**Polymer-Bitumen Composition for Application in Harsh Continental Climatic Conditions**

Samandar Shomuradov1, a), Murodjon Vapaev2, b) and Akhmadjon Ibadullaev3, c)

1*Tashkent Institute of Chemical Technology, 32 Navoi Street, Tashkent 100011, Uzbekistan*2*University of Tashkent for Applied Sciences, 1 Gavkhar Street, Tashkent 100149, Uzbekistan*3*Tashkent State Transport University, 1 Temiryulchilar St., Tashkent 100167, Uzbekistan*

*a) Corresponding author:* [*samandarshomurodov919@gmail.com*](mailto:samandarshomurodov919@gmail.com) *b)* [*murodjon.vapayev@mail.ru*](mailto:murodjon.vapayev@mail.ru) *c)*[*ibadullaev1957@bk.ru*](mailto:ibadullaev1957@bk.ru)

**Abstract.** This paper presents the results of scientific research on the creation of modified ingredients for polymer-bitumen compositions used as a protective layer and coatings in mechanical engineering and instrument making, on highways and railways, on bridges and tunnels, in the construction of residential and industrial buildings. Based on the results obtained, compositions of organomineral modifier M-1 in desert areas, M-2 in general areas, and M-3 in mountainous areas were recommended. It was established that with an increase in the content of the organomineral modifier, thermomechanically ground powder of worn rubber products, and Fergana dune sand, the compressive strength of the compositions increases, and its value is in the range of 5.2-6.4 MPa. At the same time, the maximum compressive strength was observed in a proportion of 1/2 powder, thermomechanically ground from worn rubber products and modified bitumen. Moreover, with an increase in the content of powder, thermomechanically ground from worn rubber products, and in the composition of Fergana dune sand, the shear strength increases and allows choosing a composition depending on climatic conditions. As a result, the composition and technology for producing multifunctional modifiers and organomineral modifiers have been developed to improve the operational properties of bitumens based on selected ingredients from recycled materials - rubber, waste from the chemical, oil, and gas processing industries. The influence of the physicochemical properties and content of selected ingredients and modified bitumen on the technological, rheological, physico-mechanical, dynamic, and operational properties of the polymer-bitumen composite protective layer and coating obtained on their basis is substantiated.

**Keywords:** Modifier, bitumen, composition, rheology, technology, composition, polymer-bitumen, ingredient, conditions, powder, rubber products, strength, thermomechanics

**INTRODUCTION**

Scientific research is being conducted on the creation of modified ingredients for polymer-bitumen compositions, which are used as a protective layer and coatings in mechanical engineering and instrument making, on highways and railways, on bridges and tunnels, and in the construction of residential and industrial buildings. Improving their resistance to external and aggressive environments, creating ingredients based on modified and high-molecular-weight polymer waste to increase technological, rheological, and operational properties, as well as service life, modifiers that determine the structure of the composition, the study of their physicochemical properties, structure, and scope of action, the creation of composite coating compositions, technologies, and machines for their production are all of current relevance [1, 2, 3].

To improve the operational reliability of polymer-bitumen protective layers and coatings, including: During the period of accelerated development of the bitumen industry, to obtain composite materials and coatings derived from polymer-bitumen binders, a filler-binding interfacial structure pre-defined using surfactants, lead-bitumen coatings, and reinforcing fillers, reducing the influence of aggressive components in the product on metal structures, ensuring the reliability of technological equipment, highways, and railways, increasing productivity and energy conservation through the targeted use of effective polymer-bitumen coatings based on them on the working surfaces of technological machines and structures [4, 5, 6].

The research aims to develop the composition and technology for obtaining polymer-bitumen composite protective layers and coatings intended for use in severe continental weather conditions.

**OBJECTS AND METHODS OF RESEARCH**

The organomineral modifier based on gas pyrolysis resin, waste from a copper enrichment plant, ground powder of worn-out rubber, and bitumens produced at the Fergana Oil Refinery [7, 8].

