Journal of Al-Azhar University Engineering Sector

Vol.15, No. 54, January 2020, 100- 111

EVALUATION OF SEMI-FLEXIBLE PAVEMENT PERFORMANCE

Momtaz Mohamed Gamal Othman*[1], Zeinab Salah El-Din Hussein[2] and Ahmed Ibrahim Abu El-Maaty[3]

[1] General Authority of Roads, Bridges and Land Transport, Cairo, Egypt

[2] Building Materials Research and Quality Control Institute at the National Center for Housing and Building Research, Cairo, Egypt

[3] Roads and Airports Engineering Department, Faculty of Engineering, Menoufia University, Menoufia, Egypt

*Corresponding Author E-mail: engmizoazaam@gmail.com

ABSTRACT

This study aims at characterization and design new special type of asphalt mixture having lower asphalt content and higher rutting resistance to be used in paving surface layers at heavy loads areas. To achieve this objective, grouting technique of permeable open graded asphalt mixtures was used. Such type of pavement is called as a semi-flexible pavement (SFP) or grouted macadam (GM). Different compaction efforts were used to achieve the required percent of connected air voids between the bitumen coated aggregates. Crushed silica limestone, crushed sand, and filler were used to prepare highly permeable asphalt mixtures. Asphalt contents of these mixes were determined theoretically and It was ostensibly examined by the laboratory. Marshall molds representing open graded mixtures were prepared and grouted using a grout composed of ordinary Portland cement (OPC) as well as a mixture of some concrete additives with different ratios. Choosing the suitable grout mixture depended on the flow time, flexural and compressive strengths for lab-produced grout prisms. Measuring Marshall stability, Marshall flow, and indirect tensile strength test were conducted on grouted asphalt mixes to identify their properties. The same tests were conducted on crushed silica limestone open graded mix of 2C gradation (Egyptian Standards for Roads) for comparison purposes. Analyzing the study results, positive effect of grouting open graded mixes was concluded using a mixture of OPC, fine sand, silica fume and superplasticizer. The required bitumen content for surface layers was decreased by percent between 27% to 37% compared with traditional dense asphalt mixtures. The resistance of rutting for grouted mixes was increased through increasing stability and indirect tensile strength by about 3 times and more compared with traditional open asphalt mixtures.

KEYWORDS : Semi-Flexible Pavement, Grouted Macadam, Open Graded Mixture, Ordinary Portland Cement, Silica Fume, Fly Ash, Marshall Stability.

" تقييم أداء الرصف شبه المرن "

ممتاز محمد جمال عثمان*[١] و زينب صلاح الدين حسين[٢] وأحمد إبراهيم أبو المعاطي[٣]

[١] الهيئة العامة للطرق والكباري والنقل البري ، القاهرة ، مصر

[٢] معهد بحوث مواد البناء وضبط الجودة بالمركز القومي لبحوث الإسكان والبناء ، القاهرة ، مصر

[٣] قسم هندسة الطرق والمطارات، بكلية الهندسة ، جامعة المنوفية ، المنوفية ، مصر

*البريد الاليكتروني للباحث الرئيسي : Email: engmizoazaam@gmail.com

الملخص

تهدف هذه الدراسة إلى توصيف وتصميم نوع خاص جديد من الخلطات الإسفلتية التي تحتوي على محتوى أسفلتي أقل ومقاومة عالية للكسر تستخدم في طبقات الرصف السطحية بالمناطق ذات الأحمال العالية. ولتحقيق هذا الهدف تم استخدام

تقنية حقن الخلطات الإسفلتية المفتوحة المنفذة. ويسمي هذا النوع من الرصف بالرصف شبه المرن أو المكدام المحقون. تم استخدام جهود دمك مختلفة للوصول إلى النسبة المئوية المطلوبة من الفراغات الهوائية المتصلة الموجودة بين حبيبات الركام المغطى بالبيتومين. تم استخدام الحجر الجيري السيليسي المكسر والرمل المكسر والبودرة لإعداد خلطات الإسفلت عالية النفاذية. كما تم تحديد محتوي البيتومين اللازم للخلطات نظريا وتم فحصه ظاهريا بالمعمل. تم إعداد قوالب مارشال التي تمثل الخلطات المتدرجة المفتوحة وحقنها باستخدام مونة مكونة من الأسمنت البورتلاندي العادي بالإضافة إلى مزيج من بعض الإضافات الخرسانية بنسب مختلفة. ويعتمد اختيار خليط المونة المناسبة بناء على وقت التدفق ، ومقاومة الانحناء والضغط لمنشورات المونة المنتجة في المعمل. وتم إجراء قياسات ثبات مارشال ، وإنسياب مارشال ، واختبار مقاومة الشد غير المباشر على خلطات الأسفلت المحقون لتحديد خصائصها. كما تم إجراء نفس الاختبارات على خليط متدرج من الحجر الجيري السيليسي المكسر ذات تدرج ٢ج (المواصفات المصرية للطرق) لأغراض المقارنة. وعند تحليل نتائج الدراسة لوحظ التأثير الإيجابي لحقن خلطات متدرجة مفتوحة باستخدام خليط من الأسمنت البورتلاندي العادي والرمل الناعم وغبار السيليكا ، ومادة السوبربلاستيزر. كما انخفض محتوى البيتومين المطلوب للطبقات السطحية بنسبة تتراوح بين ٢٧ ٪ إلى ٣٧ ٪ مقارنة بخلطات الإسفلت التقليدية الكثيفة. وزادت مقاومة حدوث التخدد للخلطات المحقونة من خلال زيادة الثبات ومقاومة الشد غير المباشر بما يعادل ٣ مرات وأكثر مقارنة بخلطات الإسفلت التقليدية المفتوحة.

