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EVALUATION OF TEMPERATURE PARAMETERS OF LOWGRADE MODIFIED BITUMEN IN COMPARISON WITH HIGH GRADE BITUMEN

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ABSTRACT: To ensure the durability of asphalt concrete pavements, different grades of bitumen are used based on the climatic zone. However, bitumen is susceptible to aging due to the effects of temperature and solar radiation, which reduce its elasticity, adhesion, and deformation resistance. The purpose of this study is to analyze the effect of modifying the additive on the properties of low-grade bitumen and to compare the results with the characteristics of higher-grade bitumen. Tests were conducted on samples of bitumen grades M 50/70 and M 70/100. The results of softening point measurements indicate that samples of low-grade bitumen (Type 1) demonstrated stable values of 51.2 °C before modification and 68.6 °C after modification. The increase in the coefficients of dynamic viscosity for all samples remained within the maximum permissible value of 2.5. Flash point measurements exceeded the minimum permissible value for grades 50/70 and 70/100, with a recorded temperature of 230 °C. Although the brittleness temperature of the modified low-grade bitumen did not meet the requirements for higher grades, it was lower than the average brittleness values of some higher-grade bitumens. In conclusion, the addition of a modifier to low-grade bitumen does not negatively affect its temperature performance. Moreover, in certain cases, the modified bitumen outperforms higher-grade bitumen. The use of modifying additives with low grades of bitumen leads to the improvement of their exploitation properties under the influence of high temperatures. Hence, the potential application of additives helps to increase the service life of asphalt concrete in hot climatic conditions.

Keywords: Bitumen, Bitumen softening point, Dynamic viscosity, Bitumen flash point, Brittleness, RTFOT test

1. INTRODUCTION

The climate of Kazakhstan is characterized by severe conditions that significantly impact the condition of asphalt concrete roads [1]. The country experiences sharp temperature fluctuations, including seasonal freezing and thawing, high summer temperatures, as well as considerable wind and sediment loads. These factors accelerate the destruction of road pavements, contributing to the formation of cracks, potholes, and rutting, which reduce the road comfort and safety [2].

Asphalt concrete pavements have to withstand extreme temperature fluctuations while maintaining their performance characteristics in both high summer temperatures and severe winter frosts [3]. This challenge is especially important in the northern regions of Kazakhstan, where low temperatures and prolonged frosts increase the risk of surface cracking, accelerating wear of pavements and reduces service life [4].

There are various technologies to produce combined oxidized bitumen to improve the characteristics of asphalt mixtures with improved performance properties. The authors consider methods of bitumen oxidation aimed at increasing heat resistance and adhesion. However, the addition of polymers to bitumen negatively affects the quality of asphalt concrete during operation at low temperatures, so using only polymer as a modifier is not a comprehensive solution to improve its properties.

The use of modified road bitumen with improved characteristics will make it possible to withstand high and low temperatures more effectively. The increased content of condensed aromatic structures in the bitumen composition increases its resistance to high temperatures, ensuring longer operation of the pavement [5]. Conversely, in the southern regions of the country, where summer temperatures can reach up to 50 °C, significant overheating of the road surface can lead to softening of bitumen and deformation of asphalt. To ensure road durability, it is necessary to use different grades of bitumen depending on the region’s climatic conditions: for example, grade 70/100 is used in southern areas, while grade 100/130 is preferred for northern areas, helping to extend road service life [6]. The bituminous binder plays a crucial role in the quality and durability of asphalt concrete pavements. However, its physical and mechanical properties are subject to significant changes under the influence of temperature loads, ultraviolet radiation and mechanical stresses.

Other scientists have considered methods for modifying bitumen, including using polyurethane additives [5]. Studies have shown that polyurethane components improve bitumen's resistance to aging, slowing degradation and increasing its durability.

Based on the analysis of the results on bitumen binders for asphalt concrete mixtures, we have proposed options for modifying bitumen, followed by comparison with unmodified material to determine quality indicators and recommendations. This stage is difficult from the point of view of the technological process, and we solved it by using the components of the proposed additive, including by-products of various industries. Thus, the proposed technology solves not only the tasks of improving the characteristics of the road material, but also environmental issues, in particular waste disposal.

