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SUPERPAVE VOLUMETRIC MIX DESIGN OF HOT MIX ASPHALT: CASE STUDY OF ISPARTA

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Keywords

Superpave, Volumetric mix design, Dense grade, Indirect tensile strength, Moisture susceptibility.

Abstract

Nowadays, Superpave volumetric mix design which is novel method for design of hot mix asphalt attracts the researchers. In the study, Superpave volumetric mix design procedure is examined. The procedure was employed for a case study of Isparta. The optimum binder content was determined through Superpave Gyratory Compactor. As a result, moisture susceptibility of hot mix asphalt was determined and 80% limit value is provided.

BİTÜMLÜ SICAK KARIŞIMIN SUPERPAVE HACİMSEL KARIŞIM TASARIMI: ISPARTA ÖRNEĞİ

Anahtar Kelimeler

Superpave, Hacimsel karışım tasarımı, Yoğun gradasyon, İndirekt çekme mukavemeti, Nem hassasiyeti.

Öz

Günümüzde, bitümlü sıcak karışımların tasarımında yeni bir metot olan Superpave hacimsel karışım tasarımı araştırmacıların ilgisini çekmektedir. Bu çalışmada, Superpave hacimsel karışım tasarımı incelenmiştir. Tasarım Isparta örneği için ele alınmış ve optimum bağlayıcı miktarı Superpave Yoğurmalı Sıkıştırıcı yardımıyla belirlenmiştir. Sonuç olarak, nem hassasiyeti belirlenmiş ve %80 sınır değeri sağlanmıştır.

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1. Introduction

Bitumen's importance is indisputable in the road construction material as a binder. The type of bitumen is selected according to the penetration or viscosity values. According to this value, bitumen is grouped as high and low viscosity. It is recommended to use high viscosity bitumen in hot climate region and low viscous bitumen in cold climate region (Brown et al., 2001; Hassan et al., 2008).

Penetration, Viscosity and Performance Grading are three principal value in asphalt binder grading system (Robert et al., 2002; Fourbia & Awbi, 2004). Penetration values of the bitumen are obtained according to ASTM D5 (2013). A needle with a standard mass of 100 g is released on a bitumen at 25^{0}C for 5 seconds. The sinking part of the needle determines the penetration value of the bitumen. But, because of the viscoelastic behaviour, bitumen can react differently at high or low temperature than the temperature that has been determined as 25^{0}C. Therefore, it makes more sense to group the bitumen

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according to climate conditions of the construction area instead of constant temperature (Ahmedzade et al., 2008).

Compaction procedure of Marshall Test Method is far away from compaction that occurs during highway construction on the field. According to Marshall Test Method, each specimen is compacted with 75 blows each side. However, for the compaction on the field, road rollers are used. Actually, the compaction procedure is not blowing the pavement like hammers. The rollers which have been used at low speed are compacting the pavement by driving on it. To get results which are close to reality, the compaction on the field should be simulated in the laboratory.

Another problem with Marshall Test Method is producing the specimens without losing much time. However, on the field, more time is needed for heating the binder, mixing with aggregates, loading to trucks, transporting to the construction area, paving on the ground and compacting it to the sufficient level. During this time, binder ageing occurs because of the contact with oxygen. The ageing that occurs while mixing, transporting and constructing is neglected in Marshall Test Method. Instead of neglecting it, the ageing by heating the binder and mixing with aggregates at high temperatures, by contacting oxygen during transportation, paving and compacting should be taken into account which is called short-term ageing. Of course, the traffic load and weather conditions that cause the long- term ageing should be also taken into account. (Lu & Isacsson, 2002; Ouyang et al., 2006; Zhanga et al., 2011).

The listed problems above lead to the needing for a more realistic design method. The Strategic Highway Research Program (SHRP) was focused on the new mix design between 1987 and 1993 (Kennedy et al., 1994; Ahmedzade et al., 2008). After five years of work, they present Superior Performing Asphalt Pavement (Superpave) mix design. In this study, Superpave volumetric mix design is examined and the case study of Isparta is conducted. For this aim, step by step Superpave volumetric mix design procedure is described.

2. Selection of Binder Performance Grade

The Performance Grade (PG) system is the method of categorizing an asphalt binder used in asphalt pavement relative to its rated performance at different temperatures. It was originally developed during the Strategic Highway Research Program (SHRP) in the early 1990's and was called "SuperPave™".

