Investigation of Relationship Between Water Absorption and Compaction Level of Asphalt Pavements for Field Verification

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Saha Doğrulaması İçin Asfalt Kaplamaların Su Emme ve Sıkışma Düzeyleri Arasındaki İlişkinin İncelenmesi

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Özet

Çevresel koşullara ve trafiğe dayanıklı bir asfalt betonu kaplama yapımında, karışımın doğru şekilde tasarlanması ve serme işlemlerinden sonra uygun ekipmanlarla sıkıştırılması zorunludur. Bitmiş bir kaplamada hava boşluğu miktarı ve boyutları belirli bir limitin üzerindeyse ve özellikle boşluklar birbirine bağlıysa, hava ve su girişi kaplamanın hizmet ömrünü özellikle ıslanma-kuruma ve donma-çözülme etkileri nedeniyle olumsuz etkileyebilmektedir. Bu nedenle, bitmiş bir kaplamada sıkışma düzeyinin belirli bir limit içerisinde kalması çeşitli şartnamelerce şart koşulmaktadır. Sahadaki minimum yığın yoğunluğu, tipik olarak laboratuvarda sıkıştırılmış yığın yoğunluğunun %96 ila %100'ü arasında değişmektedir. Ayrıca, Türkiye karayolu inşaatlarında amir bir şartname olan KTŞ 2013'e göre, bir günlük imalattan alınmış 10-15 cm çapındaki karot numunelerinin ortalama yoğunluğu, işyeri karışım yoğunluğunun %98'inden, tekil yoğunluğu ise %96'sından aşağı olmamalıdır. Geçirimli boşluklar nedeniyle kaplamaya sızan ve ıslanma-kuruma ve donma-çözülme çevriminde kaplamaya zarar verecek olan su miktarına ise bir sınırlandırma getirilmemiştir. Buna karşın, AASHTO T 283'e uygun olacak şekilde hazırlanan numunelerin, sudan kaynaklanan bozulmalara karşı direncin tespitinde, İndirekt Çekme Mukavemeti (İÇM) deneyi uygulanmaktadır. Fakat bu deney oldukça teferruatlı bir deney olduğu için icra edilmesi her proje, laboratuvar ve profesyonel düzeyinde mümkün olamamaktadır. Bu çalışmada, Kocaeli Büyükşehir Belediyesi sorumluluğunda bulunan asfalt yol ağından, Bitümlü Temel, Binder ve Aşınma tipi karot örnekler alınarak, sıkışma düzeyi ve su emme oranlarının belirlendiği bir kalite kontrol data setinden faydalanılmıştır. Doğrusal regresyon analizine göre, toplamda 1460 adet karotun deney sonuçlarının kullanıldığı çalışmada, deney setinin %79'unda sıkışma düzeyi açısından %96 ve daha yüksek bir seviye elde edilmiştir. Şartname kriterlerini sağlayan bu grup için kütlece su emme oranı %1 olarak tespit edilmiş olup, ilgili değerin kalite güvence sisteminde bir limit değer olarak kullanılmasının ıslanma-kuruma ve donma-çözülme çevrimlerinde kaplamada oluşacak olan hasarları en aza indirgemesi konusunda faydalı olacağı tavsiye edilmiştir.

Anahtar Kelimeler: Asfalt Karot, Sıkışma Seviyesi, Su Emme, Saha Doğrulaması

Investigation of Relationship Between Water Absorption and Compaction Level of Asphalt Pavements for Field Verification

