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Enhancement the performance of asphalt mixtures using polymers additives in dry process

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الملخص العربى :

معظم الخلطات الأسفلتية الساخنة بمصر لا تحقق الأداء المطلوب خاصةً المقاومة للإجهادات والتخدد حيث أنها أكثر العيوب الشائعة. علاوة على ذلك الزيادة الكبيرة فى الأحمال المرورية ودرجات الحرارة والتغيرات المفاجئة فى درجات الحرارة أدت إلى عيوب بسطح الرصف الأسفلتى على المدى القصير. على مدى العقد الماضي حاول الباحثون زيادة قدرة الرصف المرن على تحمل الأحمال الجديدة وتحديات الأداء. إستخدام محسنات الخلطات الأسفلتية كالبوليمر أدى إلى تحسين خواص الخلطات الأسفلتية وزيادة عمر الطريق . نظرًا لأن البيتومين هو المكون الأساسي للخرسانة الإسفلتية ، فإن زيادة قوة البيتومين ومرونته هي دائمًا إحدى الإستراتيجيات الرئيسية لإنتاج خليط أفضل. هناك طريقتان لإستخدام البوليمر كمحسن للخلطات الأسفلتية الطريقة الرطبة والطريقة الجافة . هذه الدراسة تهدف إلى تحسين أداء الخلطات الأسفلتية بإستخدام البوليمر بالطريقة الجافة . الخصائص الميكانيكية للخلطة الأسفلتية المستخدمة تم تقيمها بإستخدام إختبار مارشال ومعاملاته (الثبات ,الإنسياب) والمقاومة للرطوبة وإختبار إجهاد القص غير المباشر وإختبار معاير المرونة الديناميكى ورقم الإنسياب. تم مقارنة خصائص الخلطة الأسفلتية بعد إضافة البوليمر (سوبر بلاست) بخصائصها قبل إضافة البوليمر ولوحظ التحسن فى خصائصها . تم تحديد النسبة المثلى لإضافة البوليمر (سوبر بلاست) 5 – 10 % من وزن البيتومين.

الكلمات المفتاحية : الطريقة الجافة, الخلطات الأسفلتية, المارشال, إجهاد الشد غير المباشر, إختبار معاير المرونة الديناميكى ورقم الإنسياب.

ABSTRACT:

The majority of hot asphalt mixtures used in Egypt do not encounter the standard critical required performance. Resistance to fatigue and rutting surface deformation are two of the most common pavement surface defects in Egypt.
Furthermore, the significant increase in traffic loads, severe climate changes, and ultimate temperature variation have resulted in pavement surface defects in the short run. Over the last decade, researchers have attempted to increase flexible pavement's ability to withstand new loadings and performance challenges. Using asphalt mixture modifiers such as polymers led to improve the mechanical properties of asphalt mixtures and an increase in their service life.

Since bitumen is the primary component of asphalt concrete, expanding bitumen strength and elasticity is always one of the major strategies for producing a better mixture. Polymer is added to bitumen to improve performance using one of two methods: the wet process or the dry process (ALABASSE, 2016) (Azam et al., 2019).

Adapting dry process technique in modifying asphalt concrete performance is the main scope of this study. Performance evaluation processes were used in this study to establish the variation in asphalt mixture properties due to dry process modifications. Performance analysis included stability, flow, moisture susceptibility, indirect tensile strength, dynamic modulus test, and flow number.

SUPERPLAST mixture modifier was added to dense graded hot asphalt mixture (4 c) at varying percentages. The properties of the SUPERPLAST-added asphalt mixture were compared to the properties of the conventional mixture (control mix). The SUPERPLAST-enhanced mixture performed better than the conventional mixture in all performance analysis tests. It was found that the optimal SUPERPLAST content was 5 to 10% of the bitumen weight.

KEYWORDS:

SUPERPLAST, Dry process, Asphalt mixtures, Marshall, Indirect Tensile strength, Dynamic modulus, Flow number.

1. INTRODUCTION

The rapid and continuous increase in traffic volumes, high temperatures, climate change, and irregularity in the maintenance of Egypt's existing road network have led to the rapid suppression of the country's road network. These factors would have a deleterious impact on travel time, citizen movement, fuel consumption, and vehicle destruction, as well as the high costs required to maintain the road network in an attempt to optimize its serviceability.

The high efficiency of the road network is a great indicator of rapid economic development, attracting more local and foreign investments, providing a lifeline for people, and providing access to remote areas. As a matter of fact, it is critical to improve the characteristics of the asphalt mixture in Egypt in order to endure increased high loads, high temperatures, and climate change.

Many additives, including the polymer SUPERPLAST, were being used to optimize the process parameters of the asphalt mixture. Consequently, it would be a great solution for the previously mentioned problems to use polymers with the HMA used in Egypt.

Two main types of polymers are commonly used to improve the properties of asphalt mixtures: PLASTOMER (increase stiffness) and ELASTOMER (increase elasticity) (ALABASSE, 2016).