Optimum material selection is the key for the performance. The binders are selected using the performance-based Binder Specification (D'Angelo, 2001).

Performance grade (PG) selection in Superpave volumetric mix design is based on climate data, traffic volume and the average speed of the vehicles. Thus, asphalt binder grades are specified primarily with respect to pavement temperatures which allows one binder to be selected for a specified design combination of high and low temperatures. The loading condition related to high-temperature performance is a vehicle speed of 100 kilometres per hour and a traffic volume of less than 107 equivalent single axle loads (ESALs) (Cominsky et al., 1994).

It is necessary to determine the pavement temperature to select the PG. First of all, the air temperature data for the last twenty years is needed. From the last twenty years' data, every year's hottest seven days are determined and the average value per year is calculated. With the help of the average high temperature, pavement temperature can be calculated by the following Equation 1.

$$T_{20mm} = \begin{bmatrix} \begin{pmatrix} T_{air} - 0{,}00618Lat^2 \\ +0{,}2289Lat + 42{,}2 \end{pmatrix} \\ * (0{,}9545) - 17{,}78 \end{bmatrix} \quad (1)$$

Where; T_20mm is the pavement temperature at 20 mm below the surface (^{0}C), T_air is the air temperature (^{0}C), Lat is the Latitude of the section (degree) (Patrick, 2003; Gui-ping & Wing-gun, 2007; Khan et al., 2013; Garber & Lester, 2014). After twenty years' high-temperature data, the lowest temperature value per year is determined (FHWA, 1999). After obtaining high and low-temperature data, Figure 1 can be drawn.

Figure 1 has been drawn by using the normal distribution. Last twenty years daily high and low-temperature data from Isparta used to obtain Figure 1. Isparta is a small city in western Turkey (Figure 2). Isparta's summers are dry and hot while winters are cold and snowy. The altitude of Isparta is ~1040 m. Annual precipitation is 545.4 mm. The average temperature of Isparta is 12.2^{0}C (GDM, 2016).

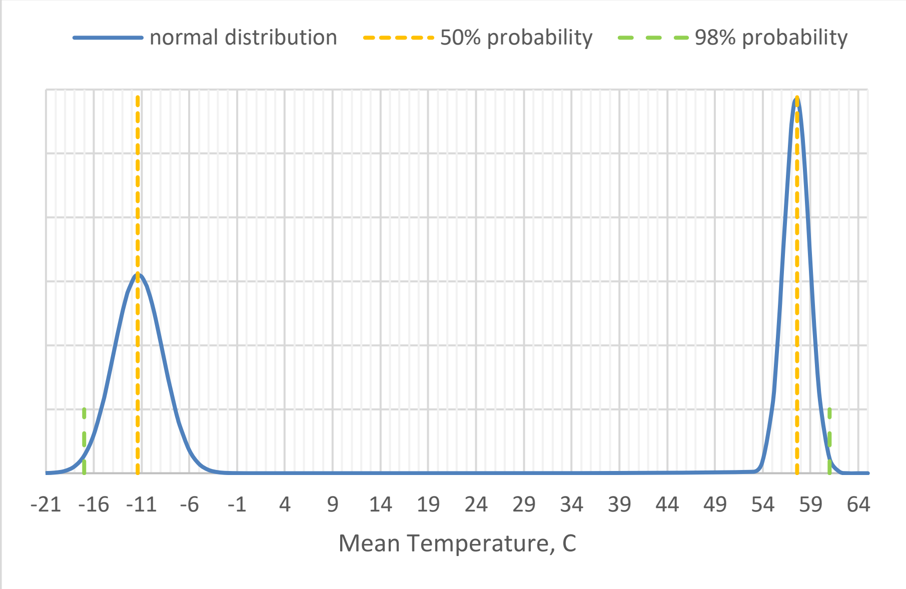


Figure 1. Normal distribution of high and low-temperature data for the last twenty years.

