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BIO-BASED REJUVENATOR FOR RESTORING THE PROPERTIES OF AGED BITUMEN

Annotation: *The aging of bitumen during production and service life leads to the formation of oxygen-containing functional groups, increased stiffness, and deterioration of pavement performance. Therefore, the development of effective and environmentally friendly rejuvenators for restoring aged bitumen remains an important task in asphalt recycling technologies.*

In this study, a bio-based rejuvenator was synthesized using oleic acid and imidazoline and applied to RTFOT-aged BND 70/100 bitumen at concentrations of 1, 3, and 5 wt.%. The influence of the rejuvenator on the properties of aged bitumen was evaluated using Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TG), and conventional physical tests.

FTIR analysis revealed changes in the intensity of carbonyl and sulfoxide absorption bands, indicating interaction between the rejuvenator and the aged bitumen matrix. TG analysis showed that the modified binders maintained high thermal stability up to 400 °C. The addition of the rejuvenator improved the physical properties of aged bitumen by increasing penetration and ductility while reducing the softening point. The most significant effect was achieved at a rejuvenator content of 5 wt.%.

The results demonstrate the potential of the developed bio-based rejuvenator for restoring the performance characteristics of aged bituminous binders and enhancing the sustainability of asphalt recycling technologies.

Key words: *aged bitumen; bio-based rejuvenator; oleic acid; imidazoline; asphalt recycling; FTIR; thermogravimetric analysis.*

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Introduction

Asphalt pavements are widely used in road construction due to their excellent performance, ease of application, and cost-effectiveness. However, during service, bituminous binders are exposed to various environmental factors, including elevated temperatures, atmospheric oxygen, ultraviolet radiation, and moisture, which lead to their gradual aging [1]. As a result of thermo-oxidative processes, the chemical composition of bitumen changes, accompanied by an increase in the content of oxygen-containing functional groups, primarily carbonyl and sulfoxide compounds. These changes lead to increased stiffness, reduced ductility, and deterioration of the performance properties of asphalt pavements [2, 3].

Current understanding considers bitumen aging as a complex physicochemical process involving oxidation, evaporation of light fractions, changes in the colloidal structure, and asphaltene aggregation. Disruption of the balance between the maltene and asphaltene phases leads to increased brittleness of the bituminous binder and reduced resistance to cracking [4, 5]. Therefore, restoring the properties of aged bitumen has become one of the key challenges in the production of recycled asphalt mixtures and in extending the service life of asphalt pavements.

One of the most effective approaches to restoring the performance characteristics of aged bitumen is the use of rejuvenators. Their primary function is to replenish the lost light fractions, reduce viscosity, and partially restore the structural–colloidal state of the bituminous system [6]. Traditionally, petroleum-derived products have been used as rejuvenators; however, their application is associated with a high dependence on non-renewable resources, significant volatility, and limited environmental sustainability [7].

In recent years, considerable attention has been devoted to the development of bio-based rejuvenators derived from renewable plant resources. According to the literature, vegetable oils and their derivatives can effectively restore the properties of aged bitumen due to the presence of long-chain aliphatic moieties and polar functional groups, which promote interactions with the components of the bitumen matrix [8,9]. Furthermore, the use of bio-based rejuvenators is consistent with the principles of sustainable development and resource conservation in modern road construction [10].

Despite numerous reports on the successful use of vegetable oils as rejuvenators, most studies have focused on individual bio-oils, whereas the mechanisms governing their interactions with the components of aged bitumen remain insufficiently understood. Particular interest has recently been directed toward plant-derived fatty acids containing long-chain aliphatic moieties and polar functional groups, which can exert a plasticizing effect and contribute to the restoration of the structural-colloidal state of the bituminous system.

Therefore, the aim of this study was to synthesize a bio-based rejuvenator derived from oleic acid and imidazoline and to investigate its effect on the properties of aged bitumen using Fourier transform infrared (FTIR) spectroscopy and thermogravimetric analysis (TGA).

