American Journal of Engineering and Applied Sciences

Original Research Paper

Assessing and Improving the Performance of Grouted Macadam

[1]Momtaz M. Othman, [2]Ahmed Ebrahim Abu El-Maaty and [3]Zeinab S. Hussein

[1]Department of Highways Engineering, Faculty of Engineering, Menoufia University, Egypt
[2]Department of Highways Engineering, Faculty of Engineering, Menoufia University, Egypt
[3]Department of Highways Engineering, National Center for Housing and Building Research, Cairo, Egypt

Article history
Received: 30-03-2020
Revised: 15-04-2020
Accepted: 28-04-2020

Corresponding Author:
Ahmed Ebrahim Abu El-Maaty
Department of Highways Engineering, Faculty of Engineering, Menoufia University, Egypt
Email: maaty5000@yahoo.com

Abstract: There are many road defects appear in flexible pavement layers. Rutting, raveling and cracks are considered the main problems in Egypt. Using grouted macadam system as a surface asphaltic layer (or called Semi-Flexible Pavement (SFP)) has many advantages such as saving the natural asphalt and enhancing the performance against deteriorations. The main scope of this research is to evaluate and improve the performance of SFP using modified grout by additives as fine sand, Silica Fume (SF), Fly Ash (FA) and Super-Plasticizer (SP). Different mixing ratios for grout contents (cement: Fine sand: Additives: Water) were tried and tested using flow time (workability), flexural and compressive strength to achieve the optimal grout characteristics. Crushed siliceous-limestone was used in preparing open graded (porous) asphalt mixtures to obtain suitable permeability. After grouting the asphalt mixtures, Marshall and indirect tensile strength tests were performed. The results indicated that the use of equal amounts from cement and fine sand was preferred in grout. Silica fume was preferred as additive for improving the grout properties. The results obtained that the grouted macadam significantly improved the performance of pavement compared with traditional flexible pavement.

Keywords: Grouted Macadam, Semi-Flexible Pavement, Air Voids, Silica Fume, Fly Ash, Marshall Stability, Indirect Tensile Strength

Introduction

There are two major types of pavement systems; flexible asphalt pavement and rigid concrete pavement. Flexible pavement requires more layers to sustain the vehicles loads compared to rigid pavement. Rigid pavement can be prone to relatively slow setting times during the construction phase, poor riding quality and noise caused by the joints required to adjust differential expansion/contraction during service (Afonso *et al*., 2016; Anderton, 2000). The increasing demand of transporting various goods leads to the emergence of many systems of paving roads techniques. Therefore, the scope of the present study is to find out a new system which avoids the disadvantages of flexible pavement and rigid pavement.

An alternative pavement that is currently new is the joint-less Semi-Flexible Pavement (SFP). SFP has also been known as grouted macadam surfacing or resin modified pavement (Bonicelli *et al*., 2019; Jacobsen, 2012). It basically focuses on the production of a permeable surface layer with high connected air voids percent which can be filled with high performance mortar (grout) (Liu *et al*., 2005; Mayer and Mikael, 2001). The first development of SFP process was carried out in the 1950's, in France and then it gained popularity across Europe, USA, Malaysia, Singapore, Netherlands, Japan, China, Korea and some African countries (Netterberg and De Beer, 2012; Nikolaides, 2015).

The SFP is generally applied in a typical thickness 50 mm thick wearing layer over an asphalt or concrete base. Meanwhile, for very heavy loading cases such as taxiway junction, the thickness design could be a single layer with 50 to 75 mm thick or double layers with 25-75 mm thick for each layer (Oliveira, 2006; Pais *et al*., 2007; Pei *et al*., 2016). Many researches indicated that the main components of SFP mixtures consist of about (91-96%) crushed aggregate, (3.5-4.6%) bitumen, (4.0%) filler and about (0.15-0.2%) fibers, where the produced air voids content in the range of 20% to 30% (Setyawan, 2006; 2005).

Grout material must be easily flow-able into the voids of the open graded (porous) mixtures skeleton as well as it should be strong enough to resist the applied stresses. The main requirements of the grout mixtures are to rapidly penetrate the porous asphalt skeleton and improve the strength and the deformation resistance of the resultant composite (Shalaby, 2016; Shen *et al*., 2005). The composition of grout mixture consists of ordinary Portland cement as well as fine sand in addition to one or more additives such as silica fume, fly ash, plasticizers and other materials that may improve the performance of grout. Water is used for mixing purposes for grout solid materials (Tran *et al*., 2018; Wu and Yanli, 2011; Zhang *et al*., 2016).

Hao *et al*. (2003) studied differences between SFP and dense-graded asphalt mixtures and emphasized on that the SFP provided better performance at low-temperature and higher moisture damage resistance. Fang *et al*. (2016) determined a cement slurry design containing poly-carboxylene based super-plasticizer and latex, which improved the working performance and equilibrium of the flexible and rigid properties for SFP. Hou *et al*. (2016) investigated the mechanical characteristics and durability of SFP and concluded that, the stability, fatigue performance and moisture damage resistance were clearly improved at high-temperature, compared with traditional asphalt mixtures. While at low-temperatures, the crack resistance also met the serviceable requirements. Yang and Xingzhong (2015) studied the durability of SFP and determined the effect of different raw materials and established a damage model based on cyclic wheel load test. Setyawan (2013) studied the compressive strength for SFP using different cementations grout, bitumen contents, aggregate types and gradations where the effectiveness of using SFP was obtained compared them with porous asphalt mixtures.

