Monitoring The Condition of Surfacing Seals With Nondestructive Tests at Field

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ABSTRACT

Surfacing seal is an asphalt pavement type preferred because of its simplicity of application and economic viability. It enables waterproof surfaces for sub-layers and creates smooth and high skid resistance for vehicles. Therefore, surfacing seals constructed on unbound base are widely used such as New Zealand, Australia and South Africa. However the performance of surfacing seals can be affected by a number of factors. If these factors are not considered, they will need to be reconstructed after a very short period. In this study, performances of surfacing seals under heavy traffic were observed for 2 years, and routine tests were performed to determine the surfacing seal's performance in relation to traffic and climate and to determine the kind of deteriorations which occurred. In this study variety of test such as sand-patch, British pendulum, density measurement with electromagnetic method, measuring surface temperature with thermal camera, light weight deflectometer, dynamic cone penetration test and layer thickness measurement were performed with ground penetrating radar technique. The results of the study show that loss of macro texture, and raveling and flushing are the most common types of deterioration especially at road sections with longitudinal slope. Furthermore, skid numbers decrease during the rainy seasons when the bearing capacity of layers also decreases, the trend of raveling deterioration decreases at roads with high traffic volume and average maximum surface temperature. However, it was determined that trend of flushing deterioration increase.

Keywords: Chip seals, Performance testing, Surface dressing

1. INTRODUCTION

Approximately 80 % of the highway network of Turkey is consists of chip sealed road pavement, and some route's annual daily traffic volume is higher than 2000000 (number of equivalent axle load). These types of pavement are expecte volumes according to theTurkish Highway Technical Specification. However, Turkey has a chip sealed road pavement that is served at high traffic condition. The performance of chip sealed road pavement is affected by factors such as design, quality of construction, higher traffic volume, duration of load, condition of drainage, climate, rehabilitation policy and methods, materials and construction techniques [1-8].

Various types of deterioration in chip sealed pavement can cause a decrease in pavement performance over time. Gransbe and James (2005), Karaşahin and Gürer (2007) stated that measurement and identification of performance in chip sealed pavement is more difficult to assess than other types of pavement. According to Gransberg and James (2005), chip seal performance is primarily either measured quantitatively through engineering principles or rated qualitativel through expert visual assessment. Except for measuring skid resistance, quantitative chip seal performance measuremen are limited in North America, but quantitative performance measures are widespread in some countries such as Australia, New Zealand, South Africa, and the United Kingdom. Skid resistance and macro texture are the only quantitative performance parameters in chip seals. Banihatti [9] reported that the service life and field performance of chip seals are related to the adhesion between the binder and the aggregate. Vonk and Korenstra [10] pointed out the importance of the binder performance with respect to chip seal's performance and showed that bitumen with modified SBS (styrene–butadiene–styrene) demonstrated superior performance in chip seal applications. Gransberg and Zaman [11] identified the elements of design and construction as acting positively and negatively on performance based on chip seal's field performance. A comparative analysis was performed on chip sealed pavement in the TDOT Atlanta district. Chip seals constructed using emulsion exhibit better performance than chip seals constructed using penetration grade bitumen.

For this aim, sand-patch, British pendulum, measuring density with electromagnetic method were conducted 2 years along under the traffic and the test result were assessed which factors was effective on the performance of chip seals was determined.

2. MATERIALS AND METHODS

2.1 Materials

Lorem This study was performed in 6 different chip sealed test road in 4 different district of General Directorate of Turkey (TCK). The properties and traffic survey results of test roads are given in Table 1 and 2 respectively. The locations of the test roads are shown in Figure 1.

Table 1: The properties of the test roads

Properties	**Test Roads**					
Route	Didim-Söke	Kadınhanı-Ilgın	Konya-Karapınar	Beynam-Bala	Kalecik-Çankırı	Kalkan-Fethiye
Road Code	**I_1**	**K_1**	**K_2**	**AN_1**	**AN_2**	**A_1**
Start Date of Opening the Traffic	July 2008	June 2008	June 2008	July 2008	July 2008	June 2008
Test Length (m)	1200	1500	1500	1800	1600	1000
Traffic Direction	Single	Single	Single	Single	Single	Single
Type of Binder ; Addition % (A)	100/160;Yes	160/220;Yes	160/220;Yes	100/150;Yes	100/150;Yes	100/150;Yes
Type of Aggregate	Limestone	Limestone	Limestone	Basalt with Andesite	Limestone	Limestone
Shoulder	Exist	Exist	Exist	Exist	Exist	Exist
Prime Coat Layer	Exist	Exist	Exist	Exist	Exist	Exist
Aggregate Diameter (mm)	12.5	12.5	12.5	19.0	12.5	12.5