The purpose of this research is to evaluate the impact of a modifying additive on the properties of low-grade bitumen and compare the findings with the characteristics of higher-grade bitumen. To achieve this objective, the following tasks were undertaken:

1. Perform accelerated aging of bitumen samples in an RTFOT oven to simulate natural aging conditions.
2. Analyze changes in softening point, dynamic viscosity, flash point, and brittleness before and after aging with the addition of the modifying additive.
3. Compare the test results of modified bitumen with those of unmodified bitumen.
4. Assess the effectiveness of the additive in enhancing bitumen's resistance to aging.
5. Conclude the applicability of modifying additives in improving the durability of bituminous materials for road construction.

2. RESEARCH SIGNIFICANCE

Bitumen aging poses a critical challenge to pavement longevity by diminishing elasticity, adhesion, and resistance to deformation—issues intensified under Kazakhstan’s extreme climate and high UV exposure. This research introduces a novel additive formulation comprising fuz, soapstock, epoxy resin, and polyethylene, specifically engineered to enhance bitumen’s aging resistance while maintaining its plasticity and mechanical integrity. The originality of this study lies in the unique combination of these components, designed to synergistically improve binder performance. Through comprehensive testing—including softening point, dynamic viscosity, flash point, and brittleness—we aim to uncover the additive’s effectiveness and offer insights for more durable asphalt solutions.

3. RESEARCH METHODOLOGY

The studies on selecting the optimal composition of modified bitumen were conducted as follows:

- Analysis of the physical and mechanical properties of bitumen grade 50/70;
- Analysis of the physical and mechanical properties of bitumen grade 70/100;
- Determination of the optimal composition for the modifying additive.

Tests were conducted on samples of bitumen grades M 50/70 and M 70/100 from different manufacturers. Since the research aimed to modify bitumen grade M 50/70 to achieve characteristics similar to bitumen grade M 70/100, all analyses were performed by comparing the properties of both grades before and after modification. Table 1 summarizes the types of bitumen binder samples and their manufacturers. To maintain confidentiality, manufacturer names were labeled with letters. For each bitumen type, at least five measurements were conducted for each indicator to ensure the relative accuracy of results, accounting for possible statistical deviations [9]. Selection of the specific modifying additive for improving bitumen properties was based on recent research findings emphasizing the necessity of tailoring bitumen performance to the specific regional climatic conditions [10].

Table 1. Types of bitumen binder samples compared

Type of sample	Bitumen grade	Manufacturer
Type 1	CB 50/70	LLP «A»
Type 2	CB 70/100	LLP «A»
Type 3	CB 70/100	LLP «B»
Type 4	CB 70/100	LLP «C»
Type 5	CB 70/100	LLP «D»
Type 6	CB 70/100	LLP «E»
Type 7	CB 70/100	LLP «F»
Type 8	CB 70/100	LLP «G»
Type 9	CB 50/70 modified	LLP «A»

The tests to determine the softening point were performed using the standard “ring and ball” method in accordance with ST RK 1227-2003. The objective of the test was to identify the temperature at which bitumen, placed in a ring of the standard size, softens and passes a distance of 25.0±0.4 mm under the force of a steel ball. For each type of bitumen, at least five measurements were conducted to obtain statistically significant results. The permissible error limits were as follows: for a softening temperature of up to 80 °C the permissible deviation is 2 °C; and for temperatures above 80 °C, the deviation is 4 °C.

Dynamic viscosity was determined using the standard method outlined in ST RK 1211-2003. The purpose of the test was to establish the relationship between shear rate and shear stress. Measurements were conducted using a viscometer with vacuum capillaries at a temperature of 60 ° C, recording the time taken for bitumen passing through the capillaries under vacuum [11]. For each type of bitumen, at least five measurements were carried out to enable statistical analysis of the results. The allowable discrepancy between measurements is no more than 10%.

The flash point was determined using the standard method specified in ST RK 1804-2008. This test aimed to establish the minimum ignition temperature of bitumen vapors in air under atmospheric pressure [12]. For each type of bitumen, at least five measurements were conducted to ensure statistical reliability, with an allowable variation of no more than 17 °C.

