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Effect of Rosin Modification on Bitumen and Hot Mix Asphalt

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Elastic modulus,
Indirect tensile strength,
Moisture susceptibility

Abstract: This study investigated the effect of rosin on modification of bitumen and hot mix asphalt performance. Generally, natural resin is obtained from the body of tree naturally and fractionated and rosin which is distilled and volatile terpenes have been removed from natural resin. It is light yellow and transparent material. Bitumen is modified with rosin in 2%, 4%, 6% and 8% by weight of bitumen in mixture. Characteristics of bitumen after modification is determined with bitumen tests (rotational viscometer, penetration, softening point, ductility, elastic recovery, and penetration index). In this study, bitumen was graded according to Performance Grading (PG) system and PG 64-22 bitumen was used. Also, stiffness modulus was calculated by empirical model. Optimum bitumen contents of modified bitumen for all percentages were determined. After optimum bitumen percentage is determined hot mix asphalt samples were prepared with these percentages according to Superpave™ mix design. After all, tensile strength and moisture susceptibility is determined with Indirect Tensile Strength test. The results showed that 2% rosin modified bitumen showed good results among the other modifications. It has highest moisture resistance. And the indirect tensile strength results of rosin modified Hot Mix Asphalt (HMA) were higher than the reference sample. Also, 6% rosin modified bitumen showed best stiffness modulus and elastic modulus according to the empirical model.

Reçine Kolofan Modifikasyonunun Bitüm ve Sıcak Karışım Asfalt Üzerindeki Etkisi

Anahtar Kelimeler
Reçine kolofan,
Bitüm modifikasyonu,
Rijitlik modülü,
Elastik modülü,
İndirekt çekme dayanımı,
Nem hassasiyeti

Özet: Bu çalışmada, reçine kolofan bitüm ile modifiye edilmiş ve bu modifikasyonun sıcak karışım asfalt performansı üzerindeki etkisi araştırılmıştır. Genel olarak, doğal reçine ağaç gövdesinden doğal yollarla elde edilmekte ve ayrıştırılmaktadır. Daha sonra damıtılmakta ve uçucu terpenler doğal reçineden uzaklaştırılmaktadır. Bu şekilde reçine kolofan elde edilmektedir. Çalışmada kullanılan reçine kolofan sarı renkli, transparan bir malzemedir. Bitüm ağırlıkça %2, %4, %6 ve %8 oranlarında modifiye edilmiştir. Bitüm karakteristikleri bitüm testleri (dönel viskozimetre, penetrasyon, yumuşama noktası, düktilite, elastik geri dönme ve penetrasyon indeksi) ile belirlenmiştir. Çalışmada bitüm performans derecelendirme (Performance Grade – PG) sistemine göre sınıflandırılmış ve PG 64-22 olarak kullanılmıştır. Ayrıca ampirik yöntemle rijitlik modülü hesaplanmıştır. Tüm modifiye bitümler için optimum bitüm içerikleri belirlenmiştir. Optimum bitüm içeriği belirlendikten sonra bu içerikler kullanılarak Superpave™ karışım tasarımına uygun olarak sıcak karışım asfalt numuneleri hazırlanmıştır. Daha sonra, indirekt çekme dayanımı ve nem hassasiyeti İndirekt Çekme Deneyi ile belirlenmiştir. Sonuçta, %2 reçine kolofan modifiye edilmiş bitüm diğer modifikasyonlara göre daha iyi sonuç vermiştir. En yüksek nem dayanımı da bu numuneyle elde edilmiştir. Ve indirekt çekme dayanımı sonuçları referans numuneden daha yüksek bulunmuştur. Ayrıca, %6 reçine kolofan modifiye edilmiş bitüm ampirik modele göre en iyi rijitlik modülü ve elastik modülü ile sonuçlanmıştır.

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1. Introduction

Bitumen obtained from crude oil which fractionated at appropriate conditions is a black colored and thermoplastic material contains hydrocarbons and asphaltenes. It is preferred in asphalt mixtures as a binder because of its binding feature and workability and also its low cost. Bitumen is used for surface pavement layer and it is exposed to environmental effects. So that surface layer tends to crack under heavy traffic loadings. At low temperatures, its strength is decreased. Deformation problems is occurred when the traffic loads increase like rutting, stripping. So that bitumen needs to modification to improve the bitumen characteristics to prevent these deformations. At the same time, rosin has unique properties like bitumen. To understand the similarity for example, asphaltite and Utah resin are petroleum bitumen, not a product secreted by plants, although it was ultimately derived from plants. Rosin's binding properties are same with the bitumen. But the workability of rosin is little bit hard because it is hardening as soon as contact with the air. So that bitumen and rosin could be a perfect material when they are mixed together. They could be work together in harmony.

