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VISCOSITY OF NEAT AND POLYMER-MODIFIED BITUMINOUS BINDERS

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Abstract. Polymer modification is widely used to improve the high-temperature performance and durability of asphalt binders; however, polymer type and dosage can substantially affect binder workability and production temperatures. This study evaluated the rotational viscosity (RV) behavior of three base bitumens (Caspi 70/100, Shymkent 70/100, and Pavlodar/PNXZ 100/130) and several polymer-modified binders prepared using Butonal (3.5% and 5.0%), SBS (3.5%), and Titan (3.5%). RV was measured using a Brookfield Thermosel viscometer in accordance with ASTM D4402 at 135 °C and 165 °C, and over a programmed temperature range from 120 °C to 190 °C with 7 °C increments to construct viscosity–temperature curves and determine mixing and compaction temperature ranges. Polymer modification increased viscosity at both 135 °C and 165 °C relative to the corresponding base binders, indicating increased stiffness. Among the modified binders, 5.0% Butonal produced the highest viscosity and the poorest workability, with mixing temperatures exceeding 190 °C and compaction temperatures near 185 °C. Reducing Butonal content to 3.5% decreased production temperatures (≈175 °C mixing and ≈163 °C compaction). The SBS-modified binder showed a smoother viscosity trend and intermediate production temperatures (≈178 °C mixing and ≈167 °C compaction). The most favorable workability was achieved with 3.5% Titan, which yielded the lowest viscosity curves and the lowest production temperatures (≈149 °C mixing and ≈144 °C compaction), while remaining below the 3000-cP handling threshold consistent with ASTM D6373. Overall, the results demonstrate that polymer type and dosage govern the balance between stiffness enhancement and manufacturability, and that multi-temperature RV profiling improves the precision of mixing and compaction temperature selection.

Key words: bitumen, super pave, rheological properties, road construction.

Introduction

The use of polymers in asphalt modification dates back to 1843, with natural and synthetic polymer patents. European research in the 1930s and the introduction of neoprene latex in the United States in the 1950s set the stage for polymer-modified asphalt (PMA). By the late 1970s, Europe had surpassed the U.S. in PMA adoption, largely due to guaranteed contractor performance and interest in reducing life-cycle costs despite higher initial expenses. In the 1980s, the U.S. began adopting European polymer technologies as new polymers became commercially available, while standards in countries such as Australia now include guidance for polymer-modified binders [1,2].

The U.S. Federal Highway Administration developed life-cycle cost analysis methods demonstrating that rubberized and polymer-modified pavements provide superior durability and cost-effectiveness, as confirmed in Arizona and California [3,4]. Surveys in 1997 showed widespread interest across states in using modified binders, with significant adoption planned [5]. Studies have consistently demonstrated that polymer-modified binders, including SBS and SBR, exhibit enhanced resistance to rutting, cracking, and environmental stress compared with unmodified binders, even when the PG grade is equivalent [6,7].

Research also highlights that polymer modification improves binder viscosity at elevated temperatures (e.g., 60 °C), enhances fatigue resistance, and increases the service life of pavements, contributing to the concept of perpetual pavements [7,8]. Thermoplastic elastomers, thermoplastics, latexes, and terpolymers are widely used, with content levels ranging from 1.5% to 12%, depending on type, offering specific advantages in elasticity, low-temperature performance, and interaction with asphalt [9,10]. The primary mechanism of PMA is the development of a polymer network within the binder, with performance dependent on polymer–bitumen compatibility, dosage, and processing conditions.

Overall, polymer-modified asphalt provides a reliable approach to enhancing pavement durability, reducing maintenance frequency, and optimizing life-cycle costs, establishing its relevance in modern pavement engineering.

Materials and research methods

Determination of Bitumen Viscosity Using a Rotational Viscometer (RV). Rotational viscosity testing evaluates the flow characteristics of bituminous binders, ensuring suitability for pumping, mixing, and compaction in hot-mix asphalt production. According to ASTM D 4402, the Brookfield Thermosel viscometer, equipped with coaxial cylinders, is commonly used to test both modified and unmodified binders.

Samples (8–11 g) are heated to a liquid state (≤150°C), placed in a preheated measurement chamber, and equilibrated for ~30 minutes. The spindle is rotated at a fixed speed (typically 20 rpm), and the torque required to maintain rotation is measured to calculate viscosity, which is displayed digitally in Pa·s (1 Pa·s = 1000 cP). Measurements are typically recorded as the average of three readings at 1-minute intervals.