The brittleness temperature was determined using the Fraass method in accordance with ST RK 229-2003. This parameter characterizes the degree of bitumen brittleness at low temperatures. The purpose of the test was to determine the temperature at which the integrity of the bituminous film is compromised under load. For each type of bitumen, at least five measurements were performed to obtain statistically reliable results, with an acceptable deviation of no more than 6 °C.

Repeated tests to evaluate changes in physical and mechanical properties of bitumen were conducted after its aging in an RTFOT oven, following the methodology specified in ST RK 1224-2023. During the aging process, the bitumen film was continuously renewed by airflow heating in a rotating flask at a temperature of 163 ± 1 °C for 75 ± 1 minutes. The drum's rotational speed was maintained at 0.25 ± 0.003 s^{1} (15.0 ± 0.2 rpm), and air was supplied at a flow rate of 4000 ± 200 ml/min. The number of samples and allowable errors were consistent with the tests conducted to evaluate the initial characteristics.

4. TEST RESULTS

4.1 Softening Point Determination

Figures 1-4 show the average softening points of the tested samples. The curves in Figure 1 present the initial and residual softening points after RTFOT aging. The straight lines in Figure 1 indicate the maximum permissible softening points of bitumen grades 50/70 and 70/100.

Figure 2 highlights the changes of softening points after aging. Figure 3 and 4 show the standard deviations and coefficients of variation of the partial softening temperatures before and after aging of 5 samples of each type, respectively. For visualization, the results are connected by lines, which do not indicate a relationship or pattern of data points, but determine the belonging of the results to a particular series of tests.

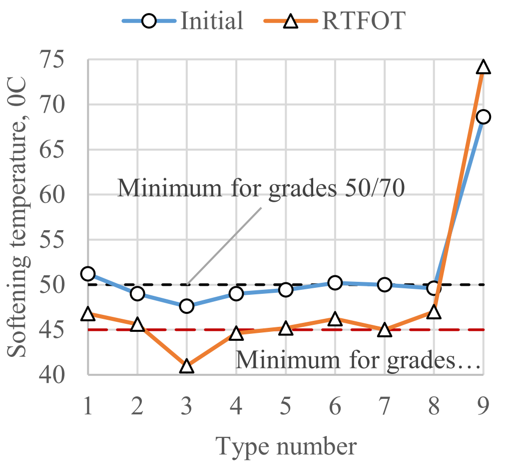

Fig. 1 Maximum permissible softening points of bitumen grades 50/70 and 70/100

The results indicate that the average initial softening point for low-grade bitumen is 51.2 °C, which meets the requirements for grades 50/70 of no less than 50 °C. Higher-grade bitumen samples showed initial softening points ranging from 47.6 to 50.2 °C, which also corresponds to the requirements for grades 70/100 of no less than 45 °C.

The highest softening points were observed in type 6 and 7 samples, with values of 50.0°C and 50.2°C. Type 2, 4, 5, and 8 samples had average values of 49.0°C, 49.0°C, 49.4°C, and 49.6°C, respectively, while type 3 samples showed the lowest values of 47.6 °C. Modified bitumen samples indicated higher softening point values ranging from 68 to 71 °C, with an average of 68.6 °C. The modified bitumen's softening point increased from 51.2 °C to 68.6 °C, aligning it with higher-grade bitumen. However, a performance evaluation under real traffic loads would validate its effectiveness further. The increase in temperature is primarily due to the presence of polymers in the composition of the modifier, which increases the stiffness of the bitumen. After aging, the softening point of low-grade bitumen averaged 8.6% and 46.8 °C in absolute values.

The maximum reduction in higher-grade bitumen was observed in types 3 and 7 samples, with decreases of 13.9% (41.0°C) and 10.0% (45.0°C), respectively. The average values observed in type 4, 5, and 6 samples were 9.0% (44.6°C), 8.5% (45.2°C), and 8.0% (46.2°C), respectively.