Bitumen can be modified by polymers, additives such as Styrene Butadiene Styrene (SBS), EVA. In the literature, there are limited work on bitumen modification with natural resin. The paper would be address the deficiency. Also, searching the specific property provided by modification by natural resin is lack of literature. In the literature, epoxy resin or polymer materials are used instead of natural resin. Cubuk et al. studied epoxy resin modified bitumen in different percentages. Optimum percentage is found as 2% epoxy resin modification. Rutting, stripping and cracking performance of modified asphalt mixtures were decreased by 2% epoxy resin [1]. Munera and Ossa, studied the polyethylene wax, SBS copolymer and crumb rubber to modify the bitumen and their optimum blends for preventing rutting, cracking. As a result, they give material selection chart for polymer modification and also material proportion versus cost chart [2]. Ahmedzade and Yilmaz studied the effect of polyester resin on bitumen properties in different proportions. Results showed that 0.75% polyester resin modified bitumen has good performance [3]. Liu et al. investigated the SBS modification for reclaimed Stone Matrix Asphalt (SMA) after 22 years of service life and compared laboratory aged asphalt. Results indicated that 5 days lab aged binder has same dynamic response. And also, they are indicated that simulation the field ageing is so hard in laboratory [4]. Zhang et al. investigated that the rheological properties of SBR modified bitumen. As a result, low and high temperature properties were improved [5]. Xiao et al. examined the two types of epoxy modified bitumen properties. Results showed that anti-skid resistance was improved [6]. Yilmaz et al. investigated performance of the SBS and gilsonite modified asphalt mixtures on permanent deformations. Best performance was obtained by 8% gilsonite and 3% SBS and 10% gilsonite modifications [7]. Xiao et al. investigated the epoxy modified bitumen on antiskid resistance of asphalt pavement. Performance of asphalt mixtures were improved by epoxy modification [8a]. Xiao et al. investigated the usability of epoxy modified bitumen instead of tar containing bitumen. Results showed that the epoxy modified bitumen can be used instead of tar containing bitumen for antiskid resistance [8b]. Epoxy modified bitumen was investigated by Yin et. al. to investigate the effects. Bitumen content was increased as a result and the performance of asphalt mixtures were improved [9]. Zhou et al. investigated the rheological properties of epoxy modified bitumen. High temperature resistance was improved by 20% epoxy modification [10]. Zhang et al. investigated performance of the epoxy binder mixed with the decabrombromodiphenyl ethane (DBDPE). As a result, no change on the viscosity is found [11]. SBS modified bitumen is investigated by Kang et al. and results showed that the performance of SBS modification is feasible [12].

As seen from the literature review there are few study about natural resin or rosin modified bitumen and its performance. This study aims to address the deficiency in the literature. For this aim, rheological properties of rosin modified bitumen was investigated and the performance of asphalt mixture was tested in accordance with the moisture susceptibility. Rosin was added to the bitumen in the rate of 2%, 4%, 6% and 8% by weight of bitumen. High shear mixer was used to modify bitumen with rosin. Modification effort was conducted at 4000 rpm and at 160 °C degree. After that, rheological tests were conducted on all modified bitumen. After modified bitumen was obtained, asphalt mixtures were prepared with rosin modified bitumen. Asphalt mixtures were prepared according to Superpave mix design procedure and compacted by Superpave Gyratory Compactor (SGC). Then the optimum bitumen contents were obtained according to 4% air void content. After all asphalt mixtures were compacted to maximum density with optimum bitumen contents. Then the asphalt mixtures were tested by Indirect Tensile Strength (ITS) to find stability of mixtures. Tensile Strength Ratio (TSR) was calculated to evaluate the moisture susceptibility. Samples were conditioned according to AASHTO T283. TSR was calculated as the ratio of conditioned and unconditioned ITS of compacted specimen.

2. Material and Method

2.1. Rosin

Resin is solid or highly viscous material which used in materials and polymer science to obtain polymer.

Resin are generally occurring in nature mixtures of organic compounds. After that resin is distilled and volatile terpenes have been removed. This material is called rosin which is used in the study. Natural resin which is obtained naturally from tree bodies contains 80% rosin and 20% turpentine oil. The rosin contains 90% resin acids and 10% neutral substances. The natural resin and rosin are given in Figure 1 (a) and (b), respectively.

Figure 1. (a) Natural resin (b) Pure rosin

2.2. Bitumen

Bitumen is obtained from TUPRAS and performance graded PG 64-22 is used in this study. Bitumen test results were given in Table 1.

Table 1. Properties of base bitumen

Test		Unit	Base Bitumen
Specific Gravity		gr/cm^3	0.995
Penetration @25 °C		0.1 mm	62.2
Softening Point (Ring & Ball)		°C	49.9
Ductility @25°C, 5 cm/min		cm	>100
RV @135 °C, ≤3Pa.s		Pa.s	0.475
RV @165 °C		Pa.s	0.15
RV @185 °C		Pa.s	0.075
DSR G*/sinδ>1 kPa @10 rad/s	Fail Temperature	°C	67.9
	Grade	°C	64
Mass Loss		%	0
Permanent Penetration		%	70.4
Change in Softening Point		°C	+3.2
DSR G*/sinδ>2.2 kPa @10 rad/s	Fail Temperature	°C	67
	Grade	°C	64
DSR G*.sinδ<5.000 kPa @10 rad/s	Fail Temperature	°C	28.6
	Grade	°C	22
BBR S≤300 MPa, m≥0.300 @60 s		°C	-12
	m-value		0.325
	Stiffness	MPa	213
Performance Grade			PG 64-22

2.3. Aggregate

Aggregate was collected from Isparta Municipality. Limestone aggregate was used in the study. HMA dense graded was chosen for wearing course. Aggregate properties and gradation was given in Table 2 and Figure 2, respectively.

