International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 4 Issue 3, March-2015, pp: (185-191), Impact Factor: 1.252, Available online at: www.erpublications.com

The effect of compaction effort on volumetric and drainage properties of porous asphalt

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Abstract: Due to its high air voids of about 20%, porous asphalt is considered as a storm water management technology by allowing water to pass through its connected air voids easily. Due to compaction and traffic volume, porous asphalt pavement is over compacted which is lead to decreasing in air voids percentage and finally drainage performance. Through this paper, the effect of compaction effort was studied. Two mixes of OGFC were investigated with specimens at two marshal compaction efforts; 2×25 and 2×50 blows in terms of bulk specific gravity, air voids, connected air voids and vertical permeability. The results shown that there was a increasing in bulk specific gravity and decreasing in total air voids, connected air voids and vertical permeability as the compaction effort is increased. Also it was shown that the effect of compaction effort on the performance of porous asphalt is much affected by aggregate gradation and binder content. Finally, compaction effort of 2×50 marshal blows was the most suitable to compact porous asphalt mixes.

Keywords: Porous Asphalt, Compaction Effort, Aggregate Gradation, Design Binder Content, Performance.

INTRODUCTION

one of the advanced technology in pavement design is open graded asphalt or which is an environmentally friendly road material as a top surface layer. Due to higher coarse aggregate and lower fine aggregate, interconnected micro air voids of about 20% are created. Those air voids provides drainage system through pavement structure in all directions which reduce aquaplaning on roads and improve visibility. [1] [2]. Also the use of open graded asphalt reduces traffic noise, improved skid resistance through its surface texture and reduction of night time glare due to its surface roughness and finally reduction of tire wear due to its reduction of rolling resistance. [3]. As a result, open graded asphalt improve safety and reduce traffic accidents, especially during wet weather. [4]

One of the open graded asphalt applications is open graded friction course. Open graded friction course is a thin permeable asphalt surface layer with high binder content when compared to dense mixes which is placed on conventional dense graded pavement as an alternative mixes to seal chip and. initially, California state was first started to reduce road noise, increase durability, and to provide better ride quality (Kandhal 2002) [5].

thus, The main purpose of porous asphalt pavement is to increase the road porosity to allow subsurface runoff in a way to decrease accident rate. Generally. One of the main important factors which the porous asphalt suffers from is the decreasing in air voids due to pavement densification. the porosity will decrease due to compaction processes from traffic flows[6] . since the performance of porous pavements is affected by the percentage of total air voids within this pavements, the effect of compaction is transferred to the other terms of porous pavement performance such as volumetric, mechanical and hydraulic properties. As the compaction effort is increased, the percentage of total air voids is decreased. So, it is important to characterize the variability in the performance of porous asphalt due to different compaction. Through this paper, the effect of compaction effort was studied in term of bulk specific gravity, total air voids, connected air voids and vertical permeability.

The study consists of volumetric and drainage evaluations to characterize locally manufactured OGFC with different compaction efforts. the compaction type was fixed on marshal compactor apparatus therefore, the variation in compaction was just in the compaction effort. for porous pavements, many authors tried to optimize the compaction effort of porous asphalt and most of them concluded that 2×75 marshal blow which specified for dense graded pavement is not suitable for compacting porous pavement specimens because of aggregate crushing probability. So, the compaction efforts which is suitable for compacting porous pavement specimens are in between 2×25 marshal blow and 2×50 marshal blow. The Marshall compactive effort of 25 blows was used based on a modified mix design procedure used by the Georgia Department of Transportation and 50 blows was used based on European mix design procedures for porous mixes[7]

Volumetric properties represents the determinations of bulk specific gravity, maximum specific gravity, air voids, connected air voids of OGFC marshal specimens were studied. Also the coefficients of vertical permeability were determined to marshal specimens as a drainage evaluation.

MATERIALS

Asphalt binder: conventional unmodified asphalt binder was used to prepare the OGFC mixes. The properties of asphalt binder were illustrated in Table (1).
Coarse aggregate:it is defined by that aggregate which retained on sieve no.4 (4.75mm). coarse aggregate should be crushed, tough and durable to resist loading which comes from traffic during the lifetime of the pavement. the properties of used coarse aggregate were shown in table (1).
Fine aggregate:Used Fine aggregate were also crushed river gravel with properties which were shown in table (1)
Mineral filler: it is defined as that constituent of the mixture which has a particles of passing sieve no.200 (0.075mm). there are many types of filler which are used in asphalt mixtures. In this paper, hydrated lime was used. the properties of hydrated lime were shown in table (1).

