Primary Causes of Aging of Bitumen Used in Asphalt Concrete and Methods of Rejuvenation

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Abstract This article presents the causes of aging of bitumen used in asphalt concrete mixtures and methods for improving bitumen performance characteristics. The materials used in the study are presented and described. The work contributes to extending the service life of bitumen, which represents a future economic benefit for infrastructure projects.
Key words: Bitumen, fatigue, aging, polymer modification.

Introduction

As in the rest of the world, the major part of Georgia's road network is surfaced with asphalt pavement. Along with the sharp increase in the number of vehicles in the country, the requirements for pavement quality continue to grow in order to ensure greater durability and wear resistance.
Using Georgia as an example, it can be stated that road pavements often fail to withstand their theoretically estimated service life and deteriorate prematurely. In addition to factors such as unstable subgrades, excessive axle loads, and similar influences, one of the principal causes of pavement failure is bitumen fatigue.
Bitumen is a material of solid or liquid consistency consisting of a complex mixture of numerous organic compounds. It is the principal material in asphalt concrete mixtures, serving as the binding agent of the aggregate skeleton. Bitumen consists of four main groups: saturates, aromatic compounds, resins, and asphaltenes (SARA). Over time, during the aging process, aromatic compounds are transformed into resins, while resins are converted into asphaltenes. As a result, when exposed to air and ultraviolet radiation, lighter fractions are transformed into heavier asphaltenes. The concentration of asphaltenes (the hardest particles) increases and the bitumen becomes more viscous, less elastic,

and more brittle, resembling aged rubber that cracks instead of remaining flexible.
Visible manifestations of bitumen aging include situations in which the bitumen can no longer retain aggregates and the pavement surface begins to disintegrate (surface ravelling effect), as well as the appearance of rectangular cracks on the surface, which are a direct result of binder hardening and drying (block cracking).
During its service life, bitumen undergoes two stages of so-called fatigue/aging:
1. Short-term aging: occurring during asphalt mixture production and paving operations. At high temperatures (150–160°C), lighter fractions evaporate and the bitumen rapidly hardens.
2. Long-term aging: occurring over many years after the pavement has been placed. The principal adverse factors are oxygen and ultraviolet radiation.
The chemical transformation of SARA fractions and the physical stages of this aging process are visually illustrated in Figure 1.

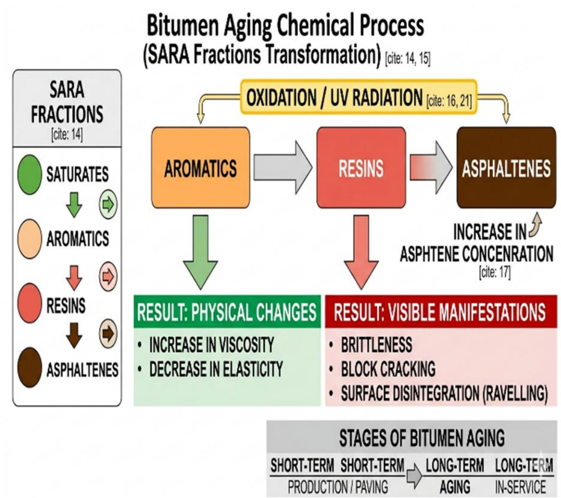

Fig. 1. Chemical process of bitumen aging and SARA fractions transformation.

Main Part

In order to determine in advance how long bitumen used in asphalt concrete mixtures will perform, it is not necessary to observe it throughout its entire service life. To evaluate bitumen aging, the road industry relies on two major systems: the European (EN) system and the American (ASTM/AASHTO) system. These standards make it possible to estimate the service life of bitumen under laboratory conditions.

For this purpose, short-term aging is simulated using the RTFOT (Rolling Thin Film Oven Test) method, while long-term aging is simulated using the PAV (Pressure Aging Vessel) method.

In the RTFOT procedure, bitumen is rapidly heated to 160°C, simulating asphalt plant production conditions, during which lighter components evaporate. In the PAV procedure, bitumen is aged under elevated pressure and temperature conditions within a chamber for 10–20 hours, simulating approximately 10 years of field service. Rheological analysis using a Dynamic Shear Rheometer (DSR) measures the complex modulus, indicating the resistance of bitumen to fatigue cracking.

Fig. 2. PAV apparatus;

Fig. 3. RTFOT apparatus;

Fig. 4. DSR apparatus.

