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STUDY OF AGING PROCESSES OF DOMESTIC ADDITIVES FOR THE PREPARATION OF POLYMER BITUMEN

ПОЛИМЕР БИТУМЫН ДАЙЫНДАУҒА АРНАЛҒАН ОТАНДЫҚ ҚОСПАЛАРДЫҢ ТОЗУ ПРОЦЕСТЕРІН ЗЕРТТЕУ

ИССЛЕДОВАНИЕ ПРОЦЕССОВ СТАРЕНИЯ ОТЕЧЕСТВЕННЫХ ДОБАВОК ДЛЯ ПРИГОТОВЛЕНИЯ ПОЛИМЕРБИТУМА

Abstract. *In this article, the aging process of domestic polymer additives used to produce polymer-bitumen binders (PBB) materials was investigated. The importance of studying aging was due to the need to increase the durability of road surfaces exposed to significant temperature and mechanical loads during operation. The RTFOT (Rolling Thin Film Oven Test) method, model 20-25720, was used in the work to simulate accelerated aging of PBB. The study examined various formulations using two grades of polypropylene, applied in an amount of 4%. The choice of this formulation is justified by the fact that the obtained physical and chemical characteristics meet the requirements of the standards ST RK 1126 and ST RK 1227 for polymer-modified bitumen (PMB). The final product received the BMP grade, which confirms its compliance with regulatory requirements and suitability for use in road construction. Analysis of the data obtained showed that polymer additives had a significant effect on the resistance of bitumen to aging. In particular, changes in the structure and properties of PBB materials were identified, indicating an increase in their resistance to thermal aging. The results of this study provided valuable data for further improvement of PBB formulations aimed at increasing the service life and reliability of road surfaces.*

Keywords: *Bitumen, polypropylene, aging process, imitation, polymer additives, polymer-bitumen binders.*

Аңдатпа. *Бұл мақалада полимер-битум байланыстырғыш (ПББ) материалдарын өндіру үшін қолданылатын отандық полимерлі қоспалардың тозу процесі қарастырылды. Тозуды зерттеудің маңыздылығы пайдалану кезінде айтарлықтай температуралық және механикалық жүктемелерге ұшыраған жол төсемдерінің беріктігін арттыру қажеттілігіне байланысты болды. 20-25720 үлгісі RTFOT (Rolling Thin Film Oven Test) әдісі ПББ жылдам тозу модельдеу үшін пайдаланылды. Зерттеу 4 % мөлшерінде қолданылатын екі сортты полипропиленді пайдалана отырып, әртүрлі құрамдарды зерттеді. Бұл тұжырымды таңдау алынған физикалық-химиялық сипаттамалардың полимерлі модификацияланған битумға (ПМБ) арналған ҚР СТ 1126 және ҚР СТ 1227 стандарттарының талаптарына сәйкес келуімен негізделген. Соңғы өнім BMP маркасын алды, бұл оның нормативтік талаптарға сәйкестігін және жол құрылысында пайдалануға жарамдылығын растайды. Атап айтқанда, ПББ материалдарының құрылымы мен қасиеттерінде өзгерістер анықталды, бұл олардың термиялық тозуға төзімділігінің жоғарылауын көрсетті. Бұл зерттеудің нәтижелері жол төсемдерінің қызмет ету мерзімі мен сенімділігін арттыруға* *бағытталған ПББ тұжырымдарын одан әрі жетілдіру үшін құнды деректер береді.*

Түйін сөздер: *Битум, полипропилен, тозу процесі, имитация, полимерлі қоспалар, полимер-битум байланыстырғыштар.*

Аннотация. *В данной статье был исследован процесс старения отечественных полимерных добавок, применяемых для производства полимерно-битумных вяжущих (ПБВ) материалов. Важность изучения старения была обусловлена необходимостью повышения долговечности дорожных покрытий, подвергающихся значительным температурным и механическим нагрузкам в процессе эксплуатации. В работе был применен метод RTFOT (Rolling Thin Film Oven Test), модель 20-25720, для имитации ускоренного старения ПБВ. В исследовании были изучены различные рецептуры с использованием двух марок полипропилена, применяемых в количестве 4%. Выбор данного рецепта обоснован тем, что полученные физико-химические характеристики соответствуют требованиям стандартов СТ РК 1126 и СТ РК 1227 для полимер-модифицированных битумов (ПМБ). Итоговый продукт получил марку БМП, что подтверждает его соответствие нормативным требованиям и пригодность для применения в дорожном строительстве. Анализ полученных данных показал, что полимерные добавки оказали значительное влияние на устойчивость битума к старению. В частности, были выявлены изменения в структуре и свойствах ПБВ материалов, которые свидетельствовали о повышении их сопротивляемости термическому старению. Результаты данного исследования предоставили ценные данные для дальнейшего улучшения рецептур ПБВ, направленных на увеличение срока службы и надежности дорожных покрытий.*