Experimental

Method for Obtaining the Bio-Based Rejuvenator

The bio-based rejuvenator was synthesized using oleic acid and imidazoline as the main components. Oleic acid (approximately 89 wt.%) was used as the primary component, while imidazoline (approximately 11 wt.%) served as a functional modifying additive.

Prior to preparation of the rejuvenator, oleic acid was preheated to 40-50°C to reduce its viscosity. Imidazoline was then gradually added under continuous mechanical stirring. The resulting mixture was stirred for 40-60 min until a homogeneous composition was obtained. To improve the stability of the formulation and promote interactions between the components, the mixture was further maintained at 60-70°C for 1 h. After completion of the preparation process, the product was cooled to room temperature and stored in a sealed container.

The resulting bio-based additive was a homogeneous viscous formulation intended for restoring the performance properties of aged bituminous binders.

Imidazoline was introduced into the composition as a surface-active and structure-stabilizing component. Its presence promotes improved compatibility of the organic components with the bitumen matrix, enhanced dispersion of asphaltene aggregates, and a more uniform distribution of the rejuvenator within the structure of aged bitumen. In addition, imidazoline can reduce the interfacial tension and improve the adhesion properties of the modified binder.

Application of the bio-based rejuvenator

The effectiveness of the prepared bio-based rejuvenator was evaluated using aged BND 70/100 bitumen. The original bitumen was subjected to preliminary aging using the Rolling Thin Film Oven Test (RTFOT), which simulates the short-term aging of bituminous binders during asphalt mixture production.

After aging, the bio-based rejuvenator was incorporated into the bitumen at concentrations of 1, 3, and 5 wt.% based on the bitumen mass. The modification process was carried out by heating the bitumen to a working temperature of 140–160 °C, followed by mechanical stirring until a homogeneous composition was obtained. The resulting samples were designated as AB-1, AB-3, and AB-5, respectively.

Evaluation of the effectiveness of the bio-based rejuvenator

The aged bitumen samples modified with 1, 3, and 5 wt.% of the bio-based rejuvenator were characterized using Fourier transform infrared (FTIR) spectroscopy and thermogravimetric (TG) analysis.

FTIR analysis was performed using a Bruker ALPHA II Fourier transform infrared spectrometer in attenuated total reflectance (ATR) mode over the wavenumber range of 4000–400 cm^{-1}. The analysis was conducted to evaluate changes in the functional group composition and to confirm the interactions between the rejuvenator components and the aged bitumen matrix after modification.

TG analysis was carried out using a NETZSCH STA 449 F3 thermal analyzer under a nitrogen atmosphere over the temperature range of 30-800 °C at a heating rate of 10 °C min^{-1}. TG analysis was used to evaluate the thermal stability of the modified bituminous binders and to determine the influence of the bio-based rejuvenator on the thermal decomposition behavior of aged bitumen.

Evaluation of the effect of the bio-based additive on the physical and mechanical properties of bitumen

To evaluate the effectiveness of the developed rejuvenator, the main physical and mechanical properties of the original, aged, and modified bitumen were determined, including penetration at 25 °C, softening point determined by the Ring-and-Ball method, and ductility at 25 °C.

Penetration was determined in accordance with ASTM D5 at 25 °C. This parameter characterizes the consistency and stiffness of the bituminous binder. The softening point was determined using the Ring-and-Ball method in accordance with ASTM D36. This parameter was used to evaluate the temperature susceptibility of the bitumen and its ability to maintain its performance properties at elevated temperatures. Ductility was determined at 25 °C according to ASTM D113. The test was performed to evaluate the ability of the bitumen to undergo deformation without failure and to assess its plastic properties.

The obtained results were used to evaluate the degree of restoration of the performance properties of aged bitumen after the incorporation of the bio-based rejuvenator and to determine the optimum content of the modifying additive.