Table 1: different properties of constituent materials

material	property	Obtained value
Asphalt binder material	Penetration (0.1mm)	61
	Softening point (°C)	44
	Ductility (cm)	120
	Flash point (°C)	255
	Specific gravity	1.02
Coarse aggregate	Bulk specific gravity	2.65
	Apparent specific gravity	2.68
	Absorption (%)	0.702
	Loss Angeles abrasion loss (%)	18.39
	Impact value (%)	12.72
Fine aggregate	Bulk specific gravity	2.49
	Apparent specific gravity	2.69
	Water absorption (%)	2.91
Filler	Specific gravity	2.47
	Fineness	6370

PROCEDURE

Aggregate gradation

There are many gradations specified by agencies that is considered as porous aggregate gradation but in this paper, ASTM recommendations for open graded friction course OGFC were chose as porous aggregate gradation. Two gradations of 19mm and 12.5mm M.A.S which were defined by ASTM as OGFC were used to form porous structure of open graded asphalt as shown in figure (1). The gradation of 19mm M.A.S has a coarse aggregate about 90% and a fine aggregate of about 7% in addition to 3% as a filler passing no.200 (0.075mm). The other gradation of 12.5mm M.A.S consists of about 75% coarse aggregate and about 20% of fine aggregate in addition to 5% as a filler. The two gradations of OGFC after adding of design binder content are referred to as Mix 1 and Mix 2.

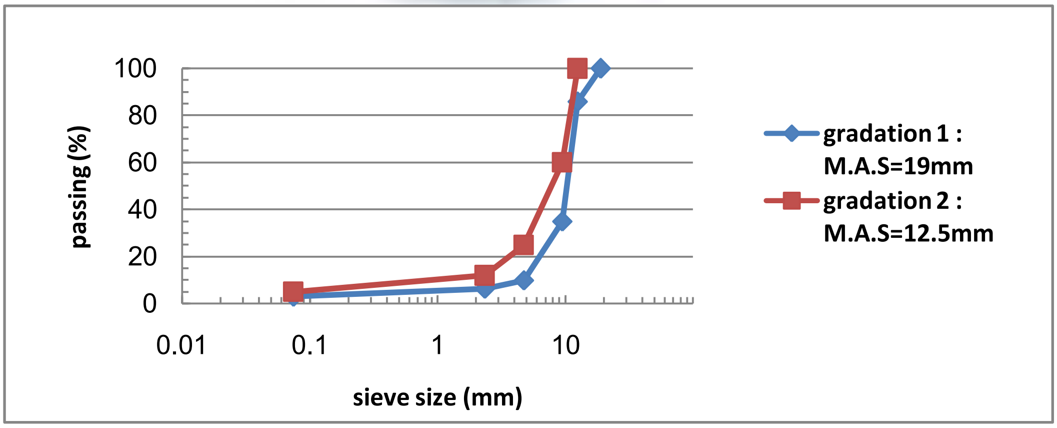

Figure 1: OGFC aggregate gradations [8]

Design binder content

Because open graded asphalt has open structure which helps rapid damage of pavement due to oxidation and moisture susceptibility, it is important to design open graded asphalt with high asphalt content to increase the lifetime of the pavement. Traditional marshall mix design way for optimum asphalt content determination is not appropriate to design porous asphalt because of the insensitivity of the marshall stability to variations in binder content. A special study for grading design of porous asphalt based on the packing theory, were found to be better than the empirical design. [9]. Transport Research Laboratory, UK [10] developed the binder drainage test in order to determine the upper limit of acceptable binder content in porous mixes. The component of the test consists of a number of baskets with wire mesh in additional to the same numbers of underneath trays to collect the drained asphalt binder. A number of binder percents are chosen. For each binder percent, a mass of 2.2kg of porous mix is needed to conduct the test two times. After preparing the mix at a temperature of 130°C, it is transferred quickly to the two sets of pre weighed baskets and trays and it is charged in the oven at drainage temperature (150°C). After a period of 3hrs, the sets are removed from the oven and the weights of each basket with retained mix and tray with drained binder and filler are obtained. The drained material is then calculated. The drained material in fact is a combination of binder and filler. The retained binder (%), R, shall be calculated from Equation 1.