Some polymers exhibit elastic behaviour (resilient), meanwhile, others show plastic one (permanent) during service temperatures (ALABASSE, 2016).

Many factors should be considered when using polymers, such as the properties of the polymers and the blending method, as many asphalt cements cannot be blended with polymers (Becker et al., 2001).

2. Material

Asphalt concrete mixes investigated in this study consisted of coarse aggregate, fine aggregate, mineral filler, conventional asphalt, and additives (polymer). According to American Association of State Highway and Transportation Officials standards (AASHTO), the engineering characteristics of the mixed materials were determined. The different characteristics of the studied materials are presented in the following sections.

2.1 coarse Aggregates

The coarse aggregate used in this study is crushed dolomite stone obtained from the ATAQAH quarry in Suez, Particles of coarse aggregate are retained on the #4 sieve (4.75 mm). Dolomite stone is the most common type of aggregate used in road construction in Egypt. The engineering properties of this aggregate were determined in the laboratory according to the specification limits set by the Egyptian Code of Practice (ECP) (Practice, 2008). These properties are presented in Table (1).

Table 1 :COARSE AGGREGATE PROPERTIES

Test	Type of aggregates	AASHTO Standard	results	Specifications Limits (ECP, 2008)
Abrasion value after 500 revolutions	Pin 2	T-96	22.5	≤ 40%
	Pin 1		23.2	
Water absorption	Pin 2	T-85	1.2	≤ 5%
	Pin 1		1.3	
Specific gravity	Pin 2	T-85		
-Bulk			2.646	
-Saturated			2.677	
-Apparent			2.733	
Specific gravity	Pin 1			
-Bulk			2.651	
-Saturated			2.686	
-Apparent			2.747	

2.2 fine aggregates

The fine aggregate (passing No. 4 and retained on No. 200) used in this research is crushed sand obtained from the ATAQAH quarry in Suez and natural sand. Its bulk specific gravity is 2.683 and 2.66 respectively .

2.3 Mineral aggregates

The mineral filler used in investigated mixes is lime stone dust with 2.74 bulk specific gravity. Table (2) presents the gradation for the coarse aggregate pin 1 and pin 2, natural sand, crushed sand, and the mineral filler.

Table 2 :AVERAGE GRADATION FOR PIN1&PIN2&NATURAL SAND

Gradation of Conventional Aggregate				
Sieve Size (Inch)	Sieve Size (mm)	% Passing pin 2	% Passing pin 1	%Passing natural sand
#1	25.00	100	100	100
#3/4	19.00	84.7	100	100
#1/2	12.5	42.3	100	100
#3/8	9.50	1.7	74.9	100
#4	4.75	0.3	5.7	100
#8	2.36		0.4	94.1
#30	0.60		0.2	49.1
#50	0.30		0.2	25.8
#100	0.15		0.2	9.7
#200	0.075		0.1	2.5

Table 3 :CONTINUE TABLE (2) AVERAGE GRADATION FOR CRUSHED SAND AND MINERAL FILLER

Gradation of Conventional Aggregate			
Sieve Size (Inch)	Sieve Size (mm)	% Passing Crushed Sand	% Passing mineral filler
#1	25.00	100	100
#3/4	19.00	100	100
#1/2	12.5	100	100
#3/8	9.50	100	100
#4	4.75	100	100
#8	2.36	74.1	100
#30	0.60	35.2	100
#50	0.30	22.8	97.00
#100	0.15	15.3	88.5
#200	0.075	4.6	75.5

2.4 Asphalt binder

The type of asphalt that was used in this study is Alexandria asphalt cement, the most common type in Egypt. Its penetration grade is 60/70 and has a specific gravity of 1.020 with minimum kinematic viscosity (320) centistokes at temperature (135) ^{o}c.
The properties of binder asphalt are presented in Table (4).

Table 4: BITUMEN BINDER VALIDATION TESTS RESULTS

Test	standard	value	ECP Limitations	
Penetration Test (25℃)	ASTM D5	65.5	60	70
Softening Point	ASTM D36	51	45	55
Rotational Viscosity at 135 ℃	ASTM D4402	430	320	…

2.5 SUPERPLAST

SUPERPLAST is a PLASTOMERIC polymeric compound of selected thermoplastic polymers made of flexible granules which are used as rheological modifiers for asphalt mixes. The SUPERPLAST physical characteristics as obtained from the manufacturer are summarized in Table (5) (*TDS Ravasol PLAST*, 2018).

Figure (1) shows the SUPERPLAST.