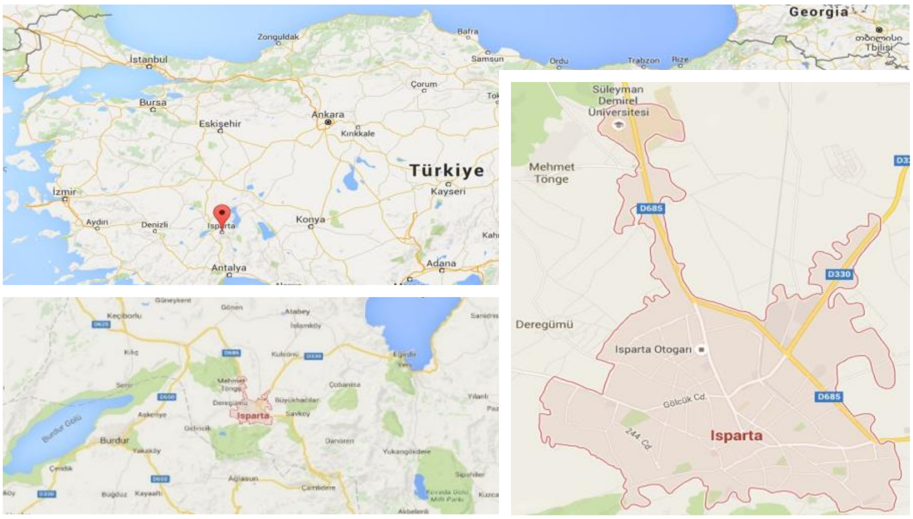


Figure 2. Location of Isparta city

Table 1. LTPP and SHRP Reliability

Algorithm	**50% Reliability**				**98% Reliability**			
	T_{max}	T_{20mm}	T_{min}	T_{20mm}	T_{max}	T_{20mm}	T_{min}	T_{20mm}
SHRP	35	57	-11	-8	39	60	-16	-13
LTPP	35	57	-11	-8	39	61	-17	-8

The peak points of Figure 1 show the temperature value which can be passed with 50% probability. It means, if the highest temperature value is selected as 57.6^{0}C, there is a 50% chance to get higher temperature values throughout the life of the highway. This changing ratio is relatively high. But, if the highest temperature value is selected as 61^{0}C, the change to get higher temperature values throughout the life of the highway increases to 98%. By this point, the designer should make a rational decision regarding the range of Figure 1. So, 61^{0}C for the highest temperature and -17^{0}C for the coldest temperature is selected according to last twenty years' temperature data.

When the hottest and the coldest temperature values with 98% reliability are obtained, the preliminary selection of the PG is performed according to AASHTO MP1. If the 98% reliability didn't match the AASHTO MP1 values, the nearest upper value is selected.

According to the LTPP, the highest temperature at 50% reliability is 57 ^{0}C and lowest temperature is -8 ^{0}C. Binder performance grade is PG 58-16 at this reliability. The highest temperature at 98% reliability for the same algorithm is 61 ^{0}C and lowest temperature is -16 ^{0}C so that the binder performance grade is chosen as PG 64-22 (Table 1).

Next, after the preliminary selection is made, the designer must also consider traffic volume and the traffic speed. High traffic volume affects the binder, as hot climate condition. Therefore, Superpave suggests one grade increase in the high temperature for more than 10*106 ESALs while requires one grade increase for over 30*106 ESALs. Also, slow traffic speed affects pavement condition, as high traffic volume. Immobile or slow-moving vehicles which causes deformation at this point affect the pavement longer. When this is taken into consideration, Superpave suggests one grade increase for slow-moving traffic (20 – 70 km/h) and two grades for immobile traffic (<20 km/h). The designer should decide the high-temperature grade, both for traffic volume and for traffic speed (FHWA, 2001).

When the high-temperature grade is raised a grade, the binder stiffness will almost double. For example, a PG 58 binder is two times stiffer than a PG 52 binder at a temperature of 52°C. Additionally, a PG 70 binder is eight times stiffer than a PG 52 binder at a temperature of 52°C. Also, traffic speed effects binder stiffness (FHWA, 2001).

3. Selection of Aggregate Gradation

In the selection of the aggregate must be considered many factors: climate, traffic, availability, cost, skid resistance, moisture sensitivity, local experience etc. (Hicks, 1991; Epps et al., 2000; Hicks et al., 2004).

The gradation chart powered 0.45 is used by Superpave for determining allowed gradation. Percent passing is on the horizontal axis of the chart. The vertical axis is upraised to the 0.45 power. For instance, the 3.12 units is indicated the 12.5 mm sieve marking to the origin's right, the unit, 3.12, is the size of the sieve, 12.5 mm, upraised to 0.45 power (Al-Khateeb et al., 2012).