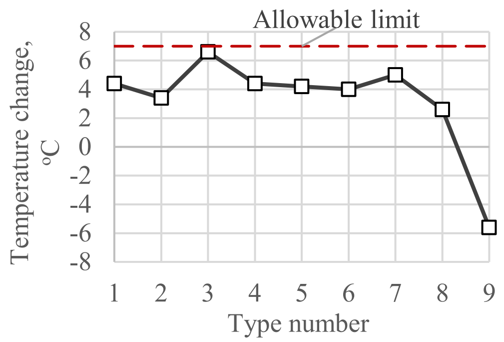

Fig. 2 Changes in softening points after aging

The minimum values for type 2 and 8, were 6.9% (45.6°C) and 5.2% (43.6°C), respectively. The results show an 8.6% reduction in softening point for aged low-grade bitumen, whereas high-grade bitumen experiences a decline of up to 13.9%, demonstrating that modification enhances thermal stability.

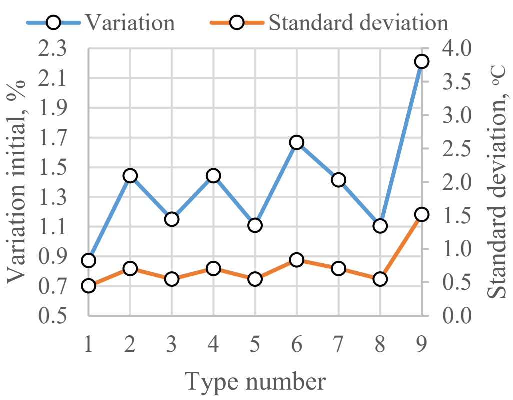

Fig. 3 Coefficient of variations and standard deviations of softening points before aging

The modified bitumen samples showed an inverse pattern of softening point changes after aging. The softening point values increased to 74.2 °C (varies from 73 to 76 °C), which is primarily due to the fact that as a result of bitumen evaporation, its volume fraction in relation to the polymer decreases, hence the bitumen becomes stiffer [13].

Thus, the results of changes in temperature after aging for low-grade bitumen was 4.4%, and 5.6% after modification. The temperature change of higher-grade samples varies from 2.6 to 6.6%.

All indicators of changes in softening point did not exceed the maximum permissible values of grades 50/70 and 70/100 (no more than 7 °C). The latter indicates the acceptability of the obtained results, their compliance with the norms and suitability for further analysis.

All coefficients of variation of the partial values of the initial softening temperatures do not exceed 2.2%, after aging do not exceed 2.0%, and the standard deviations do not exceed 1.52 ^{0}C.

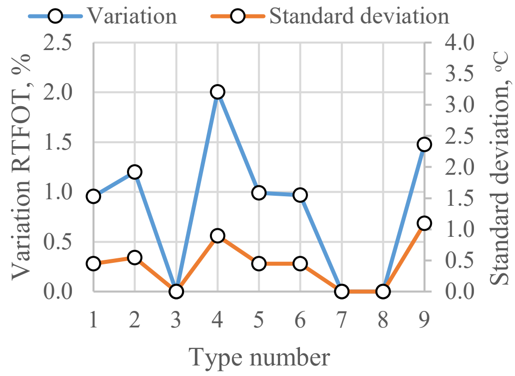

Fig. 4 Coefficient of variations and standard deviations of softening points after aging

These low variations indicate a high level of measurement accuracy and statistical reliability. Additionally, the differences between the data points does not exceed 2 °C, meeting the requirements outlined in the standard (refer to the Methods section).

4.2 Determination Of Dynamic Viscosity

Figures 5-8 show the average dynamic viscosity values for the tested samples. Curve diagrams in Figure 5 shows the initial and residual viscosity values after aging, with straight lines indicating the maximum allowable viscosity for grades 50/70 and 70/100.

Figure 6 shows the coefficient of increase in dynamic viscosity, defined as the ratio of dynamic viscosity at 60 °C after aging to the initial dynamic viscosity value.

Figure 7 and 8 show the standard deviations and coefficients of variation of the partial viscosity values before and after aging of 5 samples of each type, respectively. For visualization purposes, the samples before and after aging are conventionally connected by lines. These lines do not imply a relationship or pattern between data points but rather indicate the association of the results with a specific series of tests.