Table 5: PROPERTIES OF SUPERPLAST

Properties	
Appearance	Black granule (ϕ < 4.0 mm)
Softening point (o C)	120
Melting point (o C)	150
Bulk density (gr/cm3)	> 0.850
Ash content (%)	< 1.0

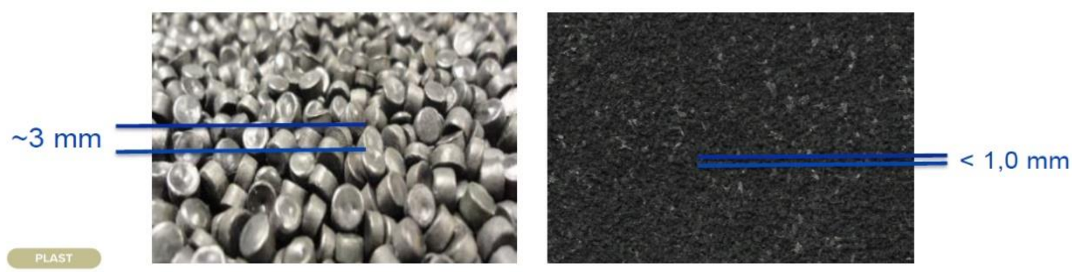

Figure 1 :SUPERPLAST GRANULAR

3. EXPERIMENTAL PROGRAM

3.1 Marshall Stability and flow

According to the AASHTO T245 procedure for both the control mix and modified asphalt mixtures, Marshall stability and flow were determined.

Five different percentages of bitumen (4.0, 4.5, 5.0, 5.5, 6.0) were mixed with the blended aggregate.

The volumetric properties of 15 Marshall specimens were determined (3 specimens at each bitumen percentage). At 60 °C, the samples were loaded into the Marshall Equipment to determine the stability and flow.
According to the Egyptian specifications (Practice, 2008), the optimum asphalt content was determined. Then this asphalt content was used to make sure it meets the mixed design criteria shown in Table (6).

Table 6 :CONVENTIONAL ASPHALT MIXTURE PROPERTIES

Property	minimum	maximum
Stability (kg)	900	….
Flow (mm)	2	4
Air Voids (AV) %	3	5
Voids in Mineral Aggregates (VMA) %	15	….

3.2 Moisture Susceptibility

To investigate the pavement's ability to resist moisture damage, the Loss of Stability test was determined, which is an important indicator of moisture susceptibility for all asphalt mixtures.
According to the ASTM D1075 procedure, this test was performed in which another three test specimens were prepared according to the same procedure mentioned before in the Marshall Stability and flow test; but the all-test specimens were placed into the water bath for 24 hours.
After that, all specimens were placed in the Marshall testing machine to determine the stability; the percentage difference between the value resulting from the loss of stability and the value of stability from the previously mentioned test, which is known as the loss of stability, as shown in the following equation:

$$\textbf{Loss of stability} = \frac{\textit{average stability of loss of stability test}}{\textit{average stability of marshal stability test}}\ \boldsymbol{x100}$$

3.3 Indirect tensile strength

According to the ASTM D6931 test procedure, the indirect tensile strength test (ITS/IDT) is performed, which is a good indicator for pavement crack resistance (fatigue cracking resistance) and permanent deformation resistance (rutting resistance).
In the ITS/IDT test, the extracted specimens were tested at 25°C on the Marshall Test machine.
With the ITS/IDT mode, the test should be carried out.
The failure load was then recorded. The indirect tensile strength was calculated using the following equation:

$$\text{ITS / IDT} = \frac{2P}{\pi t d}$$

Where: -

P: Load failure (KN)
t: Specimen thickness (m)
d: Specimen diameter (m)
ITS: Indirect tensile strength (KPa)

3.4 Dynamic modulus and flow number tests

According to AASHTO Designation: T 342-11, to indicate the pavement performance under traffic loads during different temperatures The dynamic modulus test is considered one of the most important performance tests that can be used. The normal value of the dynamic modulus is calculated by dividing the maximum (peak-to-peak) stress by the recoverable (peak-to-peak) axial strain for a material subjected to a sinusoidal loading.

A dynamic modulus test system consists of a testing machine, an environmental chamber, and a measuring system.

Dynamic modulus values measured over a range of temperatures (4.4, 21.1, 37.8, and 54°C) and frequencies of loading (0.1, 0.5, 1.0, 5, 10, and 25 Hz) can be shifted into a master curve for characterizing asphalt concrete for pavement thickness design and performance analysis.

The specimen During this test was subjected to cyclic load until the specimen strain reaches 50 to 70 micro strains; this test is considered a non-destructive test because the previously mentioned strain value falls in the viscoelastic zone.

This test specimen is prepared using the same procedure used in AASHTO Designation: T 342-11 using the gyratory compactor.

The test specimen with a 15 cm diameter and 17 cm height was cored to 10 cm diameter and sawed to 15 cm in height using a specimen core.

After setting up the test specimen in the UTM machine, it was loaded with different frequencies (0.1, 0.5, 1, 5, 10, and 25 HZ) at different test temperatures and numbers of cycles.

The specimens were loaded until permanent deformations (rutting) existed. The number of loading cycles that the test specimen resisted until permanent deformation (rutting) happened is considered the flow number, which gives a good indicator of the specimen's ability to resist permanent deformations.