The Thermosel system maintains precise sample temperatures and allows generation of viscosity – temperature curves for estimating optimal mixing and compaction conditions. Viscosity may also be measured at elevated temperatures (e.g., 165°C) depending on binder type and project requirements. Superpave specifications recommend a maximum viscosity of 3 Pa·s for pumpable binders, though this criterion may be waived if the supplier guarantees adequate handling and mixability.

Results and Discussion

The rotational viscosity (RV) of the bitumen was measured at two temperatures, 135 °C and 165 °C, as well as at multiple temperatures using a dedicated program in accordance with ASTM D4402, starting from 120 °C with a temperature increment of 7 °C. The results are presented in Table 1.

The figure illustrates the viscosity values at all measured temperatures in graphical form and indicates the mixing and compaction temperature ranges, as well as the modification indices of all bitumens (modified / base). At both 135 °C and 165 °C, an increase in viscosity is observed for polymer-modified binders compared with the base bitumen, indicating that the addition of polymers leads to increased binder stiffness.

On the other hand, the results show that the mixing and compaction temperatures vary depending on the type of polymer, allowing a comparative evaluation of the effect of different polymer modifiers.

Table 1 – Results of rotational viscosity testing of base bitumens

Viscosity type	Rotational viscometer (cP)		Temperature range (°C)	
	135ºC	165ºC	Mixing	Compaction
B1				
Caspi 70-100	310.42	72.67	149	137
Shym 70-100	312.50	74.00	149	137
B2 PNXZ 100-130	237.50	50.00	142	135

The mixing and compaction temperatures of the bitumen were determined separately for two binders. Tables 2 and 3 present the results for the neat (base) bitumen and the polymer-modified bitumen, respectively. The temperature ranges for mixing and compaction obtained using the multi-temperature approach differed slightly from those determined using only two discrete temperatures and allowed a more accurate estimation by applying 7 °C temperature increments. The Brookfield viscometer was programmed in accordance with the requirements of the relevant international technical standard. The test sequence started at 120 °C and, depending on the binder type, was carried out up to 190 °C within a total test duration of 5 hours. The results indicate that the workability of the polymer-modified bitumen decreased; however, its viscosity remained below 3000 cP, which satisfies the viscosity requirements and demonstrates that the modified binder can still be processed as a conventional bitumen in accordance with ASTM D6373.

Table 2 – Rotational viscosity of base bitumens at different temperatures

Temperature (°C)	CASPI 70/100 BASE (Pa·s)	SHYM 70/100 BASE (Pa·s)	PNXZ 100/130 BASE (Pa·s)
120	0.92	0.92	0.72
125	0.80	0.80	0.60
130	0.52	0.52	0.39
135	0.38	0.38	0.27
140	0.30	0.30	0.22
145	0.22	0.22	0.18
150	0.18	0.18	0.14
155	0.14	0.14	0.12
160	0.12	0.12	0.10
165	0.09	0.09	0.08
170	0.07	0.07	0.06
175	0.05	0.05	0.05
180	0.04	0.04	0.04
Notes: Mixing range: ~0.2 Pa·s: Compaction range: ~0.3 Pa·s			

Table 2 presents the results of the rotational viscosity measurements for the unmodified (neat) bitumen. Based on viscosity levels of 0.2 and 0.3 Pa·s, the mixing and compaction temperatures of the binders were determined. According to the results, the 70/100 penetration grade Caspi and Shymkent bitumens exhibit identical values, with a mixing temperature of 149 °C and a compaction temperature of 137 °C. In contrast, the Pavlodar bitumen with a penetration grade of 100/130 shows slightly lower temperatures, with a mixing temperature of 142 °C and a compaction temperature of 135 °C.

Table 3 presents the results of the rotational viscosity tests performed on bitumens modified with different polymers. It is evident that, as the temperature resolution increases, a more accurate determination of the characteristic temperatures can be achieved.

Describing the results from top to bottom, the first binder corresponds to the Butonal-modified bitumen with a polymer content of 5.0%. As can be observed, there is a pronounced irregularity in the viscosity curve at the initial temperature range, with relatively large temperature intervals. This behavior indicates possible inhomogeneity during polymer–bitumen blending and reflects an excessively stiff polymer-modified binder.

In addition, the mixing temperature exceeds 190 °C, while the compaction temperature is approximately 185 °C, confirming the significantly increased stiffness of this polymer-modified bitumen.

This behavior indicates very low workability of the polymer-modified bitumen, as its mixing requires a significantly longer time compared with other polymers. When the polymer content is reduced to 3.5%, as shown by the red curve, the blended bitumen becomes noticeably softer. Its mixing temperature decreases to approximately 175 °C, and the compaction temperature decreases to about 163 °C, indicating that it is more fluid than the binder modified with SBS polymer.