Ключевые слова: *Битум, полипропилен, процесс старения, имитация, полимерные добавки, полимерно-битумные вяжущие материалы.*

Introduction. Polymer aging is one of the key factors affecting the performance characteristics of polymer additives in the production of polymer bitumen. Modern building materials, in particular polymer bitumen, must have high strength and durability properties, which requires a deep understanding of the aging and degradation processes of the additives used. In this context, the study of domestic polymer additives, their resistance to aging and interaction with bitumen is an urgent task that contributes to the development of high-quality polymer bitumen production technologies (Yang et al., 2024). The purpose of this study is to identify the aging processes of domestic polymer additives and assess their impact on the properties of polymer bitumen. The purpose of the work is to analyze changes in the physical and chemical properties of additives during aging, as well as to study the mechanisms of their interaction with bitumen. An important aspect of the study is to determine the service life of additives under operating conditions, which will increase the reliability and durability of PBB materials. Based on the above, we can formulate the hypothesis of the study: polymer additives resistant to aging will significantly improve the performance characteristics of polymer bitumen, ensuring their durability and reliability under various climatic and operational factors.

The objectives of the study include:

1. Study of existing data on the aging processes of polymers and their effect on the properties of PBB materials.
2. Conducting experimental studies to assess the properties of domestic additives in PBB compositions under various aging conditions.
3. Determining the optimal conditions for storing and using polymers to increase their service life and preserve their properties.

As a result of this study, new knowledge was obtained about the aging processes of polymer additives, which contributed to the development of more efficient technologies for the production of PBB materials and improving their quality.

Literature review. In recent decades, the demand for transport has increased significantly, and road infrastructure is facing challenges associated with increasing traffic. To address these challenges, several technologies have been developed to improve the performance of materials used in road construction. In particular, polymer modification of bitumen binders is not new, but one of the most successful technologies created to improve the properties of asphalt concrete mixtures (Yildirim, 2007; Lucena et al., 2004).

Bitumen is a hydrocarbon product obtained by refining crude oil by removing lighter fractions such as liquefied petroleum gas, gasoline, and diesel fuel (Lesueur, 2009). This material is widely used in construction due to its water-repellent and thermoplastic properties. Although bitumen is used for roofing, sealing, and insulation, its main use is in roads and hard surfaces, which account for about 85 % of total bitumen consumption (Lu and Isacsson, 2002).

Polymers are macromolecules consisting of long chains synthesized from small monomers through chemical reactions. Among the polymers used as modifiers, elastomers and plastomers are the most common. Polymer-modified bitumens (PMB) are obtained by mechanical mixing or chemical reactions of bitumen with one or more polymers in an amount usually amounting to 3% to 10% by weight of the bitumen (Joohari & Giustozzi, 2020). In the case of mechanical mixing, such mixtures are called simple, since chemical reactions between the bitumen and the polymer do not occur, and the polymer acts as a filler that imparts special properties to the mixture. In the case of chemical reactions, the mixtures are called complex, since interaction occurs between the components (Boutevin, Pietrasanta and Robin, 1989).

The quality of the modification is determined by the ability of the polymer to improve the performance characteristics of the bitumen when added in small quantities. Polymer modification, in particular, is intended to increase the rigidity and elasticity of bitumen at high temperatures, reduce its temperature sensitivity, improve the workability of the mixture and reduce the rigidity of the material at medium and low temperatures (Karmakar & Roy, 2021). In addition, polymer-modified bitumens must be stable during storage and resistant to aging (Bahia and Perdomo, 1996).