Determining Dynamic Modulus and Developing Master Curves for Asphalt Mixtures (HMA) are determined according to (AASHTO, 2017) (AASHTO: T 342-11, 2015) (TP 79-15, 2017)

4. Results and Analysis

The discussion includes a comparison between the results of modified asphalt mixtures and control mixes to study the effect of using SUPERPLAST as a modifier.

4.1Conventional asphalt mixture

In this study, the 4C dense gradation for wearing course (surface mixes) according to the Egyptian specifications was selected (Practice, 2008). The specification limits of the 4C gradation and the design gradation (Job Mix Formula, JMF) of the investigated mixture are shown in the next figure (2).

To achieve this gradation, the following blend was used: 24% pin 2, 22% pin 1, 35% crushed sand, 16% natural sand, and 3% mineral filler.

Figure 2: JOB MIX FORMULA, JMF

Table 7 :JOB MIX FORMULA FOR THE DESIGNED CONTROL 4-C ASPHALT MIXTURE

Mix property	value
Asphalt binder specific gravity, Gb	1.02
Theoretical maximum specific gravity, Gmm	2.483
Bulk specific gravity, Gmb	2.385
Air voids (%)	4.0
Voids in mineral aggregate, VMA	15.25
Voids filled with asphalt, VFA	73.7
Marshal stability (KG)	1425
Marshal flow (mm)	3.15
Asphalt content by weight (%)	5.25
Marshal loss of stability (%)	17.6
Indirect tensile strength (kg/cm2)	12.96

4.2Modified asphalt mixture

The conventional asphalt mixture was modified by SUPERPLAST. The additives ranged from 5% to 12.5% of the binder's weight.

Three samples were prepared for each percentage of SUPERPLAST. The aggregate was heated to 175 °C, then the SUPERPLAST was added as recommended by the manufacturer, then bitumen was added at 150 °C, then filler was added (mixing time about 6 min and 30 seconds) (Chemical, 2018) (Polymer, 2018) (TDS Ravasol PLAST, 2018).

The following section provides the effect of using different percentages of SUPERPLAST on Marshall's test results. **These parameters are stability, flow, bulk specific gravity**.