The main objective of this study is to evaluate and improve the performance of SFP under different variables concerning the grout composition such as mixing ratios (cement: Fine sand: Additives: Water) and additive types (fine sand, silica fume, fly ash and super-plasticizer). Moreover, the effects of SFP specimen ages (from grouting process to testing) and compaction effort were studied on Marshall stability, Marshall quotient and indirect tensile strength.

Experimental Program

Materials

Aggregates

Siliceous limestone was used as aggregate for preparing the open graded asphaltic samples. The physical properties of coarse and fine aggregate are shown in Table 1 which illustrates that the aggregate properties met the requirements of Egyptian specifications (EGP, 2016). The siliceous-limestone dust used as mineral filler provided bulk specific gravity of 2.68. Moreover, the fine aggregate was used to produce the mortar for grouting the porous asphalt mixtures. The main purpose of using such fine aggregate in mortar is to improve the sustainability of the grout mix by increasing the compression and flexural strength for the mortar and reducing the grout cost.

Asphalt Cement

The soft grade asphalt is preferred to increase the flexibility of the mixtures. Consequently, asphalt of penetration grade 60/70 was used as binder material in this study. Table 2 summarizes the physical properties of this asphalt where they agreed with the Egyptian standards for highway specifications.

Ordinary Portland Cement (OPC)

The physical properties of the ordinary Portland cement used in this study were determined according to (ASTM, C150) specifications as shown in Table 3.

Table 1: Physical properties of the coarse and fine aggregates

	Test name	Designation	Egyptian standards	Test results
Coarse aggregate	Los Angeles abrasion (100)	AASHTO (T96)	≤ 10%	4.000
	Los Angeles abrasion (500)	AASHTO (T96)	≤ 40%	26.000
	Bulk specific gravity	AASHTO (T85)	--	2.616
	Sat. surface dry specific gravity	AASHTO (T85)	--	2.676
	Apparent specific gravity	AASHTO (T85)	--	2.782
	Water absorption	AASHTO (T85)	≤ 5%	2.300
	Flat or elongated particles	ASTM (D4791)	≤ 10%	2.000
Fine aggregate	Bulk specific gravity	AASHTO (T85)	--	2.470
	Sat. surface dry specific gravity	AASHTO (T85)	--	2.573
	Apparent specific gravity	AASHTO (T85)	--	2.754
	Water absorption	AASHTO (T85)	≤ 5%	2.500

Table 2: Physical properties of asphalt binder

Test Name	Code	Results	Egyptian specifications
Penetration, 0.1 mm	T 49	69	60-70
Kinematics Viscosity, Centistoke	T 201	434	≥ 320
Flash point, °C	T 48	270	≥ 250
Softening point, °C	T 53	48	45-55

Additives

Silica Fume (SF) of 1.88 g/cm^3 specific gravity and Fly Ash (FA) of 2.36 g/cm^3 specific gravity were used as grout additives to improve the mix properties. Moreover, a Super-Plasticizer (SP) of 1.1 g/cm^3 specific gravity according to (ASTM, C494) was utilized for water reduction, shrinkage resistance, early strength development and workability of grout mix. Silica fume, fly ash and super-plasticizer were obtained from Sika company, Egypt.

The Study Methodology

The methodology of this research was divided into five stages; the first is selecting the open aggregate gradation to produce asphaltic mixtures with suitable continuous air voids, the second is preparing the porous asphalt mixtures, the third is selecting the suitable the grout components ratios and mixing them, the fourth is the grouting process of the specimens and the fifth stage is the testing of semi-flexible samples.

Stage 1: Selecting the Suitable Aggregate Gradation

The objective of this section is choosing the most suitable aggregate open gradation with appropriate compaction effort for obtaining air voids ratios of (20-30%) as previous studies (Pei *et al*., 2016; Setyawan, 2013). Initially, five aggregate gradations from previous researches such as (Anderton, 2000; Densiphalt Handbook, 2000; Setyawan, 2013) were used. Open-graded asphalt mixtures were prepared to reach the desired air voids percent in the asphaltic mixtures. Table 4 shows different primary trial gradations (A, B, C, D and E) compared with the gradation of open mix (2C) according to Egyptian specifications (EGP, 2016). The asphalt content (AC%) for mixes (A to E) is assumed as fixed percent (4%) as middle value from previous researches. After mixing each aggregate gradation with bitumen, a compaction of (50 blows/side) was used for producing Marshall mixtures. The bulk specific gravity (G_{mb}) of the compacted asphalt mixtures according to (ASTM, D2726), the maximum specific gravity (G_{mm}) according to (ASTM, D2041) were calculated. The actual connected air voids ratio (V_{air}) in porous asphaltic mixtures was determined according to (ASTM, D3203) by estimating the percent of absorbed water weight to the original weight of dry asphalt mixture.