***A:** Antistripping agents.

Table 2: Traffics survey results of the test roads

Location	Year of Surveying	Automobile	Light Truck	Bus	Truck	TIR	AADT
Didim-Söke (I_1)	2008	6057	691	239	1032	314	**8333**
	2009	7301	730	252	930	253	**9466**
Kadınhanı-Ilgın (K_1)	2008	9322	339	333	1945	715	**12654**
	2009	3959	299	296	1890	1164	**7608**
Konya-Karapınar (K_2)	2008	2531	217	174	1777	586	**5285**
	2009	3596	358	277	1226	834	**6191**
Beynam-Bala (AN1)	2008	1536	178	28	508	230	**2480**
	2009	1333	170	19	377	301	**2200**
Kalecik-Çankırı (AN2)	2008	2374	222	119	458	91	**3264**
	2009	2713	235	123	531	111	**3713**
Kalkan-Fethiye (A1)	2008	1506	164	11	230	33	**1944**
	2009	5629	770	71	724	127	**7321**

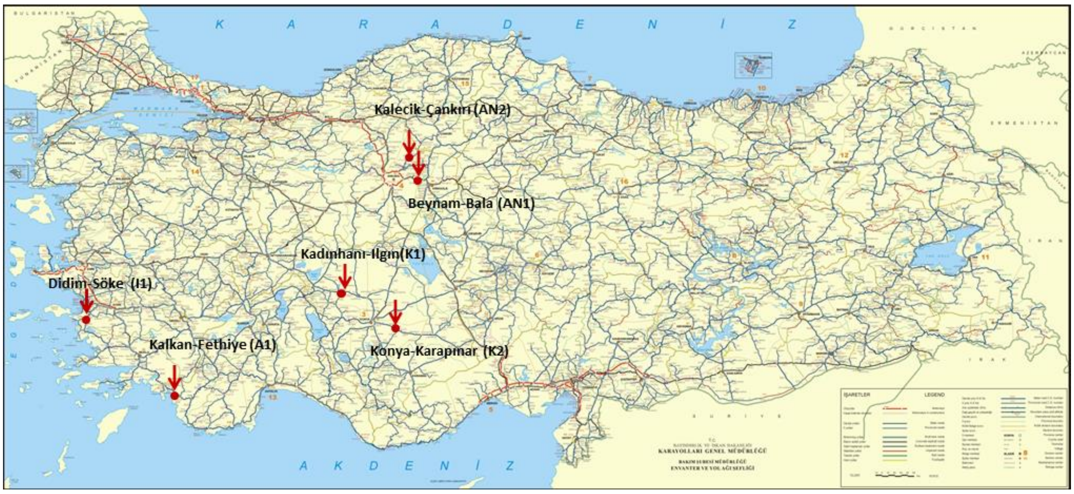

Figure 1: Location map of the test roads

2.2 Methods

After the test roads opened to traffic, variations of performance were determined over two years with nondestructive tests and visual inspections performed at 4 different periods. In addition, laboratory tests were performed on aggregate and bitumen samples taken in field. Field tests were performed on 4 different points of the right lane of the test roads. These are Shoulder (B), right wheel path (1), interval of the wheel path (2), left wheel path (3) respectively. A Schematic plan of the nondestructive test points is given in Figure 2.

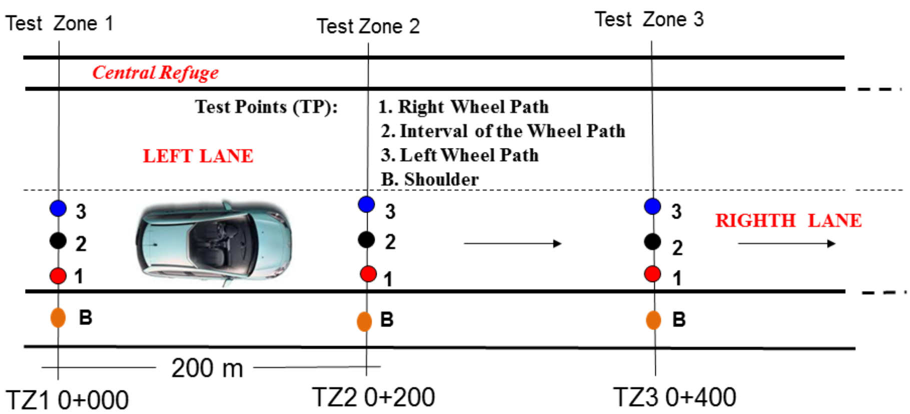

Figure 2: Schematic plan of the non-destructive test points

Sand-patch tests (ASTM E 965-96) and electromagnetic density measurements (ASTM D 7113-05) were performed in order to determine macro texture loss. Also light weight deflectometer (LWD) (ASTM D 4694-96) and dynamic cone penetrometer (DCP) (ASTM E 0303-93R03) tests were performed to find the bearing capacity change of sub layers of the test roads. British Pendulum test (ASTM D 6951-03) was performed in order to determine skid numbers of the test roads. A deterioration index was made according to the results of tests and inspections given detail at reference [28]. The values of their indexes were correlated with traffic, climate and some structural properties.