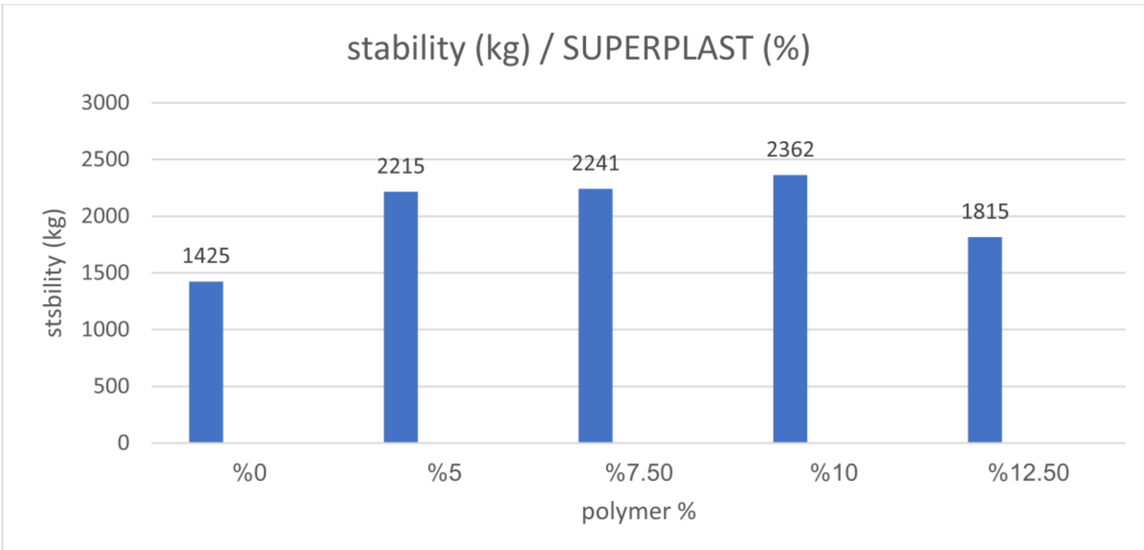

Figure 3: STABILITY VS. %SUPERPLAST

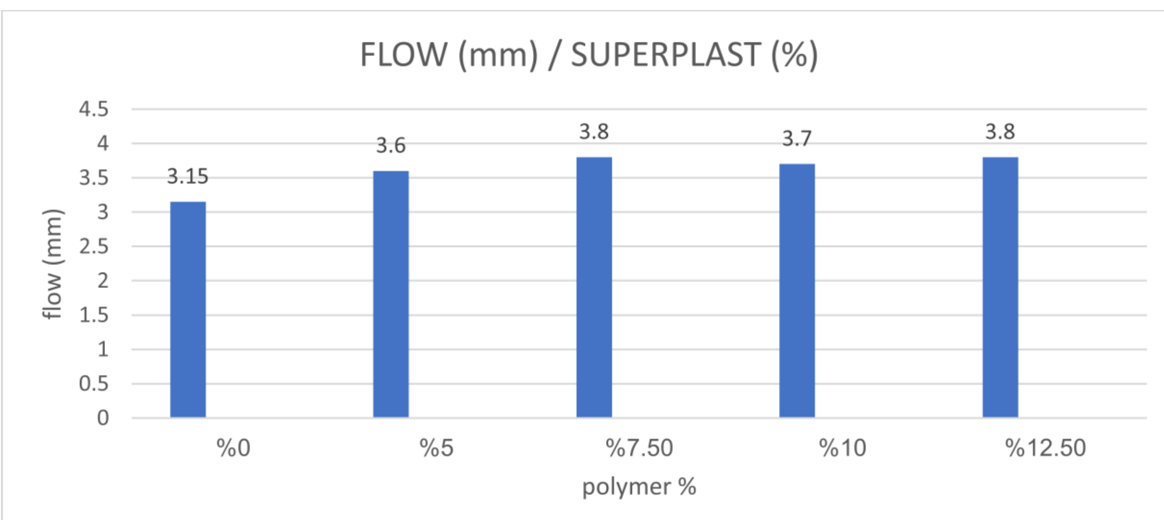

Figure 4: FLOW VS. % SUPERPLAST

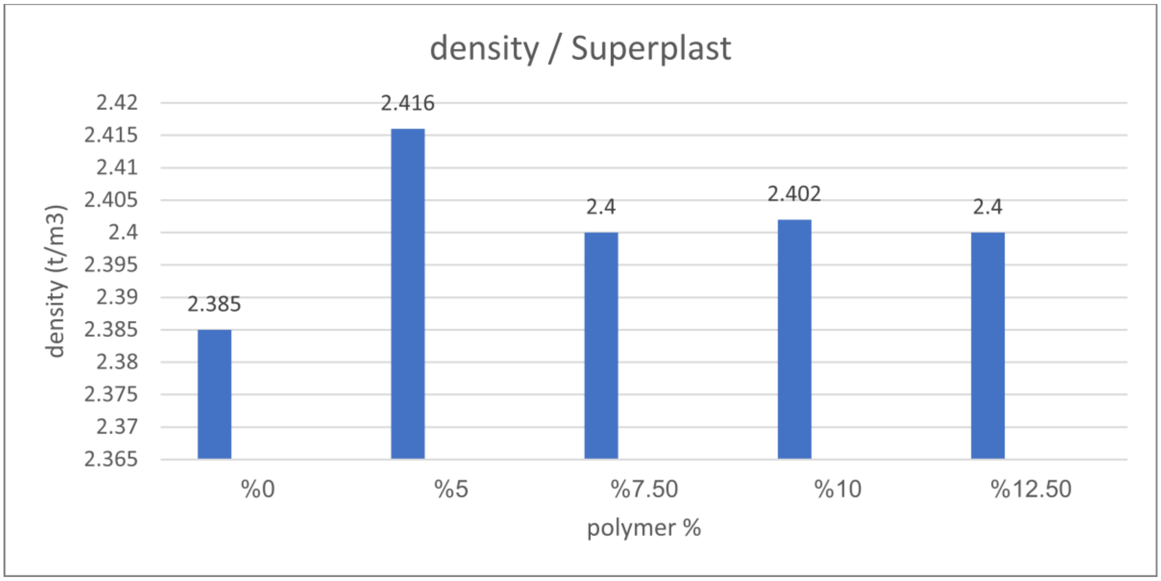

Figure 5: BULK DENSITY VS. % SUPERPLAST

compared to the control mixture. The marshal stability for the asphalt mixtures modified with SUPERPLAST was significantly higher for the modified mixtures compared to the conventional mixtures. It can be noted from the previous results that the optimum percentage of SUPERPLAST is 10%. The Marshal stability was found to increase gradually with the increase of SUPERPLAST until a certain amount, then decrease.

The following section provides the effect of using the optimum percentage of SUPERPLAST 10% on **moisture susceptibility**. These parameters are **loss of stability and indirect tensile strength**.