The Bitumen Aging Index is calculated as the ratio of the viscosity of aged bitumen to that of virgin bitumen. The lower this coefficient, the higher the quality of the bitumen and the longer the pavement can remain in service without major rehabilitation.

To extend the service life of bitumen, materials capable of slowing the aging process should be incorporated. Such materials include SBS polymers, antioxidants, and bio-based rejuvenators. These compounds enable the formation of an elastic network within the bitumen, which limits crack propagation and slows oxidation reactions.

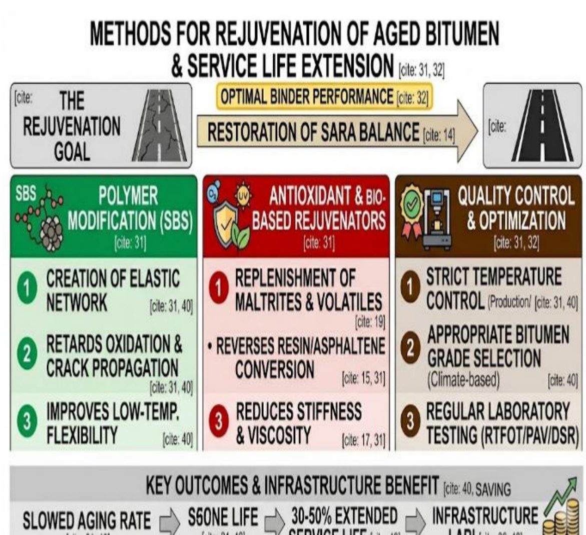

Fig. 5. Strategic layout for bitumen rejuvenation, incorporating modifier types, oxidation-slowing mechanisms, and strict field control conditions

The introduction of Styrene-Butadiene-Styrene (SBS) block copolymers into the asphalt matrix creates a continuous, three-dimensional elastomeric network that fundamentally alters the binder's rheological behavior. Under high-temperature conditions, this polymer network absorbs a significant portion of the thermal stress, effectively preventing the asphalt from undergoing excessive softening and subsequent rutting. Simultaneously, at lower temperatures, the elastic properties of the modified matrix allow for greater flexibility, thereby mitigating the risk of thermal cracking caused by rapid contraction. Furthermore, the inclusion of specific antioxidant agents and chemical rejuvenators disrupts the free-radical chain reactions responsible for oxidation. By preventing the premature conversion of flexible aromatics and resins into brittle asphaltenes, these additives maintain the internal chemical balance of the bitumen, ensuring long-term structural integrity even under severe climate loading.

Under Georgian conditions, laboratory investigations were conducted on penetration grade 50/70 paving bitumen available on the domestic market in the accredited laboratory of LLC 'Absolute Service'. The bitumen was evaluated using the RTFOT and PAV methods. Subsequently, an SBS polymer modifier was added, producing Polymer Modified Bitumen (PMB). The modified bitumen was also tested using both methods.

To simulate the short-term aging that occurs during the mixing and transportation of asphalt concrete, the Rolling Thin-Film Oven Test (RTFOT) was conducted in accordance with EN 12607-1 and ASTM D2872 standards. During this procedure, the bitumen samples were placed in specialized glass containers and subjected to a constant temperature of 163°C for 85 minutes while being exposed to a continuous airflow. This laboratory conditioning effectively replicates the oxidative hardening and volatilization of light fractions that the binder experiences in a real-world asphalt plant environment before actual field compaction.

Following the short-term simulation, long-term oxidative aging was achieved using a Pressure Aging Vessel (PAV) operating under a pressure of 2.10 MPa at elevated temperatures for 20 hours, simulating approximately 7 to 10 years of in-service pavement life. The rheological properties of both the conventional (Pen 50/70) and polymer-modified bitumen (PMB) were subsequently evaluated using a Dynamic Shear Rheometer (DSR). The DSR analysis allowed for the precise determination of the complex shear modulus (G) and the phase angle (δ), which serve as critical indicators of the binder's resistance to permanent deformation and fatigue cracking under cyclic loading.

According to laboratory results, after RTFOT aging the bitumen exhibited a high stiffness value ($G/\sin\beta$ = 3.25 kPa), whereas the corresponding value for the modified bitumen was 2.57 kPa. These results indicate that conventional bitumen became stiffer due to accelerated aging, while the polymer modifier slowed the aging process, making the modified bitumen more resistant to aging.

