Comparison Between the Effect of Tap Water and Sea water *on the Mechanical Properties of Dense - Graded Asphalt Mixtures*

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ABSTRACT

Moisture damage is a major problem for asphalt concrete pavements. Water-induced damage of asphalt mixtures produces serious distress, reduces performance and increases maintenance cost of pavements. Moisture-induced damage produces several forms of distress, including localized bleeding, rutting, shoving and ultimately complete failure as a result of permanent deformations and cracking. This damage occurs because of stripping of asphalt from aggregate. Stripping is primarily an aggregate problem, but the type of asphalt is also important. Thus it is important to evaluate both asphalt and aggregate to be used in the mixtures.

Many countries lie close to seashore. The roads of these countries have a major problem because they are subjected to seawater and other weathering conditions. Therefore, the main objective of this research is to study the major effect of seawater on the mechanical properties of asphaltic mixtures. Also, a comparison was made between the effect of tap water and seawater on these properties. In this research Marshall -, indirect tensile strength-, and vacuum saturation tests were used under different states of curing .

The study and analysis of the tests results reveals that the seawater had serious effects on the mechanical properties of dense - graded asphaltic mixtures than tap water. Also, it can be concluded that roads subjected to the seawater should receive more compactive effort than others roads.

Keywords

Materials, Dense Graded Asphaltic Mixtures, Marshall Test, Tap water, Sea water, Indirect Tensile Strength, and, Failure Strain.

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Introduction

Many countries lie close to seashore. The roads of these countries have a major problem because they are subjected to seawater and other weathering conditions. Moisture damage is a major problem for asphalt concrete pavements. Water induced damage of asphalt mixtures produces serious distress, reduces performance and increases maintenance cost of pavements. Moisture-induced damage produces several forms of distress, including localized bleeding, rutting, shoving and ultimately complete failure as a result of permanent deformations and cracking. This damage occurs as a result of stripping of asphalt from aggregate (Kennedy 1991).

The destructive influence of moisture in dense-graded asphalt concrete has been recognized for decades. Laboratory tests have been developed to predict potential moisture damage. The purpose of the tests is to assess the redesign of asphalt mixtures (changes of aggregate type, asphalt, and compaction) prior to paving in order to minimize the damage (Lottman 1982).

The main objective of this research is to compare between the influence of tap water and seawater on the mechanical properties of dense graded asphaltic mixtures. To achieve this objective , Marshall tests on asphaltic concrete mixtures are used to evaluate the effect of water type on the asphaltic mixtures in a compacted state in order to find the interaction of all the mixtures constituents. Therefore, in this investigation Marshall test, indirect tensile strength test and vacuum saturation test were used.

The effect of sodium chloride on the properties of asphalt concrete mixes were investigated (Renken 1980). Marshall samples were prepared at different voids content (2,5 and 8 vol.%) by varying the compaction effort. The compacted samples were cured in air, distilling water and sodium chloride solution. After curing, the samples were tested for Marshall stability and flow. It was concluded that voids content have a significant influence on the mechanical properties of asphalt mixes.

Materials

One type of coarse aggregate, which consists of calcareous aggregate with size (2/12.5 mm), natural sand as fine aggregate and calcareous aggregate dust as mineral filler are used in this study. A series of tests were conducted to determine the properties of this aggregate according to ASTM tests [1]. The engineering properties of the aggregates are shown in Table 1. Dense graded asphalt concrete mixture, 4C according to the Egyptian specification [2] was used in this study.

Table 1 : Engineering Properties of Aggregates

Tests	Calcareous Agg.	Natural Sand	Calcareous Agg. Dust
Abrasion Test (Los Angeles test)	10% After 100 revs. 28% After 500 revs.		
Water Absorption	3.4%		
Specific Gravity	2.52	2.61	2.70

Asphalt cement 60/70 pen. grade produced by Alexandria Petroleum Company in Alexandria City was used in this investigation.

Curing Water

Two types of water were used for curing of Marshall specimens in this study. Mediterranean sea (60 km west of Alexandria city and 1m inside the sea) and tap water. The chemical analysis of seawater is presented in Table 2.