**MATERIALS AND METHODS**

Standardized physicochemical, physical-mechanical, kinematic, and dynamic properties for polymer-bitumen compositions and their modifying effect on the complex of indicators of bitumen binders were determined according to the standards PNST 86-2016 (GOST 58400.1-2019) and PNST 88-2016 (GOST 58400.6-2019). The search for recipe-technological solutions for obtaining and applying hybrid bitumen modifiers, providing synergistic effects concerning the indicators of bitumen materials, characterizing resistance to rutting (PNST 88-2016 (GOST 58400.6-2019)), fatigue failures at positive temperatures (PNST 81-2016 (GOST 58400.7-2019)), and negative temperatures (PNST 89-2016 (GOST 58400.9-2019)).

**MAIN BODY**

The production and enhancement of the properties of petroleum bitumens for the manufacture of protective layers and coatings, given the continuing trend of increasing demand for these compositions, research aimed at expanding the use of petroleum bitumens based on local and secondary raw materials suitable for sharply continental weather conditions remains relevant [9].

To modify bitumens and improve the resistance of the protective layers and coatings obtained on their basis to sharply continental weather conditions, technological, rheological, physical-mechanical, and deformation shear and failure, ingredients based on local raw materials were selected, their physicochemical properties were studied, and based on them, the composition and technology for obtaining an organomineral modifier were created [7, 8, 9, 10].

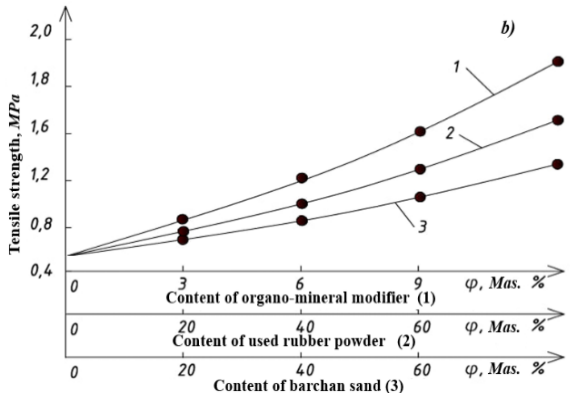
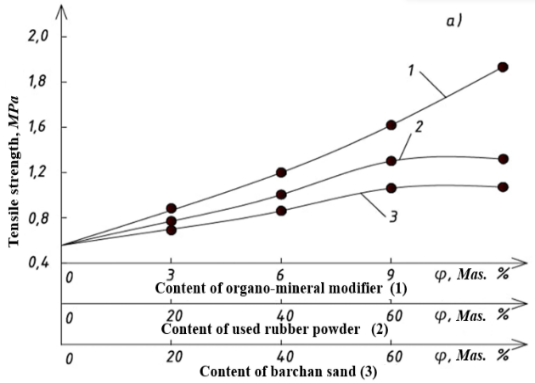
Based on the results obtained, the following compositions of the organomineral modifier were recommended (Table 1).

It is proposed to use the M-1 sample in desert zones, M-2 in general zones, and M-3 in mountainous zones when modifying bitumens used for the production of a protective layer and coatings. It is known that one of the main drawbacks on highways is the settling and displacement of asphalt concrete pavement on roads where heavy trucks travel, and at traffic lights. It has been established that, due to the vulcanization networks formed in the polymer-bitumen coating proposed by us, settling and slipping on roads is reduced (Fig. 1).

**TABLE 1.** Composition of the Developed Organomineral Modifiers

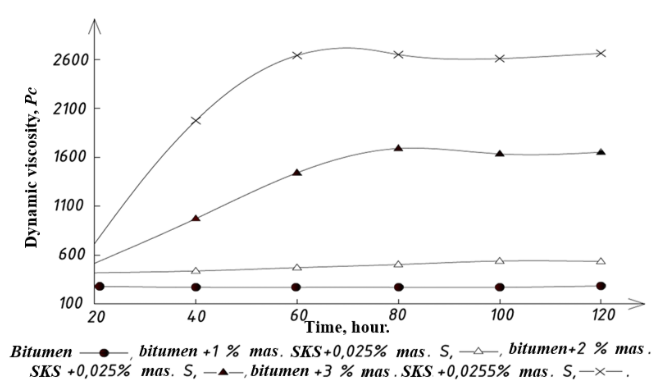
|  |  |  |  |
| --- | --- | --- | --- |
| Ingredient Names | М-1 | М-2 | М-3 |
| Ingredient Content, parts by weight per 100 parts | | |
| Still Bottoms of Gas Pyrolysis Resin | 82,0 | 77,0 | 65,0 |
| Copper Ore Processing Waste | 5,0 | 3,0 | 7,0 |
| Thermo-mechanically Ground Powder of Worn Rubber Products | 10,0 | 15,0 | 20,0 |
| Butadiene-Styrene Rubber | 3,0 | 5,0 | 8,0 |