As shown in Table 5, the air voids ratios of mixes from A to E were not meet the requirements. Therefore, adjusting these gradations and reducing the number of compaction blows were important to obtain the required voids needed to fill by grout. Gradations F1, F2, F3 and G1, G2, G3 that shown in Tables 4 and 5, were used using compaction of 15, 25 and 35 blows/side respectively. The required bitumen content was calculated approximately (as shown in Table 6) using the surface area method according to Egyptian specifications (EGP, 2016). The air voids for gradations F and G were between 20-30% as required. Gradation G was chosen to be used in this research.

Stage 2: Preparing of Porous Asphalt Mixtures

Using open gradation G, the compaction effort (number of blows/side) was varied to achieve the minimum limit of required grouting degree (the percentage of air voids that are filled with grout shouldn't less than 85%). To go over this limit, compaction efforts of 0, 10, 20 and 30 blows/side were used to produce continues air voids in the specimen. Aggregate was heated up and kept in the oven at 150°C, after almost a minute, bitumen was poured into the initial mixture as the binder. Total time set for the mixing process was 2 min. The final asphalt mixtures were subsequently stored in the oven at 130°C until the mixtures obtained this temperature as a whole. Then, samples were fabricated in cylindrical samples and were kept at room temperature for 24 h. before being moved to next stage. Figure 1 shows the asphalt mixtures with different compaction efforts.

Stage 3: Grout Mixes Design

Many grout samples were prepared to determine the suitable percent of each component and evaluate the effect of each additive on the grout performance. The liquid grout mixes were evaluated using the water to cement ratio (W/C), the viscosity and density. While the hardened grout mixes were evaluated by flexural and compressive strength. Table 6 shows the weight percentage for each component in grout mix (Ordinary Portland Cement (OPC), fine sand (FS), Silica Fume (SF), Fly Ash (FA), Super-Plasticizer (SP) and Water (W)) to the total weight.

Fig. 1: Asphalt mixtures with different compaction efforts

Table 3: Chemical and physical composition of the cement

Properties	Value
Specific gravity	3.15
Initial setting time (min)	150
Final setting time (min)	300
Finesse modulus (for retained on sieve no. 170)	2.0%
Compressive strength (MPa)	
2 days	19.14
28 days	53.5

Table 4: Trail gradations for different open mixtures

	Open gradation for grouted macadam						
Sieve (in)	A	B	C	D	E	F	G
1"	100	100	100	100	100	100	100
3/4"	100	100	100	100	100	100	100
1/2"	62.8	97.5	54	100	45	90	100
3/8"	51.5	18	38	90	28	35	90
1/4"	--	--	--	38	--	--	--
No.4	17.6	10	10	8	6	15	3
No.8	11.1	9	8	5	--	5	3
No.16	7.3	--	---	--	--	--	--
No.30	6.6	--	4	--	--	--	--
No.50	2.4	--	--	--	--	--	--
No.100	1.2	--	--	--	--	--	--
No.200	1.1	5	1	3	--	3	3

Table 5: Characteristics of primary trial gradations

Gradation code	AC (%)	Blows No.	G_{mb}	G_{mm}	V_{air} (%)
Mix 2C	4	75	2.287	2.548	13.35
A	4	50	2.09	2.512	19.53
B	4	50	2.158	2.533	16.77
C	4	50	2.239	2.551	15.85
D	4	50	2.152	2.575	18.99
E	4	50	2.211	2.569	17.46
F.1	5	15	2.166	2.502	24.84
F.2	5	25	2.127	2.502	21.76
F.3	5	35	2.198	2.502	20.33
G.1	4.2	15	2.155	2.582	28.40
G.2	4.2	25	2.195	2.582	25.70
G.3	4.2	35	2.218	2.582	22.50

Table 6: Grout samples components

Grout Mixes	Percentage by weight (%)					
code	OPC	FS	SF.	FA.	SP.	W
GTM.1	64.41	3.39	--	--	--	32.20
GTM.2	62.07	3.45	3.45	--	--	31.03
GTM.3	62.07	3.45	--	3.45	--	31.03
GTM.4	66.18	3.68	--	--	3.68	26.46
GTM.5	63.44	3.73	3.73	2.24	1.49	25.37
GTM.6	57.35	12.29	8.193	4.097	0.86	17.209
GTM.7	57.35	12.29	4.097	8.193	0.86	17.209
GCM-1	48.8	24.4	--	--	--	26.8
GCM-2	37	37	--	--	--	26
GCM-3	23.8	47.6	--	--	--	28.6
GCM-2A	32.48	32.48	4.7	--	--	30.34
GCM-2 B	26.67	26.67	8.29	--	--	38.37
GCM-2 C	23.23	23.23	11.73	--	--	41.81

Primary mixes GTM.1 to GTM.4 were prepared using high cement content to study the effect of each additive individually. Mixes GTM.5 to GTM.7 were designed to investigate the effect of combining all additives with different mixing ratios. To determine the suitable ratio between OPC and FS without any additive, control mixes GCM-1, GCM-2 and GCM-3 were prepared. Mixing ratio (OPC: FS) of (1:1) in sample GCM-2 provided better performance. Thus, modified mixes GCM-2.A, GCM-2.B and GCM-2.C were produced using different SF contents.

