste, including waste oil and crumb rubber, into a multicomponent polymer–bitumen matrix. The technological scheme consists of raw material dosing units, a masterbatch preparation reactor, and a final high-efficiency mixing unit. A two-stage production approach was implemented: (I) preparation of a polymer–bitumen masterbatch in a heated reactor under controlled temperature (170–180 °C) and high-shear mixing conditions, followed by (II) incorporation of dispersed and coarse mineral additives in a homogenizing mixer. The influence of polymer modifiers (SBS, EVA), crumb rubber, mineral fillers, and stabilizing additives on structural formation and processing behavior was analyzed. Mass balance calculations confirmed the operational stability of the proposed technological line, demonstrating that 82% of the total batch mass is processed during masterbatch formation and 18% during final homogenization. The binder phase constitutes approximately 70% of the total composition, ensuring rheological continuity and structural stability. The integration of recycled materials enhances elasticity, deformation resistance, and sustainability of the resulting composite material while maintaining technological feasibility and industrial scalability. The developed production scheme provides a scientifically justified and economically viable framework for manufacturing high-performance polymer–

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bitumen composites with improved storage stability and operational characteristics.

Keywords. Polymer–bitumen compositions, polymer-modified bitumen, crumb rubber modification, waste oil recycling, technological line design, masterbatch reactor, mineral fillers, mass balance calculation, rheological properties, sustainable road materials.

Аннотация. В данном исследовании представлены разработка и технологическое обоснование технологической линии для производства полимерно-битумных композитных материалов, предназначенных для дорожного строительства. Предложенная система интегрирует местное сырье и переработанные промышленные отходы, включая отработанное масло и резиновую крошку, в многокомпонентную полимерно-битумную матрицу. Технологическая схема включает в себя дозирующие устройства для сырья, реактор для приготовления мастербатча и конечный высокоэффективный смесительный блок. Был реализован двухэтапный производственный подход: (I) приготовление полимерно-битумного мастербатча в нагреваемом реакторе при контролируемой температуре (170–180 °C) и условиях высокоскоростного перемешивания, за которым следует (II) добавление дисперсных и крупнозернистых минеральных добавок в гомогенизирующем смесителе. Проанализировано влияние полимерных модификаторов (SBS, EVA), резиновой крошки, минеральных наполнителей и стабилизирующих добавок на формирование структуры и технологические свойства. Расчеты баланса массы подтвердили эксплуатационную стабильность предложенной технологической линии, показав, что 82% общей массы партии перерабатывается в процессе формирования мастербатча и 18% — в процессе окончательной гомогенизации. Вяжущая фаза составляет приблизительно 70% от общего состава, обеспечивая реологическую непрерывность и структурную стабильность. Интеграция переработанных материалов повышает эластичность, сопротивление деформации и экологичность получаемого композитного материала, сохраняя при этом технологическую осуществимость и масштабируемость в промышленности. Разработанная производственная схема обеспечивает научно обоснованную и экономически целесообразную основу для производства высокоэффективных полимерно-битумных композитов с улучшенной стабильностью при хранении и эксплуатационными характеристиками.

Ключевые слова. Полимерно-битумные композиции, полимерно-модифицированный битум, модификация резиновой крошкой, переработка

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отработанного масла, проектирование технологической линии, реактор для мастербатча, минеральные наполнители, расчет баланса массы, реологические свойства, экологически чистые дорожные материалы.