3. TEST RESULTS

3.1. Deterioration Indexes Changings

The general ravelling and flushing indexes of tests roads were calculated and the comparative results of the test roads are shown in Figure 3. Test and visual investigation results show that the K2 test road was in the poorest condition. Alternately the I1 test road was in the best condition in respect to general deterioration index.

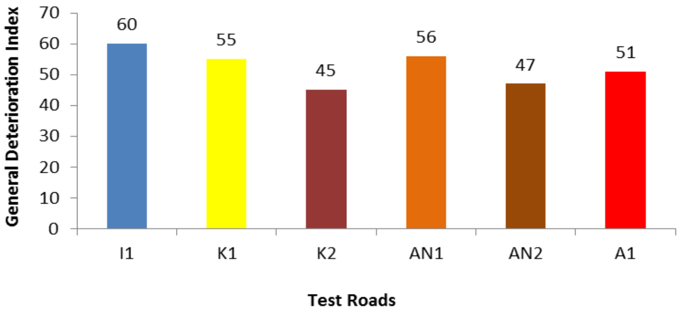

Figure 3: Test roads general deterioration indexes

In the general deterioration index, all stated types of deterioration were evaluated together. After researchers reached a conclusion about the final structural condition of the test roads. Deterioration types used to develop the general deterioration index are as follow: Potholes, ravelling, loss of texture, flushing, polishing, rutting and settlements. Ravelling is one of the most common deterioration types in chip sealed road pavements. Test roads were examined with respect to ravelling deterioration and the general ravelling deterioration index was created. The general ravelling index results showed that the AN1 test road which used volcanic aggregates was in the worst condition (Figure 6).

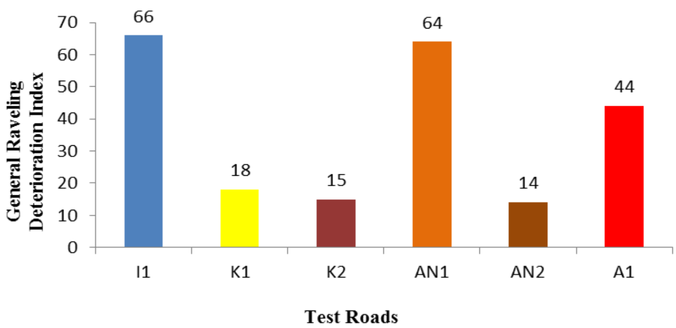

Figure 4: Test roads general ravelling deterioration indexes

Given this conclusion, the high silica aggregates content in AN1 could have an important effect on ravelling deteriorations. Previous studies show that chip seals with high content of silica aggregates are more prone to corruption due to stripping and ravelling [8, 9].

Another crucial deterioration type is flushing. Test roads general flushing deterioration index values are shown in Figure 5. Flushing deterioration is higher on the K1, K2 and AN2 test roads than the others as shown in Figure 6. While traffic is considered as a major factor for K1 and K2 test roads, vertical slope is considered as major factor for the AN2 test road.

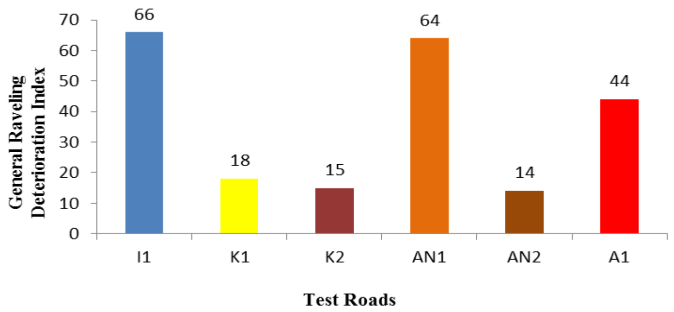

Figure 5: Test roads general flushing deterioration index values

3.2 Aggregate and Binder Test Results

3.2.1 Aggregate Test Result

One of the important parameters in the performance of chip sealed road pavement is the type and quality of the aggregate. Specifications bring some limitations to aggregates that will be used in chip seal construction. Table 4. shows aggregates used in test roads' construction including some physical and mechanical properties. Statement of "quality of aggregate affects chip seal performance" also indicated in AUSTROADS and SANRAL [3, 5] chip seal specification. Loss of Los Angeles, aggregate impact and sodium sulphate soundness tests were under the specification limits for all of the aggregate samples