As can be seen from the figure, with an increase in the content of the organomineral modifier, thermos-mechanically ground powder of worn rubber products, and Fergana dune sand, the compressive strength of the compositions increases, and its value is within the range of 5.2-6.4 MPa. At the same time, the maximum compressive strength was observed in a proportion of 1/2 powder, thermos-mechanically ground from worn rubber products and modified bitumen. In addition, with an increase in the content of powder, thermos-mechanically ground from worn rubber products and in the composition of Fergana dune sand, the shear strength limit increases and allows choosing the composition depending on the climatic conditions. Based on the study of the operational properties of road surfaces on roads, it was revealed that their main drawbacks are instability to sharply continental weather conditions and dynamic loads. To improve these properties, it is advisable to introduce ingredients into the composition that form bonds that provide its elasticity [11, 12, 13, 14]. To solve this, it was proposed to add a carbonaceous material obtained from worn tires and rubber products to the bitumen composition.



**FIGURE 1.** Dependence of the influence of the content of the organomineral modifier, thermomechanically ground powder of worn rubber products and Fergana dune sand on the shear strength (a) and compressive strength (b) of the polymer-bitumen composition

Due to the low density of the carbonaceous material and the large geometric volume, a technology of its swelling and dissolution in bitumen was used to obtain a homogeneous composition. At the same time, it is scientifically substantiated that the temperature of the technological process is 180 °C, the time is 6-8 hours, the ratio of bitumen to carbonaceous material is 1:3, at high temperature the carbonaceous material based on active organic compounds in the composition of bitumen swells during the first four hours and again for three hours, and the vulcanization networks in the composition of the carbonaceous material are interrupted, resulting in the formation of active centers. However, when 5% of high-molecular-weight isoprene rubber is added to the composition, an increase in the elasticity of the composition by 50% is observed, and when butadiene-styrene rubber is added - resistance to wear and shear by 63%. Considering that the composition consists of organic materials, in order to increase the volume without reducing the properties, a secondary product - a carbonaceous compound formed in the process of processing worn rubber products and tires by pyrolysis - was added to its composition. As a result, with an increase in the volume of the composition by 90%, positive results were achieved, while the technological and technical properties of the composition were improved [15, 16]. This may be due to the fact that the secondary product mixes well with the composition because it is an organic material, and the pores formed at high temperatures are absorbed by the high-molecular-weight compounds contained in the composition, and interfacial convergence occurs. This ensures the formation of a network in the composition and increases its shear, heat and frost resistance. Considering that elastomers and devulcanized worn rubber are added to the polymer-bitumen composition, vulcanizing ingredients are added to increase its strength, and the influence of their content is studied (Fig. 2).



**FIGURE 2.** Influence of sulfur content on the properties of the polymer-bitumen composition

As can be seen from the figure, it has been established that when sulfur is added to the composition of the polymer-bitumen composition as a vulcanizing agent, the strength of the interaction of rubber and devulcanized worn rubber added to the composition increases (Table 2).

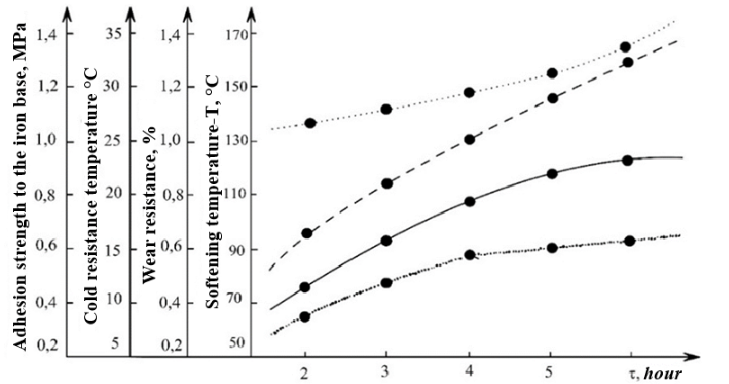
In this case, it is shown that the optimal sulfur content is 20% of the total volume. During the vulcanization process, metal oxides present in the composition of mineral fillers act as an activating agent, while phosphonoalkylamide fatty acid and secondary alkanolamines are added as accelerators in a 5:5 ratio. The vulcanization of the composition was carried out at a pressure of 450 MPa, a temperature of 200–220°C, and was completed within 360 minutes.