According to the results obtained, the average initial dynamic viscosity for low-grade bitumen is 363.7 Pas, which complies with the requirements for grades 50/70 of no less than 250 Pas. Higher-grade bitumen showed initial viscosities ranging from 188.6 to 365.0 Pas, which also complies with the requirements for grades 70/100 of no less than 145 Pas. The maximum dynamic viscosity value, which indicates the high viscosity of bitumen, was found in type 8 samples, reaching 365.0 Pas.

The average viscosity values for type 5, 6 and 7 samples are 266.5 Pas, 282.0 Pas and 264.7 Pas, respectively. The lowest values were observed in type 2, 3 and 4 samples, with 193.4 Pas, 188.6 Pas and 191.3.6 Pas, respectively.

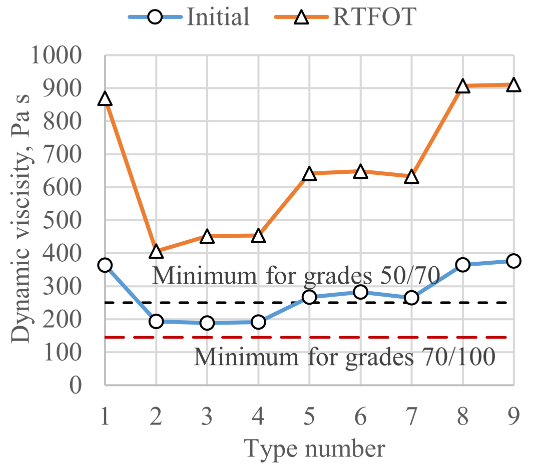

Fig. 5 Initial and residual viscosity values after aging

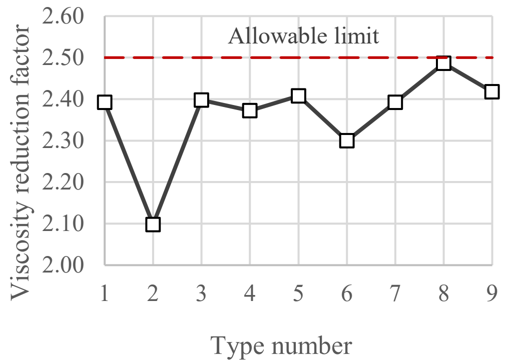

Fig. 6 Coefficient of increase in dynamic viscosity

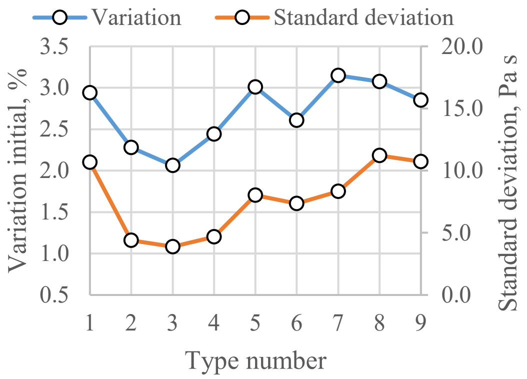

Fig. 7 Coefficient of variations and standard deviations of viscosity after aging

The samples of modified bitumen demonstrated a regular increase in viscosity relative to unmodified bitumen (50/70), primarily due to the presence of polymers in the additive composition. The viscosity of the modified bitumen averaged 376.6 Pas (ranging from 359 Pas to 386 Pas), with a coefficient of variation of 2.9%. After aging, the viscosity of low-grade bitumen increased by an average of 139%, corresponding to an absolute value of 869.5 Pas. The maximum increase in viscosity of high-grade bitumen was found in samples of type 8, in absolute values is 907.1Pas, representing a 148% relative to the initial value.

Average values were recorded for type 5, 6, and 7 samples, amounting to 641.7 Pas (140%), 648.7 Pas (130%), and 633.2 Pas (139%), respectively. The lowest viscosity values were found in type 2, 3, and 4 samples, with corresponding values of 405.9 Pas (109%), 452.1 Pas (139%), and 453.5 Pas (137%).