Table 3: Aggregates' physical and mechanical properties

Aggregate Test	Test Roads						Limit	Specification
	I_1	K_2	K_2	AN_1	AN_2	A_1		
Los Angeles Abrasion Value (% of Loss of aggregate)	30.1	28.6	20.2	13.5	21.4	17.3	≤35	ASTM C 131, 2000.
Aggregate Impact Value (% Loss of aggregate)	14.1	13.8	11.2	6.7	10.4	10.2	≤12	-
Na_2SO_4 Soundness Test (% of Loss of aggregate)	0.2	1.6	0.2	0.8	0.8	0.2	≤12	ASTM C 88-05, 2006.
Flakiness Index Test (%)	21.8	30.8	29.8	36.8	35.0	28.9	≤35	
Bulk Specific Gravity (gr/cm^3)	2.702	2.696	2.652	2.693	2.682	2.731	-	ASTM C127, 2000
Water Absorbtion (%)	0.7	0.2	0.7	0.8	0.2	0.7	-	ASTM C127, 2000
Nicholson Stripping Test (% of nonstripped aggregate surface area)	81.9	82.5	70.0	80.0	72.5	60.6	≤50	TCK Spesification, 2006
Vialit Adhesion Test (Number of droped aggregate)	3	5	4	3	3	4	≤10	BS EN 12273-2, 2003
pH	8.50	9.30	9.0	7.30	8.80	7.70	-	-

4.2.2 Binder Test Result

In order to determine the binder properties some tests were performed. These tests' results are shown in Table 4.

Table 4: Binder’s engineering properties

Properties	Values				Spesification	Limits of TCK Spesification	
	I1	K1/K2	AN1/AN2	A1		100/150	160/220
Source	Aliaga	Kırıkkale	Kırıkkale	Aliağa	-	-	-
Bitumen grade	100/150	100/150	160/220	100/150	-	-	-
Additive	-	✓	✓	-	-	-	-
Penetration	144	151	174	120	ASTM D5-06e, 2006	100-150	160-220
Softening point	41	42.6	41.0	43.6	ASTM D36, 2006	39-47	35-43
Loss of mass	0.5	1.6	0.6	0.06	-	Max. 0.8	Max. 1.0
Penetration after RTFOT	81	56	92	72	ASTM D2872, 2006	-	-
Retained penetration %	56.3	57.8	53.2	60		Min.43	Min. 37
Softening point after RTFOT	47	53	46.6	49		Min.41	Min. 37
Increase softening point	6	10.4	5.6	5.4		Max 10	Max. 11

3.3 Nondestructive Test Results

After all of the test roads opened to traffic, nondestructive tests and inspections were performed for two years. The changes in chip seal performance were determined. Shoulder points’ test result is shown in Table 6. Although the macro texture depth showed a decreasing trend in shoulder points over time, it was higher than 2 mm at all of the test points. This is mainly because wheel contact at point 4 is less than test points 1,2 and 3. In Transit New Zealand Specification, 0.9 mm macro texture depth is considered as a critical limit [16]. At the end of two years, the K2 tests road’s macro texture depth was decreased by 2.30 mm. In these test points, similar results were obtained for the loss of polishing value. All of the test roads’ number of polishing values were higher than 50 except for the AN2 test road. The main reason of the low polishing value at B test points on the AN2 test road is ravelling deterioration due to snow shovelling. With a decrease in the macro texture depth, the density of chip sealed pavement increased.

Table 5: Nondestructive test results for shoulder (B) points

Test Roads	Test Num.	Test Date	Nondestructive Tests					
			Macro Texture (mm)	Skid Number	Density of Chip Seal (t/m³)	Deformation (µm)	Base E Modulus (Mpa)	Base CBR Value (%)
I_1	1st	July 09	4.6	-	1.831	-	-	-
	2nd	Dec 09	3.7	85.3	1.845	119.4	405	100
	3rd	March 10	3.2	60.0	1.840	115.7	400	42
	4th	July 10	2.7	53.8	1.864	182.6	268	79
K_1	1st	July 09	-	-	-	-	-	-
	2nd	Oct.09	4.5	85.0	1.933	114.1	373	41
	3th	May 10	3.2	61.2	1.886	140.4	338	69
	4th	July 10	2.8	54.1	1.956	163.3	291	68
K_2	1st	July 09	-	-	-	-	-	-
	2nd	Oct. 10	4.1	79.6	1.952	104.3	420	52
	3th	May 10	2.7	60.4	2.014	119.8	364	51
	4th	July 10	2.3	52.3	2.068	138.7	407	58
AN_1	1st	July 09	-	-	-	-	-	-
	2nd	Oct 09	3.4	68.3	2.042	338.8	124	31
	3th	Apr 10	3.1	63.5	2.105	375.5	114	55
	4th	July 10	2.4	56.4	2.254	385.2	127	50
AN_2	1st	July 09	4.3	-	1.906	150.1	268	-
	2nd	Oct 09	3.3	60.9	1.931	133.3	354	71
	3th	March 10	2.9	53.0	1.977	167.3	283	23
	4th	July 10	2.3	46.0	2.005	171.4	303	57
A_1	1st	Dec 09	5.0	92.6	1.842	124.0	482	64
	2nd	May 10	3.4	65.3	1.874	119.3	433	73
	3th	July 10	2.5	55.2	1.899	84.2	769	99