Results and discussion

Effect of the bio-based additive on the composition of aged bituminous binder

The FTIR spectrum of the synthesized bio-based rejuvenator is presented in Figure 1. The spectrum is characterized by absorption bands corresponding to the functional groups of oleic acid and the imidazoline component constituting the formulation. Intense absorption bands at approximately 2920 and 2850 cm^{-1} are assigned to the asymmetric and symmetric stretching vibrations of the aliphatic $–CH_2$ and $–CH_3$ groups, which are characteristic of the long-chain hydrocarbon moieties of oleic acid.

A pronounced absorption band in the 1700–1715 cm^{-1} region is attributed to the stretching vibrations of the carbonyl (C=O) group, confirming the presence of oxygen-containing fatty acid-derived compounds in the bio-based rejuvenator.

Absorption bands in the 1450–1370 cm^{-1} region are associated with the bending vibrations of methylene ($–CH_2$) and methyl ($–CH_3$) groups in aliphatic chains. In the 1250–1000 cm^{-1} region, absorption bands assigned to the stretching vibrations of C–N and C=N bonds, characteristic of the imidazoline component, are observed.

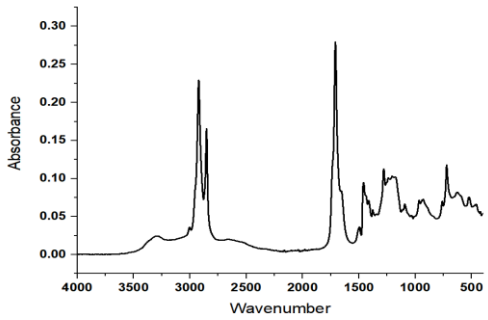


Figure 1 – FTIR spectrum of the prepared bio-based rejuvenator

The presence of long-chain aliphatic moieties together with oxygen- and nitrogen-containing functional groups indicates the potential ability of the prepared bio-based rejuvenator to interact with the components of aged bitumen. According to the literature [11], the formation of carbonyl and sulfoxide groups during the aging process increases the polarity of bitumen and disrupts its structural-colloidal state owing to enhanced aggregation of asphaltene structures. Therefore, the incorporation of compounds containing long aliphatic chains and polar functional groups may improve the compatibility between the maltene and asphaltene phases of aged bitumen [12].

The FTIR spectrum of the aged BND 70/100 bitumen is presented in Figure 2. The spectrum exhibits absorption bands characteristic of hydrocarbon-based bituminous systems.

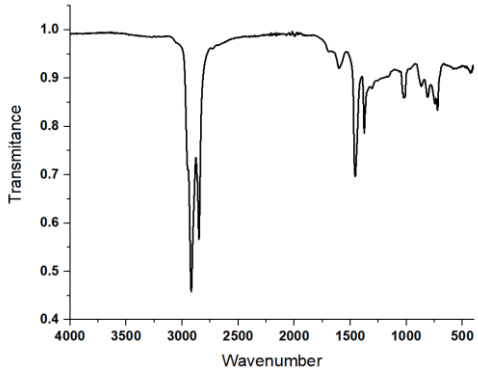


Figure 2 – FTIR spectrum of the aged bituminous binder

Intense absorption bands at approximately 2920 and 2850 cm^{-1} are assigned to the asymmetric and symmetric stretching vibrations of the aliphatic $–CH_2$ and $–CH_3$ groups present in the hydrocarbon components of bitumen. The absorption band at approximately 1600 cm^{-1} is attributed to the stretching vibrations of aromatic C=C bonds, characteristic of the aromatic structures of the bituminous binder. Absorption bands in the 1450-1370 cm^{-1} region correspond to the bending vibrations of aliphatic groups.