Table 2. Aggregate properties

Specification	Sieve Diameter		
	25-4.75 mm	*4.75-0.075 mm*	*0.075 mm*
Specific Gravity (gr/cm^3)	2.750	2.660	2.720
Saturated Surface Specific Gravity (gr/cm^3)	2.428	2.652	-
Water Absorption (%)	2.800	0.130	-
Los Angeles Abrasion Loss (%)	20.38	-	-

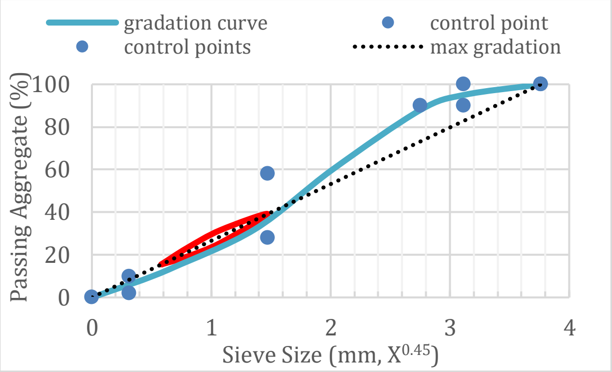

Figure 2. Gradation curve

2.4. Bitumen modification with rosin

Bitumen modification was performed via high shear mixer. High shear mixer was set as 4000 rpm shear rate and 160 °C temperature. Appropriate percentage of rosin was heated and become liquid added to hot bitumen at 160 °C. Then mixer was run at 4000 rpm for an hour.

2.5. Bitumen tests

Besides standard bitumen tests, elastic recovery, rotational viscometer tests were conducted and penetration index was calculated for base and rosin modified bitumen. Rotational viscometer test was conducted at 135 °C, 165 °C and 185 °C degrees. Temperatures which used for mixing and compaction are determined by rotational viscometer. Test was conducted by Brookfield DV-III test machine according to AASHTO TP48.

Elastic and plastic stiffness of bitumen was determined by mathematical model developed by Ulliditz and Larsen [13]. According to Ulliditz and Larsen's stiffness modulus empirical formula, in this study, stiffness modulus of bitumen was calculated. The motivation was to estimate stiffness modulus empirically was to show effect of penetration index on modification.

2.6. Performance of modified HMA

Modified Lottman test was performed to determine the Indirect Tensile (IDT) Strength and Moisture Susceptibility (Tensile Strength Retained - TSR) of HMA according to AASHTO T283. To this aim 6 samples were compacted by SGC and placed into oven at 40 °C for 72 hours. After that 3 of them was conditioned. The others were kept as unconditioned. Conditioning was conducted first placed into water bath at 25 °C for 24 hours. Then the samples were vacuum saturated while the 55-80% saturation level is achieved. After all, samples were exposed to freeze-thaw cycle for -18 °C for 16 hours then placed in a 60 °C water bath for 24 hours. Indirect tensile test was conducted on samples and strength parameters were calculated.

$$IDT = \frac{2P}{\pi dh} \qquad (1)$$

P is the maximum load, d is the diameter of specimen, h is height of specimen. Moisture susceptibility was calculated as the rate of conditioned and unconditioned strengths.

$$TSR = \frac{IDT_c}{IDT_u} * 100 \qquad (2)$$

IDT_c is the average strength of the conditioned and IDT_u is the average strength of the unconditioned specimens.

3. Results

3.1. Bitumen test results

Base bitumen was modified with rosin in the rate of 2%, 4%, 6% and 8% and rosin modified bitumen properties were given in Table 3. As seen from the results, penetration of rosin modified bitumen is decreasing and softening point of modified bitumen is increasing as compared to reference. It is expected when the penetration is decreased, softening point should be increased.

3.2. Penetration index

Penetration Index (PI) was calculated to determine the temperature susceptibility of bitumen. It is known that penetration index should be within -1 < PI < +1. If the PI was less than -1, the bitumen was so responsive to temperature change and cracks will started to occur in winter. As shown in Figure 3, 1% rosin modified bitumen has PI= -1 and it could be acceptable.