LWD deformation value was increased in all of the test roads except A1 test road. This is mainly because, the A1 test route was a tendency for landslides as well as a cutting cross-section formed by rock. High CBR and elasticity values were obtained from warm season tests because of the rock subgrade. As stated by TNZ [16], Bandara vd. [17], and Steinert [18], CBR and elasticity modulus values were also decreased, especially during the winter season because of the surface rain water and water leaking to sub layers from the poorly constructed gutters. Therefore, the shoulder points which drain the surface waters are more critical than other points with respect to load bearing capacity. Also, ravelling and pothole deteriorations were shown in the AN1 test road which has' high LWD deformation value (Table 6; Figure 6). The test road was amended with large scale after second winter season. Many researchers stated that freezing-thawing cycles could considerably change layer's elasticity modulus [18-20].

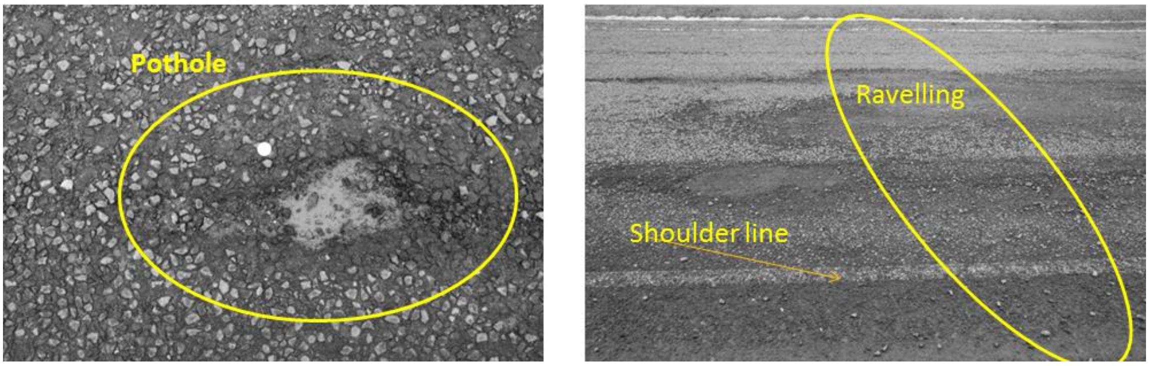

Figure 6: Some type of deteriorations at AN1 test road

The right lane and wheel points (1) are the most critical pavement locations and points for all of the asphalt pavements. The right lanes are generally used by slow moving heavily traffic. Because the heavy traffic volume is higher in this lane, deterioration is more rapid in the right lane. The final macro texture depth decreased below to 2 mm on some test roads (K1, K2, AN1, A1) unlike B points. The K1 test road in particular has a higher AADT value and the lowest macro texture depth. Also bitumen properties of K1 and K2 are exceeds the specification for 100/150, so this might have resulted in lower performance. Fig.7 shows that a considerable relationship was exist between macro texture depth and the general deterioration index. However, macro texture loss is not the only cause of general deterioration. Research performed in New Zealand shows that, the most important cause of resealing is loss of texture at level of 49.6% following that there is a ravelling deterioration with 21.3% level. Data generated in this study confirms the previous findings.

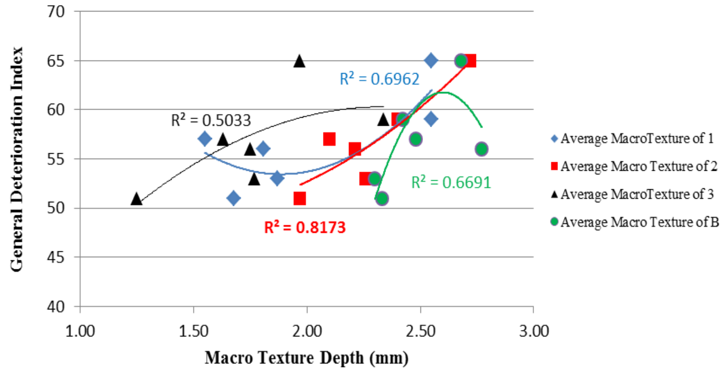

Figure7:Correlation between macro texture depth and the general deterioration index

Multiple regression model relating the macro texture depths of points 1, 2, 3 and B to the general deterioration index, was created (Figure 6). The Skid number associated with macro texture depth was decreased under 50 on some test roads. According to the Gransberg and James [2], sliding friction force developed between tire and road surface and expressed as a skid number, it is function of macro texture and micro texture. Skid numbers showed decreasing trends in all of the test roads with 1 test points. A slow decreasing rate was found at AN1 test road. This road constructed with a volcanic aggregate. Aggregates used in chip seal construction, can wear from tire contact and surface water effects. Thus sharp round surfaces of aggregates rounded and micro texture will decrease. This leads to potential risk for driving safety, decreases chip seal performance, requires repair to the chip seal after a shorter period of time [16].
decreased (Table 7). At test roads, especially clear in the fourth tests, settlements and collapses confirm this.