Liquid grout sample were evaluated by many parameters. The water to cement ratio (W/C) is affected by many factors such as percent and type of solid additive and super-plasticizer. Lower (W/C) ratio leads to higher unfilled voids and early failure under traffic. Higher (W/C) ratio leads to lowering in mixture strength and segregating of its components. The viscosity of the grout is an important property that affects the ability of the grouting process. Marsh funnel test shown in Fig. 2 was used according to (ASTM, D6910) to measure the grout viscosity as the period in seconds required for 1000 cm^3 of grout to flow out of a full marsh funnel. The desired viscosity range to get suitable workability is (8-16 sec).

Hardened grout was evaluated by flexural tensile strength according to (ASTM, C348) as well as compressive strength according to (ASTM, C349). For flexural tensile strength test, three prismatic specimens of dimensions (40×40×160 mm) for each grout mix were prepared and cured in a water bath at constant temperature degree (25±5°C) for 7 day. For compressive strength test, three prismatic specimens of dimensions (40×40×50 mm) for each grout mix were prepared and cured in a water bath at constant temperature degree (25±5°C) for 7 and 28 days.

The flexural strength test machine was capable of applying loads up to 10 kN, with an accuracy of ±1.0% of the recorded load. The rate of loading was (50±10) N/s. The flexural strength teat machine was provided with a flexure device incorporating two steel supporting rollers of (10.0±0.5) mm diameter spaced (100.0±0.5) mm apart and a third steel loading roller of the same diameter placed centrally between the other two. The flexural strength can be calculated as follows:

$$S_f = 0.0028P$$

Where:

S_f: The flexural strength, MPa
P: The total maximum load, N

The compressive strength test machine that used in this study had an accuracy of ±1.0% of the recorded load where it provided a rate of load increase of (2400±200) N/s. The compressive strength test machine was fitted with an indicating device (a memory on a digital display) which helps the value of load failure to be remaining clear after unloading the testing machine. The compressive strength can be calculated as follows:

$$Sc = 0.00062P$$

Where:

Sc: The compressive strength, MPa
P: The total maximum load, N

The failure shape in flexural test was almost being under the point of loading at the center of prism and taking the vertical cut line with a slightly tilted angle. Because the specimens were not elastic during loading, so the failure happened suddenly. Flexural strength of grout prisms with additives didn't fragment totally where only divided into two separated parts. Figure 3 shows the flexural failure shapes for silica fume modified grout. The failure shape in compressive test was almost under the area of loading taking slightly diagonal line (closer to vertical) from top to bottom. The failure happened sequentially during loading while, the collapse completed in short time. Compressive strength of silica fume modified grout prisms (GCM-2A) didn't break up totally because of the bond between cement and pozzolanic materials. While the grout mixes without additives (such as GCM-2) was broken into small portions. Figure 4 indicates the compressive failure shape.