الكلمات المفتاحية : الرصف شبه المرن ، المكدام المحقون ، الخلطات الإسفلتية المفتوحة ،الأسمنت البورتلاندي العادي، غبار السيليكا، الرماد المتطاير ، ثبات مارشال .

1. INTRODUCTION

Road surfacing or the surface course demands an adequate quality and durability to ensure satisfactory riding quality. Common road surfacing problems include surface cracks, rutting, and raveling which cause potholes and particle losses. Studies had been done to increase the quality and durability of traditional types of pavement. These studies included improving binder properties with additives (crumb rubber, plastic, polymer and others) and the usage of different types and gradations of aggregate (Asphalt Institute, 2014) (Nikolaides, 2015).

Therefore, the aim of the present work is to find out the middle path between the flexible pavement and rigid pavement. An alternative pavement that is currently new is the jointless semi-flexible pavement. SFP has also been known as grouted macadam surfacing, resin modified pavement, semi-rigid pavement (SRP), cement concrete composite, or some brand names by other agencies, regions and authorities. Most importantly, all mentioned names carry the same meaning, with just differences in its terminology. The new surface course has been introduced to resist for major pavement deterioration problems such as raveling and rutting. It basically focuses on the production of a permeable surface course with high air voids percent which can be filled with high performance grout (Oliveira, 2006) (Jacobsen, 2012) (Setyawan, 2013) (Soliman, 2016) (Tran et al., 2018) (Bonicelli et al., 2019).

SFP is suggested to be used at locations where require particularly heavy and concentrated loading, at areas where likely to have leakage of aggressive materials and at areas that require high surface rigidity. It has gradually become popular for years internationally as a surface layer of pavements under serious conditions such as in roads, road junctions, airport aprons, heavy loading yards, parking areas and container ships places in ports (Pais et al., 2007) (Wu et al., 2011).

2. EXPERIMENTAL MEASUREMENTS:

This research aims to classify the semi-flexible pavement with some variables and factors concerned with improving grout mixture compositions that used for producing SFP and also evaluating their effect on the pavement performance in Egypt.

There is a preliminarily study that precede starting experimental work. The experimental program of this study is shown in Figure (1). The Figure shows that the design program consists of two divisions. The first department scope is studying and selecting the suitable materials to compose open graded mixture with required air voids. On the other hand, the second department scope is studying and selecting the suitable materials to compose flowable grout. The investigated grout mixes composed of ordinary Portland cement, fine sand, silica fume, fly ash, super-plasticizer and water.