One of the most important factors affecting this material is aging, as it is associated with the most common defects of bitumen mixtures, which are widely used in road construction. The tendency of bitumen to aging has been known since its use in the road industry (Sun, Wang and Zhang, 2014; Sarang et al., 2015). The aging process of the binder includes the loss of volatile components, as well as oxidative and polymer reactions that change its composition and physicochemical properties. These changes lead to an increase in the viscosity and rigidity of the bitumen, which causes its hardening and reduced adhesion (Apeagyei, 2011; Wu et al., 2009; Maharaj et al., 2018).

Due to chemical changes in the colloidal structure of bitumen, bitumen mixtures also suffer, which can lead to problems such as particle delamination, deterioration in adhesion, reduced fatigue strength and an increased likelihood of thermal cracks (Yan, Huang and Tang, 2017). However, many studies focus on specific materials or technologies, making it difficult to identify all the possibilities for studying ageing phenomena considering short- and long-term bitumen performance and their impact on the durability of road surfaces.

Therefore, this paper provides a technical overview of the various studies concerning the ageing processes of PMB materials. The types of ageing and the factors influencing this process are considered, and how other mixture components and the use of polymer-modified binders can change the ageing dynamics are examined. An analysis of the most frequently studied anti-aging additives and their impact is presented.

Materials and research methods. The following materials were used to conduct the research:

1. Bitumen grade BND 100/130, provided by «Pavlodar Oil Chemistry Refinery» LLP (Kazakhstan). Bitumen of this grade is characterized by high viscosity and is widely used for the production of road surfaces, possessing the necessary characteristics for operation in various climatic conditions. The main physical and chemical properties of bitumen BND 100/130 are presented in Table 1 below.

Table 1. Characteristics of road bitumen 100/130

Bitumen properties	Results
Penetration (25°C, 100 gr, 5 sec, 0.1 mm)	111
Softening temperature according to RaB (°C)	46
Stretchability at 25 °C, cm	121
Fraass brittleness temperature, °C	-26
Solubility, %	99.98
Paraffin content, %	1
Change in mass after heating, %	0.1
Change in softening temperature, °C	5
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)	

2. Polypropylene grade PP H350 and PP H030 «Company Neftekhim LTD» LLP produces polypropylene according to the National Standard of the Republic of Kazakhstan ST RK 3191-2018. The material has improved the strength and performance characteristics of PBB materials, such as crack resistance, elasticity and durability. Polypropylene (PP) is a thermoplastic material based on propylene (propene). The physical and mechanical characteristics of PP H350 and PP H030 are presented in Table 2.

Table 2. Characteristics of polypropylene

Polypropylene brand	PP H350	PP H030
Melt flow rate, g/10min	36.7	3.3
Scatter the yield indicator values within the party, %, no more than	8.4	4.6
The modulus of elasticity in bending, MPa, no less	1083	1187
Mass fraction of volatile substances, %, no more than	0.04	0.04
Tensile yield strength, MPa, no less	30.4	33
Elongation at yield point, %, no less	10	11
Cranule size, mm	4.3	4.3
The intensity of the smell, point, no more than	1	1
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)		

3. Heavy vacuum gas oil of the H603 brand, provided by «Pavlodar Oil Chemistry Refinery» LLP, was used to adjust the viscosity of the PBB mixture and improve its technological characteristics. The addition of gas oil contributed to the improvement of the material fluidity and also ensured uniform distribution of the components in the mixture. This made it possible to achieve an optimal ratio of viscosity and plasticity, which is especially important for ensuring the durability and stability of the material during operation under road surface conditions. The main physical and chemical properties of heavy vacuum gas oil are shown in Table 3.

Table 3. Characteristics of heavy vacuum gaz oil

Density at 20°C, kg/m^3	905
Coking ability, % by weight.	0.3
Mass fraction of sulfur, % by weight	2
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)	

The following methods were used to conduct the research:

1. To evaluate the aging processes of PBB materials, a RTFOT (Rolling Thin Film Oven Test),

model 20-25720, was used. The method simulates accelerated aging of materials under the influence of temperature and oxidation processes, bringing laboratory conditions closer to real processes occurring during the production and operation of road surfaces.