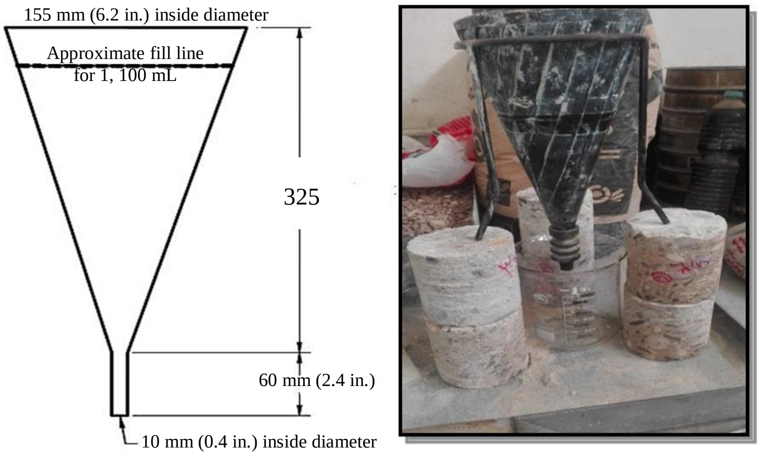

Fig. 2: Standard marsh flow cone

Fig. 3: Failure mechanism of flexural strength test

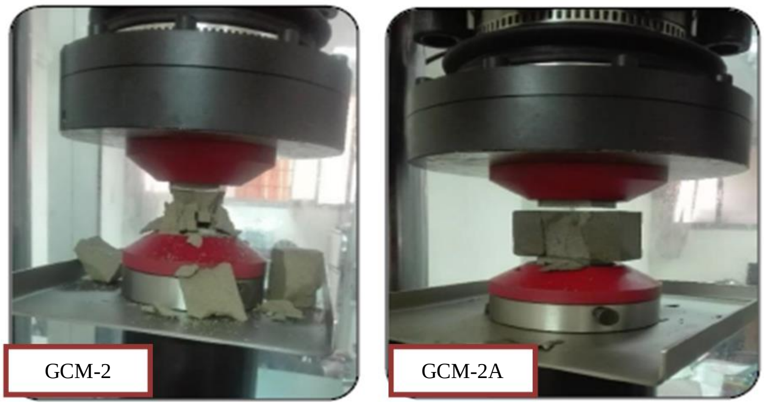

Fig. 4: Failure mechanism of compressive strength test

Figure 5 to 7 show (W/C) ratio, viscosity and density for each grout sample respectively. Figure 8 and 9 show the flexural and compression strength results for each grout mix. From Fig 5 to 9, it can be noticed that the mix GTM-2 that contains SF provided better liquid and hardened properties than mix GTM-3 that contain the same percentage of FA. Thus, using fly ash in grout could be neglected to decrease the mix cost. Mixes GCM-2A, GCM-2B and GCM-2C were produced in order to choose the best percent of silica fume. Mix GCM-2A provided lower W/C ratio (93.4%), higher flow time (13.7 sec) and higher density (1.731 gm/cm^3). The preferred mix GCM-2A according to grout liquid properties provided acceptable flexural strength of (70.22 kg/cm^2) after 7 days curing period and acceptable compressive strength of (141.75 and 255.25 kg/cm^2) after 7 and 28 days respectively. Thus, mix GCM-2A was chosen to complete this study.

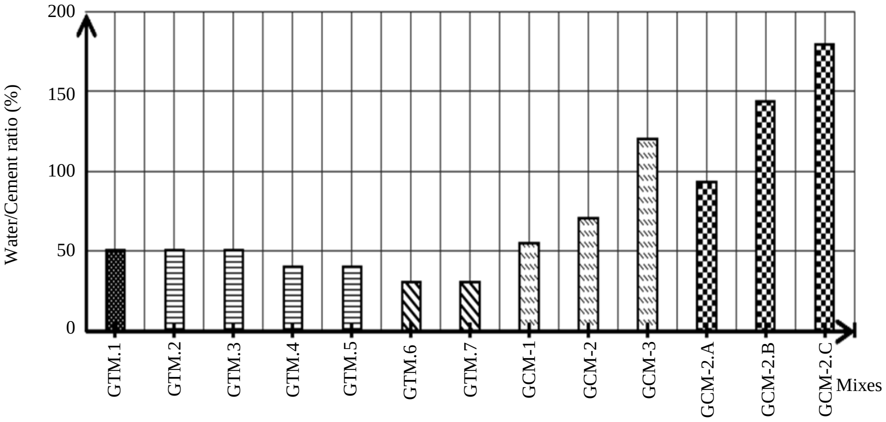

Fig. 5: Water/Cement ratio for liquid grout mixes

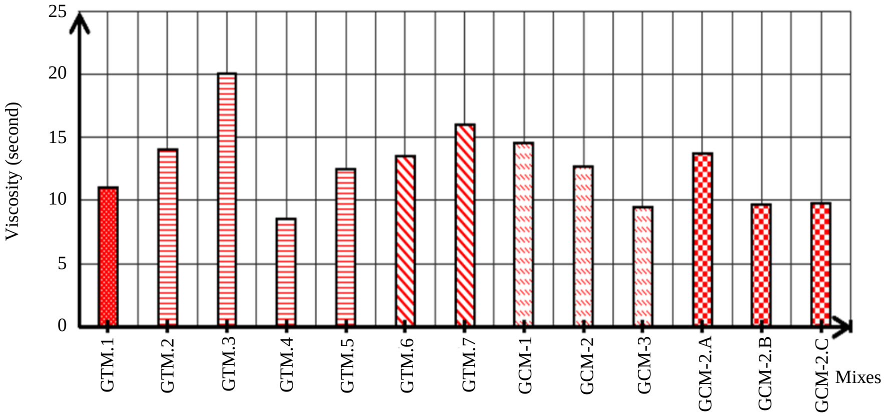

Fig. 6: Viscosity for liquid grout mixes

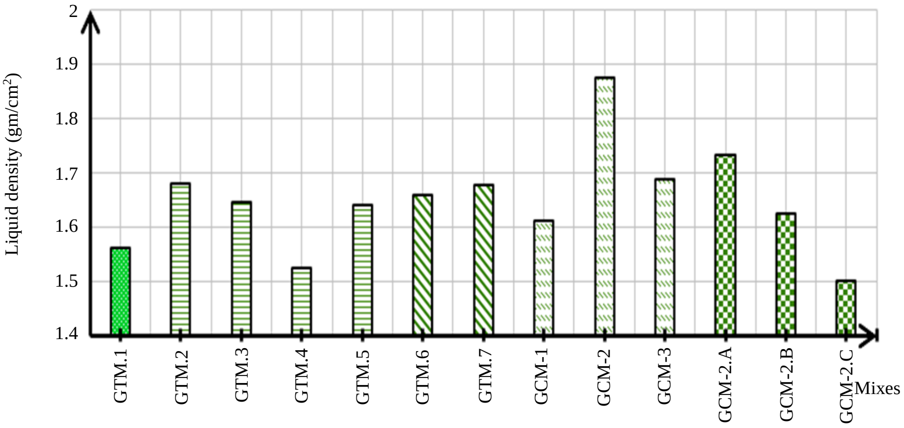

Fig. 7: Density for liquid grout mixes

Stage 4: Grouting Process of the Specimens

A grout mix was spread on the surface of porous asphalt mixtures. The process took place until bubbles did not appear and the grout was fully filled the whole depth specimen. The efficiency of grouting or the percent of air voids filled with grout (grouting degree) depends on the connected air voids and the workability of grout. Grouting degree can be calculated according to the following equation where should ranges between 85 and 100%. Figure 10 shows the difference between accepted and non-accepted grouting degree. To go over this limit, compaction efforts of 0, 10, 20 and 30 blows/side were used to produce continues air voids in the specimen. Figure 11 illustrates the grouting degree for the selected grout sample (GCM-2A) where by increasing the compaction effort, the grouting degree of SFP specimens decreased.