Table 2 : Chemical Analysis of Sea water

Compounds	Percentage in Sea water, [%]
Calcium Chloride	3.1
Sodium Chloride	75
Magnesium Chloride	1.8
Calcium Sulfates	2.0
Magnesium Sulfates	0.5
Other Compounds	13.1

Marshall Tests

To obtain the optimum asphalt content, 15 Marshall specimens were prepared and compacted using 50 blows / side at 5.0-, 5.5-, 6.0-, 6.5- and 7.0 % (*Three specimens* at each asphalt value).

The properties of asphalt concrete mixtures at optimum asphalt content (6%) were as follows: Marshall stability equal 4.3 KN, flow value equal 3.8 mm and 3.4 vol.-% air voids. Therefore, the other specimens were prepared at optimum asphalt content (6%) with three different compaction efforts 35, 50 and 75 blows/ side. Voids ratio were 2.4, 3.4 and 5.0 at 35, 50 and 75 blows/side compaction effort respectively.

Effect of Tap Water and Seawater on Stability Values at Different Degrees of Compaction and Soaking Periods

The influence of water types on the stability values at the different degrees of compaction and soaking periods is shown in Table 3. From this Table it can be noticed that:-

- Marshall stability decreased at both states of curing (Tap- and seawater). Stability values using tap water for soaking was higher than that when using seawater at all degrees of compaction and soaking periods.
- Marshall stability decreased by soaking the specimens in tap water as well as seawater at all conditions of compaction and soaking periods, but the influence of seawater was more effective.
- Loss of stability influenced by compaction effort, soaking periods and water type (tap water or seawater). The highest difference in loss of stability between tap water and seawater occurred at 3-days soaking periods. Loss of stability at 14 days curing period in tap water were 71.6-, 58.4-and 49.5% at 35, 50 and 75 blows/side compaction effort respectively. In case of seawater, loss of stability ranged between 7.2- to 36.6 % more than the case of tap water according to the compaction effort and soaking time (Table 4).

The relationship between Marshall stability (M), curing time (Ct) and compaction effort (Ce) was calculated by using computer program QS . The multi-regression relationship was as follows:

$$\mathbf{M = 1974.84 - 251.02\,(Ct) + 52.75\,(Ce)} \qquad R^2 = 0.8711 \qquad (1)$$

where

M= Marshall stability, N
Ct= Curing time, days
Ce= Compaction effort, blows/side

Table 3 : Stability values [N] at different degrees of compaction and soaking periods

Soaking periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea water	Tap water	Sea water	Tap water	Sea water
No. Soaking	4300	4300	6365	6365	7320	7320
24 hours	4100	2840	6300	4757	7200	5266
3 days	3600	2183	5973	3643	6566	4077
7 days	1812	1117	3614	2457	4372	3129
14 days	1220	910	2647	1932	3700	2700

Table 4 : Loss of Stability [%] at different Degrees of Compaction and Soaking periods

Soaking periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea water	Tap water	Sea water	Tap water	Sea water
1 day	04.70	34.00	01.00	25.30	01.60	28.10
3 days	16.30	49.20	06.20	42.80	10.30	44.30
7 days	57.90	74.00	43.20	61.40	40.30	57.30
14 days	71.60	78.80	58.40	69.70	49.50	63.10

Effect of Tap Water and Sea Water on Flow Values at Different Degrees of Compaction and Soaking Periods

The effect of water types on the flow values at different degrees of compaction and soaking periods is shown in Table 5. From this Table it could be concluded that there is slight difference in flow and not trend can be noticed. On the other hand, the gain in flow values at 14 days soaking periods ranged between 13- to 16% for tap water and between 15- to 27% for seawater according to the degree of compaction.