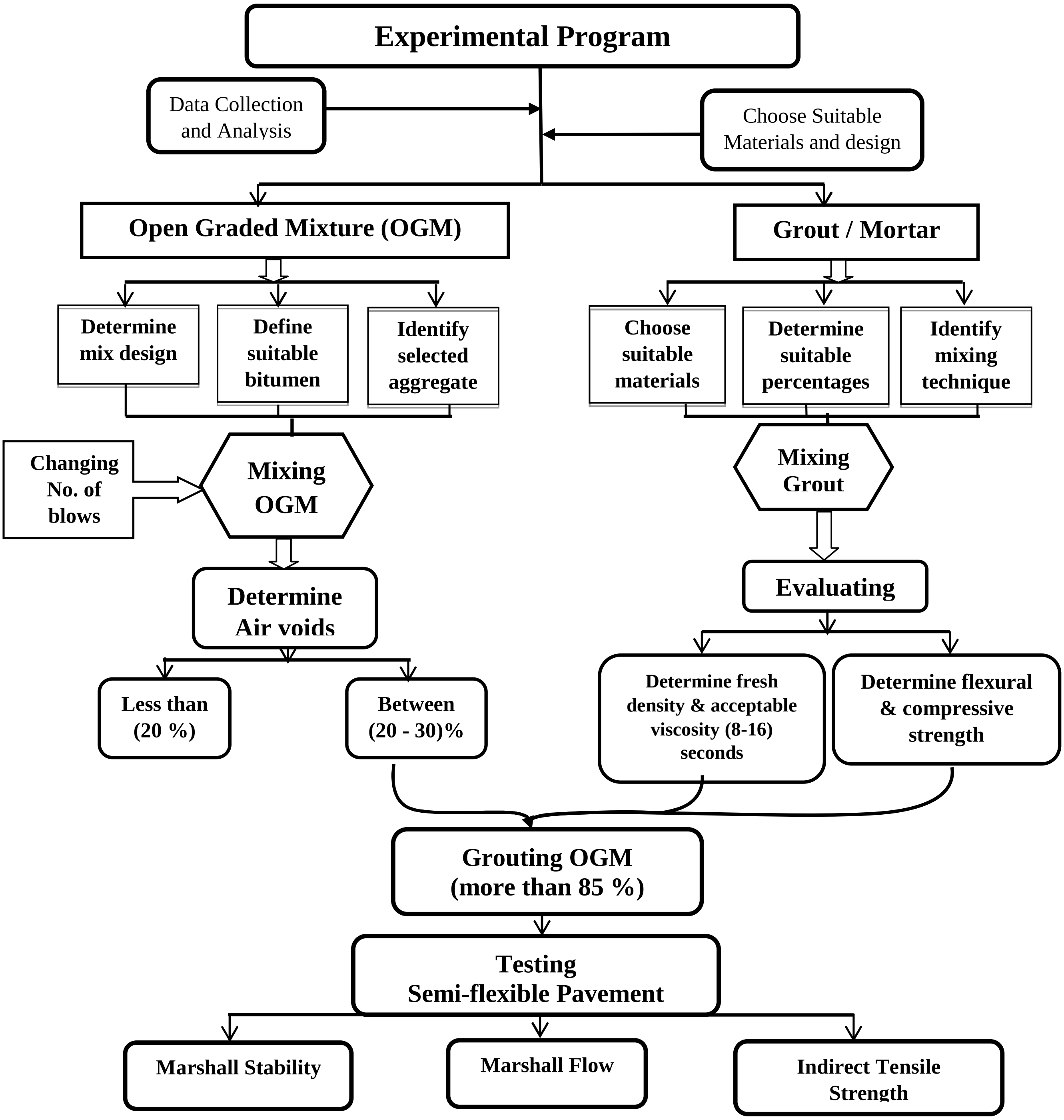

Figure (1) : Experimental Program Stages in General.

Laboratory measurements on each component of semi-flexible pavement specimens were done. The basic scope of these tests was analyzing the influence of variables such as open graded mixture (OGM) grading and grout type on the laboratory testing results and consequently on the final SFP performance. Grout evaluation was defined by testing the workability of liquid grout, flexural and compressive strength of hardened grout prisms. A mix design study for SFP was presented. This design based on fundamental properties and previous field experience. Marshall stability, flow and indirect tensile strength for the grouted open graded mixture specimens were determined according to AASHTO and ASTM specifications. For comparison results, the open graded surface mixture (2C) was selected from the Egyptian specifications. This mix was prepared and evaluated by the same tests to determine the difference between SFP and traditional OGM surface layer.

3. OPEN GRADED MIXTURES

The investigated mixes composed of silica limestone as coarse aggregate, crushed sand as fine aggregate, silica limestone dust as mineral filler and 60/70 penetration grade asphalt cement. Open graded mix gradation (2C) was selected as a control mix for comparison. Table (1) presents the gradation of coarse aggregate, crushed sand and the mineral filler.

Table (1): Gradation of the Used Solid Materials of Open Graded Mixture.

Sieve size (in)	% Passing				
	Coarse Aggregate		Fine Aggregate		Mineral Filler
	Grade 1	Grade 2	Before wash	After wash	
1.5"	100	100	100	100	100
1"	100	100	100	100	100
3/4"	100	85.00	100	100	100
1/2"	91.36	37.72	100	100	100
3/8"	51.10	11.98	100	100	100
No.4	2.73	1.14	100	100	100
No.8	0	0	91	91	100
No.16	0	0	71	72	100
No.30	0	0	47	50	100
No.50	0	0	30	33	97
No.100	0	0	18.4	23	91
No.200	0	0	10.6	15.2	80

The asphalt content of the mixture is critical and must be approximately determined in the laboratory and then precisely controlled on the site. The optimum asphalt content of a mix is highly dependent on aggregate characteristics such as gradation and absorptiveness. Aggregate gradation is directly related to optimum asphalt content. The finer the mix gradation, the larger the total surface area of the aggregate and the greater amount of asphalt required to coat the particles uniformly. Conversely, because coarser mixes have less total aggregate surface area, they demand less asphalt. To determine the optimum asphalt content (OAC), for any gradation; it is necessary to use the surface area equation method as shown below Equation (1).

Eq. (1)

$$OAC = 0.035A + 0.045B + (0.15 / 0.18 / 0.2)C + F$$

where:

A = 100 – % passing sieve no. 8
B = % passing sieve no. 8 – % passing sieve no. 200
C = % passing sieve no. 200
F = absorption constant.

Therefore, many open-graded asphalt mixtures in this study were prepared using gradations from previous researches such as (Anderton, 2000). These mixes did not meet the required percentage of air voids. Therefore, the selection of gradations (OG.1 and OG.4) used in the Soliman's study (2016) became more appropriate to reach the desired goal. Table (2) shows the different selected gradations used and also the gradation of reference mix (2C).

Table (2): Gradations of Investigated Open Mixtures.

Sieve (in)		% Passing							
		1 "	3/4 "	1/2 "	3/8 "	No.4	No.8	No.100	No.200
Mix. Code	OG.1	100	100	90	35	15	5	--	3
	OG.2	100	100	100	90	3	3	--	3
Reference Mix. (2C)		100	100	85	60	30	12.5	--	2

Air voids are a critical design component of asphalt mixtures. The air voids in a paving mixture are small pockets of air between the asphalt coated aggregate particles. After mixing the aggregate gradation of 2C mix with the approximate calculated OAC equal (4.0) %, the molds should be compacted by 75 blows per each side. The compacted mixture was tested for bulk specific gravity, air voids, Marshall Stability and flow moreover indirect tensile strength. The loose mixture was used for determining maximum theoretical specific gravity. For mix (2C), calculating the air voids percent by the following equation according to (AASHTO T-269/ASTM D-3203) depends on many factors concerns basically on the gradation mixture. The bulk specific gravity result from (AASHTO T-166 or T-275 or T-331), and the theoretical maximum specific gravity result from AASHTO T-209 are the two values needed to perform the percent air voids calculation. Although the air voids in compacted mixture can be calculated several different ways, the following equation is most commonly used as followed:

$$A_v = \frac{G_{mm} - G_{mb}}{G_{mm}} \quad \textbf{Eq. (2)}$$

Where:

Av = air voids of total mix. (%)

G_{mb} = bulk specific gravity

G_{mm} = maximum theoretical specific gravity

4. GROUT MIXTURES:

The grout mixtures groups were designed using the selected grout raw materials as ordinary Portland cement (OPC), fine sand (FS), silica fume (SF.), fly ash (FA.) and super plasticizer (SP.). These mixtures were evaluated by determining the workability of fresh grout and the flexural & compressive strength of hardened grout. The first cement grout group (GTM.1) contains 95% of ordinary Portland cement (OPC) and 5% of crushed fine sand (FS) with no additives. This grout mix was considered as a control mix between mix without additive and the other mixes with different additives.