Abstract

In order to build an asphalt concrete pavement resistant to environmental conditions and traffic, it is imperative that the mixture is designed correctly and compacted with appropriate equipment after laying operations. If the air voids distribution and dimensions in a finished pavement are above a certain limit, and especially if the air voids are interconnected, air and water intrusion may adversely affect the service life of the pavement, especially due to wet-dry and freeze-thaw cycle effects. Therefore, it is stipulated by various specifications that the level of compaction in a finished pavement should not exceed a certain limit. Minimum bulk density in the field typically ranges from 96% to 100% of compacted bulk density in the laboratory. In addition, according to KTS 2013, which is a main specification for highway constructions in Turkey, the average density of the core samples with a diameter of 10-15 cm taken from the field one day after its construction should not be less than 98% of the laboratory mix density and the single density should not be less than 96%. There is no limitation on the level of water that leaks into the pavement due to permeable voids and is likely to damage the pavement during the wet-dry and freeze-thaw cycles. On the other hand, Indirect Tensile Strength (ITS) test is applied to determine the resistance of the samples prepared in accordance with AASHTO T 283 against moisture-induced damage. However, since this experiment is a very detailed one, it cannot be performed at every project, laboratory and professional level. In this study, a quality control data set was used to determine the compaction level and water absorption rates by taking Bituminous Base Course (BBC), Binder Course (BC) and Wearing Course (WC) type core samples from the asphalt road network under the responsibility of Kocaeli Metropolitan Municipality. According to the linear regression analysis, by an experimental set in which the test results of a total of 1460 cores were used, a compacted level of 96% or higher was obtained in 79% of the set. For this group that meets the specification criteria, the water absorption rate by mass has been determined as 1% and it has been suggested that using this value as a threshold in the quality assurance system may be beneficial in minimizing possible damage to the pavement during wet-dry and freeze-thaw cycles.

Keywords: Asphalt Cores, Compaction Level, Water Absorption, Field Verification

1. INTRODUCTION

Turkey is one of the countries where asphalt roads are used relatively more than other pavements. Hot-Mix Asphalt (HMA) is densely graded mixes with coarse, fine and mineral fillers. HMA is produced in the plant and is paved and compacted with a multi-layered form. The pavement, which is expected to meet axle loads, should provide minimum properties such as friction, surface smoothness, noise control, rutting resistance, impermeability and adequate drainage. Mixing proportion is made according to Marshall Design. The purpose of the Marshall Design method is to determine rutting and fatigue resistance, low temperature crack resistance, moisture resistance, shear resistance and workability properties in order to correlate laboratory results with field performance (Asphalt Institute, MS-2, 2014). These criteria should be considered during laboratory mix design. Other design methods, such as Superpave, are not yet widely used due to their high demand for material properties that require additional investment of time and money.

The quality control processes of the compacted pavement on asphalt roads in Turkey are carried out according to HTS 2013. Bulk density of the pavement is determined by the cores taken from the marked locations by Technical Audit Engineer. Cores are taken as at least one pair from every 250 tons of production, or at least one pair every day in shorter sections made without connection with each other. Average bulk density of the cores with a diameter of 10-15 cm taken from daily construction should not be less than 98% of the laboratory mix density. In addition, core densities should be no less than 96% of the laboratory mix density for Binder Course and Bituminous Base Course and no less than 97% for Wearing Course. If the compaction level cannot be achieved, the reasons should be investigated and the sections where the compaction level is insufficient should be excavated and reconstructed. Also, no section of the road should have more than 100% compaction level. The limit for layer thickness is determined by the maximum aggregate size in the mixture. To this end, the layer thickness, which is paved and compacted at once, should not be less than 1.5 times and more than 3 times of the maximum aggregate size. In addition, the thickness tolerance of the layer is allowed to deviate up to 10% of the project thickness (HTS 2013). There is no limitation on the amount of water that leaks into the pavement due to permeable voids and is likely to damage the layer during the wet-dry and freeze-thawing cycles. On the other hand, Indirect Tensile Strength (ITS) test is applied to determine the resistance of the samples prepared in accordance with AASHTO T 283 against deterioration caused by water. However, since this test is a very detailed experiment, it cannot be performed at every project, laboratory and professional levels. In this study, a quality control data set was used to determine the relationship between compaction level and water absorption rates by taking cores (Bituminous Base Course (BBC), Binder Course (BC) and Wearing Course (WC)) from the asphalt road network under the responsibility of Kocaeli Metropolitan Municipality.

2. MATERIALS AND METHODS

2.1. Mixture Design and Field Application

Within the scope of the study, AC 50/70 bitumen was procured from the Turkish Petroleum Refineries Corporation (TUPRAS), Körfez Refinery and the physical properties of the bitumen are given in Table 1. Aggregate obtained from the Körfez-Hereke limestone quarry was used and the physical properties of the mineral limestone aggregate are given in Table 2. In the laboratory, asphalt mixture design was made according to the Marshall procedure in accordance with ASTM D6927, and then field application was made. A flow-chart of the Quality Assurance System referenced in asphalt road construction is given in Figure 1 and an activity checklist is given in Table 3.