Table 3 – Temperature-Dependent Viscosity of Polymer-Modified Bitumens

Temperature,	Butonal 5.0%	Butonal 3.5%	SBS 3.5%	TITAN 3.5%	TITAN 3.5%

°C	PNXZ, Pa·s	CASPI, Pa·s	PNXZ, Pa·s	PNXZ, Pa·s	Shymkent, Pa·s
130	3.90	1.75	1.95	0.65	0.70
140	1.85	0.80	1.10	0.40	0.42
150	1.10	0.50	0.65	0.25	0.27
160	0.75	0.35	0.42	0.15	0.17
170	0.48	0.25	0.30	0.10	0.08
180	0.38	0.20	0.22	0.08	0.06
190	0.25	0.15	0.15	0.05	0.04
Note: All polymer-modified binders show a pronounced decrease in viscosity with increasing temperature. Butonal 5.0% PNXZ exhibits the highest viscosity across the entire temperature range, indicating enhanced structural stability at elevated temperatures. TITAN-modified binders demonstrate lower viscosity values, which may allow reduced mixing and compaction temperatures.					

Considering the polymer-modified bitumen containing SBS, the viscosity curve demonstrates a more uniform and well-homogenized structure compared with the Butonal-modified binder, as evidenced by the smoother trend of the graph. The mixing temperature is about 178 °C, while the compaction temperature is approximately 167 °C. This binder is therefore stiffer than the bitumen modified with 3.5% Butonal.

Finally, the binders modified with 3.5% Titan polymer, prepared using two base bitumens with different penetration grades, correspond to the lowest curves on the graph. These binders exhibit a mixing temperature of 149 °C and a compaction temperature of 144 °C. The results for this polymer-modified bitumen are particularly favorable, since good workability and effective coating of aggregates by the binder are essential during asphalt concrete production.

Conclusion

Rotational viscosity testing (ASTM D4402) at 135 °C, 165 °C, and across 120–190 °C (7 °C increments) effectively differentiated the workability and temperature sensitivity of neat and polymer-modified binders and enabled more accurate determination of mixing and compaction temperature ranges than the two-temperature approach alone.

The neat binders showed comparable workability: Caspi 70/100 and Shymkent 70/100 exhibited identical production temperatures (149 °C mixing and 137 °C compaction), while the Pavlodar/PNXZ 100/130 binder required slightly lower temperatures (142 °C mixing and 135 °C compaction).

All polymer-modified binders exhibited higher viscosity than the corresponding base binders at both 135 °C and 165 °C, confirming that polymer addition increases binder stiffness.

Polymer type and dosage strongly controlled production temperatures and practical workability. The 5.0% Butonal binder was excessively stiff and showed poor processing characteristics, with mixing temperatures exceeding 190 °C and compaction temperatures near 185 °C, indicating limited suitability for standard hot-mix operations.

Reducing Butonal to 3.5% substantially improved workability and lowered production temperatures (≈175 °C mixing and ≈163 °C compaction), demonstrating a clear dosage-dependent effect.

The SBS-modified binder exhibited a uniform viscosity–temperature trend indicative of better homogeneity and compatibility, with intermediate production temperatures (≈178 °C mixing and ≈167 °C compaction), and was stiffer than the 3.5% Butonal binder.

The best balance between workability and processing temperature was obtained with 3.5% Titan polymer. Titan-modified binders produced the lowest viscosity curves and the lowest production temperatures (≈149 °C mixing and ≈144 °C compaction), which is beneficial for aggregate coating and asphalt mixture production.

Despite reduced workability relative to neat binders, all modified binders remained below 3000 cP during testing, supporting their processability under conventional conditions consistent with ASTM D6373 requirements.

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ТАЗА ЖӘНЕ ПОЛИМЕРМЕН МОДИФИКАЦИЯЛАНҒАН БИТУМДЫ БАЙЛАНЫСТЫРҒЫШТАРДЫҢ ТҰТҚЫРЛЫҒЫ

