Influence of top-down crack on the integrity of asphalt concrete pavement

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ABSTRACT: Surface conditions of asphalt pavement could be the key to how the pavement systems perform over its service life. The defects and deficiencies that may occur during the placement and compaction of the asphalt layer during its construction could affect some properties of the pavement and at the same time influence its environmental performance. The term environmental performance is used to describe the effects of water and its interactions with other substances on the asphalt layer and its long term performance. In order to study the effects of the defects resulting from construction of the new asphalt layer, core specimens were extracted from cracked and un-cracked field sites. Laboratory tests were performed on the cores to determine their density, permeability and effects related to the possible leaching of pollutants from the specimens. The environmental tests included the collection of the water passing through the tested specimens. The collected water samples were analyzed in the lab to examine the changes occurred to the pH, conductivity, total dissolved solids, turbidity and total carbon as a result of seepage through the asphalt cores. The pollution released from the conventionally compacted cracked cores was found to be high suggesting that asphalt surface defects and cracks can also lead to environmental problems to the road infrastructure. Also, the results of recent laboratory tests suggested that construction induced cracks will allow oil to interact with the composition of the asphalt mix leading to significant loss of its mechanical properties.

KEYWORDS: TDC, density, permeability, pavement, integrity.

1 INTRODUCTION

Construction of new asphalt pavement includes, among other operations, the placement and compaction of new hot asphalt mix. In these two operations, the loose asphalt mix is treated in a process where the aggregate particles are re-oriented to a more closely spaced arrangement reducing the percentage of air voids to reach to a desirable density and tight surface texture. Improper placement and/or compaction will cause surface defects in the form of Top-Down Crack (TDC), which could decrease the density and increase the permeability of the asphalt mix (Abd El Halim and Haas, 1994, Hammoud, 2010).

During the Canadian winter seasons, highway authorities in many parts of Canada use salt on the pavements to improve the friction between the wheels and the road surface, thus enhancing the driving conditions and overall safety. The melting action of the salt, which softens the ice and helps forming a mix of salt and water, will promote the chemical interaction with the asphalt mix in the presence of TDC. TDC plays a major role in this mechanism leading thawed ice on the road to drain through into the ground, polluting the underground layers. The contaminants carried by the melted ice may be one of the main factors that affect the integrity of asphalt pavement.

Although, the addition of commercial oil in the asphalt concrete mix is required in order to achieve certain properties for the asphalt pavement, also most bitumen consist of natural oil (Katamine, 2000), however, the escaped oil from vehicle engine which is hydrocarbon-based material in the road could be considered to affect negatively in the quality of the bitumen when it infiltrate the asphalt pavement through TDC, such as reducing adhesiveness to the aggregates, leading to stripping and raveling (Villanueva et al. 2008).

Therefore the main objectives of this paper are: (1) Investigate the influence of TDC on the density, and permeability of the extracted asphalt pavement specimens. (2) Examine the changes occurred in the chemical properties of water passing through the tested specimens. (3) Measure the percent of oil that could be absorbed by the specimen and that could seepage to the underneath layers. (4) Determine the quantity of the fragmented and the extracted materials from the specimen due to the effect of oil seepage through it, and (5) Finally, evaluate effect of the TDC on the indirect tensile strength of the asphalt specimens

2 LABORATORY AND FIELD INVESTIGATIONS

Thirty three AC specimens were selected for the lab testing. The selected specimens were recovered from two sets of asphalt cores. The first set consists of 18 specimens and were from a set of specimens extracted from asphalt field site sections compacted using the conventional compaction method; by using steel vibratory drum roller followed by pneumatic multi-wheel roller which induced visible TDCs and termed “cracked specimens”. These test specimens were labelled the symbol (SC) in this paper. The second set consist of 15 specimens and were recovered from a number of specimens extracted from the same field site which was compacted using a newly developed compactor which was developed to prevent construction induced cracks. These samples were used as reference specimens. This section was compacted using the asphalt multi-integrated roller prototype (AMIR), and termed “Un-cracked specimens” and were given the symbol (ANC). In order to assess the influence of TDC on the asphalt pavement structure, core specimens which were extracted from the two field sections were subjected to four laboratory tests as follows:

2.1 Specific Gravity Tests

This test method covers the determination of density of specimen of compacted bituminous mixtures (ASTM D 2726). The test was applied on a number of the selected specimens to compare the effect of the two compaction methods on the density of the specimens. The results revealed that the average density for the pavement cores compacted with conventional steel rollers which experienced TDC is 2.27 g/cm^3, while the average density for the reference specimens which have no surface cracks is 2.43 g/cm^3. That means the existence of TDC decreased the density of the asphalt concrete pavement by approximately 7.3 %. This shows that a higher density of the asphalt concrete specimen is achievable in the absence of TDC.