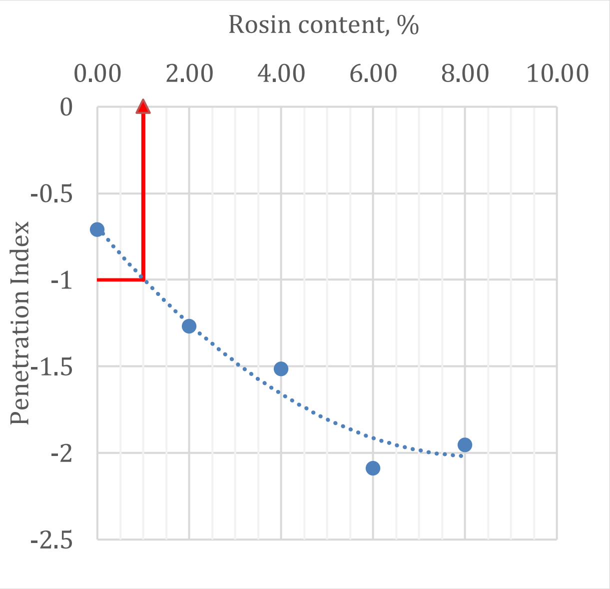

Figure 3. Penetration index

3.3. Rotational viscometer

Temperatures of mixing was found based on the cut point of 0.17±2 Pa.s and temperatures of compaction was found based on the cut point of 0.28±3 Pa.s intervals. Graph is drawn as exponentially. Figure 4 shows the results and Table 4 shows the temperatures. As seen from the graph, 2% and 8% rosin modified bitumen show different trend at 165 °C and 185 °C. It can be said that the bitumen behavior is changed when the 2% and 8% rosin added. But still, 4% and 6 % rosin modified bitumen are close to the base bitumen.

Table 3. Properties of rosin modified bitumen

Test	Unit	Reference	2% rosin	4% rosin	6% rosin	8% rosin
Specific Gravity	gr/cm^3	0.995	0.955	0.905	0.935	0.95
Penetration @25 °C	0.1 mm	62.2	44.4	40.4	35.8	35.6
Softening Point Ring&Ball	°C	49.9	50.8	50.6	49.2	49.8
Ductility @25°C, 5 cm/dk	cm	>100	>100	>100	>100	>100
Elastic Recovery	%	95	97	94	95	97
RV @135 °C, ≤3Pa.s	Pa.s	0.475	0.6875	0.500	0.5375	0.5875
RV @165 °C	Pa.s	0.15	0.200	0.1375	0.1375	0.1625
RV @185 °C	Pa.s	0.075	0.1125	0.075	0.075	0.0375

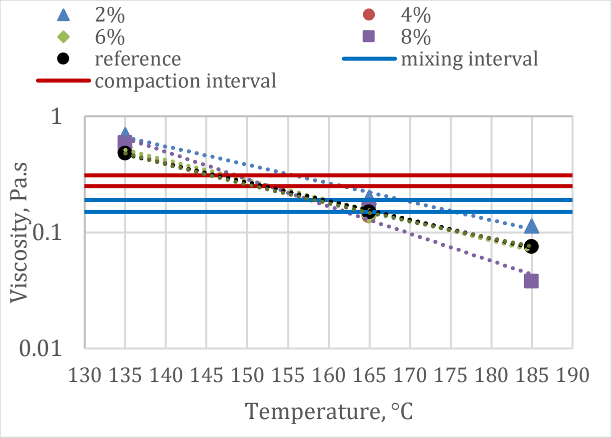

Figure 4. Mixing and compaction test results

Table 4. Mixing and compaction temperatures

	Reference	%2 rosin	%4 rosin	%6 rosin	%8 rosin
Compaction interval, °C	146-152	155.5-162	146-152	147.5-153	148.5-152.5
Mixing interval, °C	159-165.5	169-175.5	159-165.5	159.5-165.5	157.5-162
Compaction Temperature, °C	149	158.75	149	150.25	150.5
Mixing Temperature, °C	162.25	172.25	162.5	162.5	159.75

3.4. Empirical formula for stiffness modulus of bitumen

Elastic and plastic stiffness of bitumen was determined by mathematical model developed by Ullidtz and Larsen [13]. The parameters used are acting time, penetration index and softening point for elastic stiffness. Plastic stiffness was effected by viscosity and the acting time. Ullidtz and Larsen developed a model to determine the stiffness of bitumen given below:

$$S(t) = 1.157x10^{-7}t^{-0.368}e^{-PI}x(T_{rb} - T)^5 \qquad (3)$$

where $S(t)$ is stiffness modulus (MPa), t is time for load duration (s), PI is penetration index, T_{rb} is softening point (ring and ball method) (°C) and T is bitumen temperature (°C).

In this model, the time for load duration was calculated from 0.01 s to 0.1 s and the other parameters was calculated from test results. When the time for load duration is increased bitumen elastic stiffness is decreased. Practically, time for load duration is related to vehicle velocity. For example, when radius of contact area of vehicle tire on the pavement is 10 cm, pavement thickness is 10 cm and vehicle velocity is 10 km/h, time for load duration is 0.1 s. When increasing the vehicle velocity to 12 km/h at the same conditions, time for load duration is decreased to 0.09 s [14].