Annotatsiya. Ushbu tadqiqot ishida yo‘l qurilishi uchun mo‘ljallangan polimer-bitum kompozit materiallarini ishlab chiqarish texnologik liniyasini ishlab chiqish va texnologik asoslash taqdim etiladi. Taklif qilinayotgan tizim mahalliy xom ashyo va qayta ishlangan sanoat chiqindilarini, shu jumladan chiqindi moyi va maydalangan kauchukni ko‘p komponentli polimer-bitum matritsasiga birlashtiradi. Texnologik sxema xom ashyoni dozalash moslamalari, masterbatch tayyorlash reaktori va yakuniy yuqori samarali aralashtirish moslamalaridan iborat. Sxemada ikki bosqichli ishlab chiqarish yondashuvi amalga oshirildi: (I) polimer-bitum masterbatchini qizdirilgan reaktorda nazorat ostidagi harorat (170–180 °C) va yuqori tezlikli aralashtirish sharoitida tayyorlash, so‘ngra (II) disperslangan va yirik mineral qo‘shimchalarni gomogenlashtiruvchi mikserga qo‘shish. Polimer modifikatorlarining (SBS, EVA), maydalangan kauchuk, mineral to‘ldiruvchilari va stabillashtiruvchi qo‘shimchalarning strukturaviy shakllanishi va texnologik xossalari tahlil qilindi. Massa balansi hisob-kitoblari taklif qilinayotgan texnologik liniyaning operatsion barqarorligini tasdiqladi, bu umumiy partiya massasining 82% masterbatch shakllanish paytida va 18% yakuniy gomogenizatsiya paytida qayta ishlanishini ko‘rsatdi. Bog‘lovchi faza umumiy tarkibning taxminan 70% ni tashkil qiladi, bu reologik uzluksizlik va strukturaviy barqarorlikni ta‘minlaydi. Qayta ishlangan materiallarning integratsiyasi texnologik imkoniyatlar va sanoat miqyosini saqlab qolish bilan birga hosil bo‘lgan kompozit materialning elastikligini, deformatsiyaga chidamliligini va barqarorligini oshiradi. Ishlab chiqilgan ishlab chiqarish sxemasi saqlash barqarorligi va operatsion xususiyatlari yaxshilangan yuqori samarali polimer-bitum kompozitlarini ishlab chiqarish uchun ilmiy asoslangan va iqtisodiy jihatdan samarali asos yaratadi.

Kalit so‘zlar. Polimer-bitum kompozitsiyalari, polimer-modifikatsiyalangan bitum, maydalangan kauchuk modifikatsiyasi, chiqindi moyni qayta ishlash, texnologik liniya loyihalash, masterbatch reaktori, mineral to‘ldiruvchi moddalari, massa balansini hisoblash, reologik xususiyatlar, barqaror yo‘l materiallari.

INTRODUCTION.

Polymer–bitumen compositions (PBCs) have become an essential class of advanced construction materials widely applied in road pavements, waterproofing systems, roofing membranes, and hydraulic engineering structures. The growing demand for high-performance infrastructure materials capable of withstanding increasing traffic loads, extreme climatic variations, and long-term aging has stimulated intensive research into polymer-modified bitumen technologies.

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Conventional petroleum bitumen, while providing satisfactory adhesion and water resistance, exhibits significant temperature susceptibility, oxidative aging, and limited elasticity at low temperatures [1,4]. These drawbacks have motivated the development of polymer-modified systems with improved rheological and mechanical performance. The modification of bitumen with thermoplastic elastomers, plastomers, and reactive polymers significantly enhances elasticity, rutting resistance, fatigue durability, and thermal stability [2,7]. Among various modifiers, styrene–butadiene–styrene (SBS) triblock copolymers are considered the most effective elastomeric additives due to their ability to form a three-dimensional physical network within the bituminous matrix [3]. Plastomeric polymers such as polyethylene (PE), ethylene–vinyl acetate (EVA), and polypropylene (PP) improve stiffness and high-temperature stability [4,10]. Reactive modifiers, including crumb rubber and functionalized polymers, contribute to enhanced compatibility and aging resistance [2,9]. The physicochemical interaction between bitumen and polymer plays a decisive role in determining the stability and performance of polymer–bitumen compositions. Bitumen is a complex colloidal system consisting of asphaltenes, resins, aromatics, and saturates (SARA fractions). The compatibility between polymer modifiers and maltene fractions governs phase morphology, storage stability, and long-term performance. Poor compatibility often results in phase separation during storage and transportation, which remains one of the principal technological challenges in industrial production [5,11].

From a technological perspective, the production of polymer–bitumen compositions requires controlled high-temperature mixing, efficient dispersion, and homogenization processes. Industrial production typically involves continuous or batch reactors equipped with high-shear mixers, colloid mills, or rotor–stator systems. Key process parameters include temperature (160–190 °C for SBS-modified systems), mixing intensity, polymer concentration (typically 3–7 wt%), swelling time, and shear rate [6,12]. Optimization of these parameters is essential to ensure uniform dispersion, prevent thermal degradation of polymers, and achieve target rheological characteristics. Recent research emphasizes the importance of rheological characterization in designing technological lines. Dynamic shear rheometry (DSR), softening point determination, penetration index, elastic recovery, and storage stability tests are widely employed to assess product quality [1]. Moreover, infrared spectroscopy and thermal analysis techniques (DSC, TGA) are increasingly used to investigate polymer–bitumen interactions and aging behavior [2]. The development of a technological line for producing polymer–bitumen compositions must therefore integrate material selection,