During the production of a multifunctional polymer-bitumen composite protective layer and coating, bitumen modified with an organo-mineral modifier and ingredients derived from secondary raw materials were obtained. A composition was developed that exhibits optimal properties when the following are added to the modified bitumen: 80 parts by weight of devulcanized rubber compound, 3 parts of gas-pyrolysis resin, 5 parts of secondary alkanolamines, 2 parts of sulfur, 40 parts of worn tire powder, 80 parts of mineral ingredients, and 20 parts of target ingredients. It has been scientifically substantiated that during the vulcanization process, the following vulcanization networks are formed:   
–C–Sₓ–C– (60%), –C–S–S–C– (24%), –C–S–C– (13%), and –C–C– (3%).

**TABLE 2.** Influence of synthetic rubbers and sulfur on the properties of the composition

|  |  |
| --- | --- |
| Property Names | Dynamic viscosity at 60 °C, Pa·s (Pascal-seconds) |
| Bitumen | 124,0 |
| Bitumen + 1 wt.% SKS-30 (after 24 sec.) | 176,3 |
| Bitumen + 1 wt.% SKS-30 + 0.025 wt.% S (after 24 sec.) | 239,9 |
| Bitumen + 1 wt.% SKS-30 + 0.025 wt.% S (after 24 sec.) | 712,3 |
| Bitumen + 1.5 wt.% SKS-30 + 0.2 wt.% S (after 24 sec.) | 1847,3 |
| Bitumen + 3 wt.% SKS-30 (after 24 sec.) | 787,6 |
| Битум + 3 мас.% СКС-30 +0,025 мас.% S (после24 с.) | 703,2 |
| Bitumen + 3 wt.% SKS-30 + 0.025 wt.% S (after 120 sec.) | 2845,2 |
| Bitumen + 3 wt.% SKS-30 + 0.05 wt.% S (after 96 sec.) | 14063,0 |
| Bitumen + 3 wt.% SKS-30 + 0.05 wt.% S (after 264 sec.) | 27588,1 |
| Bitumen + 1 wt.% SKMS-30ARKM-15 (after 24 sec.) | 196,7 |
| Bitumen + 1.5 wt.% SKMS-30ARKM-15 + 0.2 wt.% S (after 24 sec.) | 2505,2 |
| Bitumen + 3 wt.% SKMS-30ARKM-15 (after 24 sec.) | 196,7 |
| Bitumen + 3 wt.% SKMS-30ARKM-15 + 0.05 wt.% S (after 96 sec.) | 156888,0 |

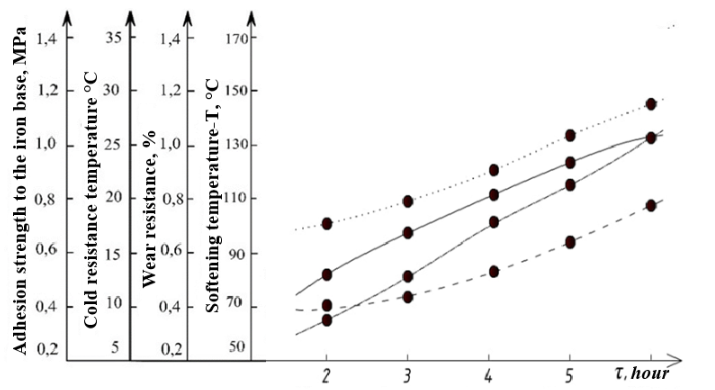
It was found that the created protective layer and coating are resistant to high temperatures and cold, and adhere well to the substrate. Three types of substrates were selected: metal products; products based on mineral binders; and products based on natural and synthetic polymers. In this case, the target ingredient added for adhesion to iron-based surfaces amounted to 5 parts by weight (see Fig. 3).