Stiffness modulus of rosin modified bitumen was calculated and compared to reference bitumen's stiffness modulus. The graph was drawn based on the stiffness modulus of reference bitumen (Figure 5). The results showed that 6% rosin modified bitumen has the best stiffness modulus as 3.95 times better than the reference sample. All modified samples showed better results when compared to reference sample, but still the 8% rosin modified bitumen showed less stiffness modulus against 6% rosin modified bitumen. It means that, when increasing the rosin percentage up to 6% the increased stiffness modulus has been obtained. Also, the other bitumen test results proved this result.

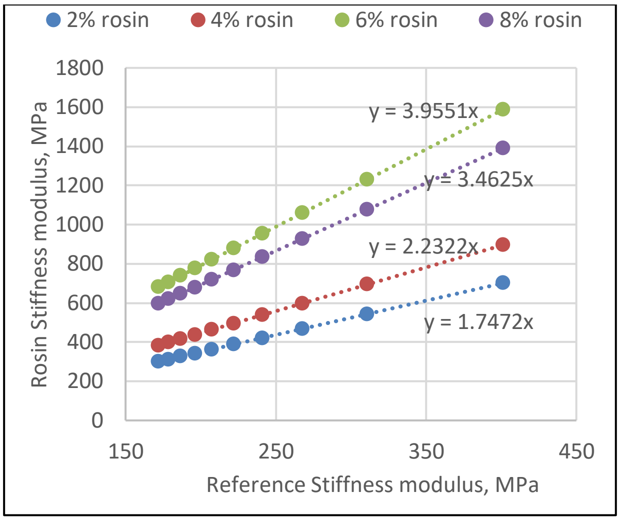

Figure 5. Stiffness modulus of reference vs. rosin modified bitumen according to Ullidtz and Larsen's model

For the plastic stiffness modulus of bitumen was determined as follows [13]:

$$S(t)_p = 3v/t_a \qquad (4)$$

where, $S(t)_p$ is plastic stiffness modulus (MPa), v is viscosity of bitumen (MPa.s), t_a is time for load duration (s).

In this model, the time for load duration was calculated from 0.01 s to 0.1 s and 135 °C viscosity was chosen because the 165 °C and 185 °C viscosity trend was different for modifications.

Plastic stiffness modulus of rosin modified bitumen was calculated and compared to reference bitumen's stiffness modulus. The graph was drawn based on the stiffness modulus of reference bitumen (Figure 6). The results showed that 2% rosin modified bitumen has the best stiffness modulus as 1.44 times better than the reference sample. Reference bitumen has the less plastic stiffness and all modified samples showed better results when compared to reference sample, but still the 2% rosin modified bitumen showed different trend. It means that, when increasing the rosin percentage up to 8% the increased stiffness modulus has been obtained. Also, the other bitumen test results proved this result.

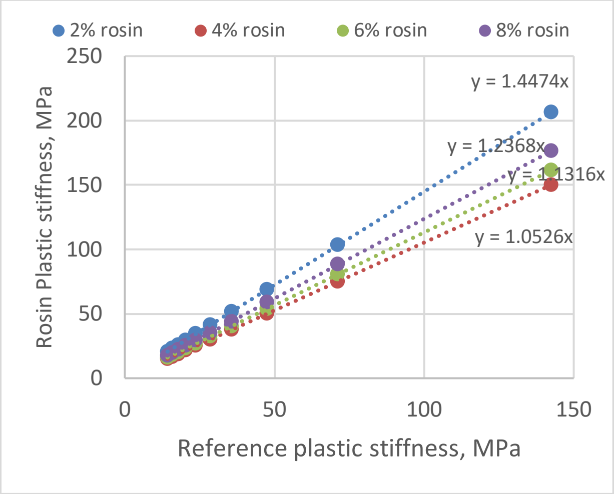

Figure 6. Stiffness modulus of reference vs. rosin modified bitumen according to Ulliditz and Larsen's model

3.5. Empirical formula for stiffness modulus of HMA

Elastic modulus was also determined by Ulliditz and Larsen's empirically as follows [13]:

$$E = S(t)x[1+\frac{\left(\frac{2.5}{n}\right)xC'_v}{1-C_v}]^n \qquad (5)$$

In this formula, aggregate concentration by volume is calculated by C'_v as follows:

$$C'_v = C_v/[0.97+0.01\big(100-(VA-VB)\big)] \qquad (6)$$

$$C_v = VA/(VA+VB) \qquad (7)$$

where, VA is aggregate volume (%) and VB is bitumen volume (%). Also, n is calculated by:

$$n = 0.83xlog(\frac{40000}{S(t)}) \qquad (8)$$

As seen from Eq. (5), mixture elastic modulus is effected by bitumen stiffness and aggregate concentration by volume. Aggregate concentration is found from air void which is 5% for HMA used in this study. Air void (Va) is constant for all base HMA and modified HMA. Parameters were given in Table 5. Also, the $S(t)$ was calculated based on the time for load duration and elastic modulus was calculated for all modifications based on the $S(t)$. In Figure 7 elastic modulus was calculated for two variables (time for load duration and $S(t)$) and given for all modifications.