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thermodynamic compatibility analysis, mixing and homogenization design, temperature control systems, and quality monitoring methods. Energy efficiency, automation, environmental safety, and reduction of emissions are also critical aspects in modern bitumen modification plants [6]. Continuous technological schemes offer advantages in productivity and consistency, whereas modular batch systems provide flexibility for different formulations. Despite extensive studies on polymer modification mechanisms, challenges remain in ensuring long-term storage stability, reducing production costs, incorporating recycled polymers, and adapting technological lines to local raw materials [5]. Therefore, systematic analysis of existing modification technologies, equipment configurations, and process optimization strategies is essential for designing efficient industrial production systems.

The objective of this study is to analyze the scientific and technological foundations of polymer–bitumen modification and to propose a conceptual framework for the development of an optimized technological line capable of producing high-performance polymer–bitumen compositions with improved operational properties and storage stability.

MATERIALS AND METHODS. Base petroleum bitumen of penetration grade 60/90 was used as the primary binder in this study. The bitumen was supplied from a refinery vacuum distillation unit and complied with standard specifications for road construction materials. The main physicochemical characteristics of the base bitumen included penetration at 25 °C of 65 ± 3 (0.1 mm), softening point (Ring-and-Ball) of 48–50 °C, and ductility at 25 °C exceeding 100 cm. Waste industrial oil was used as a plasticizing component to regulate viscosity and improve the workability of the polymer–bitumen system. The oil was предварительно filtered to remove mechanical impurities. Its kinematic viscosity at 100 °C was approximately 8–12 mm²/s, and its density at 20 °C was 0.88–0.92 g/cm³. The dosage of waste oil varied from 5 to 15 wt% relative to the total binder mass. Crumb rubber obtained from recycled automobile tires was used as an elastomeric modifier. The rubber particles had a size range of 0.5–1.5 mm and a bulk density of approximately 0.45–0.55 g/cm³. The rubber content in the compositions ranged from 8 to 15 wt%. Prior to use, the crumb rubber was dried to eliminate moisture. Styrene–butadiene–styrene (SBS) triblock copolymer with a styrene content of approximately 30 wt% was applied as the primary polymer modifier. The polymer was supplied in pellet form with a density of 0.94 g/cm³ and a melt flow index below 1 g/10 min. The SBS dosage ranged from 3 to 6 wt% of the total composition. In selected experimental formulations, ethylene–vinyl acetate (EVA) copolymer with a vinyl acetate content of 18 wt% was used as an

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alternative plastomeric modifier for comparative evaluation. The EVA density was approximately 0.95 g/cm³. Fine mineral additives, including limestone powder ($CaCO_3$), silica flour, and fly ash, were used to improve stiffness and structural stability of the composite material. The particle size of dispersed mineral fillers was below 100 μm. The total content of fine mineral additives ranged from 8 to 12 wt%. Coarse mineral additives were introduced as reinforcing components to enhance mechanical strength and resistance to deformation. These additives had a particle size between 0.5 and 2 mm and were added in amounts of 3–7 wt%. A stabilizing additive based on sulfur-containing crosslinking agents was incorporated in concentrations of 0.2–0.4 wt% to improve storage stability and compatibility between polymer and bitumen phases. All materials were used without additional chemical purification. Mineral components were предварительно dried at 105 °C to remove residual moisture prior to mixing.

The technological line for the production of polymer–bitumen compositions (PBC) used in this study corresponds to the scheme presented in Figure 1 and consists of raw material storage units, a masterbatch preparation reactor, and a final mixing unit. The installation includes the following main components: Hopper 1 – Waste oil hopper-designed for storing and dosing used (recycled) oil, which acts as a plasticizing component and viscosity regulator in the formulation. Hopper 2 – Bitumen hopper-serves as the primary binder storage unit. Bitumen is supplied in heated condition to maintain pumpability and controlled viscosity. Hopper 3 – Crumb rubber hopper-intended for storing finely ground rubber particles (0.5–1.5 mm), used as an elastomeric modifier to enhance elasticity and fatigue resistance. Hopper 4 – Modifier hopper-contains polymer modifiers (e.g., SBS, EVA) or chemical stabilizers introduced to improve compatibility and storage stability. Hoppers 5, 6, 7 – Dispersed mineral additives hoppers-designed for fine mineral fillers such as limestone powder, fly ash, silica, or other micronized materials improving stiffness and structural stability. Hopper 8 – Coarse mineral additive hopper-intended for larger mineral fractions or reinforcing fillers contributing to mechanical strength and structural reinforcement. Hopper 9 – Binder hopper-contains additional binding components or adhesion promoters used to adjust final physicochemical characteristics. Reactor 10 – Masterbatch preparation reactor-a heated and mechanically agitated vessel used for preparing the primary polymer–bitumen masterbatch. Mixer 11 – Final mixing unit-high-efficiency homogenizing mixer for the final preparation of the polymer–bitumen composition.