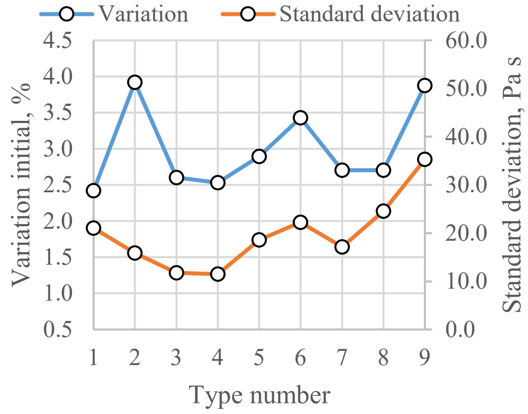

Fig. 8 Coefficient of variations and standard deviations of viscosity after ageing

In general, the modified bitumen samples showed similar viscosity dynamics after aging as bitumen grades 50/70 and 70/100, with an average viscosity of 910.8 Pas (ranging from 854 Pas to 948 Pas). The coefficients of expansion for dynamic viscosity after aging averaged 2.39 for low-grade bitumen and ranged from 2.10 to 2.49 for high-grade bitumen. With the inclusion of the modifier, the coefficient of expansion slightly increased to 2.42%. The coefficient of increase in dynamic viscosity remained within the 2.5 limit for all samples, confirming that the modifier does not negatively impact bitumen flowability under high temperatures. All coefficients of expansion remained below the maximum permissible value of 2.5 for grades 50/70 and 70/100, indicating the acceptability of the results and their compliance with standards, therefore, their relevance for further analysis. All coefficients of variation of the partial values of the initial viscosities do not exceed 3.1% (with a maximum standard deviation of 11.22 Pa s), and after aging do not exceed 3.9% (with a maximum standard deviation of 35.28 Pa s). This relatively low variation reflects a high degree of results consistency and statistical accuracy. The difference between data points did not exceed 10%, meeting standard requirements (refer to the Methods section). The effect of the modified additive on changes in dynamic viscosity was minimal, as the observed variations were within the statistical error of individual measurements and complied with normative requirements.

4.3. Determination of Flash Point

Figures 9 and 10 present the ignition temperature measurements for the samples. Figure 9 shows the average values for 5 samples of each bitumen type, while Figure 10 shows their respective coefficients of variation and standard deviations. The tests were conducted only to evaluate the initial performance without aging the samples. The latter is due to the fact that this indicator refers to the evaluation of the content of volatile flammable substances, the importance of which is relevant in the transportation and laying of bitumen from the perspective of fire safety. However, this indicator is not significant for assessing the serviceability of asphalt concrete and is not very important for long-term road usage [14].

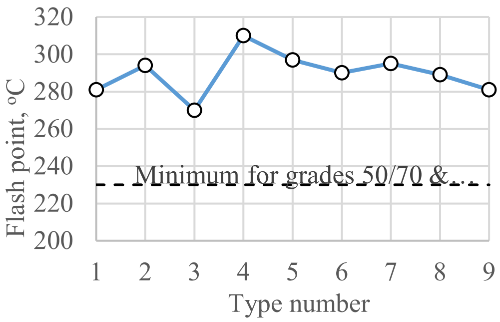

Fig. 9 Average ignition temperature values for 5 samples of each bitumen type

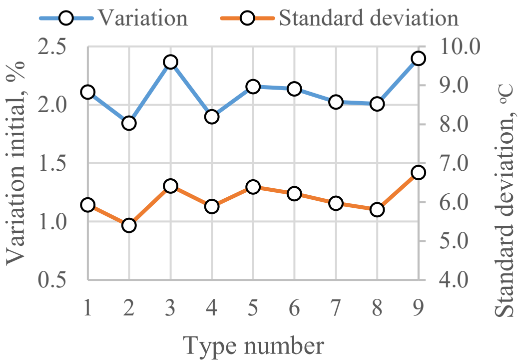

Fig. 10 Coefficients of variations and standard deviations of ignition temperature for bitumen samples