The following grout mixes were trial specimens to determine the grout materials and specify the suitable percent of each material. The second grout mixture group (GTM.2) consists of 90% OPC, 5% FS and 5% SF. only. The third grout mixture group (GTM.3) consists of 90% OPC, 5% FS and 5% FA. only. The fourth grout mixture group (GTM.4) consists of 90% OPC, 5% FS and 5% SP. only. The fifth grout mixture group (GTM.5) consists of 85%OPC, 5% FS, 5% SF., 3% FA. and 2% SP. To determine the vital effect of each additive (which better SF. or FA.) on the performance of grout, mixes GTM.6 and GTM.7 were prepared. GTM.6 includes 70% OPC, 15% FS, 10% SF. and 5% FA. (with 1.5%SP. of OPC weight). On the other side, GTM.7 includes 70% OPC, 15% FS, 5% SF. and 10% FA. (with 1.5%SP. of OPC weight). To determine the suitable ratio between the OPC and FS without any additive, mixes GCM-1, GCM-2 and GCM-3 were prepared. GCM-1 consisted of OPC: FS by ratio 2: 1, GCM-2 consisted of OPC: FS by ratio 1: 1 and GCM-3 consisted of OPC: FS by ratio 1:2 respectively. In order to achieve the approximate required percent of using SF., mixes GCM-2.A, GCM-2.B and GCM-2.C were produced. GCM-2.A contain only 5% SF. with cement and sand mixture while GCM-2.B contain 10% SF. of total mixture and GCM-2.C contain 15% SF. of total mixture. After testing, grout Mix GCM-2.A gave the best results for flow time (workability) moreover the flexural & compressive strength.

There are a lot of methods used for preparing the grout specimens for testing in laboratory. One of these methods is mixing all the solid materials with 1/2 of the required percent of water as well as 1/2 of super plasticizer percent for (90-150) seconds manually or (60) seconds by mixer (normal rpm speed). Then adding the remaining amount of water and SP. for mixing time about (60-120) seconds manually or (30) seconds by mixer (high rpm speed) to ensure the good workability of grout without any solid collections. The grout mold shall consist of three horizontal compartments so that three prismatic specimens 40 mm × 40 mm in cross section and 160 mm in length can be prepared simultaneously. Figure (2) shows the mixing device the used to mix grout materials and its bowl and blade.

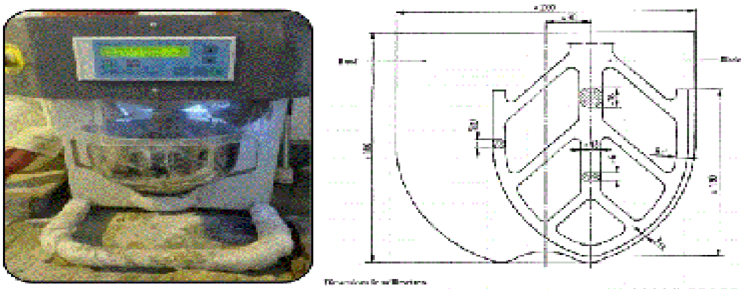

Figure (2): Grout Mixing Equipment and its Bowl and Blade.

The workability (viscosity) and density of the grout **are important properties that affect the ability of the grouting process.** Figure (3) shows the standard Marsh flow cone (Marsh funnel) that used for measuring the workability of fresh grout mixtures in seconds as the acceptable range for flow time was (8-16) seconds. The flow time for water was 9.5 seconds after calibrating the cone.

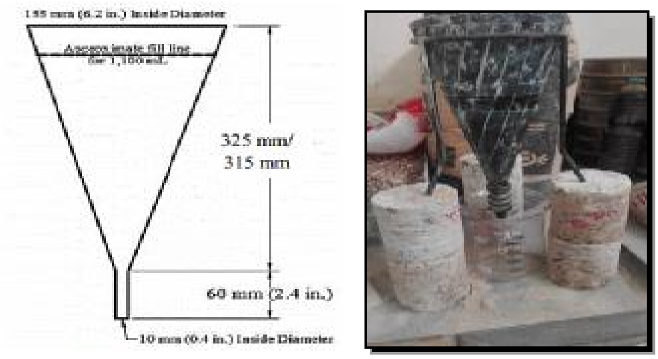

Figure (3): Standard Marsh Flow Cone (Marsh Funnel).

Hardened grout was evaluated for flexural tensile strength and compressive strength. Determining the flexural and compressive strength was done for prismatic specimens. The concept of flexural test depends basically on the AASHTO T 177-03/ASTM C-293 that concerns with flexural strength of concrete using simple beam with center-point loading. The compression test was performed on each hardened grout specimen portion of prism beam that was broken in flexural testing. Determining compressive strength was according to AASHTO T-140 /ASTM C-349. Flexural strength was conducted according to the British Specifications EN-196 for determining the validity of cement used for concrete works. The concept of this test depends basically on the AASHTO T 177-03/ASTM C-293 that concerns with flexural strength of concrete using simple beam with center-point loading. The hardened grout prism dimensions were 40* 40 * 160 mm length. The compression test was performed on each hardened grout specimen portion of prism beam that was broken in flexural testing. Determining compressive strength was according to AASHTO T-140/ASTM C-349. The specimens were half broken prisms with size dimensions (width 40 mm × height 40 mm × length more than 50 mm). Figure (4) shows the curing process of grout prisms. Figure (5) shows the testing device for flexural and compressive strength testing.