Table 1. Physical properties of bitumen (AC 50/70)

TEST	STANDARD	RESULTS
Penetration (0.1mm), 100 g, 5 s	TS EN 1426	54
Softening point (°C)	TS EN 1427	52
Specific gravity (g/cm^3)	TS 1087	1.034

Table 2. Physical properties of limestone aggregate

TEST	**STANDARD**	**RESULTS**		
		Coarse Aggregate	**Fine Aggregate**	**Filler**
L.A. abrasion (%)	TS EN 1097-2	22	--	--
Magnesium sulfate test (%)	TS EN 1367-2	1	--	--
Crushed value (%)	—	100	--	--
Flatness Index (%)	BS 812	19.5	--	--
Nicholson stripping test (%)	KTS 2013 Appendix-A	55	--	--
Plasticity Index (PI)	TS 1900	--	NP	NP
Specific gravity (g/cm^3)	TS EN 1097-6	2.723	2.721	2.696
Water absorption (%)	TS EN 1097-6	0.617	0.41	--

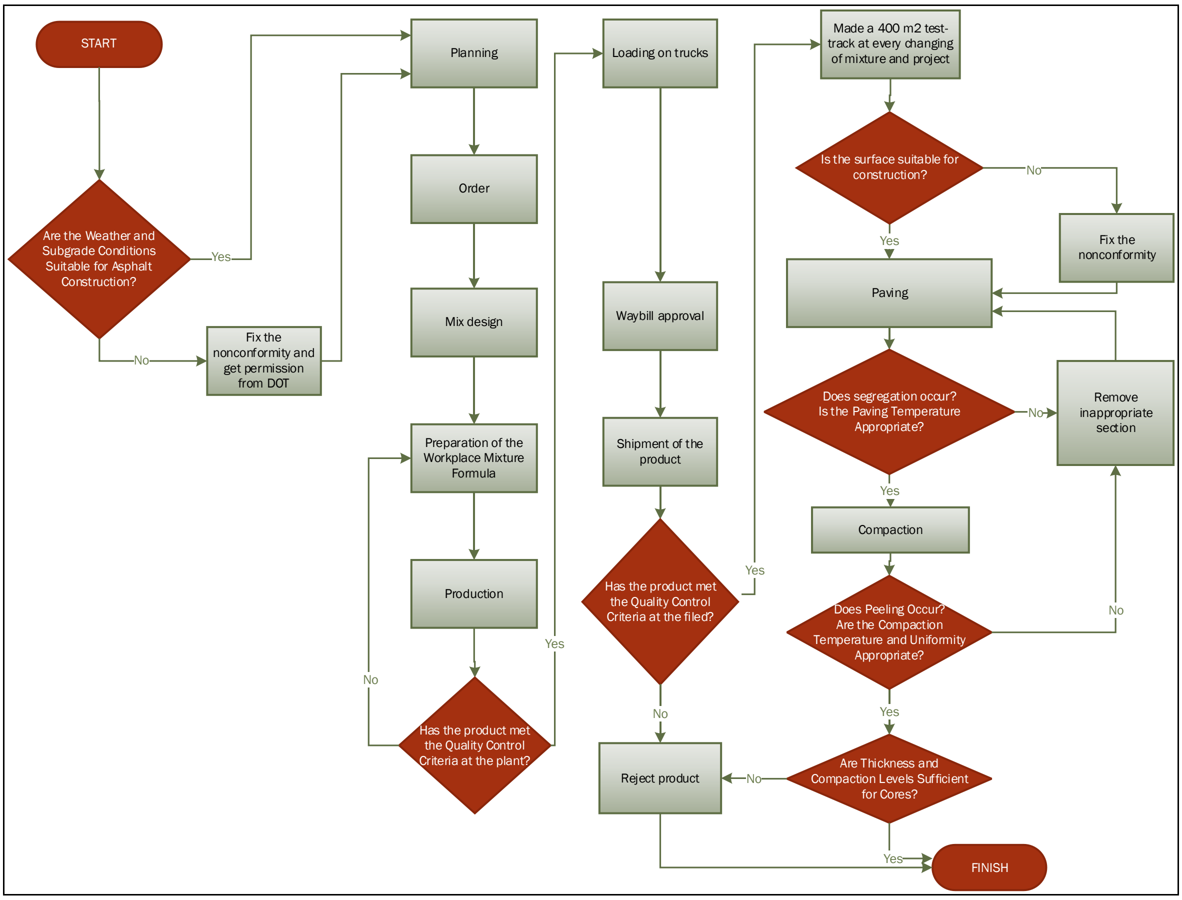


Figure 1. Reference flow-chart for asphalt road construction (Abut, 2018)