$R = 100 \times B[1-D/(B + F)]/(1100 + B)$ ------ (1)

where, D = the mass of binder and filler drained.(g)

B = the initial mass of binder in the mix (g)

F = the initial mass of filler in the mix (g)

The retained binder is plotted against the initial mixed binder content, together with the line of equality where the retained binder equals the mixed binder content. From the obtained results, the design binder content of Mix 1 and Mix 2 of OGFC were 5.2% and 6.1% respectively.

Preparation of Porous Asphalt specimen:

The preparing of open graded asphalt mixes is similar to that of conventional dense graded asphalt. The quantity of dry constituent materials are weighed and optimized according to the used gradation and needed quantity. those materials are heated to 160-170 C in an oven, then they are transferred to the mixer bowl. The pre heated quantity of binder according to the design binder content is then added gradually to the mix. The mixing process is continued until all aggregate particles are covered uniformly by binder. after conditioning period, the mix was then placed in a pre heated mold and compacted. Compaction shall be completed before the temperature of the material falls below 85°C, when 50/70pen asphalt is used. [11].

TESTING

Bulk specific gravity:[12]

Automatic Vacuum Sealing method which was specified in ASTM standards D 6752 was used to determine Bulk Specific Gravity of open graded mixes. In the beginning, dry unsealed compacted specimen was weighed accurately to the nearest 0.1gm, the weight of sealed specimen in air was determined, then the sealed specimen was weighed in water bath at 25°C. Bulk specific gravity of specimen is determined using the following formula:

Bulk specific gravity= $A/(B-E-(B-A)/FT)$---(2)

where:

A = mass of dry specimen in air, g,

B = mass of dry, sealed specimen, g,

E = mass of sealed specimen underwater, g, and

FT = apparent specific gravity of plastic sealing material at

25°C (77°F), provided by the manufacturer.

Air voids:

The air voids in open graded asphalt is generally represented by the total air voids within asphalt pavement; including closed and connected voids. The percentage of total air voids within porous pavements can be determined using the following formula: [13]

Air voids=$(Gmm-Gmb)/Gmm$---(3)

Gmm: theoretical maximum specific gravity of loose mix

Gmb : bulk specific gravity of compacted specimen

Connected air voids:[14]

The connected air voids is defined as important part of porous pavement air voids which allow water to pass through the pavement. The test is one of the important test that should be considered with large interest because the connected air voids control permeability which is considered as the most important property in porous asphalt. In this research project, the connected voids are determined from the weight of water introduced into the core sample whose side walls and the bottom part were sealed. A factor of correction depending on the maximum diameter of the solid grains allows to determine the effective volume of the connected voids without taking into account the voids at the surface of the sample. the percentage of the volume of connected voids is calculated using the following equation:

$$Pc = v/V \times 100 \quad (4)$$

Where :

Pc = Percentage of connected voids

V= the conventional volume of the core sample (cm3)

v = Volume of introduced water (cm3)

Vertical Permeability [14]

In this laboratory test procedure carried out at a temperature (25°C), a column of water was applied with a constant height of 300 mm to a cylindrical specimen. Permeability Kvis evaluated from the measured flow rate of the water Qv as follows:

$$Kv = (4\, Qv\, I)/(h\, \pi\, D2) \quad (5)$$

Where, Kv is the vertical permeability (m/s); Qv is the vertical flow rate (m3/s); I is the thickness of the specimen (m); h is the height of the water column (m) and D is the diameter of the specimen (m).

RESULTS AND DISCUSSION

Bulk specific gravity

In term of bulk specific gravity, six specimens of mix 1 and mix 2 of OGFC which were compacted with both 2×25 and 2×50 marshal blows were investigated and the results were shown in figure(2). In term of 2×25 marshal blows, the average bulk specific gravity of both mix 1 and mix 2 were 1.915 with a range of 1.890 to 1.929 and 2.015 with a range between 1.994 to 2.030 respectively. While in term of 2×50 marshal blows, the average bulk specific gravity of both mix 1 and mix 2 were 1.950 with a range of 1.927 to 1.969 and 2.082 with a range between 2.069 to 2.103 respectively. when the average bulk specific gravity values for 2×25 marshal blows were compared with that for 2×50 marshal blows, it was noted that the bulk specific gravity values for 2×50 marshal blows were more than that for 2×25 marshal blows. In fact, the bulk specific gravity is increased as the compaction effort due to mix densification.