RESULTS AND DISCUSSION. A process line for producing polymer-bitumen composite materials for road paving. A schematic diagram of a universal production line for multiphase polymer-bitumen composite materials using local

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raw materials and industrial waste is shown in the figure. The process line for producing polymer-bitumen composite materials for road paving includes a set of equipment consisting of the following elements: 1 - waste oil bin, 2 - bitumen bin, 3 - crushed rubber bin, 4 - modifier bin, 5, 6, and 7 - bins for dispersed mineral additives, 8 - bin for large-sized mineral additives, 9 - binder bin, 10 - reactor for masterbatch preparation, 11 - mixer for final preparation of polymer-bitumen composites. As the diagram shows, the process first involves preparing bitumen, pyrolysis resin, and rubber, devulcanizing rubber crumb, then preparing the other ingredients, and finally feeding them into the mixer. This is where the polymer-bitumen composite materials are produced.

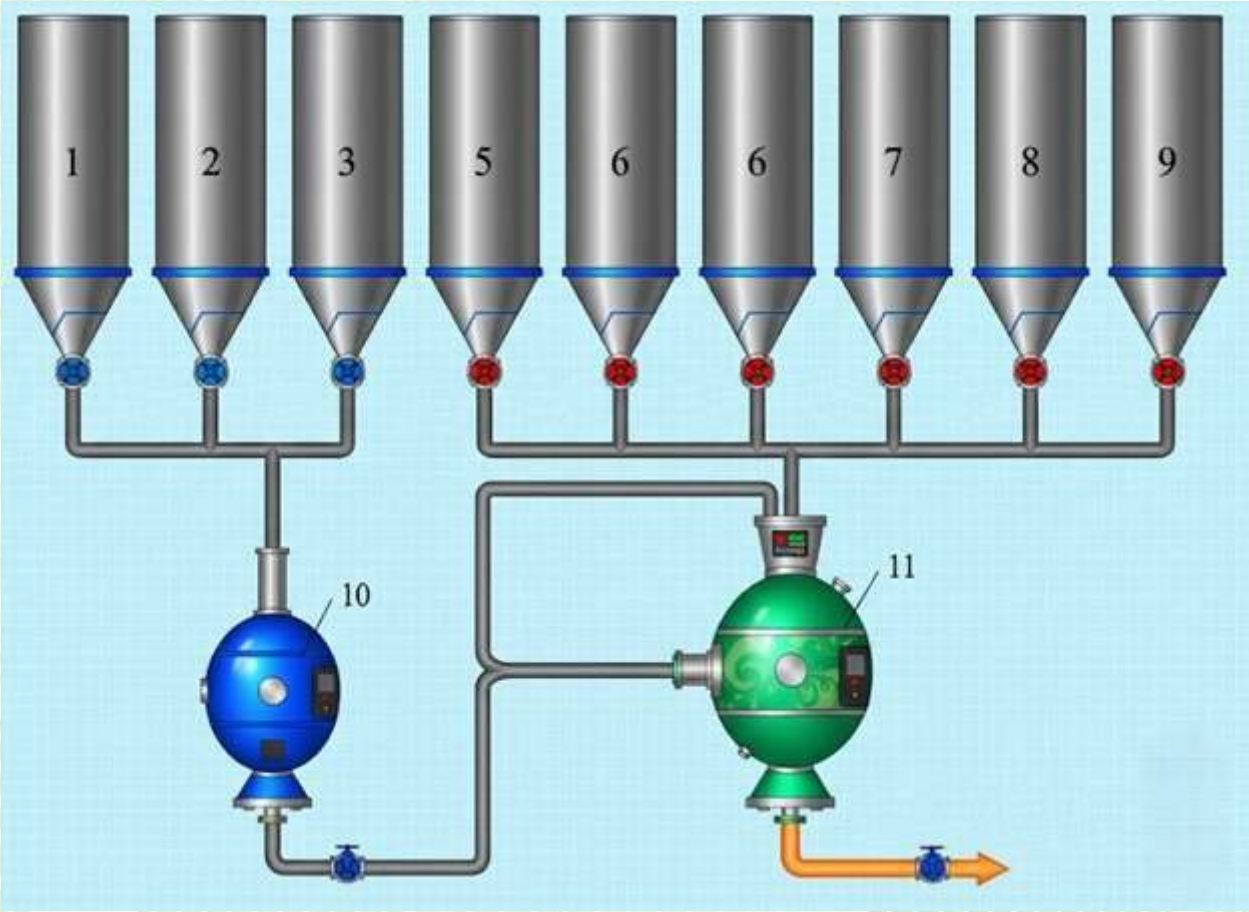


Figure 1. Process flow chart for producing polymer-bitumen compositions: 1-bin for waste oil, 2-bin for bitumen, 3-bin for crushed rubber, 4-bin for modifiers, 5,6,7-bins for dispersed mineral additives, 8-bin for large-sized mineral additives, 9-bin for binder, 10-reactor for preparing masterbatch, 11-mixer for final preparation of polymer-bitumen compositions.

Technological Procedure. Stage 1 – Preparation of Masterbatch (Reactor 10). Bitumen from Hopper 2 was pumped into Reactor 10 and heated to 170–180 °C under continuous agitation. Waste oil from Hopper 1 was gradually introduced (5–15 wt%) to adjust viscosity and improve processability. Crumb rubber from Hopper 3 was then fed into the reactor in controlled portions. The mixture was

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mechanically stirred at 1500–3000 rpm for 60–90 minutes to allow rubber swelling and partial devulcanization. Polymer modifiers from Hopper 4 were introduced during this stage (3–6 wt%), followed by high-shear mixing to ensure uniform dispersion. The result of this stage was a homogeneous polymer–bitumen masterbatch. Stage 2 – Incorporation of Mineral Additives (Mixer 11). The prepared masterbatch was transferred to