An absorption band observed at approximately 1030 cm^{-1} is assigned to sulfoxide (S=O) groups, the formation of which is associated with the thermo-oxidative aging of bitumen. According to the literature, bitumen aging is accompanied by the formation of oxygen-containing functional groups, including carbonyl and sulfoxide compounds, which increase the polarity of the system and disrupt the structural–colloidal balance of the bitumen [13]. These results confirm the presence of characteristic features of oxidative aging in the bitumen after treatment by RTFOT.

Following the incorporation of the bio-based rejuvenator, changes in the intensity of several absorption bands were observed in the FTIR spectra of the modified samples (Figure 3) compared with the aged bitumen. The most pronounced changes were detected in the 1700-1715 cm^{-1} region, where a more intense absorption band assigned to the stretching vibrations of the carbonyl (C=O) group appeared. The appearance of this band is attributed to the presence of oxygen-containing compounds derived from oleic acid, which is one of the main components of the prepared bio-based rejuvenator.

In addition, a decrease in the intensity of the absorption band at approximately 1030 cm^{-1}, assigned to sulfoxide (S=O) groups formed during the oxidative aging of bitumen, was observed. These changes may indicate a partial modification of the structural-colloidal state of the aged bituminous binder following the incorporation of the bio-based rejuvenator.

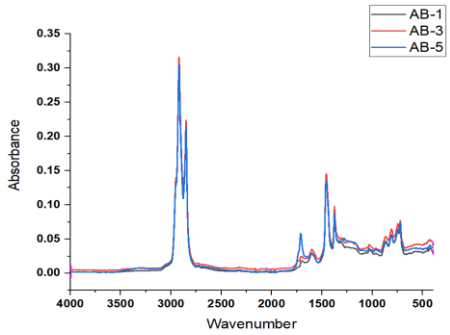


Figure 3 – FTIR spectra of aged BND 70/100 bitumen modified with AB-1, AB-3, and AB-5

Overall, the FTIR results confirm the successful incorporation of the prepared bio-based rejuvenator into the aged bitumen. The observed changes in the intensity of the characteristic absorption bands associated with oxygen-containing, aliphatic, and sulfoxide functional groups indicate interactions between the rejuvenator components and the bitumen matrix and suggest a possible partial restoration of the structural–colloidal state of the aged bituminous binder.

Effect of the bio-based rejuvenator on the thermal stability of bitumen

Thermogravimetric analysis was performed to evaluate the effect of the bio-based rejuvenator content on the thermal behavior of the modified bituminous binders. As shown in Figure 4, all the investigated samples exhibited only a slight mass loss below 200 °C, indicating sufficient thermal stability within the temperature range typically used for the production and modification of bituminous materials.

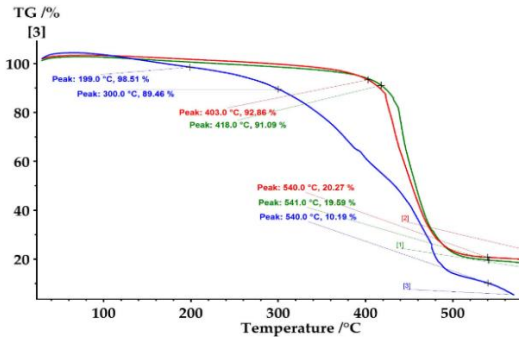


Figure 4 – TG curves of aged BND 70/100 bitumen modified with AB-1 (1), AB-3 (2), and AB-5 (3)

With further increasing temperature, a gradual mass loss was observed for all samples. More pronounced changes began at approximately 250-300°C, which may be attributed to the evaporation and thermal decomposition of the less thermally stable organic components present in the bio-based rejuvenator.

As shown in Figure 4, all the investigated samples exhibited high thermal stability up to approximately 400°C, with only a slight mass loss observed in this temperature range. A more pronounced decrease in mass occurred at approximately 420-450°C and was associated with the thermal decomposition of the organic components of the bituminous binder.