For PAV-aged samples, the parameter ($G^*\sin\beta$) should not exceed 5000 kPa. The lower the value obtained, the greater the resistance of the bitumen to aging. Laboratory results showed $G^*\sin\beta$ = 3835 kPa at 22°C for conventional bitumen, while after modification the same parameter was $G^*\sin\beta$ = 1946 kPa at 4°C. This indicates that the value obtained for conventional bitumen is already very close to the limiting criterion at its operating temperature, meaning that a further decrease in temperature may lead to premature failure. In the case of modified bitumen, the material demonstrated nearly twice lower susceptibility under much more critical temperature conditions, indicating that it can withstand a significantly greater number of temperature cycles.

Based on the obtained results, it can confidently be stated that bitumen modification is an essential condition for extending service life. Modification not only slows the rate of aging but also fundamentally preserves pavement flexibility at low temperatures, thereby minimizing the risk of crack formation during winter conditions. In addition to bitumen modification, the following conditions should be observed: strict control of temperature regimes during asphalt mixture production and paving; proper storage conditions for bitumen; and selection of appropriate bitumen grades according to the climatic conditions of the country's regions.

The complete workflow of the laboratory evaluation, a visual comparison of the rheological parameters, and the strategic solutions for pavement rejuvenation are comprehensively summarized in Figure 6.

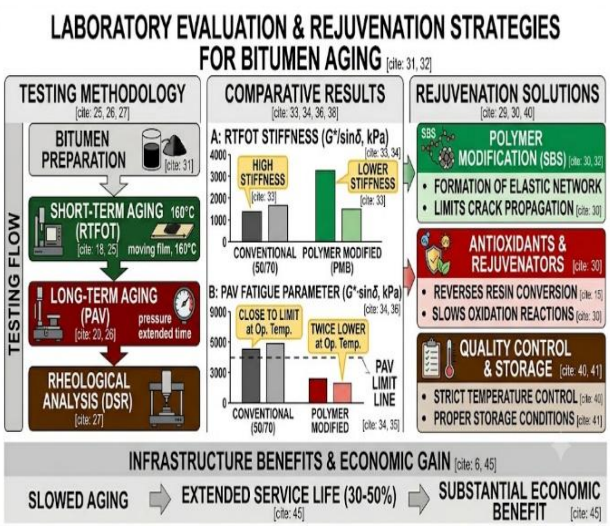

Fig. 6. Comprehensive map of laboratory testing flow, comparative DSR results (for RTFOT and PAV aged binders), and polymer-based rejuvenation strategies with related infrastructure benefits

The integration of systematic laboratory workflows, such as the RTFOT and PAV aging procedures, provides a foundational framework for evaluating the life-cycle performance of modern asphalt pavements. By quantifying the changes in the complex shear modulus and fatigue parameters, researchers and field engineers can accurately chart the degradation trajectory of alternative binders. The experimental data confirms that while conventional asphalt mixtures exhibit rapid embrittlement, the targeted introduction of elastomeric modifiers acts as a robust defense mechanism against both high-temperature rutting and low-temperature cracking. Furthermore, scaling these laboratory findings into regional infrastructure policies yields profound economic advantages. Extending the service life of major highways by 30% to 50% substantially reduces the frequency of localized maintenance cycles, minimizes traffic disruptions, and optimizes the allocation of state infrastructure funds, driving long-term sustainability in the transport sector.

Conclusion

In conclusion, it can be stated that accurate prediction of aging translates into millions of saved lari in road construction and maintenance works. In prospective terms, shifting from conventional binders to high-performance polymer-modified bitumen (PMB) represents a critical paradigm shift for the regional asset management strategies of Georgia's highway network. The empirical evidence gathered through standardized dynamic shear rheometer (DSR) profiling demonstrates that the structural longevity of pavement layers is directly dependent on mitigating early-stage oxidative aging. By implementing these performance-graded specifications into national procurement protocols, infrastructure departments can transition from reactive, short-term maintenance models to proactive life-cycle optimization. This transition not only safeguards substantial capital investments but also aligns local engineering standards with contemporary European transport infrastructure frameworks.

Furthermore, future research directions should focus on the long-term field monitoring of these modified asphalt test sections to calibrate laboratory-derived aging models with actual environmental degradation rates under real-world traffic flows. Investigating the synergistic effects of combining SBS polymers with locally sourced bio-rejuvenators could unveil even more cost-effective mixtures. Ultimately, establishing a comprehensive, performance-based database for binders will serve as an indispensable tool for engineers, driving innovation, minimizing environmental footprints, and ensuring the structural resilience of the country's primary transport corridors for decades to come.

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