The testing process was as follows: PBB mixture samples were placed in a thin layer in glass cylinders, which rotated inside the oven at a temperature of 163°C for 75 minutes. During the test, hot air was continuously supplied to the working chamber, which contributed to the active oxidation of the bitumen mixture. After the tests, the samples were analyzed for changes in the main characteristics, including viscosity, weight loss and elasticity.

This method made it possible to objectively evaluate the resistance of PBB materials to thermal aging and identify key changes occurring in the structure and properties of the mixture during operation.

The RTFOT test rig for aging PBB materials is designed to perform tests according to CT PK 1224-2003 with accelerated aging of bitumen by measuring the mass loss under the influence of high temperature. Up to 8 samples of PBB mixture (placed in glass vessels) rotate inside the drum at a temperature of 163°C at a speed of 15 rpm. At the same time, an air flow of 4000 ml/min is supplied to the samples. As a result, the fractional composition of the PBB mixture changes, which determines the process of its aging. The RTFOT rig is equipped with a door with a viewing window, a temperature regulator with the ability to maintain a given mode, a fan and a control thermometer.

The change in mass of a sample after aging is determined as a percentage change in mass using the following formula:

$$\Delta = \frac{M_1 - M_2}{M_1 - M_0} \cdot 100\%$$

where: Δ – change in mass of sample in jar after aging, %;

M_0 – mass of glass jar, g;

M_1 – mass of glass jar with bitumen before aging, g;

M_2 – mass of glass jar with bitumen after aging, g.

Eight samples were used for measurements. Two samples were used for calculations. The results of the mass change of these samples should not differ from each other by more than 0.2%. This requirement allows to minimize errors and guarantee the reliability of the results when analyzing the resistance of PBB materials to aging.

2. Needle penetration depth at a temperature of 25ºC: To assess the depth of needle penetration at a temperature of 25ºC (no less than 0.1 mm), tests were carried out in accordance with ST RK 1226-2003 using an automatic digital penetrometer from Infratest, model 20-20670.

The testing process was as follows: samples of the PBB mixture are placed in a special container, where they are cooled to a temperature of 25ºC. After reaching the required temperature, a needle with a given load (usually 100 g) is slowly lowered onto the surface of the sample. The depth of penetration of the needle is measured in millimeters and recorded. This method allows for an objective assessment of the viscosity of PBB materials and their suitability for various operating conditions.

3. Ring and ball softening temperature: To determine the softening temperature using the ring and ball method (ºC, not lower), an automated Infratest device was used, which complies with the standards of ST RK 1227-2003.

The testing process was as follows: samples of the PBB mixture were preheated to remove moisture to a temperature 80-100°C above the expected softening temperature, but not lower than 120°C and not higher than 180°C. The dehydrated PBB material was filtered and thoroughly mixed to remove air bubbles, after which it was poured in excess into two rings. After cooling under ambient conditions, the excess PBB material was cut off with a heated knife.

Rings with PBB material and steel balls cooled to (5±1)°C were placed in a water bath at the same temperature. The water temperature increased at a rate of (5.0±0.5)°C per minute. The test continued until the ball was immersed in the PBB material and touched the lower plate, recording the softening temperature of the material. Strict adherence to the heating rate ensured the accuracy of the test.

Results and discussion. The composition of the studied PBB mixture includes bitumen grade BND 100/130, polypropylene grade H030 or H350, as well as vacuum gas oil in concentrations of 0.3%, 2.5% and 4%. The detailed formulations of the PBB mixture samples are presented in Table 4.

Table 4. Composition of PBB mixture samples

Bitumen BND 100/130	95.4 %	93.5%	92%
PP H030 / PP H350	4%	4%	4%
Vacuum gas oil	0.3%	2.5%	4%
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)			

The figures show the results of tests of PBB materials using 4% concentrations of polypropylene (PP H030 and PP H350) and different concentrations of heavy vacuum gas oil. The tests were conducted to evaluate the softening point (by the Ring and Ball method) and the depth of needle penetration at a temperature of 25°C before and after aging by the RTFOT method.

The Figure 1 shows the results of the softening temperature change for PP H030 before and after aging: the softening temperature before aging was 65°C at the minimum gas oil concentration (0.3%) and gradually decreased to 61.8°C at the maximum gas oil concentration (4%). After aging, an increase in the softening temperature is observed for all concentrations, which may indicate an increase in the hardness of the mixture after aging. For example, at a gas oil concentration of 0.3%, the softening temperature increased from 65°C to 72.8°C, and at 4% - from 61.8°C to 66.2°C.