Table 5: Flow values [mm] at different degrees of compaction and soaking periods

Curing periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea · water	Tap water	Sea water	Tap water	Sea water
No. Soaking	3.8	3.8	3.3	3.3	3.0	3.0
1 day	4.1	3.5	3.2	3.7	2.8	3.2
3 days	3.7	4.2	3.8	3.3	3.2	3.1
7 days	4.2	4.4	3.7	4.1	3.0	3.3
14 days	4.4	4.6	3.8	3.9	3.4	3.8

Indirect Tensile Strength

The tensile strength of asphalt mixture is a measure of pavement resistance to tensile stresses caused by traffic. For durable asphaltic mixtures, high tensile strength values are required. The indirect tensile strength was selected to study the fatigue properties of asphaltic concrete mixtures. In the test, Marshall specimens were loaded with a vertical compressive stress in the diametrical direction and the deformations in the direction of loading and lateral direction were measured.

In this investigation, the indirect tensile strength for dense graded asphaltic mixtures was studied at different degrees of compaction and various states of soaking period. Indirect tensile strength tests were performed at room temperature using a vertical deformation rate of 50 mm/ min.

The indirect tensile strength was calculated using the following equation (Müller 1979):

$$\mathbf{Ts = 2\,P / \pi\ d\,h \quad [N/mm2]} \qquad \mathbf{(2)}$$

where

Ts = indirect tensile strength [N/ mm2]
P = load at failure [N]
d = diameter of the specimen [mm]
h = height of the specimen [mm]

Table 6 shows the indirect tensile strength values as a function of degrees of compaction, soaking type and soaking periods. From this Table it can be seen that the indirect tensile strength values increased with the increase in degree of compaction (35-, 50- and 75 blows/side). However, these values were significantly affected by increasing the soaking periods from 1 day to 14 days. At lower degree of compaction, 35 blows, the indirect tensile strength values were significantly affected by changing of the water type from tap water to seawater. However, at higher degrees of compaction 50 blows and 75 blows, these values were slightly affected by water type (Voids ratio is higher and consequently increasing of soaking periods is more effective). At 35 blows, the reduction in indirect tensile strength was 38% and 63% at 14 days soaking time for mixtures soaked in tap water and seawater respectively. After one day soaking time, the reduction in the indirect tensile strength using seawater was about 36%, 14% and 12% at 35, 50 and 75 blows respectively.

The relationship between indirect tensile strength (ITS), curing time (Ct) and compaction effort (Ce) was calculated by using computer program QS. The multi-regression relationship was as follows:

$$\mathbf{ITS = 21.19 - 1.41\,(Ct) + 0.67\,(Ce) \qquad R^2 = 0.89 \qquad (3)}$$

where

ITS = Indirect tensile strength, N/mm2

Table 6 : Indirect Tensile Strength Values [N/cm2] at Different Degrees of Compaction and Soaking periods

Curing periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea water	Tap water	Sea water	Tap water	Sea water
No. Soaking	60	60	64	64	72	72
1 day	57	38	62	55	69	63
3 days	53	30	58	52	67	61
7 days	42	26	55	45	65	60
14 days	37	22	45	40	63	58

Effect of Tap Water and Seawater on the Failure Strain [0/00]

The tensile strain at failure is directly related to cracking of the highway pavement. The occurrence of cracking increased as the failure strain decreased (Hanley et al 1984 and Brown 1989). The following equation was used to calculate the failure strain for different mixtures.

$$P = (2U/ \pi d)((1+3u) / (0.273 + u))$$

where

P = strain at failure [o/oo]
d = diameter of specimens [mm]
u = Poisson ratio, = 0.3
U = Transverse deformation [mm]

Substituting u=0.3

$$\therefore P = 6.63\, U / \pi\, d \qquad [o/oo] \qquad (4)$$

Table 7 shows the results of strain at failure for mixtures at different degrees of compaction and soaking periods. It may be noted that the values of failure strain decreased significantly with the increase in degree of compaction, while the influence of increasing soaking time is significant only at 35 blows/side compaction effort.

Moreover, It can be seen that there was no trend of strain at failure by increasing the soaking periods from 1 day to 14 days. Furthermore, mixtures with high degree of compaction, 75 blows, gave a lower strain at failure at different soaking periods and water type. From test results presented in Table

7, it can be seen that changing water type from tap water to seawater does not affect the strain at failure at different degrees of compaction and soaking periods.