Table 7: Non-destructive test results for right wheel paths (1) points

Test Roads	Test Number	Test Date	Nondestructive Tests				
			Macro Texture (mm)	Skid Number	Density of Chip Seal (t/m^3)	Deformation (kPa)	Base E Modulus (MPa)
I_1	1st	July 09	3.5	-	1.889	-	-
	2nd	Dec 09	3.1	68.2	1.889	180.9	405
	3rd	March 10	2.6	52.5	1.911	158.1	400
	4th	July 10	2.1	46.8	1.940	224.4	268
K_1	1st	July 09	3.2	-	1.945	152.6	-
	2nd	Oct.09	2.6	62.2	1.952	136.9	369
	3rd	May 10	1.8	47.3	1.966	174.8	335
	4th	July 10	1.6	43.0	2.001	191.2	294
K_2	1st	July 09	2.9	-	1.981	-	-
	2nd	Oct. 10	2.5	58.0	1.970	121.5	369
	3rd	May 10	1.9	39.2	1.978	139.2	335
	4th	July 10	1.7	36.4	2.048	154.6	294
AN_1	1st	July 09	4.3	-	2.056	222.4	126
	2nd	Oct 09	2.8	67.9	2.039	311.3	139
	3rd	Apr 10	2.6	62.0	2.171	315.5	136
	4th	July 10	2.1	54.4	2.370	338.7	136
AN_2	1st	July 09	2.4	-	1.976	152.6	268
	2nd	Oct 09	1.9	53.1	2.031	154.9	294
	3rd	March 10	1.7	48.5	2.072	161.9	295
	4th	July 10	1.4	40.6	2.158	173.8	299
A_1	1st	Dec 09	3.1	69.9	1.935	90.6	506
	2nd	May 10	1.9	50.6	2.004	84.6	556
	3rd	July 10	1.6	43.5	2.038	71.5	775

Test results show that, there is a rapidly decreasing in skid numbers on the test roads during the winter season. Woodside and Woodward [21] conducted on abrasion test on damp and dry aggregates and reported that damp aggregates exhibit weaker strength. Thus, in the presence of water, aggregates wear more rapidly. As stated by Alderson [22], aggregate's wearing accelerates under traffic. Obtained data from the test roads confirmed this case. Comparing Table 7 test results, it can be seen that test points 1's density values are above 2t/m3 in all of the test roads. The determined flushing deteriorations at these points with high traffic volume contact, confirm this fact. Indeed, Kuloğlu et.al. [23] determined that the most effective factors for flushing deterioration are traffic volume, amount of bituminous binder and temperature.

Unlike the B test points, elasticity modulus values of 1, 2 and 3 test points decreased during the rainy seasons. In particular, their deformation values tended to increase. According to the Bahia et.al. [24], the stiffness modulus of sublayers affects the deterioration that occurred on chip sealed pavements. In all of the test roads; the bearing capacities of the base, subbases and sublayers were considerably

Test roads that have collapses and settlement deterioration also have capillary cracks like fatigue cracks. These types of deteriorations 'photos (shown in K1 and I1), were given in Figure 8.

Figure 8: Fatigue cracks at some test points

The macro texture loss in the interval between the wheel path's test points (2) is generally higher than 2 mm except, on the AN2 test road (Table 8). However, a decreasing trend is observed for macro texture depth. As the macro texture loss was less than 2 mm, and this test road's route has climbing slope so traffic velocity was very slow. As a result, led to loss of macro texture and flushing.

SANRAL's chip seal specification indicated that, the performance of chip sealed pavements under slow moving traffic will be worse than chip sealed pavement under rapid traffic volume [5]. Skid numbers decreased under to 50, except I1 and AN1 test roads, at end of the last test in field. Density values were increased at all of the test points, the value was higher than 2t/m3 at AN1, AN2 and A1. The AN1 road was repaired during the investigations, so it increased the thickness of the chip sealed pavement. This led to obtain higher densities in this test road. The AN2 and A1 test roads have a route with slope, and this leads to loss of macro texture and flushing deteriorations. These cause to higher density values from the test roads . These points 'deformation values showed an increasing trend, also the elasticity modulus of test roads decreased except for A1 test road.