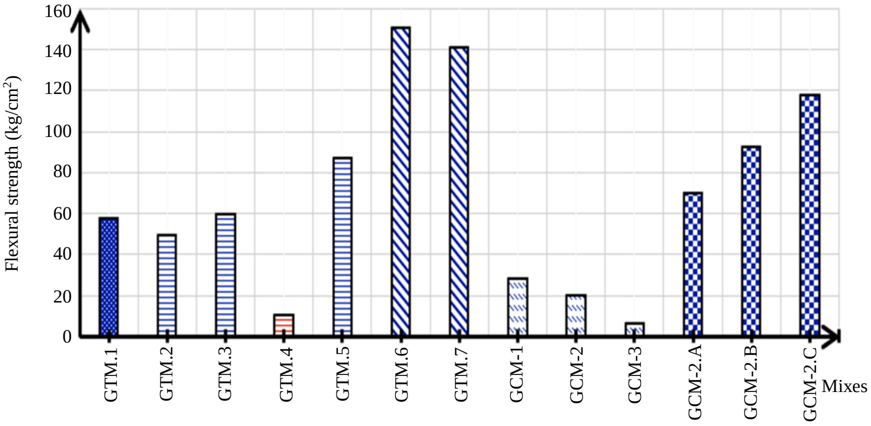

Fig. 8: Flexural strength for hardened grout mixes

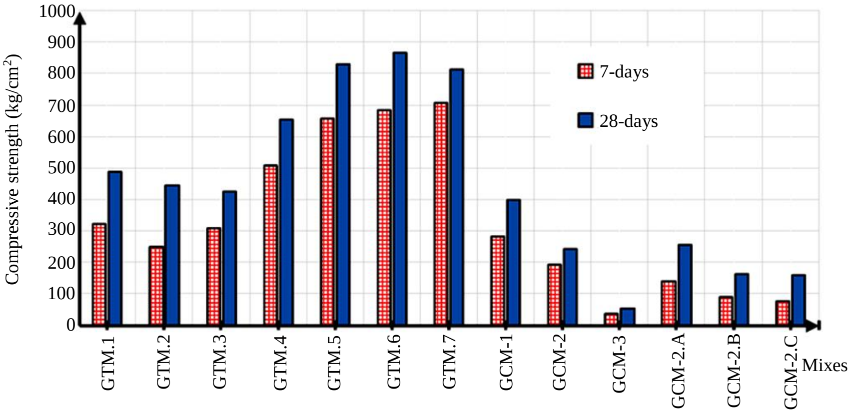

Fig. 9: Compressive strength for hardened grout mixes

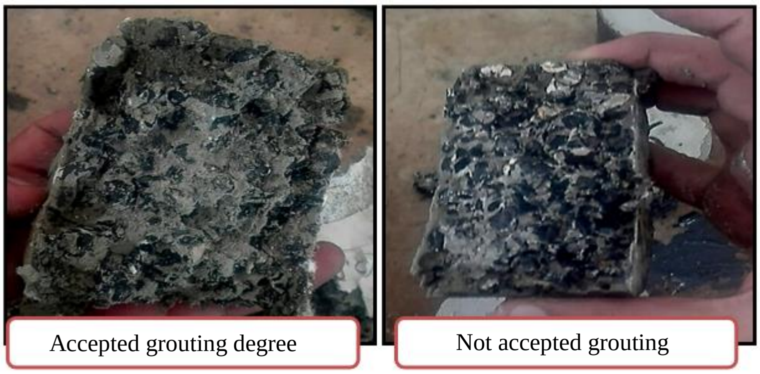

Fig. 10: Accepted and not-accepted grouting degree

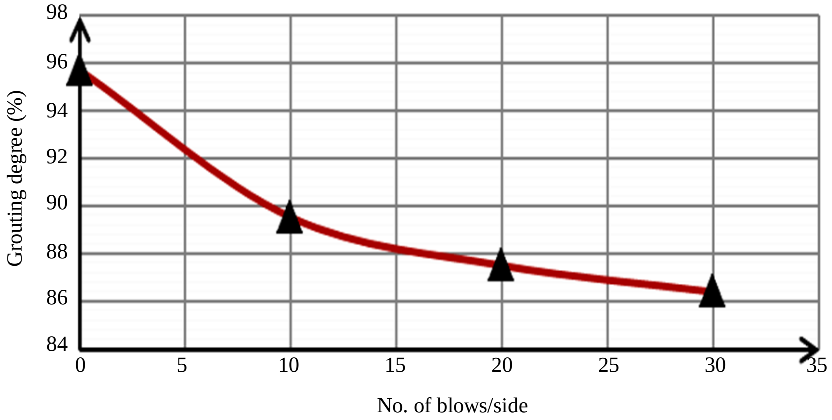

Fig. 11: Effect of compaction on grouting degree

It may be because the air voids percent decreases with increasing the compaction blows:

$$\text{Degree of grouting} =: \left(1-\frac{\text{percent of air voids in grouted specimen}}{\text{percent of air voids in specimen befor grouting}}\right)\times 100$$