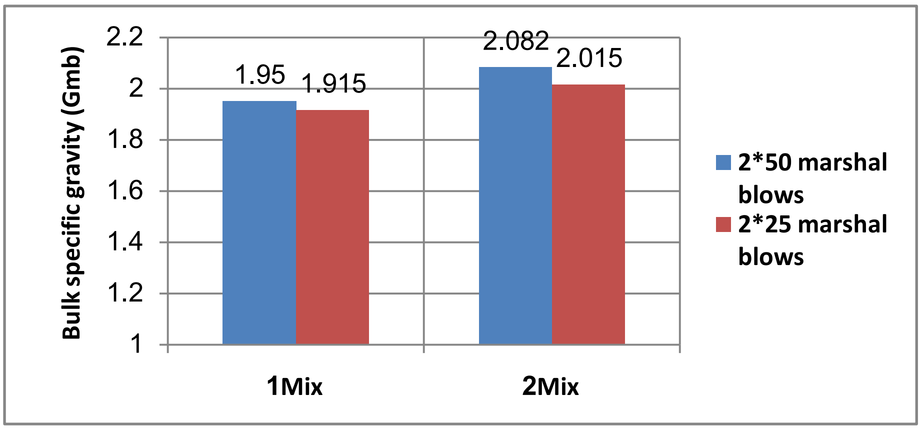

Figure 2: Average Bulk specific gravity values of Mix 1 and Mix 2 of OGFC at 2×25 and 2×50 compaction efforts

In fact, the increasing of compaction effort on porous pavement permits the divergent aggregate particles to converge and an additional amount of air voids are filled. Therefore, the volume of porous pavement specimen is increased as the compaction effort is decreased. Due to the excessive compaction effort, the aggregate particles are breakdown Causing a continuous increasing in density after the aggregate had apparently begun to interlock [7]. The nature effect of compaction effort on bulk specific gravity of porous pavement is different according to the pavement constituents and its percentages in each mix.
When the average bulk specific gravity which is obtained from 2×25 marshal blows was divided by average bulk specific gravity which is obtained from 2×25 marshal blows, the results were 98.21% and 96.78% for both mix 1 and mix 2 respectively. From the results, the effect of compaction on bulk specific gravity were existed for both mix 1 and mix 2 of OGFC but that effect was more in mix 2 than that in mix 1.

Total air voids

Total percentage of air voids of OGFC was investigated as a part of studying the effect of compaction effort on porous pavement. as mentioned before, the difference in compaction effort affects on the value of bulk specific gravity of OGFC. air voids percentage of porous pavement is substantially related to its bulk specific gravity, therefore the compaction also affects the air voids of porous pavements. In the part of this study, six specimens of mix 1 and mix 2 of OGFC were investigated at 2×25 and 2×50 marshal compaction efforts. In case of 2×25marshal compaction effort, The average value of total air voids was 22.22% with a range between 21.59% to 23.17% and 17.43% with a range between 16.80% to 18.28% for both mix 1 and mix 2 respectively. when the average value of total air voids percentage which obtained from specimens of 2×25 marshal blow was compared with about 20.73% of 2×50 marshal blow, it is shown that there are decreasing in the percentage of total air voids when the effort of compaction was increased as shown in fig (3).