The most pronounced mass loss was observed in the 450-550°C temperature range, corresponding to the thermal decomposition of high-molecular-weight resin-asphaltene structures. With further increasing temperature, the rate of mass loss gradually decreased, while the remaining residue can be attributed to the most thermally stable components of the bituminous system.

An increase in the bio-based rejuvenator content resulted in a shift of the onset of intensive mass loss toward lower temperatures. The most pronounced effect was observed for the AB-5 sample, which may be attributed to the higher proportion of the organic components of the rejuvenator in the bituminous binder. A similar trend has been reported in the literature for

rejuvenated bitumen, where the incorporation of rejuvenators leads to an earlier onset of thermal decomposition owing to the presence of lighter and more mobile organic compounds [14].

The reduction in thermal stability with increasing rejuvenator content is attributed to the plasticizing effect of the bio-based rejuvenator and the presence of aliphatic moieties derived from oleic acid, which exhibit lower thermal stability than the high-molecular-weight resin–asphaltene structures of bitumen.

Effect of the bio-based rejuvenator on the physical and mechanical properties of aged bitumen

The results of the physical and mechanical tests (Table 1) demonstrated that the incorporation of the bio-based rejuvenator had a significant effect on the properties of the aged bitumen. After aging by RTFOT, the penetration value decreased from 75 to 56 (0.1 mm), the ductility decreased from 118 to 69 cm, and the softening point increased from 48 to 52 °C, indicating an increase in the stiffness of the bituminous binder.

Table 1 – Effect of RTFOT aging on the physical and mechanical properties of BND 70/100 bitumen

Sample	Penetration at 25 °C	Softening Point (Ring-and-Ball), °C	Ductility at 25 °C
Original bitumen	75	48	118
RTFOT-aged bitumen	56	52	69

The incorporation of the bio-based rejuvenator resulted in a gradual restoration of the performance properties of the bitumen (Table 2).

Table 2 – Physical and mechanical properties of RTFOT-aged bitumen after modification with the bio-based rejuvenator

Bitumen sample after rejuvenator modification	Penetration at 25 °C	Softening Point (Ring-and-Ball), °C	Ductility at 25 °C
AB- 1	59	53	66
AB- 3	78	48	91
AB- 5	88	45	104

The most pronounced effect was observed at a rejuvenator content of 5 wt.%, where the penetration increased to 88 (0.1 mm) and the ductility reached 104 cm. At the same time, the softening point decreased to 45°C. These results demonstrate the plasticizing effect of the bio-based rejuvenator and its ability to partially compensate for the changes induced by the thermo-oxidative aging of bitumen.

Conclusions

In this study, a plant-based rejuvenator based on oleic acid and imidazoline was prepared, and its effect on the properties of aged BND 70/100 bitumen was investigated.

The FTIR analysis confirmed the presence of aliphatic, carbonyl, and nitrogen-containing functional groups in the bio-based rejuvenator. Following its incorporation into the bitumen, changes in the intensity of the absorption bands assigned to carbonyl and sulfoxide functional groups were observed, indicating interactions between the rejuvenator components and the bitumen matrix and suggesting a partial restoration of the structural-colloidal state of the bitumen.

Thermogravimetric analysis showed that the modified samples maintained high thermal stability up to 400°C. With increasing rejuvenator content, a slight reduction in thermal stability was observed, which may be attributed to the presence of plant-derived aliphatic components.

The incorporation of the bio-based rejuvenator contributed to the restoration of the physical and mechanical properties of the aged bitumen. The formulation containing 5 wt.% rejuvenator exhibited the best performance, providing the greatest increase in penetration and ductility while simultaneously reducing the softening point.

The obtained results demonstrate the potential of the developed bio-based rejuvenator for restoring the performance properties of aged bituminous binders.