Table 3. Reference checklist for asphalt road construction (Abut, 2018)

No.	**Processes**	**Yes & No**
1	Have necessary security measures been taken?	
2	Is the mix design report appropriate?	
3	Is the Workplace Mixture Formula (WMF) appropriate?	
4	Is asphalt produced using at least three different aggregate fractions?	
5	Is the aggregate used in the mix design for asphalt production?	
6	Is the declared aggregate used in the mix design for asphalt production?	
7	Has a test track of 400 m^2 been done?	
8	Does the information on the delivery note meet the material specifications required in the project?	
9	Are the air temperature and subgrade conditions suitable for asphalt construction?	
10	If the weather is not suitable, has "THE APPROVAL LETTER" been received from the Administration for asphalt construction?	
11	Does segregation occur while the HMA is being paved?	
12	Are there any uncommon materials in the mixture?	
13	The temperature of the production leaving the plant should be between 140-155 °C. Is the temperature recorded?	
14	The temperature of the mixture in the paver should not be less than 135 °C. Is the temperature recorded?	
15	The temperature of the mixture should not be below 130 °C when the rolling is started. Is the temperature recorded?	
16	Rolling should be completed before the temperature of the mixture drops below 80 °C. Is the temperature recorded?	
17	Is the product consistently produced homogeneously?	
18	Does the transportation of the product comply with the specification?	
19	Is paving done with a paver?	
20	Are paving & compaction equipment, tools, workers and foremen sufficient for the project?	
21	Does the layer paved on it meet the necessary conditions? Is the geometry and compaction level sufficient?	
22	Does the prime coat comply with the specification?	
23	Does the tack coat comply with the specification?	
24	Is the plant capacity sufficient to ensure regular production?	
25	If the granular layer is the PMB (Plant-Mix Base), has it been compacted with compactors or rollers so that there is no loose aggregate and a smooth surface?	
26	Is the compaction process done from low to high elevation?	

27	Is the compaction process done from the inside of the curve to the outside?	
28	Are the geodesy activities suitable for paving & compaction process?	
29	Did the laboratory staff take enough HMA samples?	
30	Has the compaction test been applied to the PMB (Plant-Mix Base), and is it level enough?	
31	Is the surface unevenness of the compacted asphalt suitable?	
32	Are the cylindrical samples (cores) taken from the compacted layer?	
33	Does the thickness of the cores meet the specification tolerance limits?	
34	Does the compaction level of the cores meet the specification tolerance limits?	
35	Have the necessary safety measures been taken to prevent vehicles from passing through the fresh pavement?	
36	After the last rolling, no traffic should pass over the pavement until the surface temperature reaches the ambient temperature. Is it provided?	

2.2. Field Verification

A quality control data set (1460 cores) was used to determine the compaction level and water absorption rates by taking core samples (Bituminous Base Course (BBC), Binder Course (BC) and Wearing Course (WC)) from the asphalt road network under the responsibility of Kocaeli Metropolitan Municipality. A spreadsheet of the dataset is shown in Figure 2. Bulk density tests were applied to the core samples taken from the field in this data set in accordance with ASTM D 2726 (Figure 3). Percent of Bulk Density is expressed as the percentage of the densities of the cores taken from the field and the Marshall briquette produced in the laboratory, as shown in Equation 1.

$$Percent\ of\ Bulk\ Density = \frac{In-Place\ Density\ x\ 100}{Laboratory\ Bulk\ Density} \quad (1)$$