2.2 Permeability Test

Permeability is the ability of water and air to pass through the surface of a finished asphalt mix, where the primary purpose of the use of hot mix asphalt is to drain water off the pavement surface and prevent it from leaching through the asphalt layer. This will eliminate and/or prevent the interactions between the dissolved materials in the water with the asphalt components, consequently reducing the negative influence on the integrity of the road pavement (Kandil, 2002). Lab permeability test is a procedure performed in the laboratory to determine the permeability of asphalt pavement specimens and was conducted to quantify the effect of the TDC on the measured permeability of the finished asphalt layer (Hammoud, 2010). The test results were used to observe the highest value of the permeability of the cracked specimen and compare it with that of the reference specimens. Field tests were also conducted to investigate the permeability of cracked and un-cracked pavement sections.

2.2.1 Laboratory Permeability Test

A special laboratory permeameter device was assembled in the lab to fit the diameter of the specimens extracted from the two field sections. The laboratory permeameter was assembled to allow a head of water applied on the top of the tested specimen and at the same time to collect the water that leaked through the body of the tested core. The time spent by the water to pass through the specimen was measured for both types of core specimens (ASTM Geotechnical Testing Journal, 2002). The average values of the test results of the permeability tests for the AMIR compacted specimens which have no TDCs and those which compacted with traditional compactors and show TDCs were plotted and are given in Figure 1.

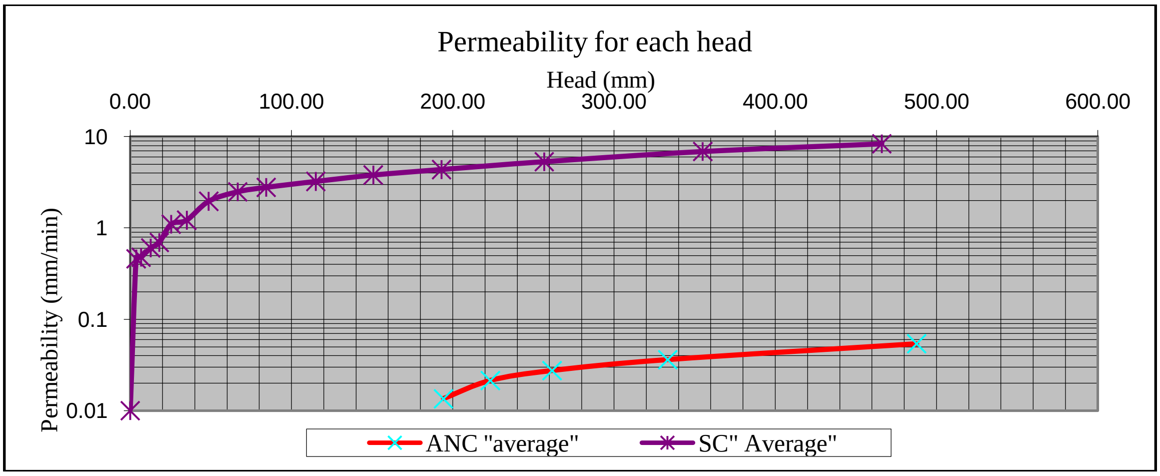

Figure 1: Calculated average permeability

As seen in the figure, the un-cracked cores show a significant improvement in reducing the permeability of asphalt concrete layers. At water head of 200 mm the average permeability of the specimens which have TDC was about 200 times the average permeability for the specimens which have no TDC. At the same water head, the variance in the average permeability for the cracked specimens was 140 while the variance in the average permeability for the un-cracked specimens was 1.5E-4.

