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Araştırma Makalesi Research Article

INVESTIGATION OF THE EFFECT OF AGGREGATE SPECIFIC GRAVITY ON OPTIMUM BITUMEN CONTENT OF HOT MIX ASPHALT

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Keywords
Aggregate Specific Gravity,
Superpave,
Indirect Tensile Strength,
Moisture Sensitivity.

Abstract

In this study, effect of aggregate specific gravity, which is directly related to origin of aggregates used in hot mix asphalt on optimum bitumen content, indirect tensile strength and tensile strength ratio of hot mix asphalt, was investigated. Specific gravity (SG) values of one kind of limestone aggregate were calculated according to Turkish Standard (TS), American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) standards, separately. Although one kind of limestone aggregate and 50/70 penetration grade bitumen are used in the mixtures, different values were obtained in terms of optimum bitumen content, indirect tensile strength and moisture sensitivity due to differences in the specific gravity values of the aggregates. Optimum bitumen contents were found by using TS, ASTM and AASHTO standards as 5.03%, 4.75% and 4.59%, respectively. According to the cost – benefit analysis, it can be said that changes in aggregate specific gravity values, which were calculated, based on different standards provide economic benefit. Overall, the results indicated that specific gravity values of one kind of limestone aggregate used in hot mix asphalt have significantly affected optimum bitumen content and indirect tensile strength of the mixtures.

SICAK KARIŞIM ASFALTIN OPTİMUM BİTÜM ORANI ÜZERİNE AGREGA ÖZGÜL AĞIRLIĞININ ETKİSİNİN İNCELENMESİ

Anahtar Kelimeler
Agrega Özgül Ağırlığı,
Superpave,
İndirekt Çekme Dayanımı,
Nem Hassasiyeti.

Öz

Bu çalışmada, sıcak karışım asfaltta kullanılan agregaların kökeni ile doğrudan ilişkili olan agrega özgül ağırlığının, sıcak karışım asfaltın optimum bitüm oranı, indirekt çekme dayanımı ve çekme dayanımı oranı üzerine etkisi araştırılmıştır. Bir tür kireçtaşı agreganın özgül ağırlık değerleri Türk Standardı (TS), Amerikan Test ve Malzeme Kurumu (ASTM) ve Amerika Devlet Karayolu ve Ulaştırma İdareleri Birliği (AASHTO) standartlarına göre ayrı ayrı hesaplanmıştır. Karışımlarda tek çeşit kireçtaşı agrega ve 50/70 penetrasyon sınıflı bitüm kullanılmasına rağmen, agregaların özgül ağırlık değerlerindeki farklılıklardan dolayı optimum bitüm oranı, indirekt çekme dayanımı ve nem hassasiyeti açısından farklı değerler elde edilmiştir. Optimum bitüm içerikleri TS, ASTM ve AASHTO standartları kullanılarak sırasıyla %5,03, %4,75 ve %4,59 olarak bulunmuştur. Fayda – maliyet analizine göre farklı standartlar esas alınarak hesaplanan agrega özgül ağırlık değerlerindeki değişimlerin ekonomik fayda sağladığı söylenebilir. Genel olarak sonuçlar, sıcak karışım asfaltta kullanılan bir tür kireçtaşı agregasının özgül ağırlık değerlerinin, karışımların optimum bitüm oranını ve indirekt çekme dayanımını önemli derecede etkilediğini göstermiştir.

Alıntı / Cite

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1. Introduction

Properties of aggregates and bitumen affect significantly design parameters of hot mix asphalt (HMA). The physical (such as specific gravity, angularity, water absorption, surface texture etc.) and mechanical properties (including resistance to crushing, polishing, weathering etc.) of the aggregates which consisted of 95% by weight of hot mix asphalt affect the performance of the pavement. In addition, it is known that the chemical, rheological and physical properties (such as viscosity, softening point etc.) of bitumen also affect the performance of the pavement. Different studies are carried out on properties of bitumen and aggregates to improve the properties of hot mix asphalt.

The angularity of coarse and fine aggregates has an impact on the strength, stiffness, permeability and air void parameters of asphalt mixtures. Ramli et al. (2013) investigated the effect of angularity of fine aggregates on tensile strength and rutting resistance of HMA. As the angularity of fine aggregates increases, the interlocking of the aggregates in the asphalt mixture increased. Thus, it was seen that the tensile strength and rutting resistance of asphalt mixtures are increased. The study fails to consider the different characteristics of aggregates in different origin. It is well-known that the aggregates in different origin show different physical properties including shape, angularity and surface texture and these characteristics may cause positive or negative effects on HMA design parameters (Bessa et al., 2015). Moreover, structural and functional performance of HMA is affected by these aggregate properties.

Depending on the crushing type, origin and shape (cubical, rounded, flat, and elongated) of aggregates, the performance of mixture can be differed. Since cubical aggregates provide excellence interlocking and good internal friction, they are preferred (Li et al., 2019). This aspect can be proved with a study which Adiseshu et al. (2011) investigated the shape characteristics of aggregates on HMA performance. Asphalt mixtures prepared using angularity coarse aggregates have exhibited higher strength than asphalt mixtures prepared using flat-elongated coarse aggregates. It is also indicated that interlocking among the coarse aggregates provide significantly uniform load distribution and strengthen pavement surface against repeated traffic loads and harsh environmental conditions. Contacts among aggregates cause an increase in internal forces that result in fraction on aggregates. Mahmoud et al. (2010) evaluated the effect of aggregate gradation, shape and strength of aggregates on degradation of asphalt mixes. According to their comprehensive survey, it was seen that as internal friction increases, degradation in aggregates which observed is less.