The maximum density gradation is an important property of this chart. By the origin of the maximum aggregate size, gradation is drawn as a linear line. Standard ASTM sieves set and the description in connection with aggregate size is used by Superpave (Roberts et al., 1996; Anonymous, 2001). Largest sieve size which is used for the gradation is called maximum sieve size, and one sieve size larger is the nominal maximum size. (Bahia et al., 1998; Faheem & Bahia, 2005).

The gradation that the aggregate particles suited altogether in their densest feasible layout are the maximum density gradation. However, there are very small aggregate voids which decreases the asphalt film thickness around the aggregates. (Dessouky et al., 2004).

A restricted zone and control points are plotted to the chart powered 0.45 for identifying aggregate gradation. Control points are emplaced on the nominal maximum size that is interim size of aggregate which is 2.36 mm and the size of dust which is 0.075 mm (AASHTO, 2002).

Along the maximum density, gradation is fitted the restricted zone between the interim size and the 0.3 mm size. It set ups a strip where gradations should not go through. It gets hard to compact during construction and propose decreased resistance to permanent deformation throughout its performance life. By achieving mix shear strength, gradations disrupting the restricted zone may possess weak aggregate skeletons depending so many on asphalt binder stiffness. These mixes can simply become plastic and are also very tender to binder content.

It is recommended that mixes should be graded beneath the restricted zone. It is recommended that, as traffic level rises, gradations act closer to the coarse control points, too.

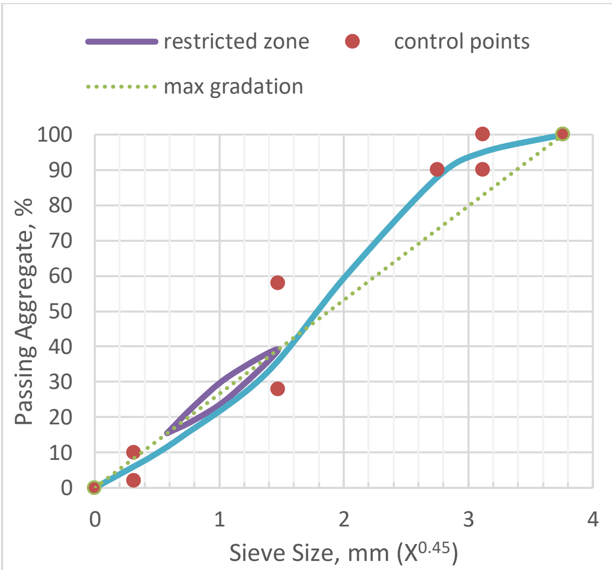


Figure 3. Passing aggregates gradation.

Example gradation for this state of the art is given the Table 2 below.

Table 2. Selected gradations for mixes.

Passing %	Weight g	Sieve No	Sieve Size (mm)
100		3/4"	19
95	60	1/2"	12,5
88	84	3/8"	9,5
60	336	4	4,75

32	336	10	2
14	216	40	0,425
9	60	80	0,18
5	48	200	0,075
	60	Mineral Dust	

4. Determining the Optimum Binder Content

Design aggregate structure selection is depending on identifying predicted optimum binder content and preparing test samples by utilizing three alternative aggregate gradations. For continuous purification, the gradation which closest to the given requirement is selected. By preparing samples with the chosen aggregate gradation and using a series of binder contents this requirement is ensured. Giving an air void content of 4% at design gyrations and ensuring the specification values for Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA) and specific gravity is the design binder content (Cominsky et al., 1998; AASHTO, 2000; Hossain & Chen, 2002). The compacted specimen should provide a tensile strength ratio of minimum 80% according to AASHTO T 283.

The first step is determining the traffic load for the 20 years regardless of actual roadway design life. When the traffic load is determined the number of gyrations is selected according to the Table 3.

Table 3. A number of gyration for Ninitial, Ndesign, Nmax (AASHTO, 2000).