2.2.2 Field Permeability Test

Measurement of the permeability of asphalt concrete surface layer in terms of the coefficient of permeability (k) was conducted in two types of pavement sections in the city of Ottawa, Canada. The first section showed visible TDC while there were no surface cracks visible on the other section. Ten independent tests were performed along different test site locations spaced at about 13 m apart in the cracked section, and three tests were performed in the un-cracked section to facilitate a comparison between the permeability of the cracked and un-cracked pavement.

To evaluate the field permeability of an asphalt concrete pavement, the NCAT field permeameter developed by NCAT and purchased from Gilson, Inc as shown in Figure 2 was used. The apparatus was used to measure the permeability in the field. The test is a falling head permeability test using water as the permeate. The water level in the permeability tube dropped from its top to the second portion or level of the standpipe when used on the cracked pavement sections due to the rapid flow of the head through the section as shown in Figure 2 while in the un-cracked pavement section the flow of water was slow enough so that the first portion of the standpipe was selected for efficient recording of data as shown in Figure 3 (Operation & Maintenance Manual, 2004).

Figure 2: More permeable pavement

Figure 3: Low permeable pavement

The average permeability coefficient of each of the ten and the three individual measurements tests was calculated and the results revealed that the average permeability of the cracked section was approximately 90 times the average permeability of the un-cracked section. This result validate the lab permeability test results, were the average permeability of the specimens which have TDC was 200 times the average permeability of the specimens that do not have TDC.

2.3 Chemical Analysis of Water

Chemical analyses tests were applied to evaluate the environmental effect of the TDC. The test was performed by analyzing samples from the water used for the permeability test before and after going through the specimens. The water used for the permeability test was fully distilled water in the first stage to insure that all the contamination associated with the collected water was as a result of the water interaction with the asphalt specimen components. In the second stage salt was added to the water in the amount of 50 g/l. The conducted chemical analysis tests are: pH, conductivity, total dissolved solids, turbidity, and total organic carbon. Table 1 illustrates the results of the chemical test and they were analysed as the following:

1- Case of applying still water to the cracked specimens, as an example.

(a) Results from specimens SC2.

- pH slightly changed after the water goes through the asphalt specimen. Before the test pH was about 7 and after the test it gets a little bit lower but still not far from 7 and this can be due to some acidity released from the specimen as the water goes through it (Arnold et al. 1992).

- Conductivity and the total dissolved solids have increased after the water went through the specimen. This could be explained due to some interaction with the asphalt specimen which causes some releasing of the ions; and that causes other reactions which lead to the increase in the total carbon.
- The increase in Turbidity in the outcome water means that the water has extracted some substances from the asphalt specimen as it goes through. These substances are higher in the first collected quantities, as the water washes the specimen and then continues to move through..

(b) Results from specimen ANC5.

- pH slightly changed after the test, it gets a little bit lower and higher but still not far from 7 and this can be because of some acidity or alkalinity released from the specimen as the water goes through it.
- The increase in the conductivity and the total dissolved solids looks much higher than that of the cracked specimens specifically in the second letter.
- The time duration for the water to interact with the specimen was much higher in the un-cracked specimen and that was the cause of the increase in the turbidity and the total carbon in the collected water.
- The time factor here is considered a significant factor where the total pollution is much higher in the water collected from the cracked specimens.

2- Case of applying still water with 50 g/L salt as an example,

(a) Results from specimen SC3 are presented:

- It is noticed that the amount of total carbon increased, that could be due to some reactions between the salted water and the specimen, and we can see that in the reduction of alkalinity, conductivity and the total dissolved solids, where the dissolved salt was a factor causing the increase of these parameters.

(b) Results from un-cracked specimen ANC6.

- The time duration for the water to interact with the specimen was much higher and this enables the release of more carbon, also the alkalinity has reduced significantly.

The time duration for specimen SC3 was 11 min for the total carbon to increase by 4.91 mg/l while it took 7931 min to increase the total carbon by 18.1 mg/l for specimen ANC6. This means that the rate of pollution produced by the cracked specimens (0.446 mg/l/min) is almost 225 times that for the un-cracked specimen (0.002 mg/l/min). This is considered very high rate which could cause serious damage to the environmental and can affect the long term performance of the asphalt pavement.