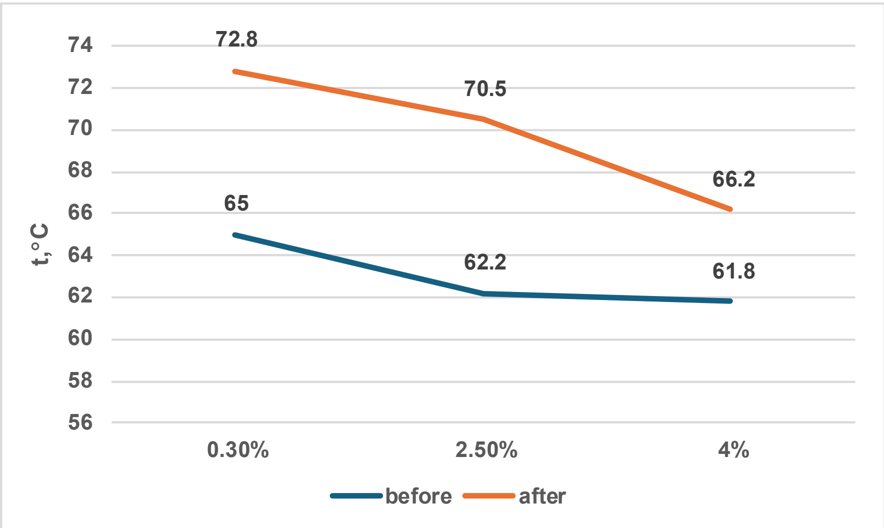


Figure 1. Softening temperature of PBB materials before and after aging
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)

Thus, aging affects the change in the temperature characteristics of PBB materials, which must be taken into account when analyzing their thermal stability.

The Figure 2 shows the softening temperature change results for PP H350 before and after aging:

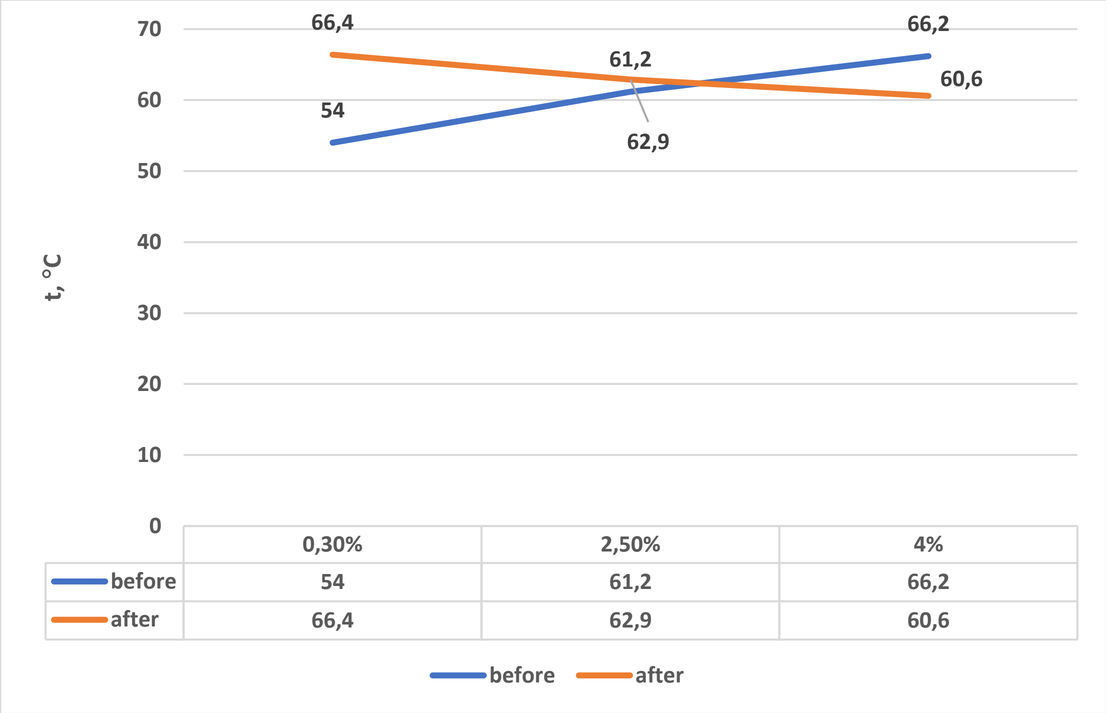


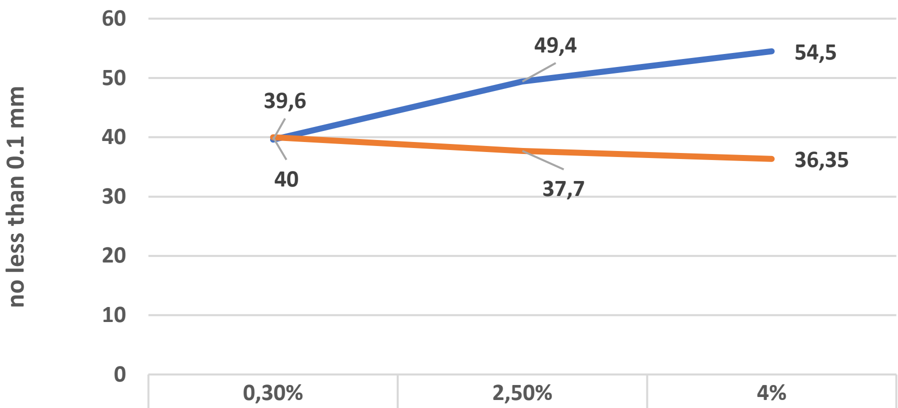
Figure 2. Softening temperature of PBB materials before and after aging
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)

Polypropylenes (PP H030 and PP H350) show different reactions to the addition of gas oil and the aging process. For PP H030, the addition of gas oil leads to a decrease in the softening temperature before aging, but after aging, the softening temperature increases significantly, indicating its resistance to thermal aging. At the same time, for PP H350, a decrease in the softening temperature before aging is also observed, but after aging, the softening temperature decreases, indicating lower resistance to aging compared with PP H030.

The following two figures show the results of measuring the depth of needle penetration into PBB materials before and after aging.

The Figure 3 shows the results of the needle penetration depth for polypropylene H030 before and after aging. Before aging, the needle penetration depth varied from 39.6 mm at the minimum gas oil concentration (0.3%) to 54.5 mm at the maximum concentration (4%). This indicates an increase in the plasticity of the material with an increase in the gas oil content. After aging, the needle penetration depth decreased for all concentrations, indicating an increase in the rigidity of the PBB mixture after thermal aging. For example, at a concentration of 0.3%, the penetration depth decreased from 39.6 mm to 40 mm, and at 4% - from 54.5 mm to 36.35 mm.

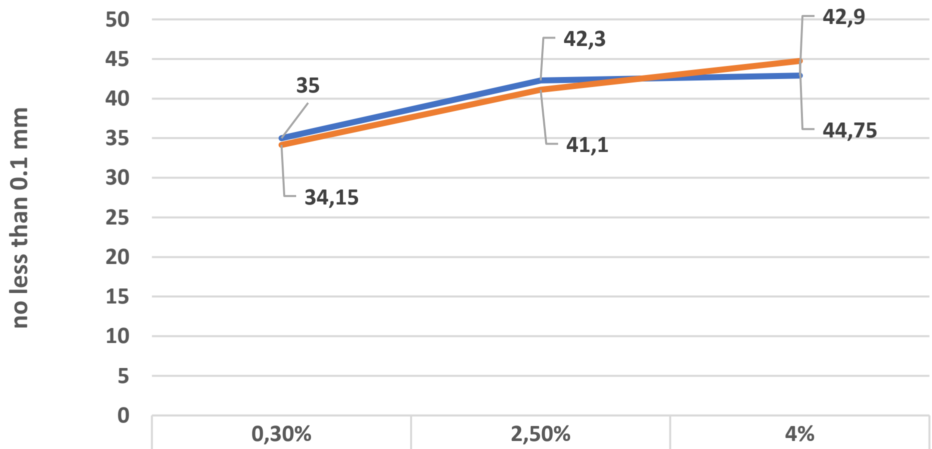
Thus, it can be concluded that aging makes the PBB mixture harder, especially at high gas oil content, which is evident from the significant decrease in penetration depth at 4%.