1460

	A	B	C	D	E	F	G	H	I	J	K	L
1	YEARS	LAB NO	CORE TYPE	THICKNESS (mm)	Mass of the dry specimen in air (g)	Mass of the specimen in water (g)	Mass of the saturated surface-dry specimen in air (g)	Laboratory Bulk Density (g/cm3)	Mass of the water (g)	In-Place Density (g/cm3)	COMPACTION LEVEL (%)	WATER ABSORBTION (%)
2	2007	2	WEARING COARSE	41.5	673.0	386.0	677.5	2.505	4.50	2.309	92.2	0.67
3	2007	2	WEARING COARSE	62.5	1092.0	638.0	1094.5	2.505	2.50	2.392	95.5	0.23
4	2007	2	WEARING COARSE	53.0	924.0	540.0	926.5	2.505	2.50	2.391	95.4	0.27
5	2007	3	WEARING COARSE	83.3	1450.0	836.5	1451.0	2.424	1.00	2.360	97.3	0.07
6	2007	3	WEARING COARSE	61.5	1031.5	583.0	1037.0	2.424	5.50	2.272	93.7	0.53
7	2007	3	WEARING COARSE	57.9	983.0	561.5	984.5	2.424	1.50	2.324	95.9	0.15
8	2007	4	WEARING COARSE	77.6	1281.0	723.5	1285.5	2.452	4.50	2.279	93.0	0.35
9	2007	4	WEARING COARSE	56.3	926.0	526.0	931.5	2.452	5.50	2.284	93.1	0.59
10	2007	5	WEARING COARSE	83.3	1449.0	831.0	1449.5	2.470	0.50	2.343	94.8	0.03
11	2007	5	WEARING COARSE	63.2	972.5	558.5	978.5	2.470	6.00	2.315	93.7	0.62
12	2007	5	WEARING COARSE	74.2	1253.0	704.5	1259.0	2.470	6.00	2.260	91.5	0.48
13	2007	6	WEARING COARSE	51.1	931.5	533.5	940.5	2.323	9.00	2.289	98.5	0.97
14	2007	6	WEARING COARSE	64.8	1065.5	614.0	1072.5	2.323	7.00	2.324	100.0	0.66
15	2007	6	WEARING COARSE	50.1	788.0	458.5	800.0	2.323	12.00	2.307	99.3	1.52
16	2007	7	BINDER COARSE	82.0	1417.5	839.0	1420.5	2.474	3.00	2.438	98.5	0.21
17	2007	7	BINDER COARSE	82.4	1425.5	837.5	1428.5	2.474	3.00	2.412	97.5	0.21
18	2007	7	BINDER COARSE	108.0	1820.5	1070.5	1844.0	2.474	23.50	2.354	95.1	1.29
19	2007	8	BINDER COARSE	54.1	913.0	527.5	916.0	2.437	3.00	2.350	96.4	0.33

... 2007 2008 2009 2010 2011 2013 2014 2015 2016 2017 2018 2019 TC ...

Figure 2. The spreadsheet for cores used in field verification

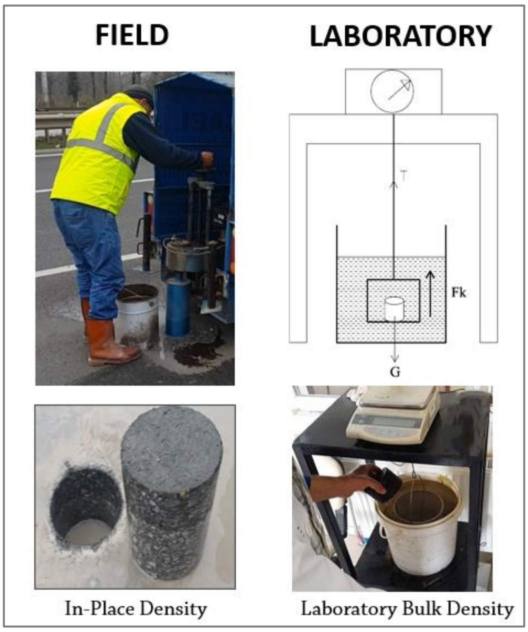
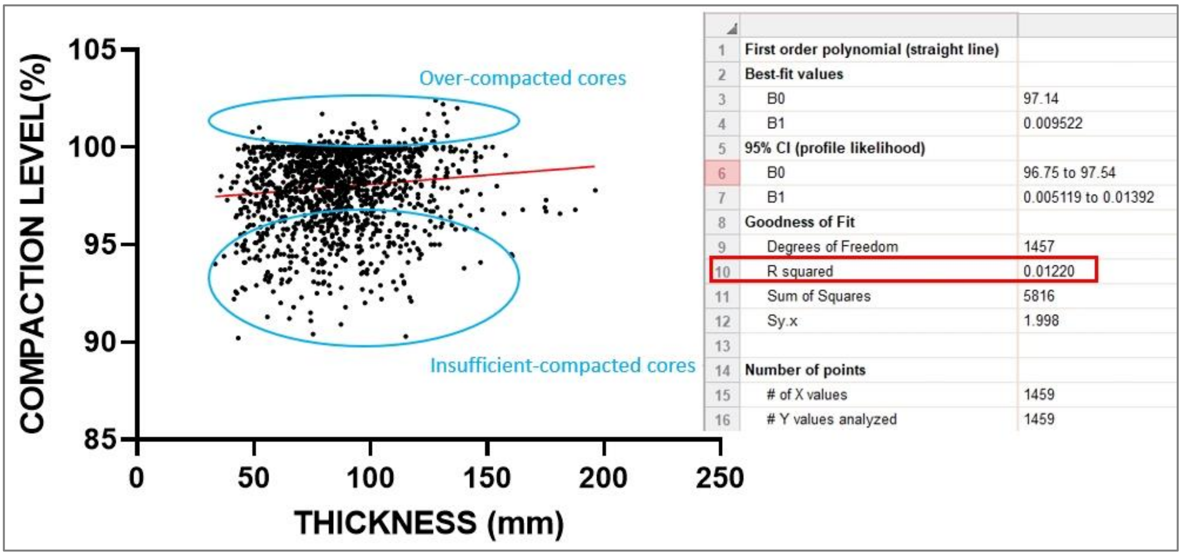