In the left wheel path test point's (3) loss of macro texture decreased test points 1 similarly, a high degree of macro texture loss was determined in the AN2 and A1 test roads. In addition to this density values were higher than 2 t/m^3 at these points and skid number was less than 50. One of the most common types of deterioration of these test roads is flushing. Skid number values are under 50, except AN1, like a similar other test roads. The density values of 3 points obtained as AN1>AN2>K2>A1>I1>K1 (Table 9). It was found that points with high density values also have a vertical slope and flushing deteriorations. The points that water leakage is more difficult from slope surface also have a less deformation value than B, 1 and 2 however higher elasticity value than B, 1 and 2.

Table 8: Average non-destructive test results for the wheel paths interval (2) points

Test Roads	Test Num.	Test Date	Nondestructive Tests				
			Macro Texture (mm)	Skid Number	Density of Chip Seal (t/m^3)	Deformation (kPa)	Base E Modulus (MPa)
I_1	1st	July 09	4.5	-	1.874	-	-
	2nd	Dec 09	3.8	73.0	1.860	176.6	245
	3rd	March 10	3.1	59.7	1.869	199.0	223
	4th	July 10	2.7	53.1	1.894	203.9	229
K_1	1st	July 09	3.7	-	1.937	136.0	310
	2nd	Oct.09	3.2	68.8	1.922	133.7	336
	3rd	May 10	2.5	51.6	1.930	157.6	281
	4th	July 10	2.2	44.9	1.969	168.0	255
K_2	1st	July 09	3.7	-	1.943	-	-
	2nd	Oct. 10	3.4	59.9	1.945	123.1	351
	3rd	May 10	2.5	44.5	1.949	140.9	321
	4th	July 10	2.3	38.4	1.990	163.3	307
AN_1	1st	July 09	4.84	-	2.014	228.2	118
	2nd	Oct 09	3.69	65.3	1.982	304.1	145
	3rd	Apr 10	3.05	61.1	2.070	318.0	135
	4th	July 10	2.40	56.9	2.249	343.3	142
AN_2	1st	July 09	2.73	-	1.995	152.2	279
	2nd	Oct 09	2.55	55.7	1.986	149.8	305
	3rd	March 10	2.20	51.8	2.048	170.7	269
	4th	July 10	1.97	43.8	2.097	169.4	272
A_1	1st	Dec 09	4.00	73.0	1.902	84.6	617
	2nd	May 10	2.69	54.7	1.971	92.8	532
	3rd	July 10	2.10	43.3	2.014	80.0	745

Table 9: Non-destructive test results for the left wheel paths (3) points

Test Roads	Test Number	Test Date	Nondestructive Tests				
			Macro Texture (mm)	Skid Number	Density of Chip Seal (t/m^3)	Deformation (kPa)	Base E Modulus (MPa)
I_1	1st	July 2009	3.32	-	1.888	-	-
	2nd	Dec 2009	3.18	74.8	1.881	143.6	299
	3th	March 2010	2.33	55.9	1.916	189.6	229
	4th	July 2010	1.97	49.4	1.958	172.6	301
K_1	1st	July 2009	3.40	-	1.933	130.3	318
	2nd	Oct.2009	3.04	66.1	1.885	119.1	375
	3th	May 2010	2.04	50.1	1.902	155.9	287
	4th	July 2010	1.75	44.3	1.943	173.8	267
K_2	1st	July 2009	3.07	-	1.946	-	-
	2nd	Oct. 2010	2.83	54.1	1.965	119.0	363
	3th	May 2010	1.96	38.1	1.975	132.1	366
	4th	July 2010	1.77	34.1	2.026	141.8	327
AN_1	1st	July 2009	4.16	-	2.054	240.3	111
	2nd	Oct 2009	3.48	64.9	1.983	304.2	134
	3rd	Apr 2010	2.78	60.2	2.027	318.0	133
	4th	July 2010	2.34	56.2	2.222	343.3	142
AN_2	1st	July 2009	1.99	-	1.975	149.6	268
	2nd	Oct 2009	1.77	48.6	1.978	148.0	316
	3rd	March 2010	1.53	44.9	2.018	167.0	274
	4th	July 2010	1.25	39.2	2.087	178.4	281
A1	1st	Dec 2009	3.00	68.7	1.892	78.6	602
	2nd	May 2010	1.97	50.0	1.976	78.2	527
	3rd	July 2010	1.63	43.3	1.983	77.2	669

The temperature variations of chip sealed pavement were measured during the non-destructive field test. Test results show that the average maximum temperature variations were critical with respect to the chip sealed pavement (Figure 9).