2.4 Effect of Spilled Oil on the Asphalt Pavement Integrity

Oil can spilled on the surface of the asphalt roads due to leak of engines of different vehicles or during transportation of oils as commodities. A test was conducted to measure the damage that could be inflicted due to the presence of oil products on a cracked surface of asphalt road. The test was performed on 9 un-cracked specimens and 12 cracked specimens. Oil was applied over each specimen after fitting the specimen in the same assembled permeameter that was used for the water permeability test with the oil is up to a level of 100mm. The oil was left over the specimen until it all went through the specimen or for a period of time of about 24 hours. The amount of oil that could pass through the specimens, and that could be absorbed by it was determined and presented in Figures 4 & 5. The test results showed the total amount of oil that was applied over the asphalt specimen has fully passed through the surface of most of the test specimens with cracked surface. On the other hand, it was noted

Table 1. Results of chemical analysis tests

Specimen No	Time duration		pH	% Increase in pH	Conductivity (uS/cm)	% Increase in Conductivity	Total dissolved solid (mg/L)	% Increase in Total dissolved solid	Turbidity	% Increase in Turbidity	Total Carbon (duplicate)			
	h	min									Total Carbon mg/L	% increase in Total Carbon	Total Organic Carbon mg/L	Inorganic Carbon mg/L
DW no salt (before)			7.22		3.22		2.08		0		1.085		0.42	0.67
SC2 1st, 2nd L	0	20	6.43	-11	9.7	201	6.63	219	0.19		4.21	288	2.06	2.15
SC2 4th liter	1	19	6.73	-7	13.14	308	8.88	327	0.02	-89	5.18	377	2.65	2.53
ANC5 1st L	45	49	7.15	-1	62.8	1850	41.6	1900	0.3	58	10.38	857	6.94	3.44
ANC5 2nd L	70	3	7.45	3	465	14341	309	14756	0.3	58	14.75	1259	9.86	4.89
					mS/cm		**g/L**							
DW + salt 50g/L (before)			9.68		330		221		2		9.25		6.85	2.40
SC3 1, 2 nd L	0	11	9.4	-3	309	-6	213	-4	0.4	-80	14.16	53	10.73	3.43
SC3 3rd liter	0	20	9.53	-2	324	-2	215	-3	0.34	-83	11.33	22	9.15	2.18
SC3 4th liter	0	50	9.52	-2	307	-7	204	-8	0.48	-76	11.92	29	8.99	2.93
ANC6 1st L	5	47	9.14	-6	320	-3	215	-3	1.41	-30	16.83	82	12.4	4.43
ANC6 2nd L	7	52	9	-7	324	-2	216	-2	1.44	-28	18.79	103	13.01	5.78
ANC6 3rd L	28	20	8.58	-11	338	2	228	3	1.02	-49	20.45	121	12.37	8.08
ANC6 4th L	132	11	7.58	-22	336	2	224	1	0.66	-67	27.35	196	14.59	12.76
DW + 25g/L salt (before)			9.06		114.9		77.4		0.18		4.838		3.74	1.10
ANC7 1st L	22	35	8.82	-3	117.9	3	78.5	1	0.41	128	17.6	264	17.04	0.56
ANC7 (2,3,4) L	117	20	7.04	-22	117.1	2	79.4	3	1.22	578	22.85	372	9.96	12.89

that hardly any of the oil on top of the un-cracked specimens has gone through them as illustrated in Figure 4. This is a very important observation since oils are known to attack the asphalt mixtures and damage the bond between its aggregates and the asphalt binder, thus causing serious damage to the mix and its ability to provide its expected function. Figures 4 and 5 shows that not only the amount passing through the body of the asphalt core was much higher for the cracked specimens but also the amount absorbed by the same specimens. Clearly, the passing and absorbed amounts would increase the damage caused to the road which could be stripping, softening and disintegration of the mixture itself in addition to the environmental effects of the oil seepage into the soil and water sources.