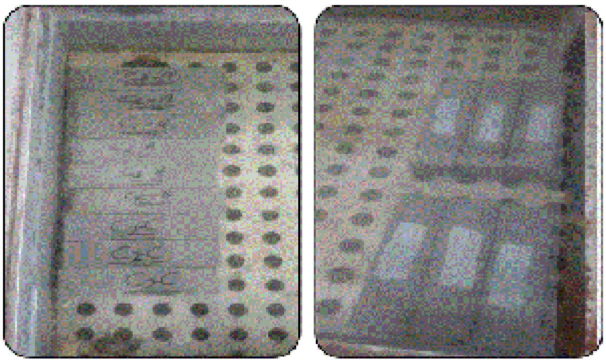

Figure (4): Curing Process of Grout Prisms.

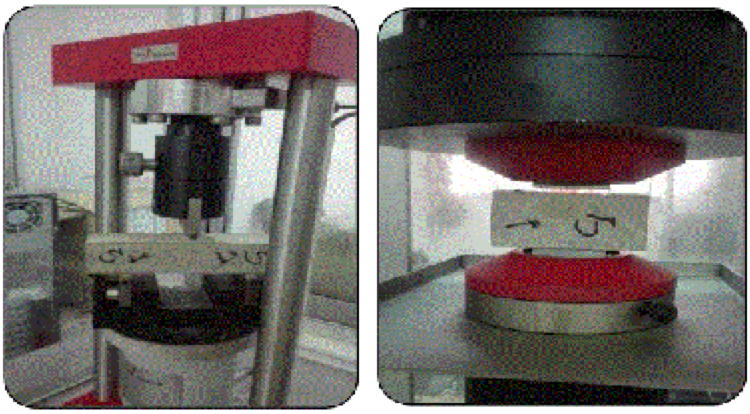

Figure (5): Testing Flexural and Compression Strength of Grout Prisms.

5. GROUTED ASPHALTIC MIXTURES:

After getting the required air voids (20-30) %, injection process of grout started into the interlocked air voids between coated aggregates. Grout was only prepared when the samples totally cooled down. Cylindrical samples had to be covered at sides and bottom with paper and plastic as the mold for grout pouring. The process of mixing grout and pouring it into skeleton of OGM lasted roughly 4 min for every sample (3 min for grout mixing, and a minute for pouring). It must be noticed that there is no water evaporation or segregation of grout components.

The efficiency of grouting of hot asphalt porous mixes depends on the connected air voids of asphaltic mold and the workability of grout. The percent of air voids filled with grout can be expressed by degree of grouting. Grouting degree can be calculated as shown in Equation (3). Percent of grouting should range between 85 and 100% of permeable air voids for all investigated grouted hot asphalt mixes.

$$\text{Degree of grouting} = \left(1 - \frac{Av{\cdot}a.g}{A_v{\cdot}b{\cdot}g}\right) \times 100 \qquad \textbf{Eq. (3)}$$

Where:

$Av._{a.g}$ = permeable Air voids in grouted asphalt specimen, (%);

$Av._{b.g}$ = permeable Air voids in open graded specimen, (%);

Curing has great clear effect on the results. Figure (6) shows the curing process of grouted molds by immersing them in a water bath at constant temperature. Low temperature degrees affect positively on the results of testing grouted molds. Inversely, high degrees weaken the performance of grouted molds.

Figure (6): Grouted Asphaltic Molds during Curing Process.

Testing the grouted asphaltic molds was at ages of 1,7,28 days after grouting. Marshall stability and flow test provides measuring the prediction performance for the mix design. This test is performed in accordance with marshal method of mixture design (AASHTO T-245). In this study, indirect tensile strength testing is preferred for estimating tensile strength according to (ASTM D-6931). The indirect tensile test is performed by loading a specimen (4 in diameter and 2.5±0.2 in thickness) with a single compressive load, which acts parallel to the vertical diametric plane. Figure (7) shows the Marshall and indirect tensile strength tests for the grouted molds.

Figure (7): Marshall and Indirect Tensile Testing for Grouted Asphaltic Molds.

6. RESULTS AND DISCUSSION:

Testing the molds composed of the reference gradation mix in Marshall method was according to AASHTO T-245. Marshall stability of HMA for 2C gradation (compacted by 75 blows/side) which mixed by 4.0% Ac is slightly more than the same mixture mixed by 4.5%Ac. While the flow indicator increases with increasing the bitumen content. Figure (8) shows the effect of bitumen content on the Marshall stability and flow for mixture 2C.