Figure 3. Comparison of field and laboratory densities (Abut, 2018)

3. RESULTS AND DISCUSSION

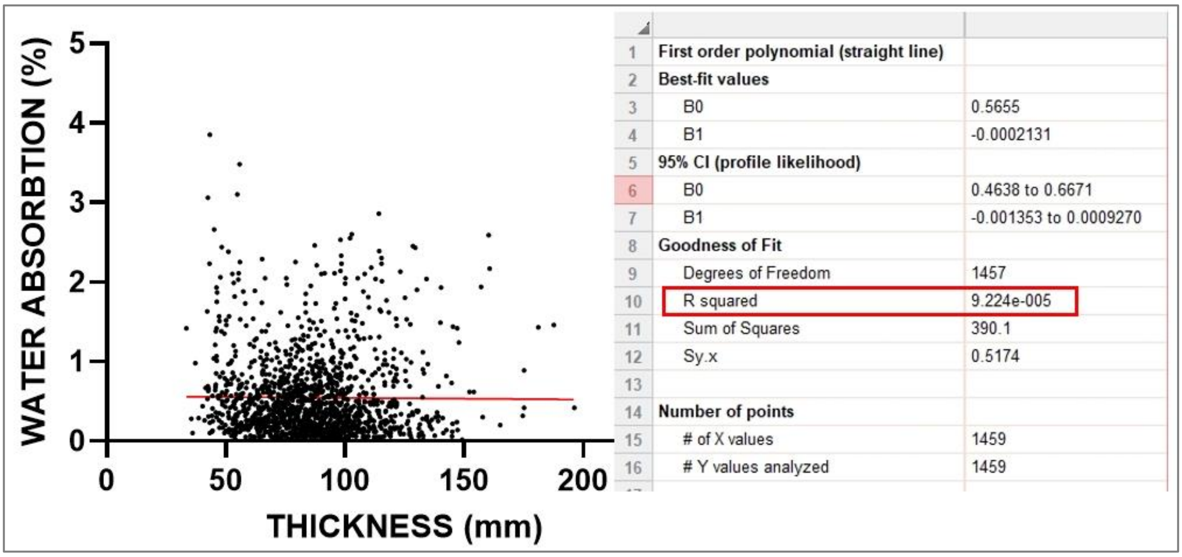
The following results were obtained according to the regression analysis;

- It has been determined that the values in the blue circle shown as over-compacted and insufficiently compacted cores do not meet the specification limits (Figure 4). Root cause analysis of such deficiencies should be done with the control forms and charts of the quality assurance system given in Figure 1 and Table 3. As the pavement thickness increases, better results can be obtained for the compaction level results, and although there is a trend, it can be said that this relationship is not very significant (Figure 4, R^2=0.01).
- Figure 5 shows the relationship between pavement thickness and water absorption. Thick or thin pavement did not have any effect on the water absorption rate. It can be said that water absorption varies depending on other effects (temperature, roller types, number of rollers passes, slope, early traffic opening, etc.) independent of the pavement thickness.
- Figure 6 shows the relationship between compaction level and water absorption. According to the linear regression analysis, by an experimental set in which the test results of a total of 1460 cores were used, compacted level of 96% or higher was obtained in 79% of the set (R^2=0.40). For this group that meets the specification criteria, the water absorption rate by mass has been determined as 1% and it has been suggested that using this value as a threshold in the quality assurance system may be beneficial in minimizing possible damage to the pavement during wet-dry and freeze-thaw cycles.