The deteriorations in the pavement occur due to environmental conditions (temperature, life of pavement), repeated wheel, poor mixture design (air void, gradation curve) and the properties of the aggregates and bitumen forming the mixture. Aggregates used in mixtures significantly affect the performance of mixtures under applied external loads and environmental conditions. The most effective parameter in the formation of rutting on the pavement is the aggregate properties. Both the types of aggregates and determined aggregate gradation are effective in resistance to rutting. For example, some studies, which examined the relationship between the rutting characteristics of HMA and type of aggregate, promoted that rutting resistance is predominantly affected by aggregate type (Afaf, 2014; Al-Khateeb et al., 2013). While rutting behavior depending on temperature has changed linearly for asphalt mixtures prepared using basalt, it has changed exponentially for asphalt mixes prepared using limestone. The optimum bitumen content also largely depends on the types of aggregate and aggregate gradation. Aggregate gradation is one of the most important aggregate properties that affect the permanent deformation of hot mix asphalt. When the aggregate gradation curve approaches the lowest limit, permanent deformation and rutting resistance of the mixtures increase and decrease, respectively (Golalipour et al., 2012). Fatigue cracking is another common deterioration of the pavement due to repeated traffic loads and temperature changes. Moreno and Rubio (2013) investigated the effect of different aggregates (ophite and limestone) origin on fatigue cracking performance of HMA. Although the moisture sensitivity values of hot mix asphalt prepared using ophite and limestone aggregates were similar, it showed better resistance to fatigue cracking of hot mix asphalt which prepared using limestone aggregates. When asphalt mixtures are exposed to water, deteriorations such as raveling, stripping may be observed due to the decreasing of adhesion between aggregate and bitumen. The chemical structure of aggregates used in the mixture plays an important role on water-resistant capability of HMA (Cui et al., 2014). In Behiry's study, HMA mixtures prepared with limestone exhibited better stripping resistance than the ones prepared with granite (Behiry, 2013). In addition, when it comes to sensitivity to water, the chemical structure of aggregate is more important than its porosity (Cui et al., 2014). Besides the environmental conditions and traffic volume, types of aggregates used in the mixtures affect the occurrence of stripping in the pavement. It has been observed that, when compared with mixtures prepared with limestone, more stripping has been occurred in mixtures prepared with aggregates such as granite, gravel (Behiry, 2013). The deteriorations such as fatigue cracks and rutting which are affected the performance and structure of pavement may be increased with moisture. As the adhesion between aggregate and bitumen increases in HMA mixtures, the structural and functional performance of the pavement increases. Stripping resistance of HMA mixtures is significantly increased in as a result of the modification of bitumen with polyethylene for both limestone and granite aggregates (Nejad et al., 2013).

In current study, it was aimed to determine the specific gravity of one kind of limestone aggregates according to different standards. The standards used in the study other than the Turkish Standard (TS) were determined by considering the standards used in previous studies (Table 1). When Table 1 is examined, it seen that although there are aggregates of different origin and their specific gravity is calculated using different standards, the specific gravity value of aggregate is slightly different in some studies. The effect of these differences seen in the calculation of specific gravity of aggregate on bituminous hot mixes was examined. In this study, specific gravities of one kind of limestone aggregates were calculated according to TS, ASTM and AASHTO standards. Optimum bitumen content, indirect tensile strength and moisture sensitivity of bituminous hot mixes which prepared by taking into account obtained values of specific gravity were examined. According to the calculated optimum bitumen contents, cost-benefit analysis was performed for the 400 m^3 hot mix asphalt mixtures (wearing course with 5 cm thick and 1 km pavement length and 8 m platform width).

Table 1. Specific gravity values of limestone aggregates

Research	Standard	Specific Gravity of Limestone (g/cm^3)		
		Coarse Aggregate	Fine Aggregates	Filler
Kök and Çolak, 2011	ASTM C 127	2.613	-	-
	ASTM C 128	-	2.622	-
	ASTM D854	-	-	2.711
Nejad et al., 2012	ASTM C 127	2.643	-	-
	ASTM C 128	-	2.633	-
	ASTM D 854	-	-	2.640
Arabani and Hamedi, 2011	ASTM C 127	2.643	-	-
	ASTM C 128	-	2.633	-
	ASTM D854	-	-	2.640
Arabani et al., 2017	ASTM C 127	2.641	-	-
	ASTM C 128	-	2.645	-
Ameri et al., 2016	AASHTO T 85	2.654	-	-
	AASHTO T 84	-	2.617	-
	AASHTO T 84	-	-	2.702
Haghshenas et al., 2015	AASHTO T 85	2.520	-	-
	AASHTO T 84	-	2.510	-
Hesami et al., 2013	AASHTO T 85	2.643	-	-
	AASHTO T 84	-	2.633	-
	ASTM D854	-	-	2.640
Nejad et al., 2013	ASTM C 127	2.643	-	-
	ASTM C 128	-	2.633	-
	ASTM D854	-	-	2.640
Behiry, 2013	ASTM C 127	2.60	-	-
	ASTM C 128	-	2.65	-
	ASTM C 128	-	-	2.72
Al-Khateeb, 2013	AASHTO T 85	2.699	-	-
	AASHTO T 84	-	2.549	-
Muniandy and Aburkaba, 2011	ASTM C 127	2.620	-	-
	ASTM C 128	-	2.580	-
Hamedi and Tahami, 2018	ASTM C 127	2.58	-	-
	ASTM C 128	-	2.57	-
	ASTM D854	-	-	2.54

2. Material and Method

2.1. Bitumen and Aggregates

In the study 50/70 penetration grade bitumen is used. Penetration, softening point, specific gravity and viscosity tests were performed on the bitumen. Properties of bitumen and limestone aggregates are given in Table 2 – 3.

Table 2. Properties of bitumen

Test	Bitumen	Standard
Penetration (0.1 mm)	51	TS EN 1426,
Softening Point (°C)	50.3	TS EN 1427
Specific Gravity (g/cm^3)	1.031	TS EN 15326+A1
Rotational Viscometer (cP)	504 at 135 °C 138.2 at 165 °C	ASTM D 4402

Table 3. Properties of limestone aggregates

Test	Aggregate	Standard
Resistance (Los Angeles wear loss) (%)	18.48	ASTM C 131-03
Resistance (Micro – Deval wear loss) (%)	9.95	TS EN 1097-1
Methylene Blue	0.25	TS EN 933-9
Flakiness Index	12.8	TS EN 933-3
Magnesium Sulphate (%)	1	TS EN 1367-2

In the study, the aggregates were used in three size that are classified as coarse aggregates (remaining on the 4.75 mm sieve), fine aggregates (passing through 4 mm sieve and remaining on the 0.063 mm sieve) and filler (passing 0.063 mm sieve).