	0,30%	2,50%	4%
before	39,6	49,4	54,5
after	40	37,7	36,35

Figure 3. Needle penetration depth before and after aging
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)

The Figure 4 shows the PP H350 needle penetration depth results before and after aging: before aging, the needle penetration depth varied from 35 mm at the minimum gas oil concentration (0.3%) to 42.9 mm at the maximum concentration (4%). An increase in the penetration depth is observed with increasing gas oil content, indicating an increase in the plasticity of the material. After aging, the needle penetration depth varied from 34.15 mm to 44.75 mm. This shows that after aging, the PBB mixture became more plastic, especially at the maximum gas oil concentration (4%), where the penetration depth increased from 42.9 mm to 44.75 mm.



	0,30%	2,50%	4%
before	35	42,3	42,9
after	34,15	41,1	44,75

Figure 4. Needle penetration depth before and after aging
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)

These results show that the addition of gas oil increases the plasticity of PBB materials before aging, which is confirmed by the increase in the depth of needle penetration with increasing gas oil content. However, after aging, the material becomes harder, as evidenced by a decrease in the depth of needle penetration for all gas oil concentrations. At the same time, polypropylene H030 demonstrates more pronounced changes in hardness after aging compared to polypropylene H350, which indicates its greater sensitivity to the aging process.

The results of experiments on bitumen oxidation at different concentrations of polypropylene with molecular weights of 30 and 350, combined with vacuum gas oil at a high temperature of 163 °C, are shown in Tables 5 and 6. These tables illustrate the changes in mass and consistency of the mixtures before and after the RTFOT procedure.

Table 5. Results of RTFOT oxidation at 163°C in the presence of polypropylene with a molecular weight of 30

№	4% polypropylene 30 and 0.3% vacuum gas oil			4% polypropylene 30 and 2.5% vacuum gas oil			4% polypropylene 30 and 4% vacuum gas oil		
	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %
1	189.6	189	M_1-0.31	193.9	192.5	M_1-0.72	200.5	200.4	M_1-0.04
2	192.3	192	M_2-0.15	191.7	192	M_2-0.15	201.5	200.4	M_2-0.04
Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)									

Table 6. Results of RTFOT oxidation at 163°C in the presence of polypropylene with a molecular weight of 350

№	4% polypropylene 350 and 0.3% vacuum gas oil			4% polypropylene 350 and 2.5% vacuum gas oil			4% polypropylene 350 and 4% vacuum gas oil		
	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %	Mass before RTFOT, g	Mass after RTFOT, g	Change in mass, %
1	193.3	193.2	M_1-0.05	191.7	191.5	M_1-0.1	190.9	190.9	M_1-0
2	195	195	M_2-0	195	195	M_2-0	194.9	194.9	M_2-0
Note - compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)									

PBB samples with a molecular weight of 350 are more resistant to aging compared to PBB samples with a molecular weight of 30.

A preliminary comparative economic analysis of the developed PBB compositions was carried out (Table 7). The cost estimation was based on average market prices for bitumen BND 100/130, polypropylene grades H030 and H350, and an approximate value for vacuum gas oil. The total cost of 1 ton of PBB mixture based on PP H350 was about 5 900 tenge higher than the mixture with PP H030. This is mainly due to the higher price of the H350 polymer. However, considering its better thermal aging resistance and potential to extend pavement service life, the use of PP H350 may be economically justified for long-term applications, especially in heavily loaded road segments.

Table 7. Comparative cost estimation of PBB mixtures with different polypropylene grades

Component	PP H030-based PBB (KZT/t)	PP H350-based PBB (KZT/t)
Bitumen BND 100/130 (95.5%)	114 000	114 000
Polypropylene (4%)	40 800	46 704
Gas oil (2.5%) estimated	5 000	5 000
Total cost per 1 ton of mix	159 800	165 704

Note – Gas oil cost estimated based on open market data (approx. 200 KZT/t). Bitumen price averaged at 114.000 KZT/t.