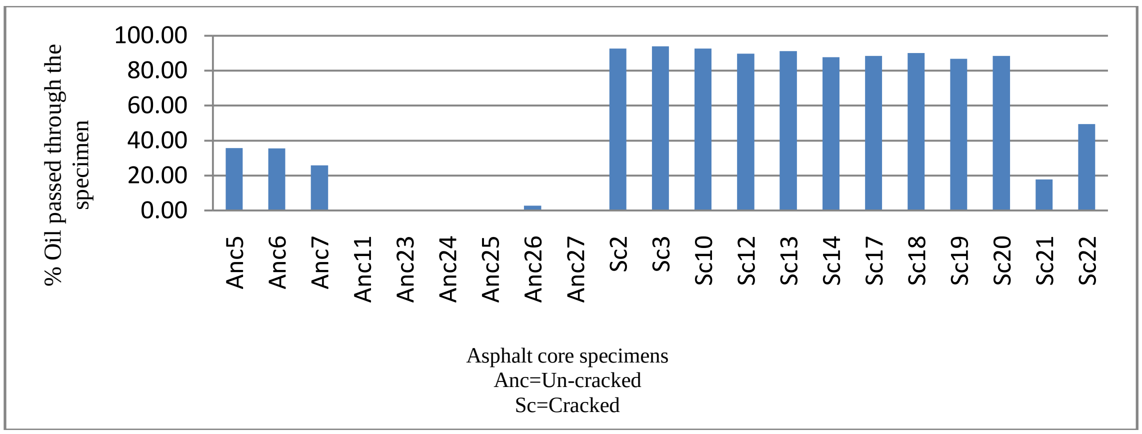

Figure 4: Percent of penetrated oil through the specimen

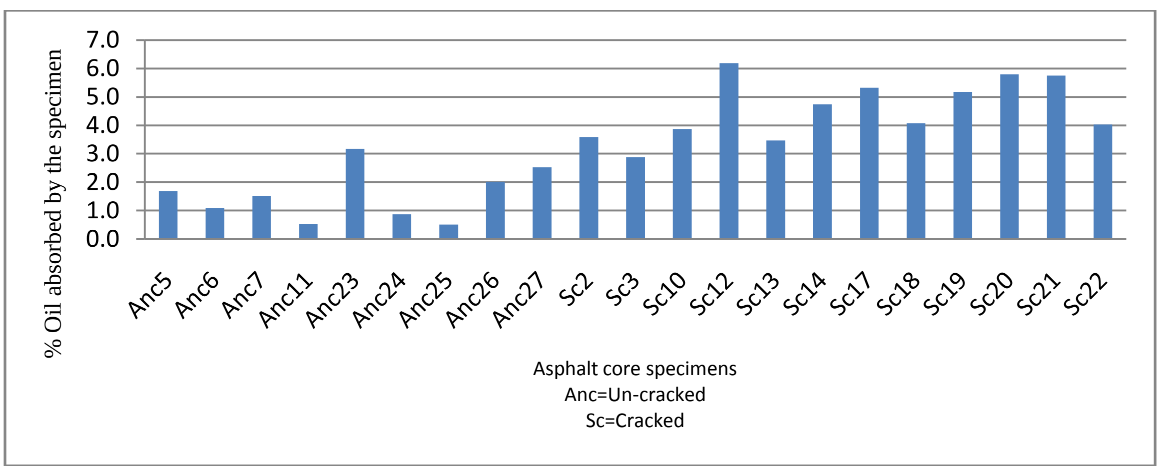

Figure 5: Percent of absorbed oil by the specimen

The weight of the fragmented parts which were separated from the test specimens under the effect of oil was calculated and presented in Figure 6. Based on the findings of the present laboratory oil test, it was demonstrated that with the existence of TDC on the pavement surface, oil exposed to cracked asphalt pavement could negatively affect the quality of the pavement such as reducing the adhesiveness to the aggregates, leading to stripping. It was revealed that the average percent of the released and fragmented material from the un-cracked tested asphalt specimens showed low value, which was less than 1.5% the weight of the specimen, while it showed high value of more than 4% in the case of cracked asphalt specimen. This is a significant ratio of 267%.