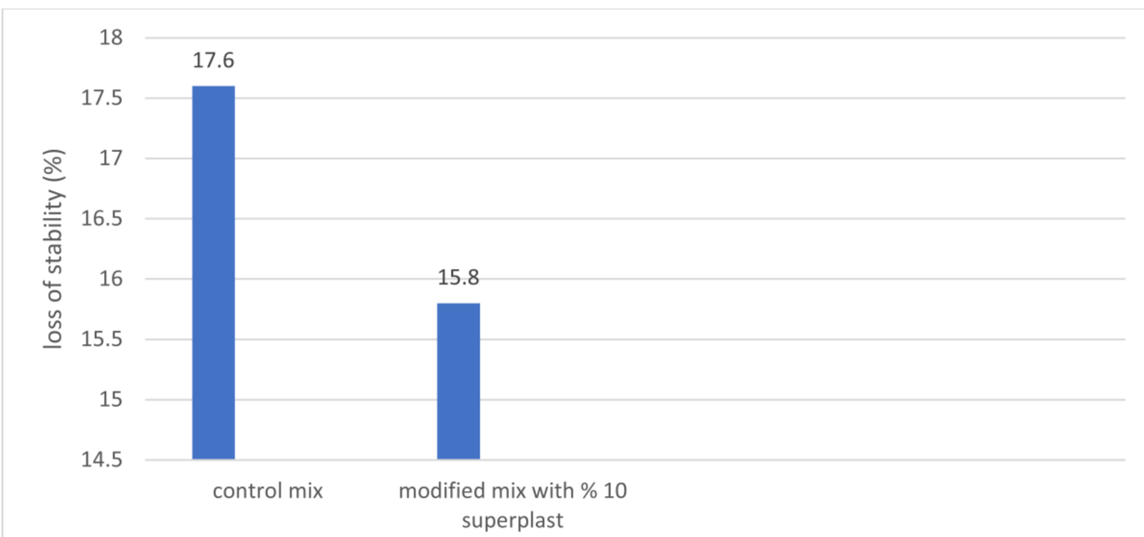

Figure 6: LOSS OF STABILITY VS. % SUPERPLAST PERCENTAGE

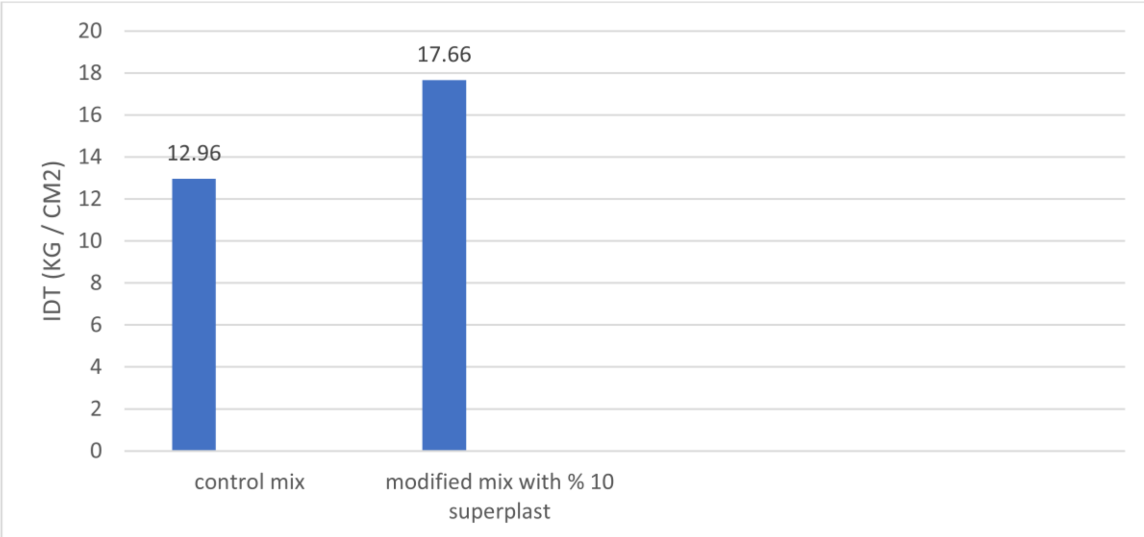

Figure 7: : IDT VS. % SUPERPLAST PERCENTAGE

The results indicate improvement of values of loss of stability and indirect tensile strength for the asphalt mixtures modified with SUPERPLAST due to the improvement of stiffness which leads to an increase in the resistance against cracks and failure.

Dynamic modulus and flow number

The dynamic modulus test and flow number test can represent how the different asphalt mixtures will react with different temperatures and different loading frequencies.

Figure (8) represents the test results of dynamic modulus of control mixture.