Table 7 : Failure Strain [o/oo] at Different Degrees of Compaction and Soaking periods

Curing periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea water	Tap water	Sea water	Tap water	Sea water
No. Soaking	4.5	4.5	4.0	4.0	3.6	3.6
1 day	4.2	4.0	3.8	3.6	3.4	3.2
3 days	3.8	3.5	3.2	3.5	3.2	3.1
7 days	3.5	3.2	3.4	3.2	3.0	3.0
14 days	3.6	3.4	3.0	3.3	3.0	3.2

Relation Between Marshall Stability and Indirect Tensile Strength:

In order to obtain a relation between Marshall stability (M) and Indirect tensile strength (ITS) of dense graded mixtures at different compaction levels and soaking periods, a statistical regression analysis was applied. Tables 3 and 5 show the values of M and ITS at different degrees of compaction and soaking periods. The relationship may be approximated by an exponential equation. The following equation is used to fit the data by a least squares procedure:-

$$\mathbf{ITS = a\ e^{(b\,M)}} \qquad \mathbf{(5)}$$

Where,

ITS = The Indirect tensile strength Values [N/mm2] at different soaking times

M = Marshall stability values [N] at different soaking times

a and b are the parameters [-] dependes on type of water and degree of compaction.

R^2 correlation coefficient [-]

s standard deviation

Table 8 : Regression Coefficients

Curing periods	35 Blows		50 blows		75 Blows	
	Tap water	Sea water	Tap water	Sea water	Tap water	Sea water
a.	31.3889	17.5203	38.9320	34.5108	56.8273	51.4251
b.	0.00015	0.00028	0.00007	0.00010	0.00003	0.00004
R2	0.994	0.977	0.855	0.962	0.860	0.950
s.	0.0192	0.0682	0.0612	0.0408	0.0225	0.0214

Table 8 represents the values of two constants "a" and "b", the correlation coefficient and standard deviation for the six cases under study. According to the results given in this Table, it can be clearly seen that the tap water had a higher values of parameter " a" than the seawater at the same degree of compaction. It was also found that the value of parameter " a" increased by increasing the degree of compaction from 35 blows to 75 blows.

On the other hand, it could be seen that the values of parameter " b" for mixtures using tap water were higher than those of mixtures using seawater at different degrees of compaction. Moreover, value of the parameter "b" was significantly influenced by increasing the degree of compaction from 35 blows to 75 blows at different water types. In case of tap water, it can be noted that the increase in the degree of compaction from 35 blows to 50 blows and from 50 blows to 75 blows, led to a decrease in the parameter " b" by about 53% and 57%, respectively. In case of sea water; by increasing the degree of compaction from 35 blows to 50 blows and from 50 blows to 75 blows, a decrease in the parameter "b" by about 64% and 60%, respectively were noticed.

Generally, it can be concluded that the two parameters "a" and "b" depend on the experimental results, type of water and degrees of compaction used in this investigation.

Properties of Mixtures Using Vacuum Saturation Tests

Vacuum saturation test consists of immersing the specimens in jars filled with tap water, pulling a 26-inch Hg vacuum and keeping the submerged specimens in jars for 1 day ,3 days, 7 days and 14 days at atmospheric pressure. After that, the specimens are submerged in a water bath at the test temperature for 30 min. The water under pressure forces the air in specimens voids to leave, then the water fills the voids. By these methods of tests, the deterioration of specimens becomes more effective. After soaking periods the specimens were tested using Marshall test machine. Maximum stability- and flow values are determined. Referring to Table 9, it appears that soaking periods has an influence on the properties of dense asphaltic mixtures using vacuum test. It should be noted that stability values before soaking is approximately from 2 or 3 times higher than those produced after 14 days soaking according to degrees of compaction. Furthermore, the results showed that there is no appreciable difference between the Marshall properties of dense graded asphaltic mixtures using vacuum saturation test and traditional tests.