Mixer 11 for final homogenization. Fine mineral additives from Hoppers 5, 6, and 7 were dosed sequentially to improve stiffness and structural integrity. Mixing was maintained at 160–175 °C. Coarse mineral additives from Hopper 8 were added to enhance mechanical reinforcement and resistance to deformation. Binder or adhesion-promoting agents from Hopper 9 were introduced during the final mixing phase to optimize adhesion and compatibility. Final homogenization was conducted for 30–45 minutes at controlled shear conditions until uniform consistency was achieved. Each experiment was performed in triplicate, and statistical processing was conducted using analysis of variance.

Mass Balance Calculation. To develop a material balance for the technological line, a steady-state operation was assumed with no material losses due to evaporation, leakage, or thermal degradation. The system was considered closed, and accumulation inside the equipment was neglected after reaching stable operating conditions. The calculation basis was selected as: Production capacity: 1000 kg of finished polymer–bitumen composition per batch Table 1. All mass fractions are expressed in weight percent (wt%).

Table 1.

A representative formulation used for the mass balance calculation is presented below:

Component	**Source Unit**	**Mass Fraction (%)**	**Mass (kg)**
Bitumen	Hopper 2	55 %	550 kg
Waste oil	Hopper 1	10 %	100 kg
Crumb rubber	Hopper 3	12 %	120 kg
Polymer modifier (SBS/EVA)	Hopper 4	5 %	50 kg
Fine mineral additives	Hoppers 5–7	10 %	100 kg
Coarse mineral additives	Hopper 8	5 %	50 kg
Additional binder/stabilizer	Hopper 9	3 %	30 kg
Total	—	**100 %**	**1000 kg**

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The developed material balance confirms that, reactor 10 handles 82% of total batch mass (masterbatch formation), mixer 11 incorporates the remaining 18% of mineral and stabilizing components, the system operates without material accumulation under steady-state conditions, the binder phase constitutes the dominant structural component (70%), ensuring rheological continuity. The presented mass balance model can be further expanded to include, energy balance, moisture correction factors, material losses (1–2% industrial allowance), scale-up calculations for industrial capacity (10–20 t/h).