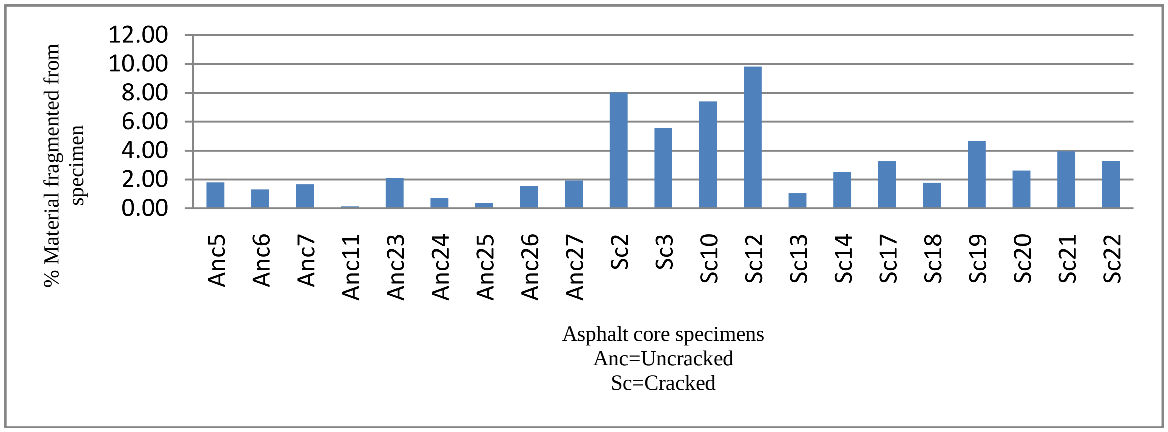

Figure 6: Percent of fragmented material from the specimens

2.5 Indirect Tensile Strength Test

All specimens went under the oil test were subsequently subjected to indirect tensile strength test. The indirect tensile test was also conducted on another 12 specimens, six from each site section, these 12 specimens were not subjected to the effect of oil; hence they were treated as reference specimens. The indirect tensile strength of the specimens was determined at failure (Texas Department of Transportation, 2004). The average value of the indirect tensile strength tests for the six reference un-cracked specimens was 1165.56 kPa. The cracked specimens showed decreased tensile strengths with an average of 690.04 kPa. The difference in the indirect tensile strength values of the specimens are illustrated in Figure 7. TDC was the major distress mechanisms which causes a decrease in the tensile strength of the asphalt specimens of about 40%.

Figure 8 illustrates the results of the indirect tensile strength test for all the specimens which were exposed to the oil test. The average indirect tensile strength of the cracked and the un-cracked specimens is 216 kPa, and 1032 kPa respectively. Although the decrease in the tensile strength values of the reference specimens was 40% due to the existence of TDC in the specimens, however, when both the cracked and the un-cracked specimens were exposed to the effect of oil, the decrease in the strength was relatively very high, it reached up to 80%. It is important to note that the measured tensile strength of un-cracked surface specimens were not significantly affected by the presence of oil since it did not penetrate into the body of the tested specimens. Clearly, the higher tensile strength in the un-cracked specimens is the result of a stronger resistance to the effect of oil and its prevention from seeping into the asphalt specimen.

3 CONCLUSIONS

- Measured densities of asphalt specimens extracted from the field were the first indication of deficiencies of the asphalt concrete mix as higher densities of the asphalt concrete specimen is achievable in the absence of TDC.