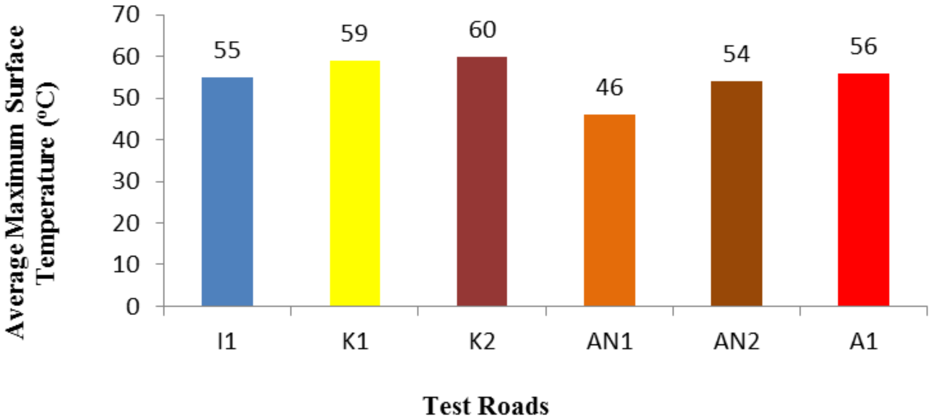

Figure 9: Average maximum surface temperature

When these values were associated with the flushing and ravelling deteriorations, the relationship in Figure 10 was obtained.

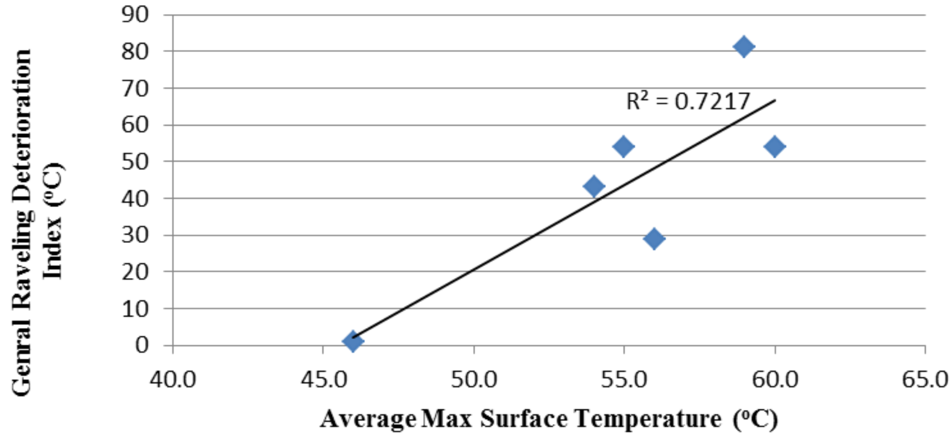

Figure 10: Correlation between the general ravelling deterioration index and average maximum surface temperature

A moderate relationship was obtained between a flushing deterioration index and the average maximum surface temperature since flushing deterioration was associated with many factors. According to Figure 17, with the increase of a pavement's average surface temperature, ravelling deterioration decreased. One of the most important reasons for this condition was that results of the bitumen was reached to softening points and then aggregate reached to effective embedment depth quickly than expected. In this case, a tendency of flushing deterioration occurs [7, 16]. A lot of factors could affect the flushing deteriorations in chip sealed pavements such as aggregate, condition of base layers, traffic configuration, velocity of the traffic, binder type and application amount, tire pressure, construction stage and so on [6, 7, 26].

4. CONCLUSIONS AND DISCUSSIONS

After the roads were constructed and opened to traffic, performance of 6 different chip sealed test road were monitored with nondestructive test and visual investigations and the following conclusions were reached:

- As indicated in TNZ Specifications [16], macro texture depth was pronounced as the most important deterioration type in all of the test roads and this was followed by ravelling.
- Roads with a steep vertical slope showed a faster increase in density and loss of macro texture. Flushing was determined to be the most common type of deterioration on these types of roads. The lower speeds of heavy traffic using the right lanes caused to an increase in the loading time of the wheels and lead to an acceleration of this type of deterioration. Some measures in vertical curves of road's routes at construction stage should be taken in order to slow down to flushing deterioration. These measures include: using modified bitumen,

number of rolling pass, using bigger size aggregate and other chip seal construction techniques. In fact, Wood and Olson [26] reported that susceptibility to flushing decreases with the use of modified bitumen.

- The single and traditional double layer chip seals are the 2 variety of chip sealed pavements constructed in Turkey. According to previous literature 11 different methods of construction of chip seal exist [5, 7, 16, 27]. Climatic factors are not the only reason chip seals deteriorate, but they can adversely affect the performance of chip seals. Depending on the road project, different types of double layer chip seal application will be used in construction, Turkey, which has many different climatic zones, depending on the project, different types of surface coating applications will construct, so that the chip seals on the granular base will show better performance than traditional double layer chip seal.
- In Turkey, South Africa, New Zealand and Australia, chip seals will continue to be used as pavement because of their cost, speed and ease of construction. Many factors affect these type of pavement's performance, including project traffic volume and configuration, the geometric properties of route (alignment, horizontal and vertical curves), climate condition, aggregate and binder properties. These should be assessed carefully in order to gain better performance from chip sealed pavements.

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