CONCLUSIONS. The present study was devoted to the development and technological justification of a production line for polymer–bitumen compositions incorporating waste oil, crumb rubber, polymer modifiers, and mineral additives. Based on theoretical analysis and process modeling, the structural configuration of the technological scheme—including raw material hoppers, masterbatch reactor, and final homogenization mixer—was substantiated. The proposed two-stage processing approach, consisting of (I) masterbatch preparation in Reactor 10 and (II) final homogenization in Mixer 11, ensures effective dispersion of polymer and rubber particles within the bituminous matrix. Controlled temperature conditions (170–180 °C) and high-shear mixing were identified as critical parameters for achieving uniform phase distribution and preventing polymer degradation. Mass balance calculations confirmed the operational stability of the system under steady-state conditions and demonstrated that 82% of the total batch mass is processed during masterbatch formation, while the remaining 18% corresponds to mineral and stabilizing components introduced during final mixing. The binder phase (bitumen, waste oil, and polymer) constitutes approximately 70% of the final composition, ensuring rheological continuity and structural integrity. The integration of recycled materials—specifically waste oil and crumb rubber—contributes to improved elasticity, enhanced deformation resistance, and increased sustainability of the resulting composite material. The incorporation of dispersed and coarse mineral additives provides structural reinforcement and improved mechanical performance.

Overall, the proposed technological solution provides a scientifically substantiated and industrially feasible framework for producing high-performance polymer–bitumen compositions with improved operational characteristics and storage stability.

REFERENCES

1. Yildirim, Y. (2007). Polymer modified asphalt binders. Construction and Building Materials, 21(1), 66–72. [https://doi.org/10.1016/j.conbuildmat.2005.07.007].

ISSN 3030-3907

2. Zhu, J., Birgisson, B., & Kringos, N. (2014). Polymer modification of bitumen: Advances and challenges. European Polymer Journal, 54, 18–38. [https://doi.org/10.1016/j.eurpolymj.2014.02.005].
3. Airey, G. D. (2003). Rheological properties of styrene–butadiene–styrene polymer modified road bitumens. Fuel, 82(14), 1709–1719. [https://doi.org/10.1016/S0016-2361(03)00146-7].
4. А.С.Ибадуллаев, Э.Э.Машаев. Ўзбекистон йўл қопламалари учун модификацияланган резина битумли боғловчилар яратиш // Нефт-газ саноатида инновациялар, замонавий энергетика ва унинг муаммолари ҳалқаро конференцияси // Ташкент, ТКТИ, 2020, 289-291 б.
5. Lu, X., & Isacsson, U. (1997). Modification of road bitumens with thermoplastic polymers. Polymer Testing, 16(5), 447–466. [https://doi.org/10.1016/S0142-9418(97)00006-3].
6. Polacco, G., Filippi, S., Merusi, F., & Stastna, J. (2015). A review of the fundamentals of polymer-modified asphalts: Asphalt/polymer interactions and principles of compatibility. Advances in Colloid and Interface Science, 224, 72–112. [https://doi.org/10.1016/j.cis.2015.07.010].
7. O'.R.Azamatov, E.E.Mashayev. Research of properties of oil road bitumens modified by rubber crumb. International conference Innovations in the oil and gas industry, modern power engineering and actual problems. Tashkent, TCTI, 2020, pp. 283-286.
8. Becker, Y., Méndez, M. P., & Rodríguez, Y. (2001). Polymer modified asphalt. Vision Tecnológica, 9(1), 39–50.
9. Singh, B., Kumar, P., & Gupta, M. (2013). Studies on bituminous blends prepared with SBS and EVA copolymers. Journal of Applied Polymer Science, 127(1), 67–78. [https://doi.org/10.1002/app.37660].
10. В.Н. Жураев, Э.Э. Машаев, М.Д. Вапаев, А.С. Ибадуллаев, Модификация битума для получения тепло-морозостойких дорожных композиций // Узбекский химический журнал // №4, 2019, с. 40-46.
11. Presti, D. L. (2013). Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review. Construction and Building Materials, 49, 863–881. [https://doi.org/10.1016/j.conbuildmat.2013.09.007].
12. Cong, P., Chen, S., & Yu, J. (2011). Investigation of the properties of polymer modified asphalt containing various polymer components. Construction and Building Materials, 25(5), 2834–2840. [https://doi.org/10.1016/j.conbuildmat.2010.12.026].

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