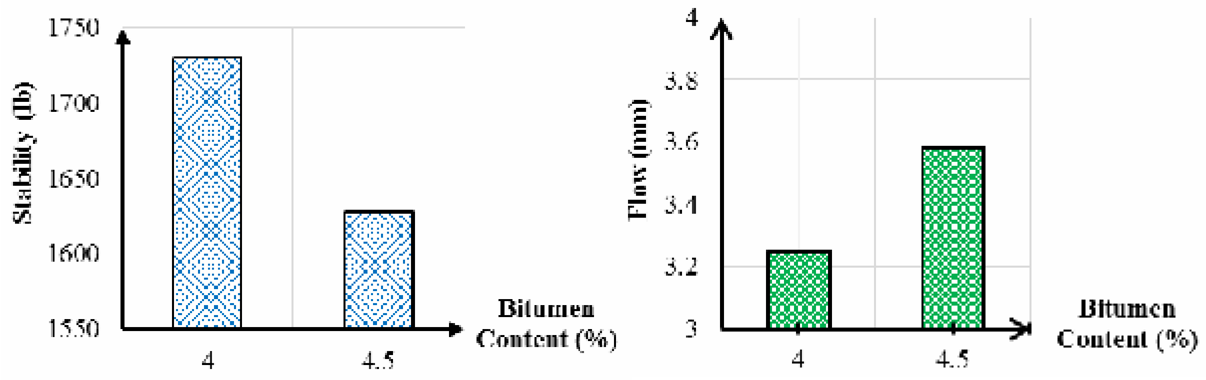

Figure (8): Effect of Bitumen Content on Marshall Stability and Flow for Open Mix (2C).

The liquid density of grout mixes can be calculated by dividing the weight of unit volume on this volume. The liquid densities depend basically on the w/c ratio and the percent of workability additive used. It also affected by the type of pozzolanic additives and its interaction with cement. The liquid densities for different tested grout mixtures are shown in Figure (9) for different grout mixes. By increasing SF. percent, the w/c percent required for

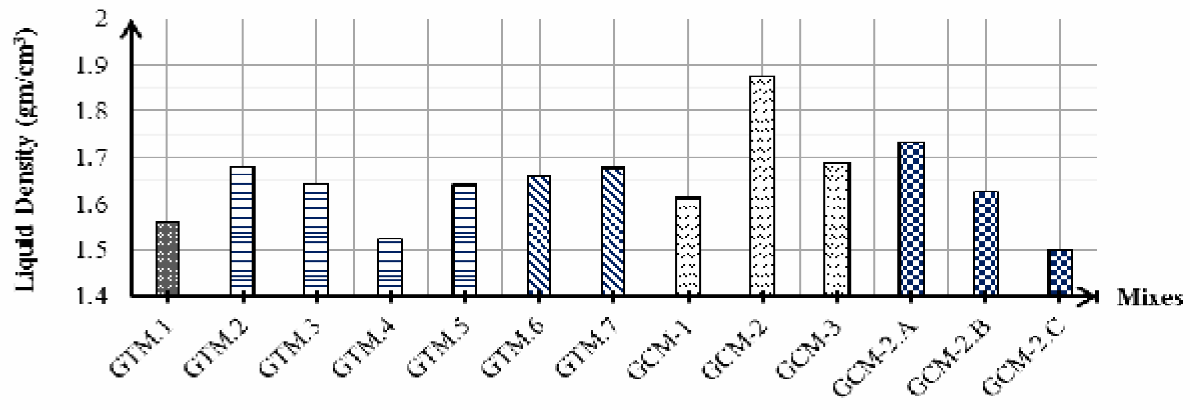

Figure (9):Liquid Density for Fresh Grout Mixes

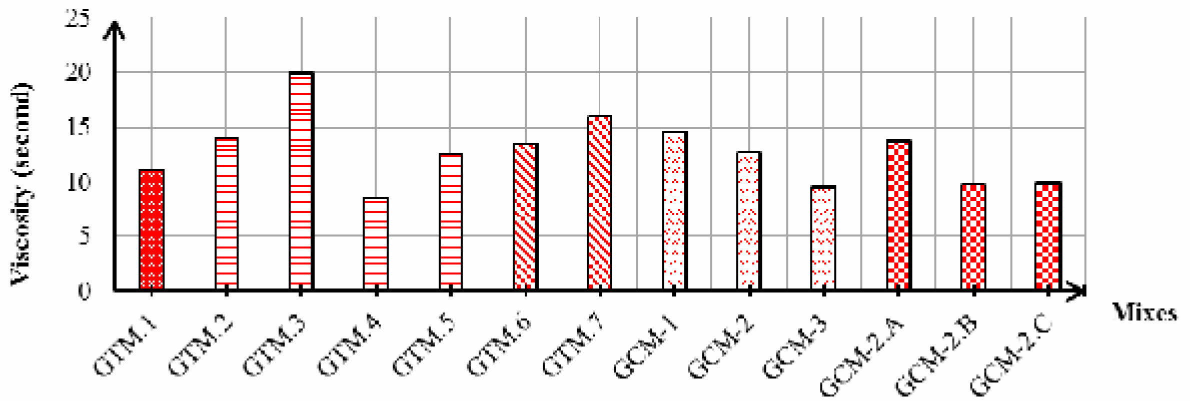

Figure (10): Viscosity for Fresh Grout Mixes.

achieving allowable viscosity increases. Figure (10) illustrates the effect of using additives on the water/cement ratio and consequently on the viscosity.

The results of conducting Marshall stability on grouted asphalt mix are shown in Table (3) and illustrated in Figure (11). Table (3) indicates that the highest stability value after 1-day curing (1092.54 Ib) is achieved at 30 blows; whereas the lowest stability value (381.09 Ib) is achieved at zero blows. It is found that the stability increases with the increase of testing age. Marshall stability of grouted molds increases with increasing the air voids of asphalt mixture skeleton. This may be because when the air voids in the asphalt skeleton increase, more space is provided to be filled with the cementitious grout, and thus the strength of grouting material is much higher than that of the asphalt mixture skeleton.

Table (3): Marshall Stability of Grouted Asphaltic Molds.