The results show that the average flash point for grade 50/70 bitumen was 281.2 °C, with data points ranging from 272 to 285 °C and a coefficient of variation of 2.1%. For grade 70/100, the average flash points ranged from 271.2 to 310.2 °C, with coefficients of variation not exceeding 2.4%. The average flash point across all types of 70/100 samples was 292.4 0C, with a coefficient of variation of 3.96 % and a quadratic deviation of 6.01 ^{0}C. These results demonstrate high reliability within individual sample sets, as indicated by low coefficients of variation. The average flash point of modified bitumen was 281.8 0C, with a coefficient of variation of 2.4% and a quadratic deviation of 6.76°C. All measured flash points exceeded the minimum permissible threshold of 230°C for both grades 50/70 and 70/100. Any observed changes in flash point values were insignificant, falling within the statistical margin of error. This indicates that the inclusion of modifier components in the bitumen composition did not significantly affect the flash point.

The flash point values of both the modified low-grade bitumen (281.8 °C) and high-grade bitumen samples (average 292.4 °C) exceed the minimum safety requirement of 230 °C, indicating compliance with relevant standards. However, when compared to polymer-modified bitumen (PMB), which typically exhibits flash points in the range of 300–320 °C due to the inclusion of stable synthetic polymers, the tested samples show slightly lower thermal stability in terms of flammability.

4.4. Determination of Brittleness Temperature

Figures 11 and 12 show the results of brittleness temperature measurements. Figure 11 shows the average values for 5 samples of each bitumen type, and Figure 12 shows their respective coefficients of variation and standard deviations.

According to the test results, the average brittleness temperature for 50/70 bitumen was -18.5°C, with data points ranging from 17.8°C to 19.7°C, and a coefficient of variation of 1.9 %.

The average brittleness temperature for grade 50/70 bitumen was -18.5°C, with data points ranging from -17.8 °C to -19.7 °C and a coefficient of variation of 1.9%. For grade 70/100, the brittleness temperatures varied significantly by manufacturer, ranging from -13.4 °C to -23.1°C. The overall average for 70/100 samples was -20.1°C. Coefficients of variation within individual sample sets did not exceed 2.7%, indicating reliable results. However, the coefficient of variation across all 70/100 samples was 17.8%, reflecting lower repeatability. The average brittleness temperature for modified bitumen was -17.2 °C, with a coefficient of variation of 2.7%.

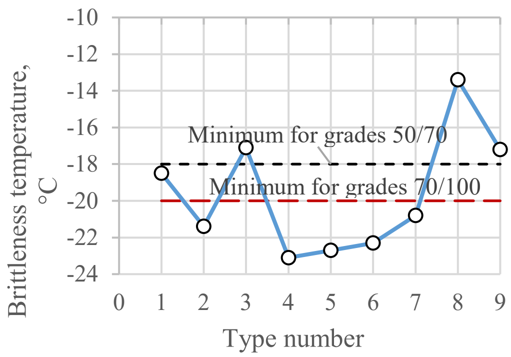

Fig. 11 Average brittleness temperatures for 5 samples of each bitumen

The obtained average flash point values within each sample exhibit a high degree of reliability, with coefficients of variation not exceeding 2.7%, and a standard deviation of 0.62 °C. The mean value of the brittleness temperature of the modified bitumen was -17.2%, with a coefficient of variation of 2.7% and a standard deviation of 0.46°C. The changes in brittleness temperature were minor and within the statistical margin of error, suggesting that the inclusion of modifier components had a negligible effect. When compared to normative values, all low-grade bitumen samples met the requirement of a threshold no higher than 18.0°C.

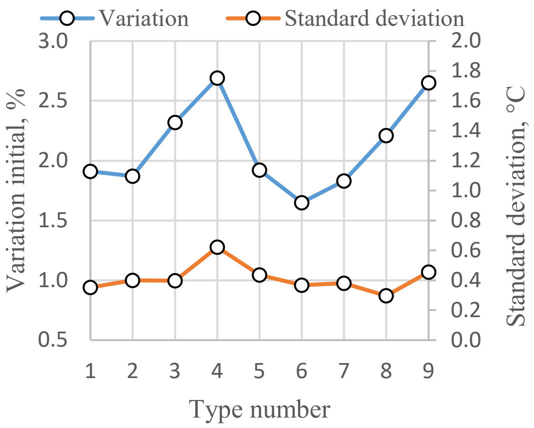

Fig. 12 Coefficients of variations and standard deviations of brittleness temperature for bitumen samples

Nonetheless, the brittleness temperature of the modified bitumen (–17.2 °C) remains higher than the average value recorded for high-grade bitumen (–20.1 °C), suggesting comparatively lower resistance to low-temperature cracking. This result highlights the need for further refinement of the modifier formulation to enhance the material's performance under severe winter conditions, particularly in cold climatic regions.