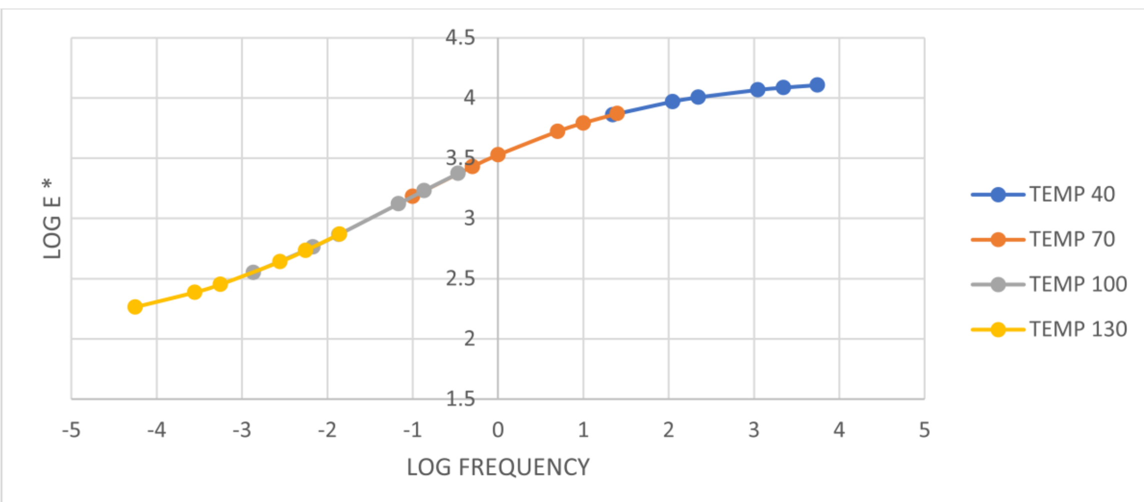

Figure 8: CONTROL MIX E* VS. LOG REDUCED FREQ

Figure (9) represents the test results of the dynamic modulus of the modified mixture.

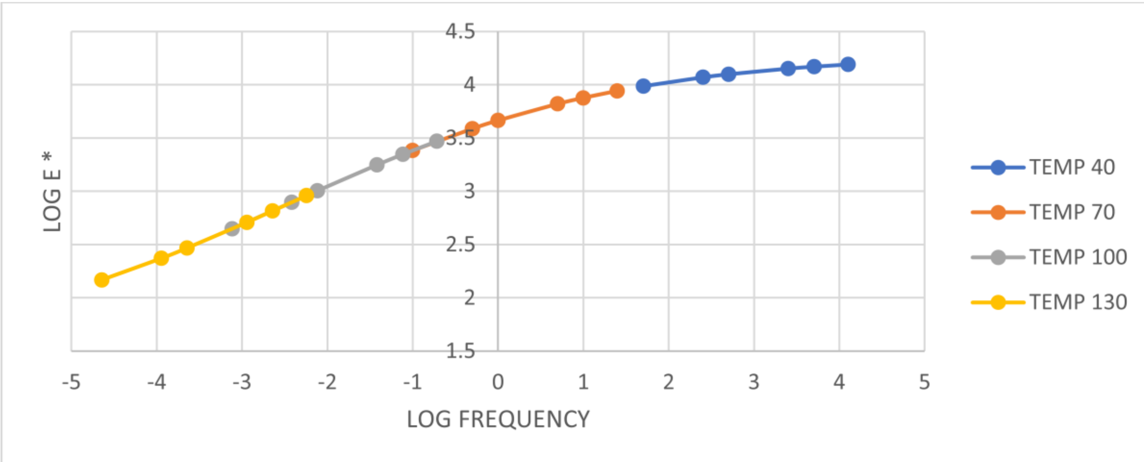

Figure 9: MODIFIED MIX E* VS. LOG REDUCED FREQ

Figure (10) represents the comparison between the test results of the dynamic modulus of control and the modified mixture.

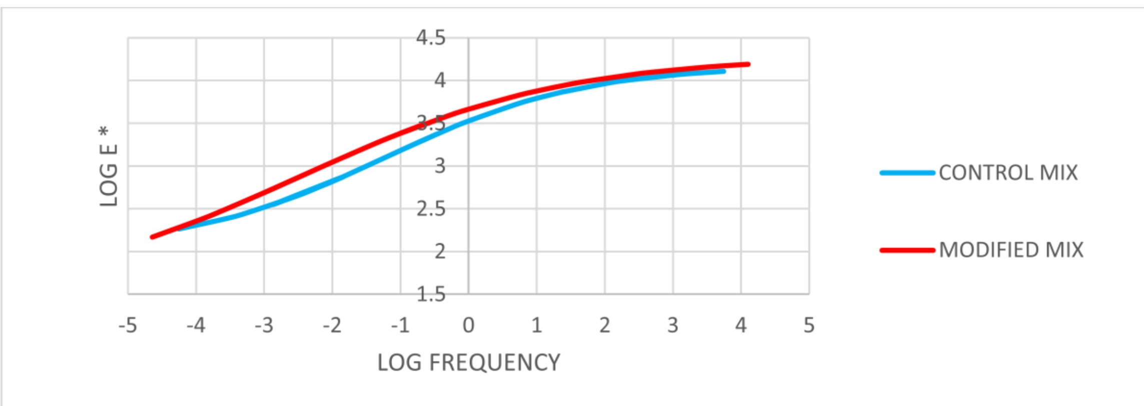

Figure 10: MASTER CURVES FOR CONTROL & MODIFIED MIXTURES

According to the previous charts, it was found that mixtures that contained SUPERPLAST with a percent of 10% gave better performance than the control mixture. The results indicated that adding SUPERPLAST increased the values of $|E^*|$ compared to the control mix. These results indicated that improving the performance of the modified mixes against rutting and cracks at different temperatures and frequencies. Also, the results are compatible with those obtained from the Marshall and indirect tensile tests.