No. of Blows/side	Stability (Ib)		
	1 day	7 days	28 days
0	381.09	3585.81	9673.1
10	564.07	2804.49	8757.69
20	720.87	2450.54	7761.75
30	1092.54	2387.85	6111.85

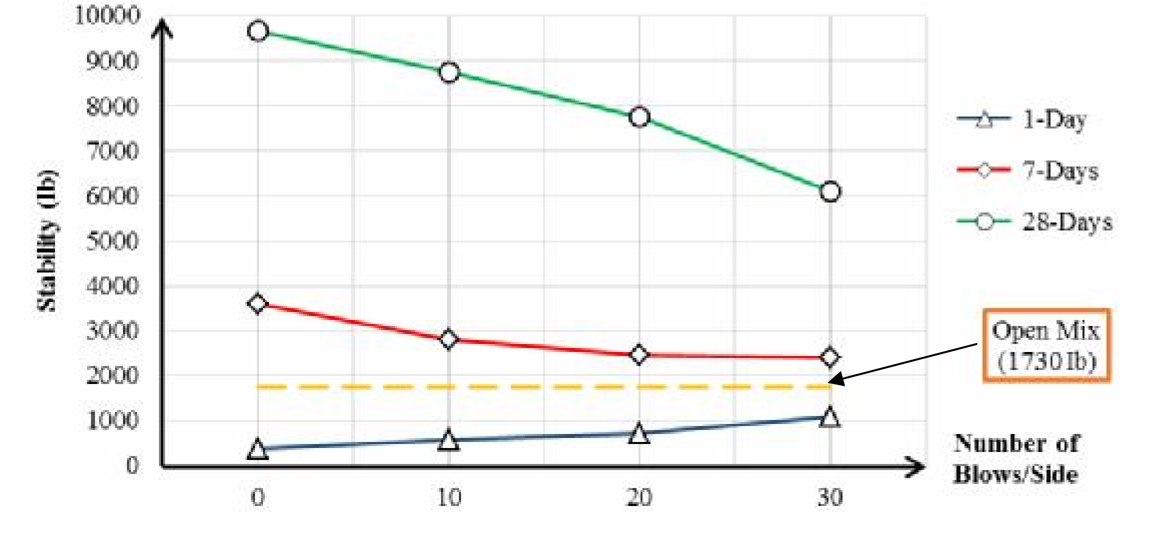

Figure (11):Stability of Grouted Asphaltic Moulds at Different Ages

Figure (12) indicates the fracture shape resulting from Marshall testing of the grouted asphalt molds injected with concrete mortar. It is illustrated that there isn't a complete collapse of the mold although, the molds are different and there aren't fully separated. Failure mechanism is almost typically unique for all grouted molds after Marshall testing. There is no segregation between mold parts where it still one unit despite failure. This reaction may be due to the interlocking and cohesion between grouts and coated aggregates.

Figure (12): Failure Shape of Marshall Testing for Grouted Molds.

After curing the grouted molds by putting the samples in water bath for the test age of days, the stability values increase with decreasing the curing temperature degree as shown in Table (4) and Figure (13). Immersing the SFP samples in 60 °c water bath for 30 minutes weakens the resistance of molds and causes the collapse of them. It may be because the high temperature affects the cohesion and hardening of grout inversely or the molds are not fully grouted. While, submerging the molds in 25 °c water bath for 1 hour causes increasing the stability of grouted specimens. Thus, the curing age and temperature are very important factors that affect the performance of SFP.

Table (4): Effect of Curing on SFP Marshall Stability.

No. of Blows/side	Stability (Ib) after curing at 60°c	Stability (Ib) after curing at 25°c
0	355	641
10	368	576
20	372	520
30	378	470

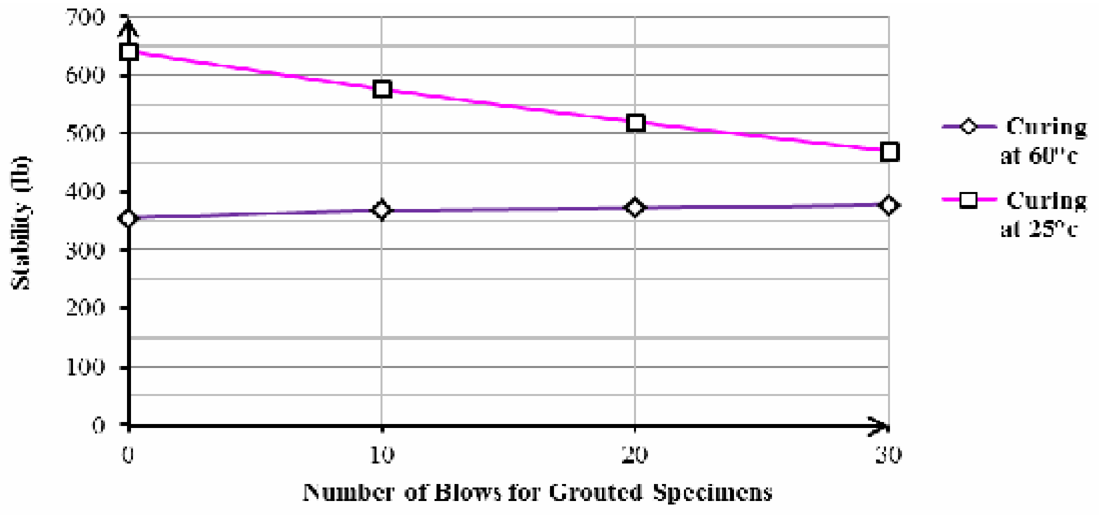

Figure (13): Effect of Curing Temperature Degrees on the Stability of SFP Specimens.