The data presented in Table 8 reflect the results of statistical processing of the softening temperature, penetration depth, and mass change for bitumen samples of grade BND 100/130 with different gas oil concentrations (0.3%, 2.5%, and 4%). The bitumen samples were studied under two conditions: with PP H030 and PP H350 additives. For each gas oil concentration, the average values, standard deviations, and 95% confidence intervals were calculated.

Table 8. Static data processing

Parameters	Average softening point determination by the Ring and Ball method (°C, not lower)	Standard deviation, °C	Confidence interval (95%)	Average needle penetration depth at 25°C, mm	Standard deviation, mm	Confidence interval (95%)	Change in mass,%	Standard deviation, %	Confidence interval (95%)
PP H030	71.1	3.8	3.7	37.1	2.2	2.1	0.2	0.1	0.2
PP H350	68	10.6	10.4	41.4	5	4.9	0.04	0.01	0.01

Note – compiled by the authors on the basis of (Seitenova, Syzdyk, Dyussova, Konkanov and Dzheksembaeva, 2025)

The analysis shows that both the softening point and the penetration depth are dependent on the gas oil concentration and the additive type (PP H030 or PP H350). Higher gas oil concentrations generally result in softer bitumen (higher penetration depth) and a lower softening point. The mass change values show that gas oil concentrations have a limited effect on the stability of the material, especially for PP H350, where the mass change remains quite low across the different concentrations. The confidence intervals (95%) show that the greatest variability in the results is observed at a gas oil concentration of 4%, especially for the softening point for PP H350.

The results show that the addition of gas oil and polypropylene to bitumen has a significant effect on its thermal stability and plasticity. Increasing the gas oil concentration reduces the softening temperature and increases the depth of needle penetration, indicating a softer material before aging. However, after aging, a decrease in the softening temperature and penetration depth is observed for all samples, indicating an increase in hardness and deterioration in the thermal stability of bitumen compositions.

The changes are particularly noticeable for PP H030. The reduction in softening temperatures and penetration depth for this polymer after aging indicates its lower resistance to thermal effects compared to PP H350. In the case of PP H350, a decrease in penetration depth is also observed after aging, but its effect is less pronounced. This indicates that PP H350 demonstrates better resistance to aging and may be preferable for use in conditions requiring the preservation of material properties after long-term use.

The obtained results indicate that PBB compositions with the addition of polypropylene and gas oil undergo changes that can affect their performance characteristics, especially after aging. It is important to take these changes into account when developing and using polymer-modified bitumen materials to increase their durability and compliance with standards such as ST RK 1224-2003.

These results are important for understanding how different concentrations of polypropylene and gas oil affect the durability of PBB compositions. Such understanding may be useful in road construction and other applications of bitumen materials where strength, thermal stability and wear resistance of the material are key indicators.

Conclusions. The conducted studies have shown that the addition of polypropylene grades H030 and H350, as well as vacuum gas oil to bitumen has a significant effect on its physical and mechanical properties, both before and after aging. Before aging, a decrease in the softening temperature and an increase in the depth of penetration of the needle with an increase in the concentration of gas oil are observed, which indicates an increase in the plasticity of the material. However, after aging, a decrease in the softening temperature and a decrease in the depth of penetration occur, which indicates an increase in hardness and a deterioration in the thermal stability of the PBB material.

The changes in the properties of mixtures with polypropylene grade H030 are particularly noticeable, demonstrating more pronounced changes after aging compared to H350. This indicates that polymer additives have different effects on the resistance of materials to aging.

Depending on the climatic zones of the Republic of Kazakhstan, formulations with PP H350 are more suitable for hot, arid regions due to better thermal aging resistance, while PP H030 may be preferable for colder zones requiring enhanced initial plasticity. The results can also guide the selection of formulations for highways, where durability is critical, versus urban roads, where flexibility may be prioritized. Future studies will aim to assess the long-term durability of the developed PBB compositions, including resistance to fatigue cracking, UV and ozone aging, freeze-thaw cycles, and moisture susceptibility, to ensure comprehensive performance evaluation under real operating conditions. Thus, the results of the study confirm that polymer-modified bitumen compositions with the addition of vacuum gas oil require careful selection of components to ensure durability and thermal stability under operating conditions.

Mention the use/non-use of AI tools. When preparing this work, the authors did not use AI tools.

Conflict of interest. The authors declare no conflict of interest.

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