2.2. Experimental Studies

Specific gravity (SG) and water absorption (WA) values of aggregates that have different sizes (coarse, fine aggregate and filler) were determined according to different standards (AASHTO, ASTM and TS).

The SG and WA values of coarse aggregates were determined with the standards codded with AASHTO T 85, ASTM C127 and TS EN 1097-6, whereas that of fine aggregates were determined with AASHTO T 84, ASTM C128 and TS EN 1097-6 standards. The specific gravity of the filler was calculated with the standards used to determine the specific gravity of fine aggregates. The tests, which carried out within the scope of this study, are shown in the flow diagram (Figure 1). In this section, the test procedures of the standards used for each type of grain sizes are presented in detail.

2.2.1. Determination of the Specific Gravity of Coarse, Fine Aggregates and Filler

The specific gravity of the coarse aggregates which used in the study was calculated according to TS EN 1097-6, BS EN 812-2, ASTM C127 and AASHTO T85 standards. Coarse aggregates remaining on a 4.75 mm sieve in TS EN 1097-6 and BS EN 812-2 standards are placed with in the wire basket and immersed in a tank containing water with 22±3 °C for 24 hours. In ASTM C127 and AASHTO T85 standards, coarse aggregates remaining on a 4.75 mm sieve are kept in a tray containing water with 22±3 °C for 24 hours and 15 hours respectively. When the specific gravity of coarse aggregates is calculated according to TS EN 1097-6 and BS EN 812-2 standards, the aggregate mass, the apparent mass of the wire basket containing the saturated aggregate sample in water and the apparent mass of the empty wire basket in water are taken into account. In ASTM C127 and AASHTO T85 standards, the mass of the air-dried test sample, the mass of the air-saturated surface dry test sample and the mass of the aggregate sample are taken into account.

The specific gravity of the fine aggregates which used in the study was calculated according to TS EN 1097-6, BS EN 812-2, ASTM C128 and AASHTO T84 standards. There are minor differences between TS EN 1097-6, BS EN 812-2, ASTM C128 and AASHTO T84 standards used to determine the specific gravity of fine aggregate. In TS EN 1097-6 standard, one kilo fine aggregates are placed in a water-filled pycnometer with 22±3 °C and kept in a water bath with 22±3 °C for 24 hours. According to BS EN 812-2 standard, 500 gr fine aggregates is waited in the water-filled tray. ASTM C128 and AASHTO T84 standards, one kilo of fine aggregate is kept in the water-filled tray with 22±3 °C for 24 hours and 15-19 hours respectively. The only difference between ASTM C128 and AASHTO T84 standards is the waited time of fine aggregates in water.

TS EN 1097-7, AASHTO T 84 and ASTM C128 standards were followed to determine the specific gravity of the filler materials. According to three different standards, only apparent specific gravity is calculated.

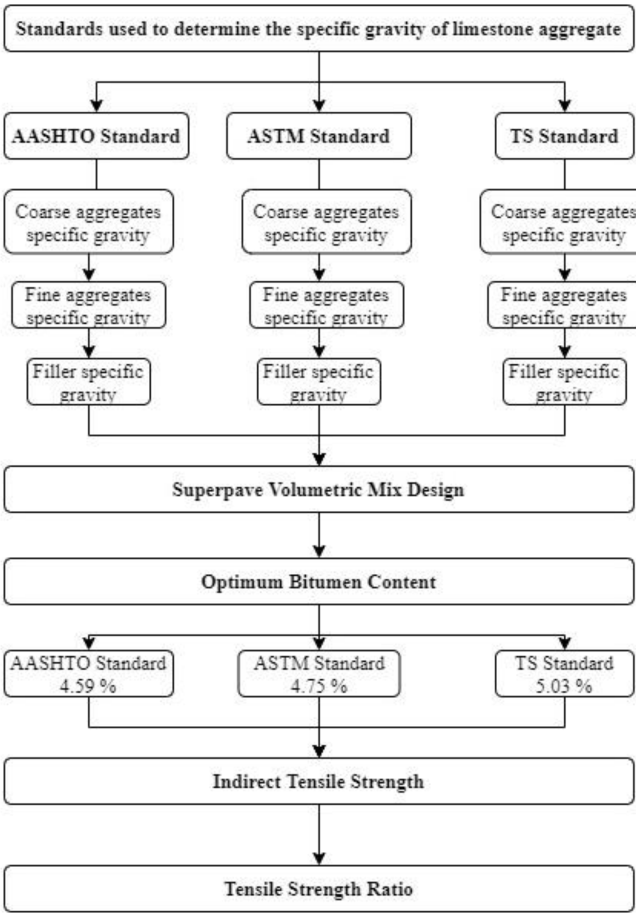

Figure 1. The tests that carried out within the scope of this study

2.2.1. Determination of the Specific Gravity of Coarse, Fine Aggregates and Filler

The specific gravity of the coarse aggregates which used in the study was calculated according to TS EN 1097-6, BS EN 812-2, ASTM C127 and AASHTO T85 standards. Coarse aggregates remaining on a 4.75 mm sieve in TS EN 1097-6 and BS EN 812-2 standards are placed with in the wire basket and immersed in a tank containing water with 22±3 °C for 24 hours. In ASTM C127 and AASHTO T85 standards, coarse aggregates remaining on a 4.75 mm sieve are kept in a tray containing water with 22±3 °C for 24 hours and 15 hours respectively. When the specific gravity of coarse aggregates is calculated according to TS EN 1097-6 and BS EN 812-2 standards, the aggregate mass, the apparent mass of the wire basket containing the saturated aggregate sample in water and the apparent mass of the empty wire basket in water are taken into account. In ASTM C127 and AASHTO T85 standards, the mass of the air-dried test sample, the mass of the air-saturated surface dry test sample and the mass of the aggregate sample are taken into account.

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TS EN 1097-7, AASHTO T 84 and ASTM C128 standards were followed to determine the specific gravity of the filler materials. According to three different standards, only apparent specific gravity is calculated.