References

1. Wang R. Review on the Mechanism and Performance Enhancement of Biomass-Based Rejuvenators in Reclaimed Asphalt Recycling / R. Wang, X. Chen, P. Cheng // Polymers. – 2026. – Vol. 18, № 5. – Article 585. https://doi.org/10.3390/polym18050585.
2. State of the art: multiscale evaluation of bitumen ageing behaviour / Y. Hu et al // Fuel. – 2022. – Vol. 326. – Article 125045.
3. Recovering the properties of aged bitumen using bio-rejuvenators derived from municipal wastes / Y. Hu et al // Construction and Building Materials. – 2024. – Vol. 438. – Article 137268. https://doi.org/10.1016/j.conbuildmat.2024.137268.
4. Evaluating the ageing degrees of bitumen by rheological and chemical indices / Y. Hu et al // Road Materials and Pavement Design. – 2023.
5. Towards an enhanced understanding of the functional groups within bitumen during ageing processes / Y. Hu et al // Advances in Functional Pavements. – Boca Raton: CRC Press, 2024. – P. 83-87.
6. Application of Rejuvenators in Asphalt Binders: Classification and Micro- and Macro-Properties / C. Xing et al // Coatings. – 2025. – Vol. 15. – Article 1177. https://doi.org/10.3390/coatings15101177.
7. Performance evaluation of aged asphalt rejuvenated with various bio-oils based on rheological property index / J. Wang et al // Journal of Cleaner Production. – 2023. – Vol. 385. – Article 135593. https://doi.org/10.1016/j.jclepro.2022.135593.
8. Babagoli R. Bio-binders in sustainable asphalt technologies: A comprehensive bibliometric analysis / R. Babagoli // Results in Engineering. – 2026. – Vol. 29. – Article 109426. https://doi.org/10.1016/j.rineng.2025.109426.
9. Evaluating efficacy of bio-based and non-bio rejuvenators for sustainable asphalt restoration and durability / R. Liu et al // Construction and Building Materials. – 2025. – Vol. 505. – Article 144733. – https://doi.org/10.1016/j.conbuildmat.2025.144733.
10. The Rejuvenation Effect of Bio-Oils on Long-Term Aged Asphalt / J. Wang et al // Materials. – 2024. – Vol. 17. – Article 3316. https://doi.org/10.3390/ma17133316.
11. Experimental and molecular simulation insights into rejuvenation mechanism of bio-rejuvenated asphalt binders: Tailoring epoxy groups in bio-rejuvenators / Y. Chen et al // Construction and Building Materials. – 2025. – Vol. 495. – Article 143725. https://doi.org/10.1016/j.conbuildmat.2025.143725.
12. Beyond oxidation: a new framework for understanding and effective simulation of asphalt aging in the era of climate-adaptive pavements / F. Ghasemi et al // Road Materials and Pavement Design. – 2026. – P. 1-90. https://doi.org/10.1080/14680629.2026.2660314.
13. Oil Sludge as a Rejuvenator for Aged Bitumen: Structural and Thermal Effect / G. Aitkaliyeva et al // Applied Sciences. – 2025. – Vol. 15. – Article 6757. https://doi.org/10.3390/app15126757.
14. Multi-Characterization of Rejuvenators' Impact on Aged Asphalt Binder Properties / S. Hu et al // Materials. – 2025. – Vol. 18. – Article 4060. https://doi.org/10.3390/ma18174060.

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БИТУМ ҚАСИЕТТЕРІН ЖАҚСАРТУҒА АРНАЛҒАН ӨСІМДІК ТЕКТІ ҚОСПА

Битумның өндіру және пайдалану процесіндегі қартаюы оттекті функционалдық топтардың түзілуіне, қаттылығының артуына және жол жабынының пайдалану қасиеттерінің төмендеуіне алып келеді. Осыған байланысты қартаюға ұшыраған битумның қасиеттерін қалпына

келтіруге арналған тиімді әрі экологиялық қауіпсіз реювенаторларды әзірлеу асфальтбетонды регенерациялау технологияларындағы өзекті мәселелердің бірі болып табылады.