Stage 5: Testing of Semi-Flexible Samples

Marshall test according to (ASTM, D1559) as well as indirect tensile strength according to (ASTM, D6931) were performed on SFP mixtures. The curing process was performed by immersing the grouted samples in a water bath of 25°C for 1 h before indirect tensile strength test. Curing the specimens for 1 h in 25°C then for 0.5 h in 60°C was performed before Marshall test.

The indirect tensile test was performed on specimens of (4 inch diameters and 2.5±0.2 inch thickness) with a single compressive load, which acts parallel along the vertical diametric plane. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load along the vertical diametric plane, which ultimately causes the failure by splitting along the vertical diameter of the specimen. The vertical load was applied in such a way that it produces a constant deformation rate of 50 mm/min. The ultimate load was recorded at failure. The Indirect Tensile Strength (ITS) is calculated as follows:

$$ITS = 2P / (\pi \times H \times D)$$

where, P is the ultimate applied load at failure, H is the thickness of specimen and D is the diameter of specimen.

The Effect of compaction effort (0, 10, 20, 30 blows/side of specimen) and the specimens age from grouting to testing (1, 7 and 28 days) were investigated on Marshall Stability (MS), Marshall Quotient (MQ) and Indirect Tensile Strength (ITS). The Marshall quotient which measures the material’s resistance to permanent deformation or the stiffness of the specimen is known as the ratio of Marshall stability to flow.

Results and Discussion

Marshall Stability and Quotient Results

Figure 12 and 13 show the Marshall stability that indicates the maximum load for failure and Marshall quotient that indicates the rigidity of SFP respectively. It can be indicated that with increasing the specimen age, Marshall stability and quotient increased due to grout hardening with time. With increasing the compaction effort, Marshall stability and quotient obviously decreased at specimens age of 28 days, slightly decreased at 7 days and increased at specimens age of 1 day. These results may be because at lower air voids caused by increased compaction effort, lower grout was injected and thus lower stiffness was obtained. While, for specimens age of 1 day, Marshall stability and quotient depended on the compaction effort not on grout hardening. Moreover, it can be noticed that about (37.0-42%) of 28 days Marshall stability and about (25-47%) of 28 days Marshall quotient were achieved after 7 days.

Figure 14 indicates the fracture shape of the grouted asphalt mixtures resulting after Marshall test. It is illustrated that there isn't a complete collapse for all samples of different compaction efforts. This may be due to the interlocking and cohesion between grouts and coated aggregates.

Indirect Tensile Strength

The effects of compaction effort and specimens age on Indirect Tensile Strength (ITS) are shown in Fig. 15. After 1 day from grouting, it can be noticed that with increasing the compaction effort, the ITS significantly increased. While at partially grout hardening after 7 days and full hardening after 28 days, the ITS obviously decreased with increasing the compaction effort. About (76-93%) of 28 days indirect tensile strength was achieved after age of 7 days. Figure 16 shows the fracture shape resulting from ITS test. It is clear that there was no division of the mixture while the width and depth of cracks increased with increasing the loading during testing. Approximately similar shapes of failure were noticed at all compaction efforts. The shape of failure for SFP was completely different from concrete specimens. This is a good indicator that the grouted asphalt mix or SFP is still an asphalt flexible mix.