2.2.2. Superpave Volumetric Mix Design

Superpave volumetric mix design method consists of four steps: material selection, aggregate gradation, optimum bitumen content and moisture sensitivity. During all these steps, the temperatures and traffic volume are kept same. Aggregate grading curve for asphalt mixtures is given in Figure 2.

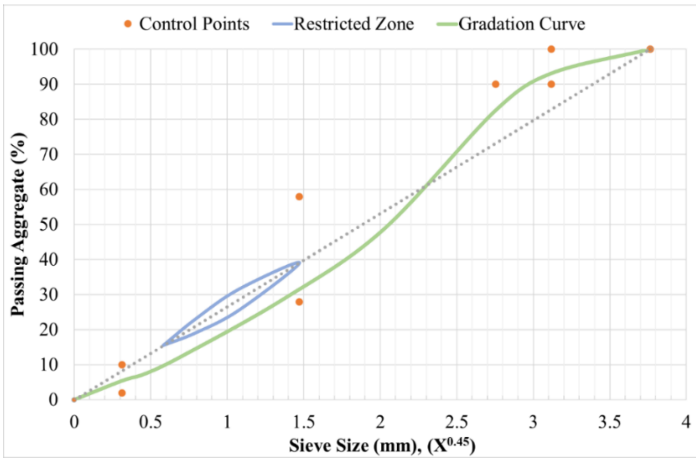

Figure 2. Gradation curve of aggregate mixture

The estimated traffic for 20-year design period is considered to be more than $30x10^6$ equivalent standard axle loads. Within the scope of study, optimum bituminous binder content has been determined using volumetric mix design. N_{design} has been selected as 125 gyros for the estimated 20-year traffic load. While the optimum bituminous binder content is calculated, Voids in the Mineral Aggregate (VMA) Voids Filled with Asphalt (VFA) limit values, which are minimum. 14% and 65-75%, respectively, and 4% air void criteria have been taken into consideration.

2.2.3. Indirect Tensile Strength Test

The final step of the Superpave volumetric mix design method is to determine the moisture sensitivity of the prepared mixtures. In order to determine the moisture sensitivity, Indirect Tensile Strength test (ITS) is performed on the prepared HMA samples in accordance with AASHTO T 283 standard. ITS value of mixtures which compressed with Superpave gyrator compactor is calculated with Eq. (1). Afterwards, unconditioned (ITS_{dry}) and conditioned (ITS_{wet}) values for all samples are recorded. Using the results of ITS in dry and wet case, tensile strength ratio values are calculated using Eq. (2). It is worth to say that the required limit of TSR values is 80% (FHWA, 2000).

$$S_t = \frac{2P}{\pi t D} \quad (1)$$

Where ITS is indirect tensile strength (kPa), P means maximum load (kN), t is sample thickness (m) and D represents sample diameter (m).

$$TSR = \frac{ITS_{wet}}{ITS_{ddry}} \quad (2)$$

Where TSR is tensile strength ratio (%), ITS_{wet} is average tensile strength of conditioned specimen (kPa) and ITS_{dry} is average tensile strength of unconditioned specimen (kPa).

3. Results and Discussions

3.1. The Specific Gravity of Coarse Aggregates

The specific gravity of the coarse aggregates used in the present study was calculated according to different standards (TS EN 1097-6, ASTM C127 and AASHTO T 85). In three different standards, specific bulk gravity, specific bulk gravity (saturated-surface-dry), apparent specific gravity and value of water absorption of coarse aggregates were determined as presented in Figure 3 and Figure 4. The only difference from AASHTO T85 standard of ASTM C127 standard is that coarse aggregates are kept in water for 9 hours more. This difference created 0.014 g/cm^3 difference between the specific bulk gravity (saturated-surface-dry) of the coarse aggregates. The difference between TS EN 1097-6 and ASTM C127 standards is that the coarse aggregates are kept in the wire basket and tray, respectively. Due to the difference in the places where the coarse aggregates are kept in water, 0.012 g/cm³ difference has occurred in the specific bulk gravity (saturated-surface-dry) of the coarse aggregates.

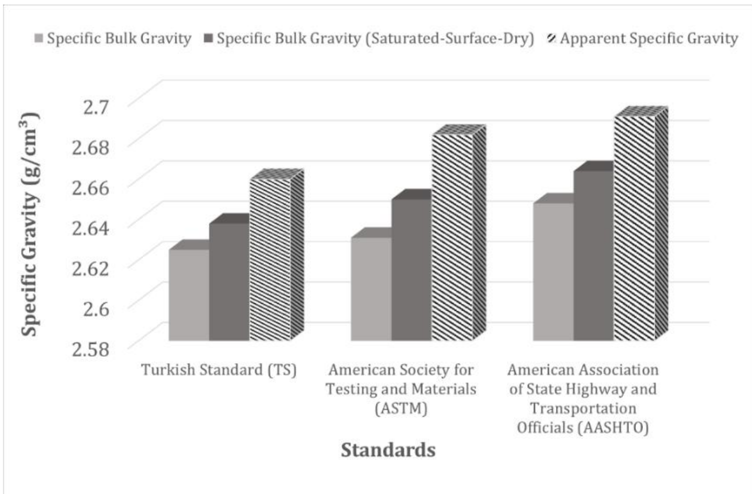

Figure 3. Specific gravity values of coarse aggregates

As Figure 3 is examined, it can be seen that the highest value of specific bulk gravity for coarse aggregates were found from the test done based on the AASHTO T 85 standard. According to obtained results, the lowest coarse aggregate specific gravity was calculated considering the TS EN 1097-6 standard. It is well-known that increasing the specific bulk gravity of coarse aggregates results decrease in the volumetric ratio of them in the total volume of HMA. According to the followed standards, the WA values were also determined and presented in Figure 4.