20-yr Traffic Loading	Number of Gyrations		
(10^6 ESALs)	$N_{initial}$	N_{design}	N_{max}
<0.3	6	50	75
0.3 to 3	7	75	115
3 to 30	8	100	160
≥ 30	9	125	205

The traffic load for Isparta more than 30*106 ESALs for the 20 years. Ndesign is selected as 125 gyrations (AI-Khateeb et al., 2002; Cooley et al., 2007). When the gyration number is selected, specimens with four different binder contents (4.5%, 5%, 5,5% and 6%) is prepared. All of them have been compacted with the Ndesign gyration numbers. After the compaction, the air void contents, VMA contents, VFA contents and specific gravity values are calculated according to Equations.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) * 100 \quad (2)$$

$$G_{mb} = \frac{w_D}{W_{SSD} - W_{sub}} \quad (3)$$

$$G_{mm} = \frac{W_{agg} + W_b}{V_{eff} + V_b} \quad (4)$$

$$V_{eff} = V_{agg} - V_{BA} \quad (5)$$

Where; V_a is the air void content (%),G_{mb} is bulk specific gravity (g/cm^3), G_{mm} is the maximum theoretical specific gravity (g/cm^3), w_D is the dry weight (g), W_{SSD} is the saturated surface dry weight (g), W_{sub} is the weight submerged in water (g), W_{agg} is the weight of aggregate (g), W_b is the weight of binder (g), V_{eff} is the effective volume of aggregate (cm^3). V_b is the volume of binder (cm^3), V_{agg} is the volume of aggregate (cm^3) and V_{BA} is the volume of absorbed asphalt (cm^3) (Vavrik & Carpenter, 1998; Tam, 2005).

When the air voids are calculated the corresponding VMA and VFA values are calculated with the Equations 6 and 7.

$$VMA = 100 - \left[\frac{(G_{mb} * P_s)}{G_{sb}}\right] \quad (6)$$

$$VFA = VMA - P_a \quad (7)$$

Where; VMA is the voids in mineral aggregate (%),P_s is the aggregate content by weight of mix (%),G_{sb} is the bulk specific gravity of the aggregate (g/cm^3)), VFA is the voids filled with asphalt (%) and P_a is the percent of air voids (%) (Christensen & Bonaquist, 2005; DeVol et al., 2007). Calculated VMA and VFA values are checked from the Table 4.

For a 12.5-mm mixture, the minimum VMA value is 14%. VFA values depend on traffic level—at higher traffic levels, the permissible range for VFA in the Superpave system is 65 to 75%. Figure 4 is drawn when all the four specimen's Air Void, VMA, VFA and specific gravity values are calculated. A best-fit curve through data points is drawn. From the drawn curve the binder content corresponding to 4% air void is selected as optimum binder content and check if the other requirements are met.

According to the test results, the optimum binder content is 5,125% by weight (Figure 4). When the optimum binder content is determined a specimen with this binder content should be prepared and compacted with Nmax. After compaction, the air void has to be more than 2%. At last the binder content should ensure the dust to binder rate which is 0.6 – 1.2. Dust to binder rate is calculated as follow (Gogula et al., 2003).

$$R_{db} = \frac{P_{dust}}{P_b} \quad (8)$$

Where; R_{db} is the dust to binder ratio (%),P_{dust} is the percentage of dust in the mixture (%) and P_b is the percentage of binder (%).

5. Testing the Moisture Susceptibility

AASHTO T283 (2011) test procedure is used to obtain the Indirect Tensile (IDT) strength. Firstly, six mixtures for optimum binder content are prepared as will have 101,6 mm diameter. The mixtures are compacted with 75 blows for each side. Compacted specimens are left to cool down for 24 hours. Then the specimens are pulled out from the mould and placed in an oven at 40^{0}C. Specimens are cured in that oven for 72 hours. Then the specimens are taken out from the oven and waited till they cool down to 25^{0}C (Hamzah et al., 2011). After the specimens are cooled down, half of the specimens are loaded with the rate of 50,8mm/min till failure. The max load values are recorded as IDTdry (unconditioned) strengths (Buchanan et al., 2004). The remaining specimens are placed in a water bath at 25^{0}C for 24 hours. After 24 hours, the specimens are getting out from the water bath and vacuum saturated till the specimens' saturation level is between 60 – 80% (Scherocman et al., 1986; Gordon & Young-Kyu, 2002; Buchanan et al., 2004). The saturation level is calculated by Equation 9.

$$SL = \frac{(m_{Surf.Dry} - m_a)}{(V_a * V_s)} * 10000 \quad (9)$$

$$V_a = \frac{(G_{max} - G_{bulk})}{G_{max}} \quad (10)$$

$$V_s = m_{Surf.Dry} - m_w \quad (11)$$

$$G_{bulk} = \frac{m_a}{V_s} \quad (12)$$

Table 4. Minimum VMA requirements and VFA range requirements.