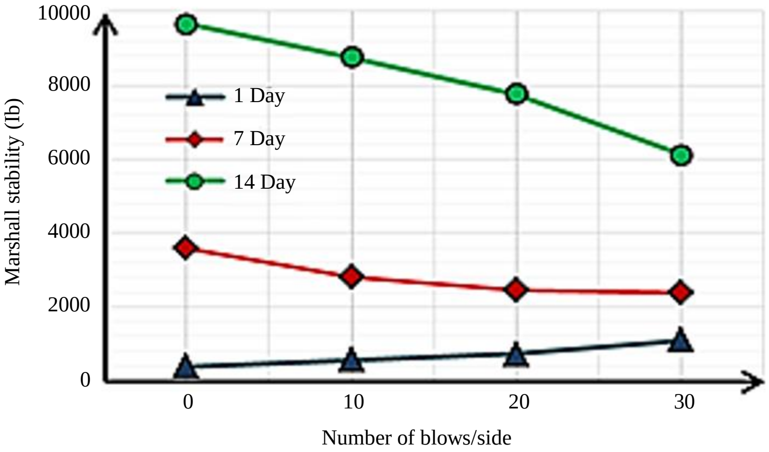

Fig. 12: Effect of specimen age and compaction effort on Marshall stability

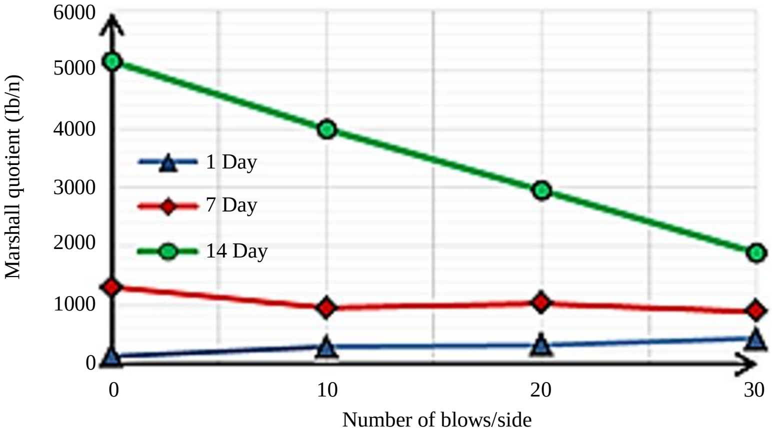

Fig. 13: Effect of specimen age and compaction effort on Marshall quotient

Fig. 14: Failure shapes after Marshall test

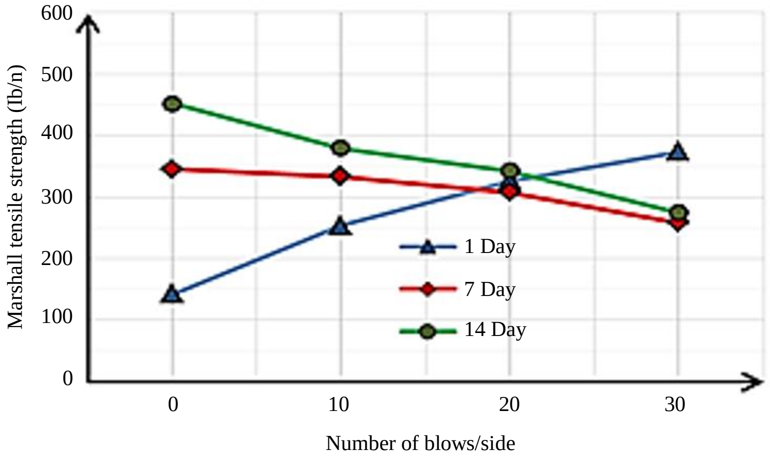

Fig. 15: Effect of specimen age and compaction effort on indirect tensile strength

Fig. 16: Failure shapes after indirect tensile strength test

Conclusion

- Suitable viscosity, density, water/cement ratio and high strength grouts that can permeate the porous asphaltic layer can be generated using additives. The main ingredients in generating grout samples are a sufficient percentage of cement, fine sand, water and pozzolanic additives such as silica fume and super-plasticizer. The convenient operation for generating improved cementitious grout samples was provided in this research
- The grout mix GCM-2.A that including 32.48% Ordinary Portland Cement (OPC), 32.48% Fine Sand (FS), 4.7% Silica Fume (SF) and 30.34% water content, provided appropriate properties for liquid grout such as workability and density. Moreover, it improved the compressive and flexural strengths compared with other grout mixes
- Adding Silica fume improved the grout properties and facilitated the grouting process compared with using fly ash at the same percent
- For hardened grout strength, after 7 and 28 days, the grout mix GCM-1 that contain (2:1 OPC:FS)

produced significant effect on flexural and compressive strength. While using grout mix GCM-2 that containing (1:1 OPC: FS) was more acceptable for grouting process where achieved higher grouting degree. Moreover, using grout mix GCM-3 that containing (1:2 OPC:FS.) was not effective

- Indirect Tensile Strength (ITS) of specimens grouted by modified mix GCM-2A after 7 days of curing provided about (76-93%) of ITS values at age of 28 days. Moreover, about (37.0-42%) of 28 days Marshall stability and about (25-47%) of 28 days Marshall quotient were achieved after 7 days
- With increasing the compaction effort, Marshall stability, quotient and indirect tensile strength obviously decreased at specimens age of 28 days, slightly decreased at 7 days and increased at specimens age of 1 day where the grout strength depended on the compaction effort not on grout hardening
- From the fracture shape of indirect tensile strength test. It was clear that there was no division of the mixture. Approximately similar shapes of failure were noticed at all compaction efforts. The failure shape grouted macadam was completely different from concrete specimens. This is a good indicator that the grouted asphalt mix or SFP is still a flexible mix

Acknowledgement

The authors gratefully acknowledge the Egyptian General Authority for Roads, Bridges and Land Transportation (GARBLT) for providing necessary support and laboratory equipment.

Funding Information

This research was internally supported by authors only.

Author’s Contributions

This paper is extracted from a master thesis prepared by Momtaz Othman, which was conducted under the supervision of Associate Prof. Ahmed Abu El-Maaty and Prof. Zeinab Hussein.

Momtaz Othman: Conducted the laboratory tests, collected the literature review and analyzed the results.

Ahmed Abu El-Maaty: Wrote and organized the manuscript, provided technical consultancy about the obtained results, participated in analyzing the data and discussing the results.

Zeinab Hussein: Managed and revised the analyses of the study.

Ethics

This manuscript in its current form has not been published elsewhere. So there are no ethical issues know to authors that may arise after the publication of this manuscript.

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