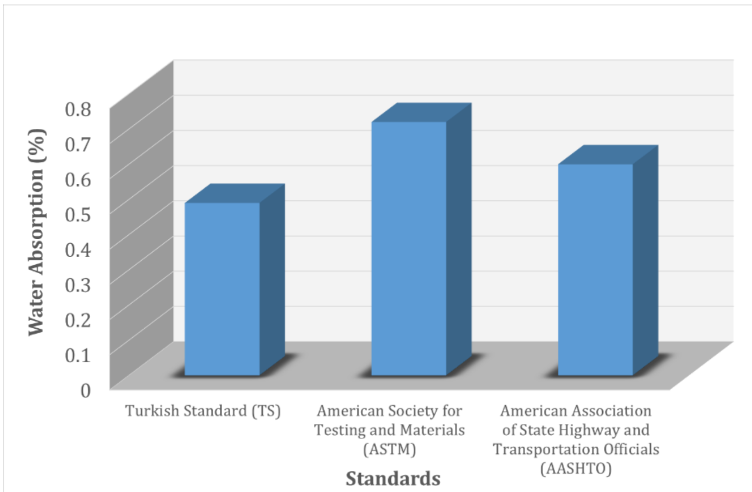

Figure 4. Values of water absorption of coarse aggregates

Due to the differences between the standards mentioned above, 0.23% and 0.12% difference was observed between TS EN 1097-6 and ASTM C127 and ASTM C127 and AASHTO T85 standards in water absorption of coarse aggregates, respectively. It is clearly seen in Fig. 4 that the highest WA value of coarse aggregate is calculated according to the ASTM standard. These results prove that some differences in obtained values can be seen due to the differences in methods of different standards applied on the same aggregates.

3.2. The Specific Gravity of Fine Aggregates and Filler

Just as used to calculate the specific gravity values of coarse aggregates, the mentioned three standards were applied to find out the SG values of fine aggregates. The results of SG of fine aggregates are given in Figure 5. Due to the fact that the fine aggregates were kept for 24 hours in ASTM C128 standard and for 15-19 hours in AASHTO T84 standard, 0.03 g/cm³ difference has occurred in the specific bulk gravity (saturated-surface-dry) of fine aggregates. The difference between TS EN 1097-6 and ASTM C128 standards is that the fine aggregates are kept in the pycnometer and tray, respectively. Due to the difference in the places where the fine aggregates are kept in water, 0.025 g/cm³ difference has occurred in the specific bulk gravity (saturated-surface-dry) of the fine aggregates.

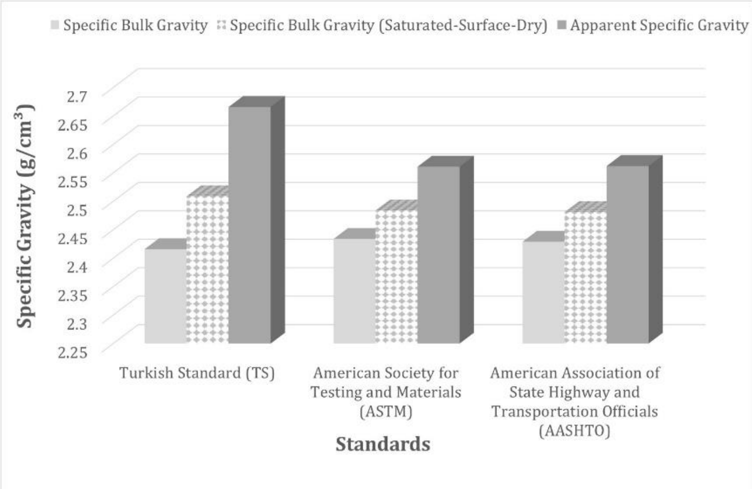

Figure 5. Specific gravity values of fine aggregates

The Figure 5 showed that the opposite result that found for coarse aggregates. Since, the lowest value of apparent specific gravity for fine aggregates was obtained from the test applied based on AASHTO T 84 standard. But the results are close to the results found for ASTM C128. On the other hand, the highest value of specific gravity was obtained with TS EN 1097-6 standard. Being low of specific gravity values of fine aggregates has meant increasing contribution rate in volume in HMA. The usage of fine aggregates, which have low values of specific gravity, can decrease the air void ratio of mixture.

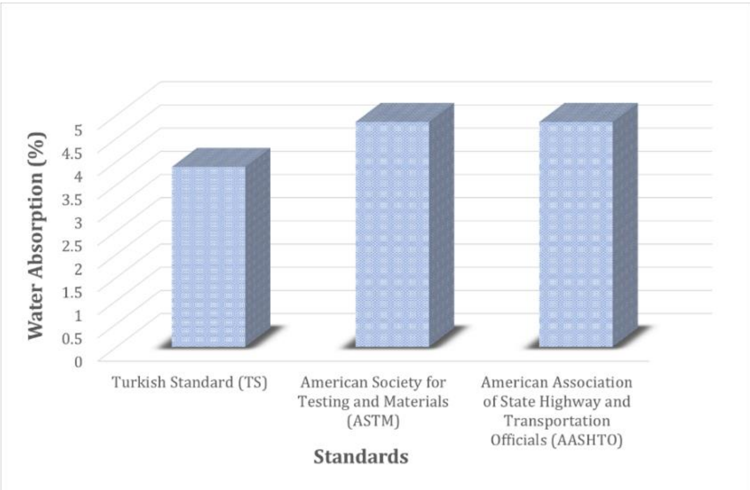

Figure 6. Values of water absorption of fine aggregates

When Fig. 6 is examined water absorption values of fine aggregates have the same value in ASTM and AASHTO standards but this value is lower in TS. Due to the differences between the standards mentioned above, 0.97% difference was observed between TS EN 1097-6 and ASTM C128 in water absorption of fine aggregates. Difference wasn't observed in water absorption values of fine aggregates calculated according to ASTM C128 and AASHTO T84 standards.

The apparent specific gravity value of filler was calculated as 2.625 g/cm^3 by taking into consideration TS EN 1097-7, AASHTO T 84 and ASTM C128 standards. In the optimum bitumen content and strength calculations of all standards, the apparent specific gravity of filler was considered as 2.625 g/cm^3.