Table 5. Variables used in the model

	VA (%)	VB (%)	Va (%)	C'_v	C_v	n
Reference	84.8	10.2	5	0.7292	0.8926	1.964
2% rosin	83.3	11.7	5	0.6992	0.8768	1.7631
4% rosin	82.8	12.2	5	0.6895	0.8715	1.6748
6% rosin	83.4	11.6	5	0.7011	0.8778	1.4686
8% rosin	83.1	11.9	5	0.6953	0.8747	1.516

As seen from Figure 7, highest elastic modulus was obtained by 6% rosin modified HMA. All modifications have higher elastic modulus than the reference HMA. The results were satisfying which is expected. Because the elastic modulus was effected directly the bitumen stiffness.

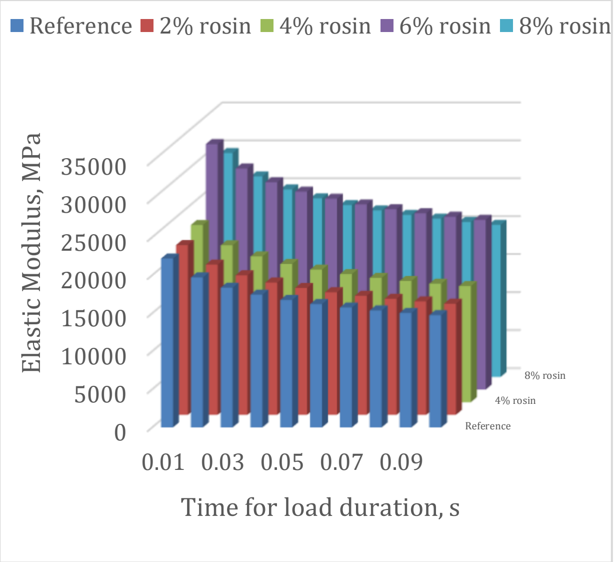

Figure 7. Elastic modulus of HMA samples according to Ulliditz and Larsen's model

3.6. Optimum bitumen content

Superpave mix design is adopted to obtain optimum bitumen contents. Samples were compacted based on the maximum density to achieve 4% air void. Then the air void graphs of four bitumen contents (3.5%, 4%, 4.5% and 5% for base bitumen) and (4.5%, 5%, 5.5% and 6% for modified bitumen) were drawn and 4% is marked on the graphs. Marked point is drawn to bitumen contents which is the optimum bitumen content. Optimum bitumen contents were obtained as 4.5%, 4.9%, 5.0%, 4.85% and 5.1% for base bitumen, 2%, 4%, 6% and 8% modified bitumen, respectively. Then the Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA) graphs were drawn and checked whether the specification limits were ensured. Figure 8 shows the optimum bitumen graphs for base bitumen and Figure 9 shows the optimum bitumen graphs for modified bitumen.