The higher values of E* perform the behaviour of HMA in cold conditions and at different frequencies.

Also, the lower values of E* perform the behaviour of HMA in hot conditions and at different frequencies.
In hot climates like the upper Egypt areas, Rutting increases with the increase in temperature or at slow speeds (low frequency of repetition loading). Therefore, increasing the thickness of the asphalt layer is not a practical solution, but increasing stiffness is a perfect solution.
An improvement in fatigue cracking was observed at high speeds (high frequency) or in cold regions.

Flow number

Test specimens that were used in the dynamic modulus tests were also used in the flow number test.
In this test, the specimens were loaded until permanent deformations existed. The number of loading cycles that the test specimen resists until permanent deformation happens is called the flow number.
Figure (11) represents a comparison between test results between the control mixture and the modified mixture with SUPERPLAST.

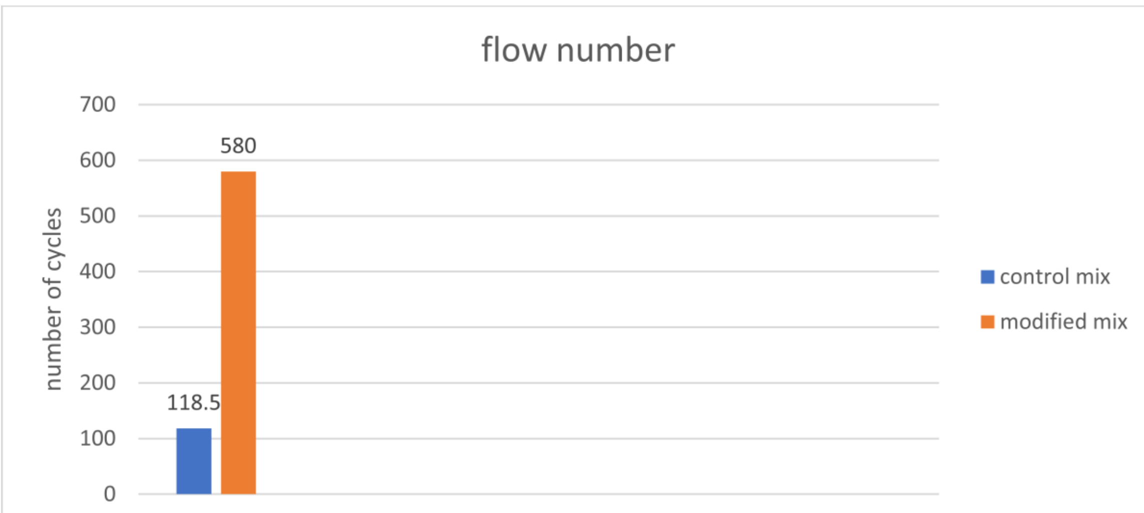

Figure 11: FLOW NUMBER OF CONTROL & MODIFIED MIXTURE WITH SUPERPLAST

Adding SUPERPLAST to HAM increased dynamic modulus │E*│ and flow number (FN) values, which indicate that the performance of hot asphalt mixtures against cracks and rutting has been improved.
According to AASHTO Designation: TP 79-15, the value of flow number (580) cycles is considered good for traffic between 10 and 30 million ESALs (TP 79-15, 2017).

Table 8 : Summary for all testing of modified HMA

Mix property	value
Asphalt binder specific gravity, Gb	1.02
Theoretical maximum specific gravity, Gmm	2.501
Bulk specific gravity, Gmb	2.395
Air voids (%)	4.24
SUPERPLAST content by weight of bitumen (%)	10
Marshal stability (KG)	2362
Marshal flow (mm)	3.6
Asphalt content by weight (%)	5.25
Marshal loss of stability (%)	15.8
Indirect tensile strength (kg/cm2)	17.66

5. Conclusion

According to the previous results, the major conclusions of the research are summarized as follows:

1-The optimum percentage for the SUPERPLAST was 10% by the weight of the asphalt binder based on Marshall properties.

2-Marshall stability was increased by about 65% with adding of SUPERPLAST.

3-The values of loss stability for the modified asphalt mixtures were improved compared to the conventional mixture.

4-The indirect tensile strength results for the modified asphalt mixture were improved by about 36% with adding of SUPERPLAST.

5-Adding SUPERPLAST to HAM increased dynamic modulus $|E^*|$ and flow number (FN) values, which indicate that the performance of hot asphalt mixtures against cracks and rutting has been improved in extreme climate conditions, especially in high-temperature environments.

6-According to AASHTO Designation: TP 79-15, the value of flow number (580) cycles is considered good for traffic between 10 and 30 million ESALs (heavy duty).

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