**FIGURE 3**. Bonding of the composition to an iron substrate. Softening temperature: 180±5°C (\_\_\_\_), resistance to abrasion (…),   
to cold (---), adhesion strength to iron substrate (...•...). (Bonding temperature: 51±5°C)

It was found that the sheet composition bonds well to the cleaned surface of the iron substrate when heated to 151±5°C. The primary reason for this is that the active centers formed on the surface of cleaned iron through mechanical forces create mutual chemical bonds (R–X–R) with the organic composition. Secondly, upon cooling, the vulcanized composition adheres tightly to the surface due to the contraction of the crosslinked networks [17, 18, 19, 20, 21]. This can be explained by the increased bonding strength between the composition and the substrate.

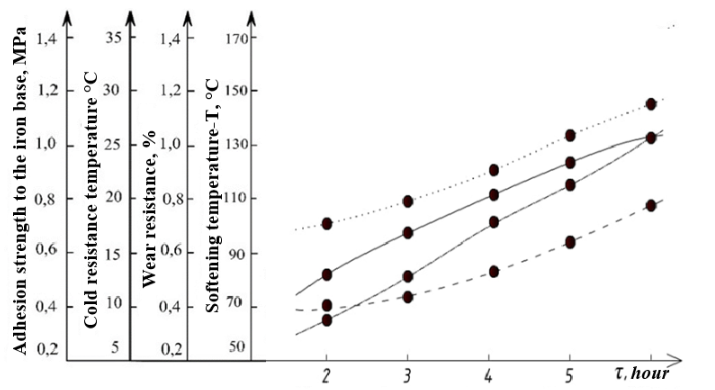
Furthermore, over time, the composition's resistance to heat, cold, and solvents increases, indicating that the formation of vulcanization networks continues for a certain period. The polymer-bitumen composition developed from the selected ingredients was tested on concrete products (see Fig. 4). The results showed that it is advisable to reduce the amount of the target ingredient in the composition to 2.5 parts by weight.

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**FIGURE 4.** Bonding of the composition to a concrete substrate. Softening temperature: 180±5°C (\_\_\_\_\_),   
resistance to abrasion (…..), to cold (---), adhesion strength to concrete substrate (...•...) (Bonding temperature: 151±5°C)

The improvement in the positive performance characteristics of the composition may be attributed to the addition of powder from worn rubber-technical products and tires. This powder adsorbs low-molecular-weight organic binders, including the added target ingredient, and bonds with the inorganic ingredients contained in the powder, acting as both a filler and a crosslinking agent. This ensures their integration and promotes the formation of vulcanization networks within the filler. As a result, the composition penetrates the pores of the concrete substrate and bonds firmly.

At the same time, we found it necessary to study the operational properties of the composition in polymer-based products (see Fig. 5).

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**FIGURE 5.** Bonding of the composition to an organic substrate. Softening temperature (\_\_\_\_), resistance to abrasion (….),   
to cold (----), adhesion strength to organic material (...•...) (Bonding temperature: 151±5°C)

The studies showed that the selected product samples were based on organic substances. Therefore, a target ingredient was added to the composition in an amount of 0.5 parts by weight. As a result, it was established that the polymer-bitumen composition adheres to the surface of the product with high strength, which suggests that a chemical reaction may occur at the interface between the composition and the organic-based product at the process temperature.

**CONCLUSION**

Ingredients derived from secondary raw materials—rubber and waste from the chemical and petrochemical industries—are recommended for use in composite protective layers and coatings based on bitumen, in accordance with requirements for use in sharply continental climatic conditions. A formulation and technology were developed for producing multifunctional modifiers and organo-mineral modifiers aimed at improving the performance properties of bitumen, using selected ingredients from local and secondary sources—rubber and petrochemical waste.

The influence of the physicochemical properties and content of the selected ingredients and modified bitumen on the technological, rheological, physico-mechanical, dynamic, and operational properties of the polymer-bitumen composite protective layer and coating produced from them has been substantiated.

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