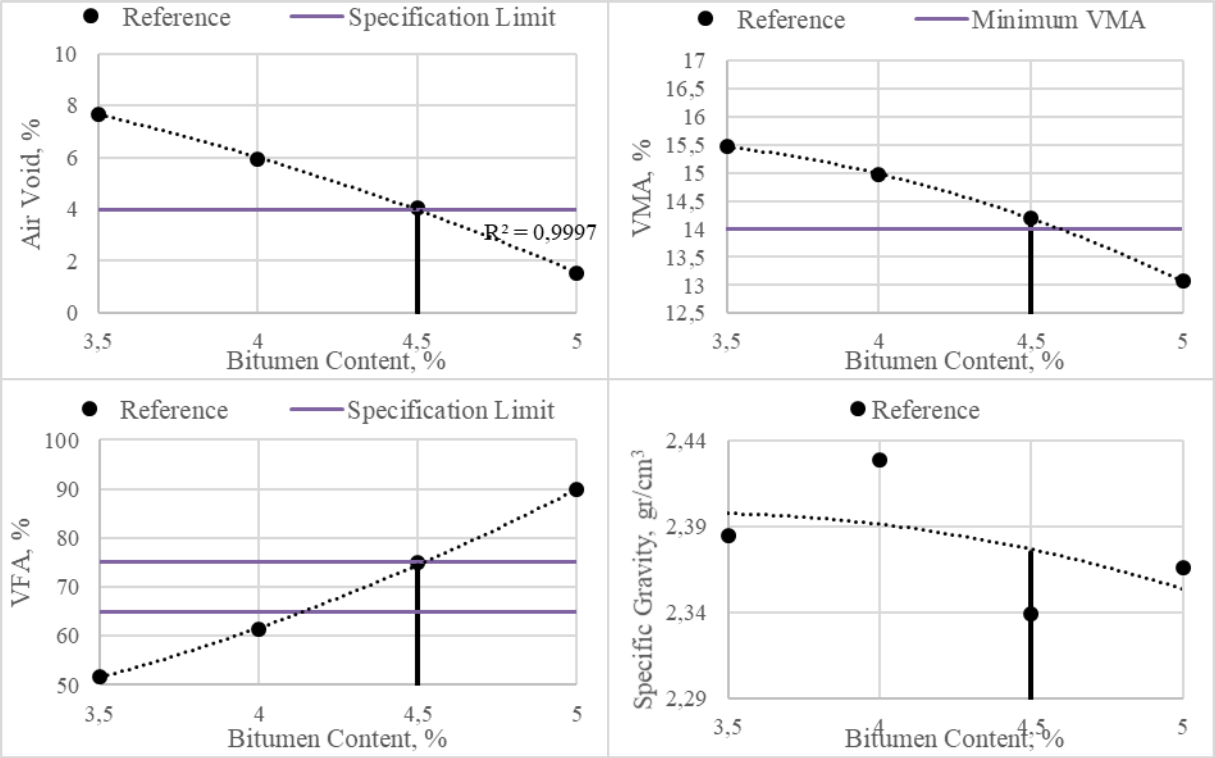

Figure 8. Optimum bitumen contents for base bitumen

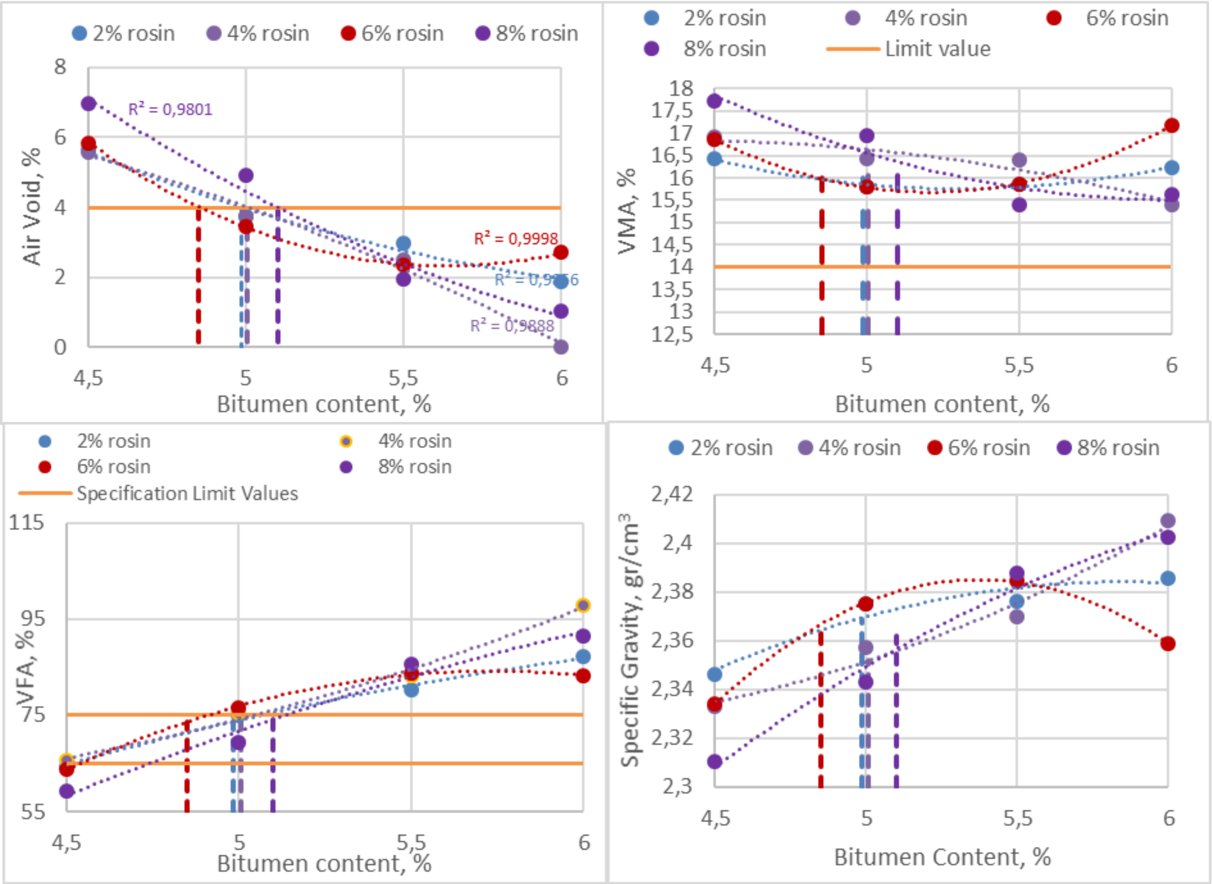

Figure 9. Optimum bitumen contents for rosin modified bitumen

Optimum bitumen contents showed trend among base bitumen, 2%, 4% and 8% rosin modified bitumen. Except 6% rosin modified bitumen has the lower optimum bitumen content against other modifications. But still 6% rosin modified bitumen has the higher optimum bitumen content according to base bitumen. 6% rosin modified bitumen has the different trend for optimum bitumen graphs. So that, the 6% rosin modified bitumen has different and better performance against the other modifications.