20-yr Traffic Loading	Minimum VMA (%)					VFA Range
(10^6 ESALs)	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm	(%)
<0.3						70 – 80
0.3 to 3	15	14	13	12	11	65 – 78
≥ 3						65 – 75

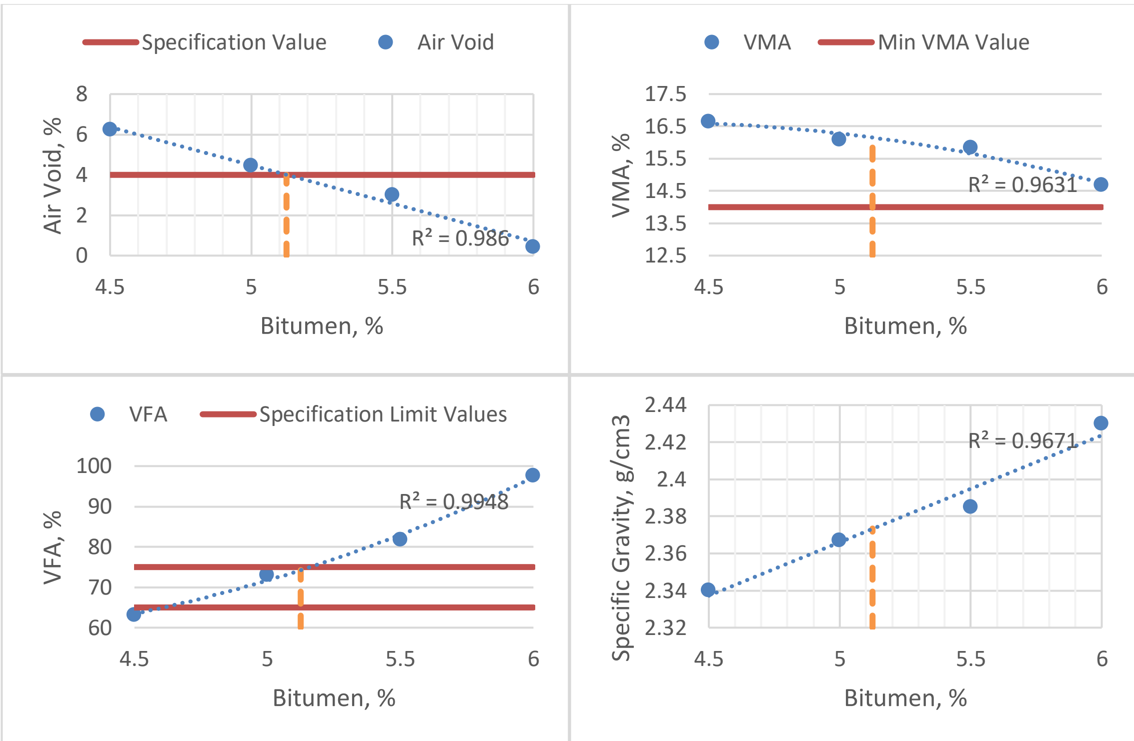


Figure 4. Selection of optimum asphalt binder content

Where SL is saturation level (%),$m_{Surf.Dry}$ is saturated surface dry weight (g), m_a is weight in air (g), V_a is air voids (%), V_s is volume of the specimen, G_{max} is theoretical gravity, G_{bulk} is bulk specific gravity and m_w is the weight of the specimen in water.

When the specimens reached the saturation level, they are put into freeze cabin at -18^{0}C for 16 hours. After

16 hours, they are put into a water bath at 60^0C for 24 hours. Finally, they are put into a 25^0C water bath for 2 hours (Lottman, 1979; Lottman, 1982). After 2 hours, they are loaded at a load speed as 50,8mm/min. The failure load values are recorded as IDTwet (conditioned) strengths. The IDT strength is calculated by Equation 13. The ratio of the wet specimen strength to dry specimen strength is Tensile Strength Ratio (TSR) (Equation 14). TSR is used to determine the moisture susceptibility (Choubane et al., 2000). A minimum TSR value of 80% is recommended (McGennis et al., 1996; Pan & White, 1999; Khosla et al., 2000; GDH, 2013; Sarsam & Alwan, 2014).