For high-grade bitumen, two out of seven manufacturers exceeded the threshold limit of -20.0 °C, which does not meet the normative requirements. The brittleness temperature of modified bitumen also failed to meet high-grade requirements, although in some cases, it was lower than the average brittleness values observed for high grades.

This finding underscores that even bitumen classified as high-grade may fail to meet regulatory standards for low-temperature performance, depending on the specific formulation and production technology used by the manufacturer. Therefore, the selection of bitumen for use in cold climates should consider not only grade specifications but also supplier-specific quality characteristics.

5. CONCLUSIONS

1. A series of tests was conducted to assess the temperature parameters of bitumen of various grades and manufacturers. The research aimed to compare the temperature indicators of bitumen grade 50/70 before and after modification with those of bitumen grade 70/100. The control indicators included the softening point, ignition point, brittleness temperature, and dynamic viscosity.

2. The control samples of low-grade bitumen (Type 1) showed stable softening point results of 51.2°C before modification and 68.6°C after modification. The increase in the softening point is attributed to the presence of polymers in the modifier, which increases the stiffness of bitumen. High-grade bitumen samples (Types 2–8) had an average softening point of 49.3 °C. For high-grade samples, temperature changes after aging ranged from 2.6% to 6.6%. In comparison, low-grade bitumen samples showed an average change of 4.4% after aging, and 5.6% after modification. These changes are primarily due to bitumen evaporation, which increases the polymer-to-bitumen ratio, resulting in higher stiffness. The inverse pattern of softening point changes in modified samples is more favorable, as the values remain further from the maximum permissible limit of 7 °C for grades 50/70 and 70/100.

3. According to the results of dynamic viscosity measurements, the dynamic viscosity results of low-grade bitumen control samples (Type 1) were 363.7 Pas before modification and 376.6 Pas after modification. The modified additive did not significantly affect dynamic viscosity, as changes were within the statistical error of individual measurements and complied with normative requirements. For high-grade samples (Types 2–8), the dynamic viscosity showed significant variability, with a coefficient of variation of 26% and an average value of 250.2 Pas. All Coefficients of Expansion of dynamic viscosity remained below the maximum permissible value of 2.5 for grades 50/70 and 70/100, indicating compliance with standards. The flash point of low-grade bitumen control samples (Type 1) was 281.2 °C before modification and 281.8 °C after modification. For grade 70/100, flash point values ranged from 271.2 °C to 310.2 °C, with an average value of 292.4 °C across all sample types. All measured flash point values exceeded the minimum permissible threshold of 230 °C for grades 50/70 and 70/100.

The brittleness temperature of low-grade bitumen samples (Type 1) was -18.5 °C before modification and -17.2 °C after modification. The inclusion of the modifier did not significantly affect brittleness temperature, as changes were within the statistical margin of error. For grade 70/100, brittleness temperatures varied widely depending on the manufacturer, ranging from -13.4 °C to -23.1 °C, with an average value of -20.1 °C. While all low-grade bitumen samples met the threshold limit of -18.0 °C, 2 out of 7 high-grade bitumen samples exceeded the normative requirement of -20.0 °C. The brittleness temperature of modified bitumen also complied with high-grade requirements in some cases but was below the average values of high-grade samples in others.

The study confirms that modified low-grade bitumen offers improved thermal performance and cost-efficiency, making it a viable solution for use in both high and low temperature regions. To fully assess its durability, further evaluation of fatigue resistance, rutting under cyclic loading and long-term aging via the PAV method is required. These assessments will provide a more complete understanding of the material's behavior under real service conditions.

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