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Аңдатпа. Полимерлік модификация асфальт байланыстырғыштарының жоғары температурадағы қасиеттерін және ұзақ мерзімділігін арттыру үшін кеңінен қолданылады, алайда полимердің түрі мен мөлшері байланыстырғыштың өңделгіштігіне және өндірістік температураларға елеулі әсер етуі мүмкін. Бұл зерттеуде үш негізгі битумның (Caspi 70/100, Shymkent 70/100 және Pavlodar/PNXZ 100/130) және Butonal (3,5% және 5,0%), SBS (3,5%) және Titan (3,5%) полимерлерімен модификацияланған бірнеше байланыстырғыштардың айналмалы тұтқырлық (RV) сипаттамалары бағаланды. RV өлшемдері ASTM D4402 стандартына сәйкес Brookfield Thermosel айналмалы вискозиметрінде 135 °C және 165 °C температураларда, сондай-ақ 120 °C-тан 190 °C-қа дейін 7 °C қадаммен бағдарламаланған температуралық диапазонда жүргізілді. Бұл тәсіл тұтқырлық–температура қисықтарын тұрғызуға және араластыру мен тығыздау температураларының диапазондарын анықтауға мүмкіндік берді. Полимерлік модификация 135 °C және 165 °C температураларда негізгі битумдармен салыстырғанда тұтқырлықтың артуына әкеліп, байланыстырғыштың қаттылығының жоғарылағанын көрсетті. Модификацияланған байланыстырғыштардың ішінде 5,0% Butonal ең жоғары тұтқырлықты және ең төмен өңделгіштікті көрсетті: араластыру температурасы 190 °C-тан жоғары, ал тығыздау температурасы шамамен 185 °C болды. Butonal мөлшерін 3,5%-ға дейін азайту өндірістік температураларды төмендетті (араластыру ≈175 °C, тығыздау ≈163 °C). SBS-пен модификацияланған байланыстырғыш тұтқырлықтың бірқалыпты өзгеруін және аралық өндірістік температураларды көрсетті (араластыру ≈178 °C, тығыздау ≈167 °C). Ең қолайлы өңделгіштік 3,5% Titan қолданылғанда байқалды: тұтқырлық қисықтары ең төмен мәндерді және ең төмен өндірістік температураларды көрсетті (араластыру ≈149 °C, тығыздау ≈144 °C), әрі ASTM D6373 стандартына сәйкес 3000 cP шегінен аспады. Жалпы алғанда, алынған нәтижелер полимердің түрі мен мөлшері қаттылықты арттыру мен өңделгіштік арасындағы тепе-теңдікті айқындайтынын және көптемпературалы RV-профильдеу араластыру мен тығыздау температураларын таңдаудың дәлдігін арттыратынын көрсетті.

Түйін сөздер: битум, Superpave, реологиялық қасиеттер, жол құрылысы.

ВЯЗКОСТЬ НЕМОДИФИЦИРОВАННЫХ И ПОЛИМЕР-МОДИФИЦИРОВАННЫХ БИТУМНЫХ ВЯЖУЩИХ

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Аннотация. Полимерная модификация широко применяется для улучшения высокотемпературных свойств и долговечности асфальтовых вяжущих, однако тип и содержание полимера могут существенно влиять на технологичность вяжущего и производственные температуры. В настоящем исследовании оценены характеристики вращательной вязкости (RV) трёх базовых битумов (Caspi 70/100, Shymkent 70/100 и Pavlodar/PNXZ 100/130), а также нескольких полимер-модифицированных вяжущих с использованием полимеров Butonal (3,5% и 5,0%), SBS (3,5%) и Titan (3,5%). Измерения RV проводились на вращательном вискозиметре Brookfield Thermosel в соответствии со стандартом ASTM D4402 при температурах 135 °C и 165 °C, а также в программируемом температурном диапазоне от 120 °C до 190 °C с шагом 7 °C. Такой подход позволил построить кривые «вязкость–температура» и определить диапазоны температур перемешивания и уплотнения. Полимерная модификация привела к увеличению вязкости при 135 °C и 165 °C по сравнению с базовыми битумами, что свидетельствует о повышении жёсткости вяжущего. Среди модифицированных вяжущих битум с 5,0% Butonal показал наибольшую вязкость и наихудшую технологичность: температура перемешивания превышала 190 °C, а температура уплотнения составляла около 185 °C. Снижение содержания Butonal до 3,5% привело к уменьшению производственных температур (перемешивание ≈175 °C, уплотнение ≈163 °C). Вяжущее, модифицированное SBS, характеризовалось более равномерным изменением вязкости и промежуточными производственными температурами (перемешивание ≈178 °C, уплотнение ≈167 °C). Наиболее благоприятная технологичность была достигнута при использовании 3,5% полимера Titan: кривые вязкости показали минимальные значения и наименьшие производственные температуры (перемешивание ≈149 °C, уплотнение ≈144 °C), при этом вязкость не превышала порог 3000 cP в соответствии со стандартом ASTM D6373. В целом полученные результаты показывают, что тип и содержание полимера определяют баланс между повышением жёсткости и технологичностью, а многоступенчатое профилирование RV по температуре повышает точность выбора температур перемешивания и уплотнения.

Ключевые слова: битум, Superpave, реологические свойства, дорожное строительство.