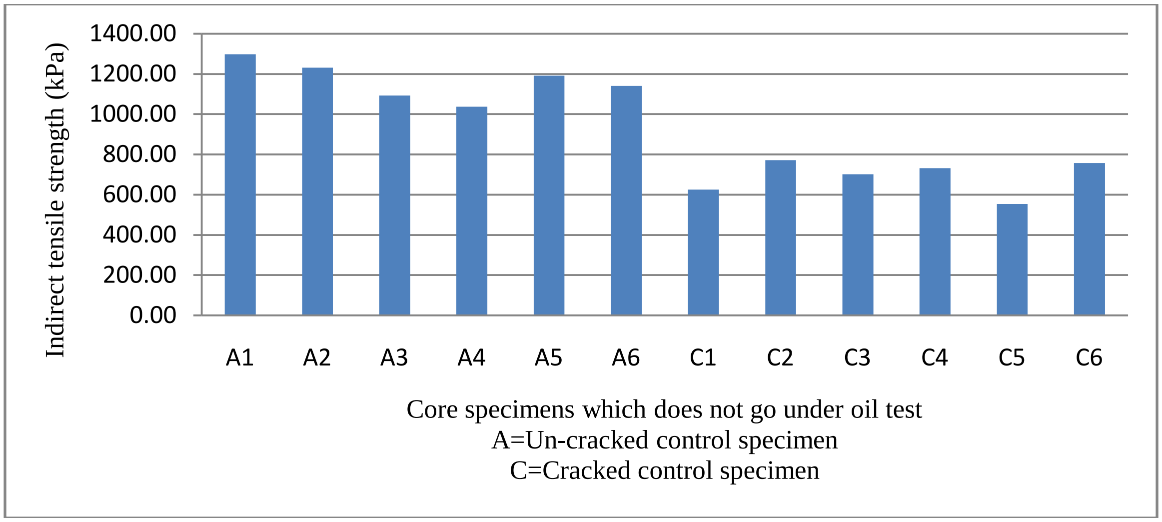

Figure 7: Measured indirect tensile strength test for control specimens.

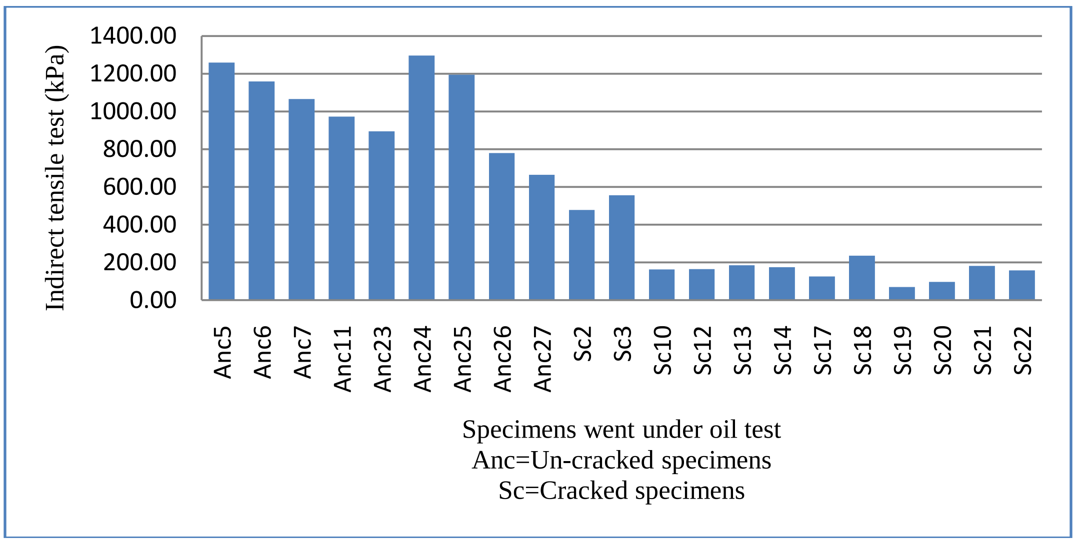

Figure 8: Effect of oil spill on the measured indirect tensile strength

- Laboratory and field investigations revealed that the permeability of the cracked specimens was found to be much higher than the un-cracked specimens and that could only be explained due to the existence of Top-Down Cracks.
- As the layers become permeable, water can infiltrate into the mix and subsequently cause moisture damage in the pavement, therefore, influencing badly on the environmental performance of the pavement.
- TDC promoted the chemical interaction between the salt in the melted ice and the asphalt mix, hence, increases the reaction occurring with asphalt.
- The total pollution produced by the cracked specimens was almost 200 times that for the un-cracked specimen.

- Oil exposed to cracked asphalt pavement could negatively affect the integrity of the asphalt pavement such as reducing the adhesiveness and bond to the aggregates, leading to stripping and reduction in the tensile strength of the asphalt pavement.
- It was demonstrated that the presence of TDC in asphalt concrete pavement reduces the tensile strength of the asphalt concrete pavement.

The results of the laboratory and field tests presented in this paper showed that surface cracks induced in the wearing asphalt course could lead to several deficiencies ranging from lower densities to fully damaged layer and seriously threatening the environment. It is time that pavement engineers and researchers pay more attention to developing effective methods to prevent the occurrence of surface cracks not only to protect the initial investment in the construction of the pavements but also to protect the environment and our water resources.

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