3.3. Determination of Optimum Bitumen Content

In order to provide 4% air void criteria of the mixtures prepared by using Superpave volumetric mix design method, bitumen at different contents were added to aggregates and they were mixed until aggregates completely coated. The bitumen contents determined using SG values obtained following the TS EN 1097-6 and TS EN 1097-7 were 4.5%, 5%, 5.5% and 6%. On the other hand, 4%, 4.5%, 5% and 5.5% bitumen content are obtained as using the aggregate SG values found according to AASHTO and ASTM standard methods. Then the mixtures were compacted with the Superpave Gyratory Compactor (SGC) which has a constant speed of 30 revolutions per minute, 0.820 ºC compaction angle and 600 kPa stress using the volumetric mixing method.

The procedure given bellow were followed to analyze the HMA samples:

- The content of bitumen, corresponding to 4% air void, was determined from the air void graph.
- It was checked whether the determined content of bitumen satisfies the conditions of a minimum value of 14% on the VMA graph,
- The bitumen content was checked for the criteria of VFA that is 65-75%. This was done form the VFA/bitumen content graph.
- After all these steps were finished, the optimum bitumen content of mixtures prepared by using the SG values of the aggregates found according to the TS, ASTM and AASHTO Standards were determined.

The above-mentioned steps were implemented for the HMA samples prepared by considering aggregate SG values determined by TS, ASTM and AASHTO standards. The graphs for each case are given in Figure 7-9 and it can be seen the figures that the bitumen contents are determined as 5.03%, 4.75% and 4.59%, respectively in the figures.

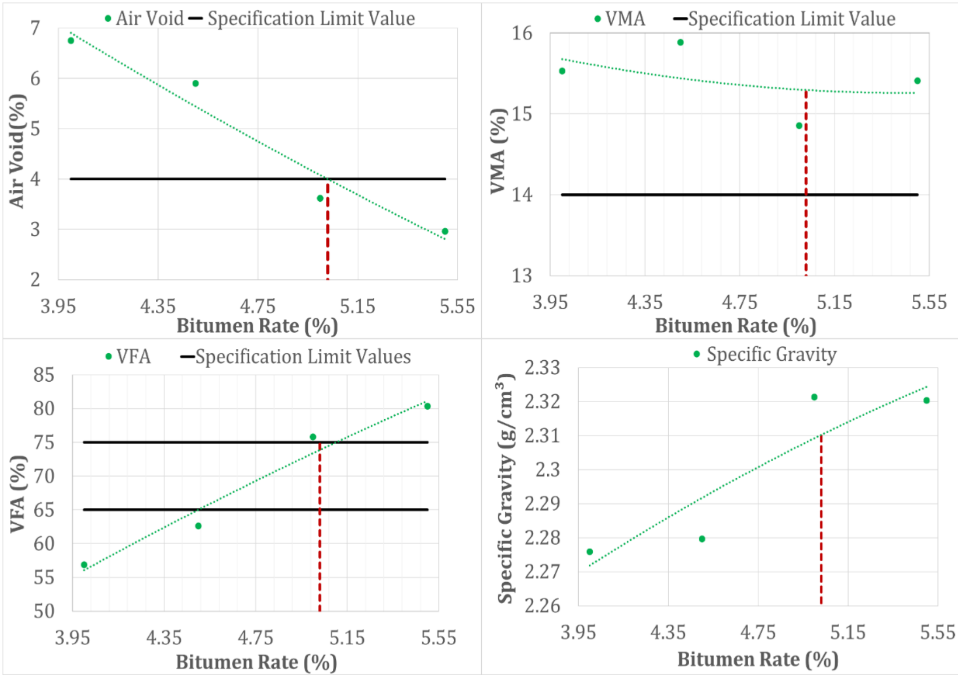

Figure 7. Graphs obtained by using specific gravity values found according to TS standards

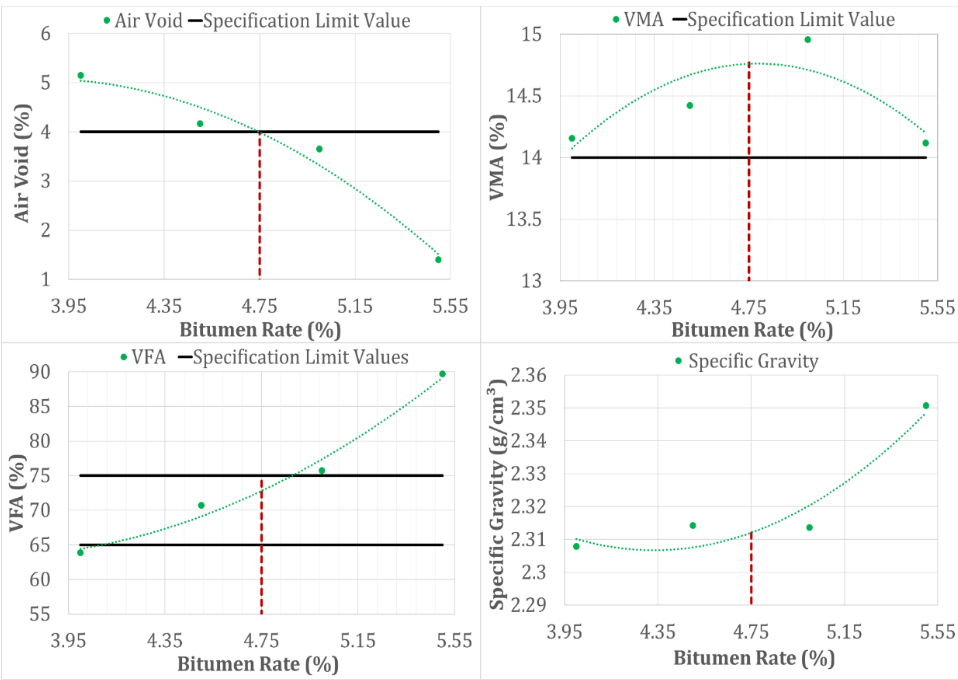

Figure 8. Graphs obtained by using specific gravity values found according to ASTM Standards