$$IDT = \frac{2P}{\pi dh} \quad (13)$$

$$TSR = \frac{IDT_{wet}}{IDT_{dry}} * 100 \quad (14)$$

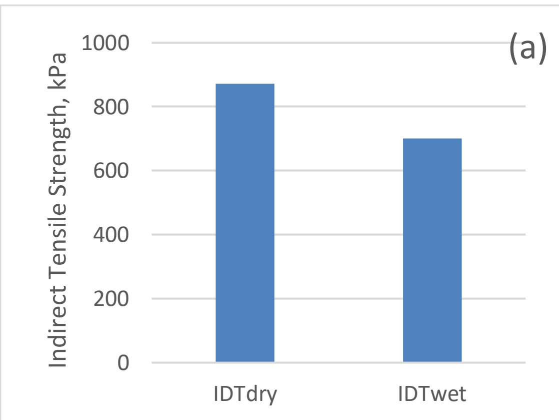
Where IDT is the indirect tensile strength, P is the max load, d is the diameter of the specimens, h is the height of the specimens.

IDT_{wet} is the average strength value of the conditioned specimens and IDT_{dry} is the average strength value of the unconditioned specimens.

6. Moisture Susceptibility results for HMA

Hot Mix Asphalt (HMA) samples are prepared according to Superpave™ mix design. Tensile Strength Ratio (TSR) is obtained from Indirect Tensile Strength test (Modified Lottman Test-AASHTO T283). According to these test results, the moisture susceptibility of asphalt mixtures is examined.

Figure 5 (a) shows the Indirect Tensile (IDT) Strength of HMA mixtures. IDTdry values are increasing and HMA mixture shows higher strength. Indirect Tensile Strength of HMA mixture is improved. The high-performance HMA mixtures are obtained by Superpave mix design.



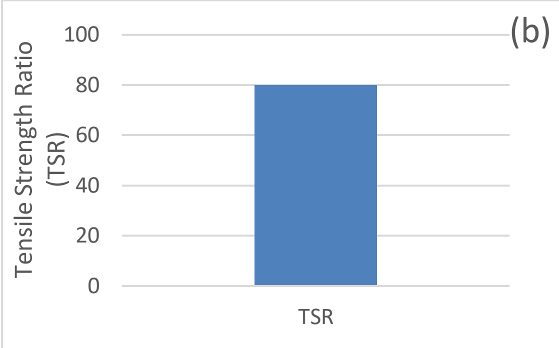


Figure 5 (a) IDTdry and IDTwet values (b) Tensile Strength Ratio of HMA Mixtures

7. Conclusion

The objective of the research, described in this paper, was to create a better understanding of Volumetric Mix Design with Superpave Gyratory Compactor and conduct an example for Isparta region. In this state, the different binder rates and aggregate gradations are prepared and the optimum binder content with the aggregate gradation is obtained. Specimens compacted with SGC are tested according to AASHTO T 283 procedure to determine the IDT strengths and moisture susceptibility.

Binders used in Marshall Stability test procedure are categorized according to the penetration values. But, because of the viscoelastic behaviour, the binder can react differently on high or low temperature than determined at 25^0C. Therefore, it makes more sense to group the binder according to climate conditions of the construction area instead of constant temperature values. Binder used in the Volumetric Mix Design is graded according to performance. Suitable PG is selected according to temperature data which obtained from the climate of the construction region.

Laboratory compaction procedure of Marshall Test Method is far away from compaction that occurs during highway construction on the field. Each specimen is compacted with 75 blows each side. However, for the compaction on the field, road rollers are used. Actually, the compaction procedure is not blowing the pavement like hammers. The rollers which have been used at low speed are compacting the pavement by driving on it. To get results which are close to reality, the compaction on the field should be simulated in the laboratory. Therefore, SGC is more realistic equipment than Marshall Compactor.

Binder ageing occurs because of the contact with oxygen. The ageing that occurs while mixing, transporting and constructing is neglected in Marshall Test Method. Instead of neglecting it, the ageing by heating the binder and mixing with aggregates at high temperatures, by contacting oxygen during transportation, paving and compacting should be taken into account which is called short-term ageing. Of course, the traffic load and weather conditions that cause the long- term ageing should be also taken into account.

According to results for Isparta, Performance Grade is chosen PG64-22. The minimum criteria for tensile strength ratio is 80.0% is ensured for Isparta.

Conflict of Interest

No conflict of interest was declared by the authors.

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