3.7. Indirect tensile strength

Indirect tensile strength (IDT) values were determined for unconditioned (IDT_{dry}) and conditioned (IDT_{wet}) HMA samples. Figure 10 shows the IDT strengths of all rosin modified HMA samples and reference HMA. As seen from the Figure 10, IDT values show the expected trend that increasing when rosin percentage was increased. When compared to reference sample strength values were increasing by modification of HMA. It has been concluded that when the rosin additive percentage was increased strength values were increased. However, while conditioning the HMA sample IDT strength was decreased. But still IDT strength values of modified HMA were clearly higher than the reference HMA sample. This trend indicates that performance of HMA was increased by modification with rosin.

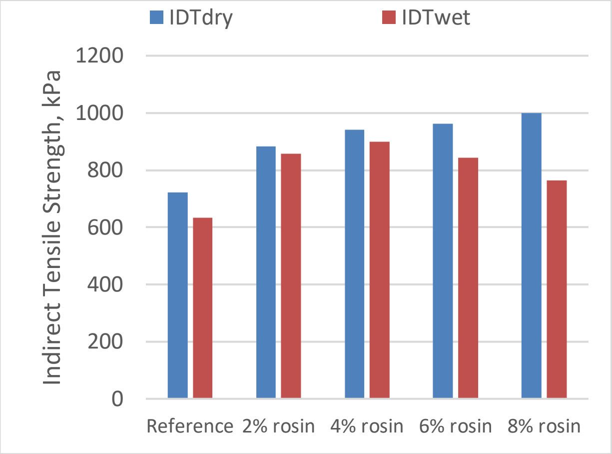

Figure 10. Indirect Tensile Strength for rosin modified HMA

3.8. Moisture susceptibility

Moisture susceptibility of HMA samples were determined as the ratio of IDT strength. The results were given in Figure 11. As a conclusion of results, rosin modified HMA samples showed higher resistance against moisture. According to the specification, 0.80 moisture resistance is needed at least. All modified HMA samples were provided specification limit value.

Evaluating the TSR values, 2% and 4% rosin modified HMA samples have higher resistance against moisture than the reference HMA sample. Also, highest moisture resistance was obtained by 2% rosin modified HMA sample. 6% rosin modified HMA sample was provided the specification limit, however it has same moisture resistance with the reference HMA sample. Although, 8% rosin modified HMA sample has the highest IDTdry strength, sample showed lowest moisture susceptibility and wasn't provided the specification limit.

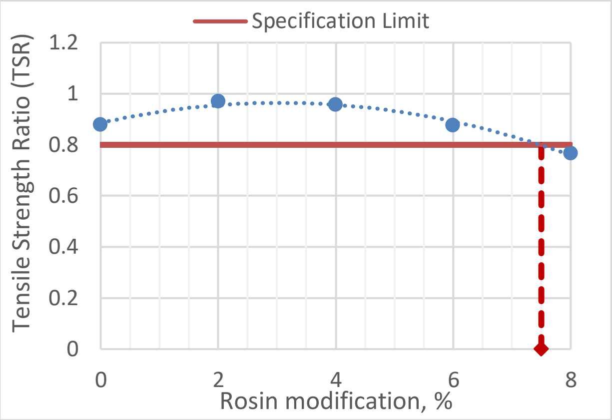

Figure 11. TSR values of rosin modified HMA

4. Discussion and Conclusion

In this study, the effect of rosin modification was investigated. Bitumen properties and HMA performance was determined. Conclusions can be drawn as follows:

According to penetration index, all modifications were in the limit and means that they are less susceptible to temperature than base bitumen. Rosin is effected the viscosity of bitumen in different trend. Mixing and compaction temperatures were increased with the rosin modification except 8% rosin for mixing temperature. 6% rosin modified bitumen showed highest stiffness modulus obtained by empirical model. And also, 2% rosin modified bitumen showed highest plastic stiffness. Time for load duration, penetration index, softening point and temperature is effective for stiffness modulus. Lowest penetration index is obtained by 6% rosin modification so that the highest stiffness modulus is obtained by 6% rosin modification. 6% rosin modified HMA showed highest elastic modulus. Lowest optimum bitumen content was obtained by 6% rosin modified HMA. IDT_{dry} strengths were increased by rosin modification. Also, IDT_{wet} strengths were higher than the reference HMA. Performance of HMA was improved by rosin modification. Highest moisture susceptibility was obtained by HMA modified with 2% rosin.

As a result, rosin modification has satisfying performance. Percentage of rosin which usable in asphalt mixtures is depend on the desired performance criteria. If the temperature susceptibility is considered 1% rosin modification can be acceptable. If the stiffness was considered 6% rosin modification could be acceptable. But if the tensile strength was considered 8% rosin modification could be acceptable, exception of HMA was exposed to moisture. If the moisture susceptibility is considered 2% rosin modification could be acceptable.

As a conclusion, the best performance was obtained by 6% rosin modified HMA.

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