Table 9 : Marshall Properties Using Vacuum Saturation Condition (Case of Tap water)

Curing periods	35 Blows		50 blows		75 Blows	
	Stability [N]	Flow [mm]	Stability [N]	Flow [mm]	Stability [N]	Flow [mm]
No. Soaking	4300	3.8	6365	3.3	7320	3.0
1 day	4160	3.5	6350	3.7	7210	3.2
3 days	3450	4.2	5880	3.3	6600	3.1
7 days	1780	4.4	3410	4.1	4220	3.3
14 days	1320	3.8	2590	3.9	3400	3.8

CONCLUSIONS

Based on the results and analysis presented in this research, the following can be concluded.

1. Seawater has a great effect on the mechanical properties of asphaltic mixtures than tap water under different variables used in this study.

2. Compaction effort and soaking period have great effect on the tensile strength of the dense graded asphaltic concrete mixtures.

3. It can also concluded that there is no appreciable difference between the Marshall properties of dense graded asphaltic mixtures using vacuum saturation test and traditional tests according to the conducted tests.

4. The variation in the strain at failure due to the changing of the water type from tap to sea water is not significantly affected by soaking periods at the same degree of compaction

5. The indirect tensile strength can be related to the stability values at the same degree of compaction with reasonable values of correlation coefficients as follows:-

$$ITS = a\ e^{(b\,M)}$$

where

ITS = The Indirect tensile strength Values [N/cm2] at different soaking times

M = Marshall stability values [N] at different soaking times

a and b are the constants [-] depended on type of water and degree of compaction.

6. It can be concluded that the roads subjected to seawater should be constructed using compaction effort higher than other roads to eliminate the influence of seawater.

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مقارنة بين تأثير المياه العذبة ومياه البحر على الخواص الميكانيكية لخلطات الخرسانة الإسفلتية ذات التدرج الكثيف

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ملخص البحث:

إن الضرر الذى يسببه تأثير المياه والرطوبة يمثل مشكلة كبيرة للرصف الإسفلتى حيث أن هذا الضرر يسبب سلسلة من الاجتهادات ويقلل الأداء وأيضا يؤدى إلى زيادة تكاليف عمليات الصيانة للرصف ويمكن أن يؤدى إلى النضح والتخدد وانفصال الركام من سطح الطريق وتكون نتيجة ذلك انهيار كامل للرصف بسبب التشكل الدائم والشروخ. ولذلك يجب عمل التصميم الهندسى الجيد المطابق للمواصفات للخلطات الإسفلتية المستخدمة فى هذه الطرق المعرضة للمياه.

إن الطرق المجاورة لشواطئ البحار فى البلاد الساحلية تتعرض لمشكلات كثيرة من تأثير مياه البحر وأيضا من عوامل الطقس الأخرى بالمناطق الساحلية. لذلك كان الهدف الأساسى من هذا البحث هو دراسة مدى تأثير المياه بصفة عامة وماء البحر بصفة خاصة على الخواص الميكانيكية للخلطات الإسفلتية. وأيضا عمل مقارنة بين تأثير كلا من المياه العذبة والمياه المالحة (ماء البحر) على هذه الخواص. وفى هذا البحث تم استخدام اختبار مارشال واختبار الشد الغير مباشر لقياس الخواص الميكانيكية للخلطات الإسفلتية ، وتم أيضا معالجة العينات لفترات زمنية مختلفة للتشبع بالمياه فى وجود الهواء بالفراغات والتشبع بالمياه بعد تفريغ العينات من الهواء المحصور فى فراغاتها.

من دراسة وتحليل نتائج هذا البحث أتضح أن مياه البحر لها تأثير أقوى من المياه العذبة على ضعف وسوء الخواص الميكانيكية للخلطات وبالتالى على انهيار الرصف. ولذلك أوصى البحث بضرورة زيادة طاقة الدمك لتقليل الفراغات وبالتالى تقليل تأثير مياه البحر وذلك بالنسبة للطرق المجاورة للبحار فى المدن الساحلية.