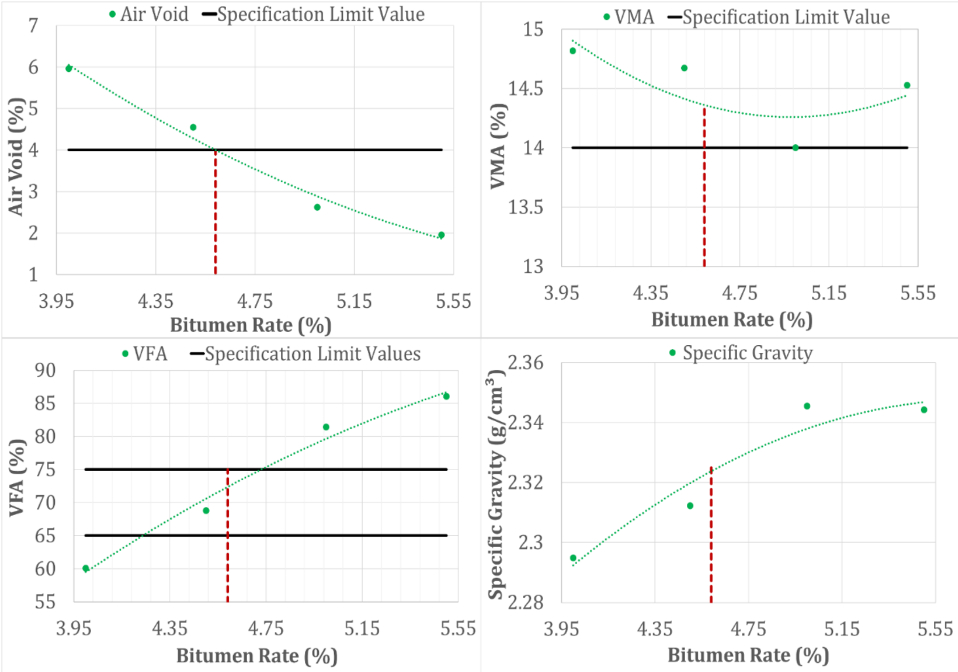

Figure 9. Graphs obtained by using specific gravity values found according to AASHTO Standards

It can be indicated that the highest value of specific bulk gravity for coarse aggregates was found based on AASHTO T 85 standard. The meaning of it is that the volumetric ratio of coarse aggregates in the total volume of hot mix asphalt will decrease. With this decrease, it is expected a decrease in the volume of voids filled among the coarse aggregate grains. The amount of aggregates whose surface will be covered with bitumen will also decrease. In addition, it was seen that the lowest value of specific gravity for fine aggregates was obtained with the AASHTO T 84 standard. Using of fine aggregates with low SG values make an increase in their volume in HMA. Thus, fine aggregates can further fill voids between coarse aggregates. The usage of fine aggregates with low SG values may decrease the air void ratio of mixture. Determining the lowest optimum bitumen content with coarse and fine aggregate SG values found according to the AASHTO Standards has proved all of the mentioned statements. Therefore, it can be said that the usage of coarse and fine aggregate specific gravity values obtained according to the AASHTO standards may be effective in decreasing the optimum bitumen content. Optimum bitumen contents of samples prepared by using aggregates that have SG values which were determined according to TS, ASTM and AASHTO standards are given in Fig. 10. As can be seen from the graph, while the highest optimum bitumen content was obtained by using aggregate specific gravity values determined according to TS standard, the lowest optimum bitumen content was obtained by using aggregate specific gravity values determined according to AASHTO standard.

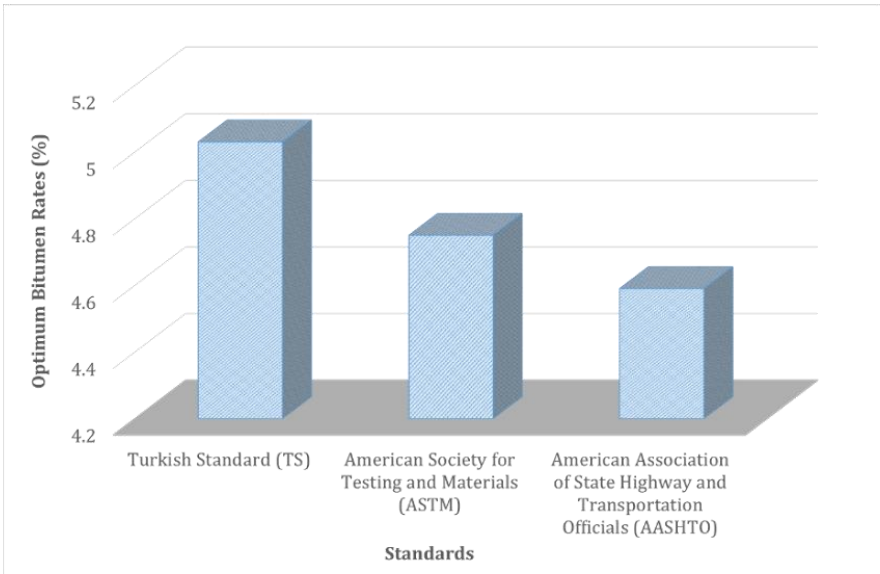

Figure 10. Optimum bitumen contents according to standards

3.4. Cost - Benefit Analysis According to the Optimum Bitumen Content

A cost – benefit analysis was done for 1 km road section which has 8 m width and 5 cm pavement thickness (Table 4). Also, cost of HMA for 1 m3 was calculated. When the optimum bitumen content decreases in 8.8%, the cost for 1 m3 of hot mix asphalt decreases approximately 16.7%. The lower optimum bitumen content provides economic and environmental benefits.

Table 4. Cost – benefit analysis according to optimum bitumen contents

Properties	TS	ASTM	AASHTO
Amount of bituminous binder (g)	60.36	57.00	55.08
Weight of the sample (g)	1260.36	1257	1255.08
Volume of the sample (m^3)	0.0020	0.0020	0.0020
Volume of platform (m^3)	400	400	400
Cost of bituminous binder ($/ton)	290,47	290,47	290,47
Total cost ($/m³)	8,76	8,03	7,3
Total cost (TL/m³)	69,38	63,60	57,82

3.5. Determination of Moisture Sensitivity

So far it was understood that aggregate SG values obtained by using different standards are effective on optimum bitumen content. The content of optimum bitumen is an effective parameter on mixture strength, as well. To investigate the unconditioned and conditioned indirect tensile strengths, 18 HMA samples were prepared with each optimum bitumen content. The test results are given in Figure 11.