1	First order polynomial (straight line)	
2	Best-fit values	
3	B0	97.14
4	B1	0.009522
5	95% CI (profile likelihood)	
6	B0	96.75 to 97.54
7	B1	0.005119 to 0.01392
8	Goodness of Fit	
9	Degrees of Freedom	1457
10	R squared	0.01220
11	Sum of Squares	5816
12	Sy.x	1.998
13		
14	Number of points	
15	# of X values	1459
16	# Y values analyzed	1459

Figure 4. Variation of Pavement Thickness and Compaction Level



1	First order polynomial (straight line)	
2	Best-fit values	
3	B0	0.5655
4	B1	-0.0002131
5	95% CI (profile likelihood)	
6	B0	0.4638 to 0.6671
7	B1	-0.001353 to 0.0009270
8	Goodness of Fit	
9	Degrees of Freedom	1457
10	R squared	9.224e-005
11	Sum of Squares	390.1
12	Sy.x	0.5174
13		
14	Number of points	
15	# of X values	1459
16	# Y values analyzed	1459

Figure 5. Variation of Pavement Thickness and Water Absorption

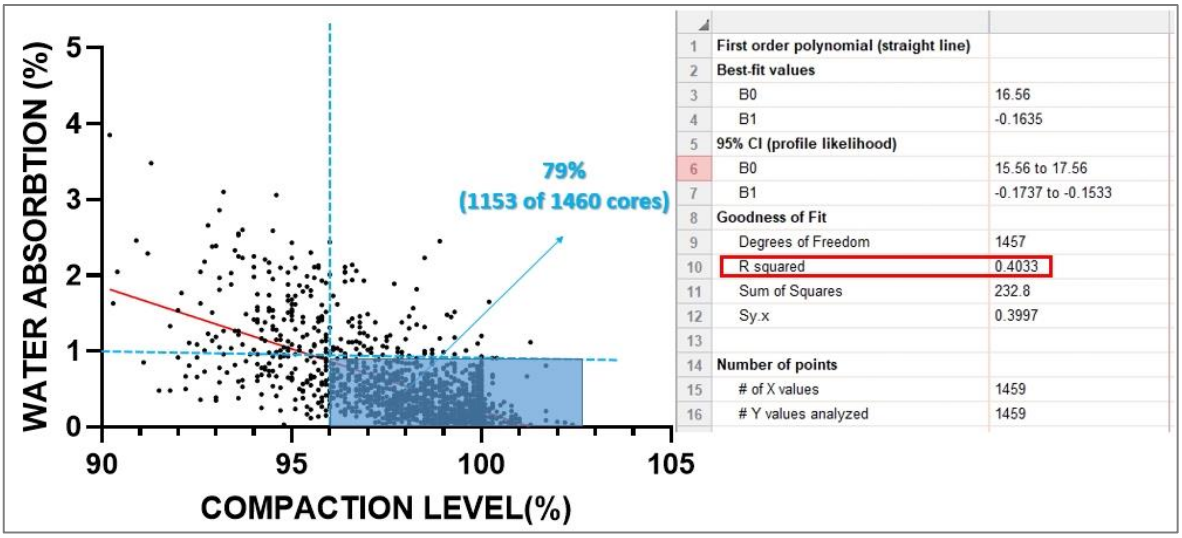


Figure 6. Variation of Compaction Level and Water Absorption

CONCLUSION

Turkey is one of the countries where asphalt roads are used relatively more than other pavements. The quality control processes of the compacted pavement on asphalt roads in Turkey are carried out according to HTS 2013. Average bulk density of the cores with a diameter of 10-15 cm taken from daily construction should not be less than 98% of the laboratory mix density. In addition, core densities should be no less than 96% of the laboratory mix density for Binder Course and Bituminous Base Course and no less than 97% for Wearing Course. There is no limitation on the amount of water that leaks into the pavement due to permeable voids and is likely to damage the pavement during the wet-dry and freeze-thaw cycles. With this work, the water absorption rate by mass has been determined as 1% and it has been suggested that using this value as a threshold in the quality assurance system may be beneficial in minimizing possible damage to the pavement during wet-dry and freeze-thaw cycles.

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