Бұл жұмыста олеин қышқылы мен имидазолин негізінде өсімдік текті реювенатор синтезделіп, оның БНД 70/100 маркалы қартаюға ұшыраған битум қасиеттеріне әсері зерттелді. Биоқоспа RTFOT әдісімен қысқа мерзімді қартаюға ұшыратылған битумға 1, 3 және 5 масс.% мөлшерінде енгізілді. Реювенатордың әсері ИҚ Фурье-спектроскопиясы, термогравиметриялық талдау және стандартты физика-механикалық сынақтар әдістерімен бағаланды.

FTIR талдауы карбонил және сульфоксид топтарына сәйкес келетін жұтылу жолақтарының қарқындылығы өзгеретінін көрсетті, бұл реювенатор компоненттерінің битум матрицасымен өзара әрекеттесуін дәлелдейді. Термогравиметриялық талдау модификацияланған үлгілердің 400°C-қа дейін жоғары термиялық тұрақтылығын сақтайтынын көрсетті. Биоқоспаны енгізу пенетрация мен созылғыштық көрсеткіштерінің артуына және жұмсару температурасының төмендеуіне ықпал етті. Ең жоғары тиімділік реювенатордың 5 масс.% мөлшерінде байқалды.

Алынған нәтижелер әзірленген өсімдік текті реювенаторды қартаюға ұшыраған битум тұтқырларының пайдалану қасиеттерін қалпына келтіру және асфальтбетонды регенерациялау технологияларының тиімділігін арттыру үшін қолданудың перспективалы екенін көрсетті.

Түйін сөздер: *қартаюға ұшыраған битум; өсімдік текті реювенатор; олеин қышқылы; имидазолин;асфальтбетонды қайта өңдеу; ИҚ Фурье-спектроскопиясы; термогравиметриялық талдау.*

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РЕЮВЕНАТОР РАСТИТЕЛЬНОГО ПРОИСХОЖДЕНИЯ ДЛЯ ВОССТАНОВЛЕНИЯ СВОЙСТВ СОСТАРЕННОГО БИТУМА

Старение битума в процессе производства и эксплуатации сопровождается образованием кислородсодержащих функциональных групп, повышением жесткости и ухудшением эксплуатационных характеристик дорожных покрытий. В связи с этим разработка эффективных и экологически безопасных реювенаторов для восстановления свойств состаренного битума является актуальной задачей технологий регенерации асфальтобетона.

В данной работе синтезирован реювенатор растительного происхождения на основе олеиновой кислоты и имидазолина и исследовано его влияние на свойства состаренного битума марки БНД 70/100. Биодобавку вводили в битум, подвергнутый краткосрочному старению методом RTFOT, в количестве 1, 3 и 5 мас. %. Влияние реювенатора оценивали методами ИК Фурье-спектроскопии, термогравиметрического анализа и стандартных физико-механических испытаний.

Результаты FTIR-анализа показали изменение интенсивности полос поглощения карбонильных и сульфоксидных групп, что свидетельствует о взаимодействии компонентов реювенатора с битумной матрицей. Термогравиметрический анализ установил сохранение высокой термической стабильности модифицированных образцов до 400 °C. Введение биодобавки способствовало улучшению физико-механических характеристик состаренного битума за счет увеличения пенетрации и дуктильности при одновременном снижении температуры размягчения. Наиболее выраженный эффект был достигнут при содержании реювенатора 5 мас. %.

Полученные результаты подтверждают перспективность применения разработанного реювенатора для восстановления эксплуатационных свойств состаренных битумных вяжущих и повышения эффективности технологий регенерации асфальтобетонных материалов.

Ключевые слова: *состаренный битум; реювенатор растительного происхождения; олеиновая кислота; имидазолин; регенерация асфальтобетона; FTIR-спектроскопия; термогравиметрический анализ.*

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