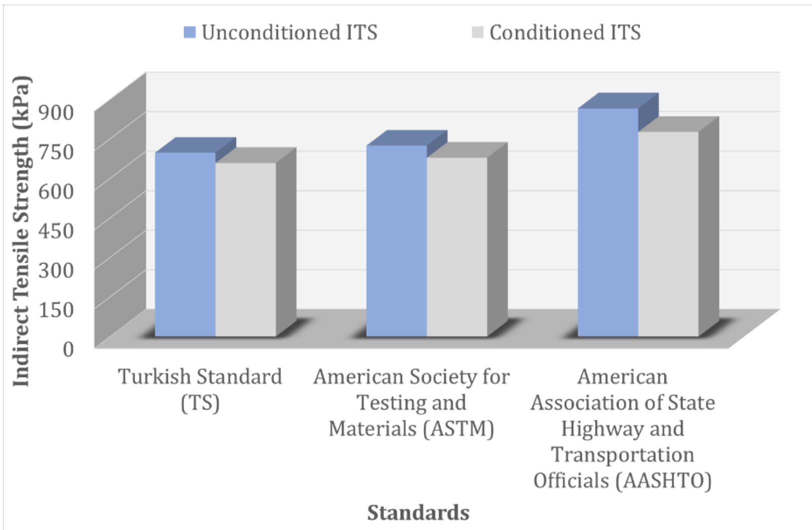

Figure 11. Indirect tensile strengths of samples

It has been observed that the best conditioned and unconditioned strength of bituminous hot mixes calculated using the highest coarse aggregate specific gravity and the lowest fine aggregate specific gravity determined according to AASHTO standard provided. The lowest conditioned and unconditioned strengths of bituminous hot mixes calculated using the lowest coarse aggregate specific gravity and the highest fine aggregate specific gravity determined according to TS standard were obtained.

It can be highlighted from the results presented in Figure 11, the samples prepared with SG value determined according to the AASHTO standards that ensures the lowest optimum bitumen content has the highest unconditioned and conditioned indirect tensile strength among the others. With respect to the results, the tensile strength ratios (TSR) of the samples are calculated and the results given in Figure 12.

As mentioned before that, the tensile rate should be at 80 in percentage. As examining the Figure 12, it can be clearly seen all samples provided the specification limit value. However, the samples prepared with the SG values, which were determined by AASHTO standards, showed the lowest resistance to moisture damage.

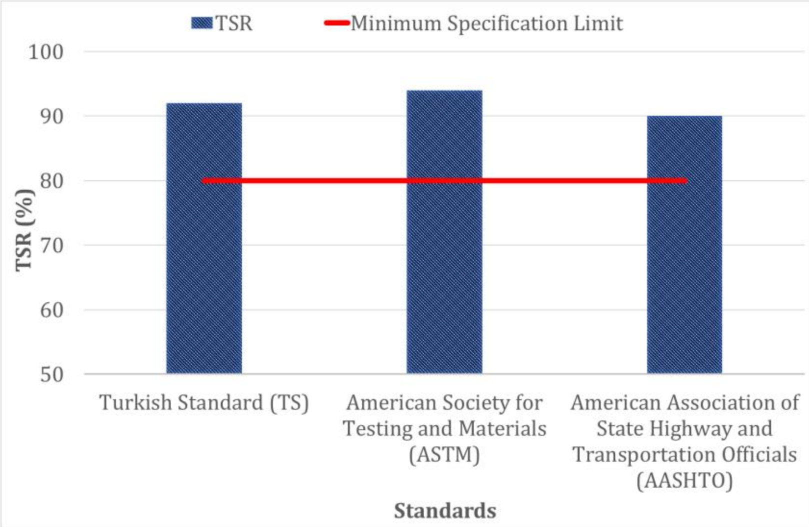

Figure 12. Tensile strength ratios of samples

4. Conclusions and Recommendations

It is known that the differences in the properties of the aggregates and bitumen that formed the hot mix asphalt affect significantly the properties of the hot mix asphalt. Therefore, when the studies in the literature are examined, while the properties of the bitumen are generally evaluated in order to improve the properties of the hot mix asphalt, the properties of aggregates have been examined in a limited number of studies. However, it has not been examined whether there is a difference between different standards used to calculate the specific gravity of the same type of aggregate. In this study, the specific gravity values of one kind of limestone aggregate which have three different sizes (coarse, fine aggregate and filler) were calculated according to TS, ASTM and AASHTO standards. In this study, it has been observed that small differences between the procedure steps of the standards can affect the specific gravity values of limestone aggregates which have three different sizes (coarse, fine aggregate and filler). According to the results, the highest and the lowest values of specific bulk gravity for coarse aggregates were found for the AASHTO T 85 and TS EN 1097-6 standards, respectively. The highest and the lowest values of SG for fine aggregates were found for the TS EN 1097-6 and AASHTO T 84 standards, respectively. The apparent specific gravity value of filler was calculated as 2.625 g/cm^3 according to all three standards. The effect of specific gravity of limestone aggregates on the optimum bitumen content, tensile strength and tensile strength ratio of hot mix asphalt was investigated. The optimum bitumen contents of the hot mix asphalts prepared using the aggregate specific gravity values calculated according to TS, ASTM and AASHTO standards were found to be 5.03%, 4.75% and 4.59%, respectively. Analysis based on SG values of aggregates that can be unique for each type of aggregates might be an alternative method for determination of optimum bitumen content in HMA. According to the cost – benefit analysis performed depending on the optimum bitumen content, it has been thought that the determination of bitumen content based on SG values can provide significant economic benefits. Thanks to this study, it has been determined that the specific gravity values of the aggregates used in hot mix asphalts are effective on the optimum bitumen content, indirect tensile strength and moisture sensitivity. In addition to this, specific gravity values of different types of aggregates can be calculated and the effects of them on mixture design can be examined.

Conflict of Interest

No conflict of interest was declared by the authors.

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