7. CONCLUSIONS

1) Open graded mixture saved about (27 – 37) % of asphalt used for producing traditional dense asphalt mixtures (average optimum asphalt content = 5.5 %). While, mixing the aggregates particles of open graded mixes with 3.50 % bitumen content before grouting saved enough coating for these particles and thus the total layer was still slightly flexible.
2) After 7 and 28 days, grout mixes contain (48.8% ordinary Portland cement (OPC) with 24.4% fine sand (FS.)) achieved positive and significant effect on flexural and compressive strength compared with the other mixes with additives. While using grout mix having (37% OPC and 37% FS.) was more acceptable for grouting properties than using (48.8% OPC and 24.4% FS.). Moreover, using grout mix (23.8% OPC and 47.6% FS.) was not effective.
3) Grout mixes containing fly ash consumed water quantities higher than silica fume mixes consequently, the flexural and compressive strength were lower. Thus, grout mixes containing fly ash were not recommended.
4) After testing the fresh and hardened cases of all grout mixtures, grout mix GCM-2.A gave the most acceptable results for flow time (workability) moreover the flexural & compressive strength. But the modified mix GCM-2.A which contains 35.21 % OPC, 35.21% FS., 4.23 % silica fume with 2.11 % super-plasticizer and 23.24 % water perform better in workability and prevent separation between sand and other grout materials.
5) After 1-day, the mix (OG.2) (whose aggregate gradation consists of 10% retained on 3/8 sieve, 87% retained on no.4 sieve and 3% passed sieve no.200) that grouted by modified GCM-2.A provided low Marshall stability, and indirect tensile strength compared to the traditional mix (2C). High stability of grouted mix (1092.54 Ib) was about 63% of the corresponding value of reference mix 2C (1730 Ib). While indirect tensile strength for grouted mix (373.83 Psi) was about 381% of indirect tensile strength for mix 2C (97.91 Psi).

6) After 7 days, the mix (OG.2) which grouted by modified GCM-2.A provided stability for grouted molds about 2.0 times of mix 2C stability. While this mix achieved indirect tensile strength about 3.53 times of indirect tensile strength for mix 2C.
7) After 28 days, the mix (OG.2) which grouted by modified GCM-2.A produced stability about 5.59 times of mix 2C stability and achieved indirect tensile strength about 4.62 times of mix 2C.
8) Marshall stability of semi-flexible pavement molds grouted by modified mix GCM-2.A after 7 days of curing provided about (31-39) % compared with the stability after curing age of 28-days.
9) Grouting the open graded mixtures by high performance mortar led to decreasing the flow values compared to the flow values for open graded mix (2C).
10) Indirect tensile strength (ITS) of semi-flexible pavement molds grouted by modified mix GCM-2.A after 7- days of curing provided about (76-93) % compared with ITS after curing age of 28-days.
11) The low value of unconfined compression strength testing of grouted molds after 28 days (1071.16 psi) was recorded for zero blows while the high value (1606.75 psi) was obtained for 30 blows per side.

REFERENCES

1. Anderton. Gary. L., (2000), "Engineering Properties of Resin Modified Pavement (RMP) for Mechanistic Design." Vicksburg: U.S. Army Engineer Research and Development Center.
2. Asphalt Institute, M-2. (2014), "Asphalt Mix Design Methods." USA.
3. Bonicelli Alessandra, Preciado Jaime, Rueda Ana, Duarte Alejandro, (2019), "Semi-Flexible Material: A Solution for High-Performance Pavement Infrastructures." IOP Conference Series: Materials Science and Engineering (p. 11).IOP Publishing.
4. Jacobsen Sofie, (2012), "The Effectiveness of Grouted Macadam at Intersections - A Life-Cycle Cost Perspective." Stockholm: Royal Institute of Technology (KTH).
5. Nikolaides Athanassios, (2015), " Highway Engineering Pavements, Materials and Control of Quality." Boca Raton:USA, CRC Press Taylor & Francis Group.
6. Oliveira Joel R., (2006), "Grouted Macadam – Material Characterisation For Pavement Design." Nottingham, University of Nottingham.
7. Pais Jorge C., Oliveira Joel R., Thom Nick, Zoorob Salah S., (2007), "A Study of the Fatigue Properties of Grouted Macadams." Research Gate, 112-123.
8. Setyawan A., (2013), "Asessing the Compressive Strength Properties of Semi-Flexible Pavements." The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering (pp. 863-874). Indonesia, Elsevier.
9. Soliman Mohamed Abd El-Aziz Shalaby, (2016), "Evaluation Of Grouted Hot Asphalt Mixtures." Ph.D. Thesis, Zagazig University, Zagazig, Egypt.
10. Tran T. Nhan, Nguyen H. Tai, Nguyen K. Son, Nguyen N. Huynh, (2018), "Semi-flexible Material: The Sustainable lternative for the Use of Conventional Road Materials in Heavy-Duty Pavement. " Proceedings of the 4th Congrès International de Géotechnique - Ouvrages -Structures (pp. 552-559). Vietnam, Springer Nature Singapore.
11. Wu Dong Qing, Daud, Zhang Yanli, (2011), "The Semi-Rigid Pavement with Higher Performances for Roads and Parking Aprons." CAFEO 29, Sustainable Urbanization – Engineering Challenges and Opportunities (p. 7), Brunei Darussalam: Chemilink Technologies Group, Singapore.