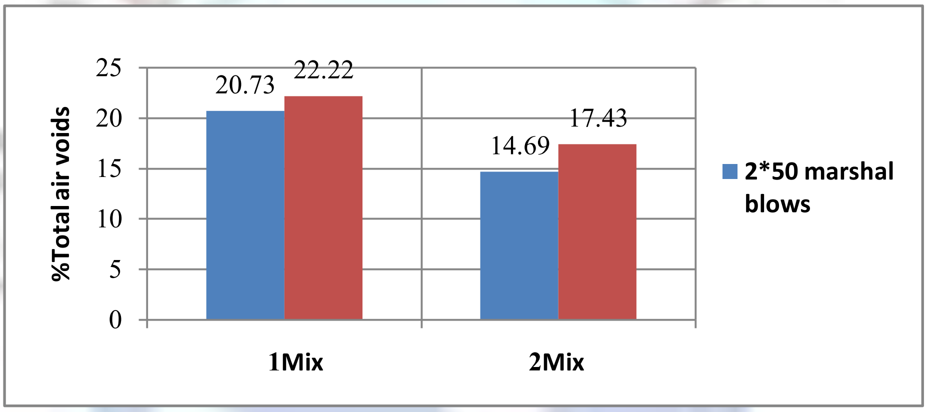

Figure (3): Average total air voids percentage of Mix 1 and Mix 2 of OGFC at 2×25 and 2×50 marshal compaction efforts

It was shown that the compaction effort affects inversely the percentage of total air voids of OGFC. the air voids of porous asphalt is decreased as the compaction effort increase. in fact, the effect of compaction on air voids percentage is different according to the mix type. for mix 1 and mix 2 of OGFC, the percentage of total air voids was varied from 20.73% to 22.22% and 14.69% to 17.43% when the compaction effort was decreased from 2×50 marshal blow to 2×25 marshal blow. it was shown that the percentage of increasing in total air voids for mix 2 was greater than that for mix 1. In fact, the densification mechanism for the two mixes are different. In case of mix 1, the little amount of fine materials increases the friction action between the coarse particles and finally restricts the densification in the mix. In the other hand, the over compaction of porous pavement leads to aggregate crushing so, the magnitude of compaction effort should be considered in case of porous pavements with very little fine materials. In fact, the densification of that types of porous pavement may be increased by re arrangement action due to compaction increasing. In case of mix 2 of OGFC, the presence of about 25% of fine aggregate and filler beside asphalt binder provides soft lubricated mastic which decrease the friction between coarse aggregate during compaction. As a result, the convergence of coarse particles is promoted. The convergence of particles decreases the percentage of total air voids. Finally the increasing of compaction effort is effective to promote the densification of porous pavements.

Connected air voids:

In term of connected air voids, the effect of compaction effort was studied. Six specimens of both mix 1 and mix 2 of OGFC with a compaction effort of both 2×25 marshal blows and 2×50 marshal blows were investigated. In case of 2×25 marshal blows, the average percentage of connected air voids were 19.89% with a range between 19.32% to 21.43% and 13.71% with a range between 13.15% to 14.56% for mix 1 and mix 2 respectively. In case of 2×50 marshal blows, the average percentage of connected air voids were 18.28% with a range between 17.14% to 19.12% and 11.36% with a range between 10.16% to 12.36% for mix 1 and mix 2 respectively When this results were compared, it was shown that also there are increasing in the percentage of connected air voids as the compaction effort was varied from 2×50 marshal blows to 2×25 marshal blows as shown in figure (4).

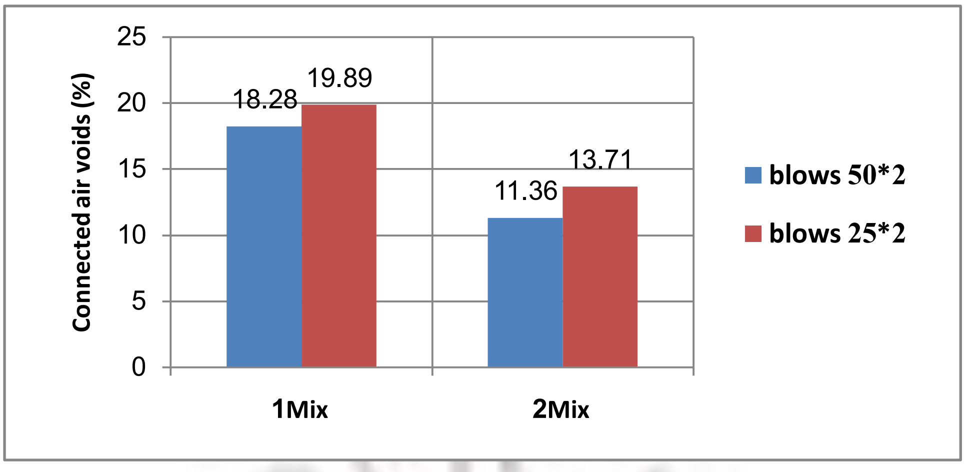

Figure (4): Average connected air voids of Mix 1 and Mix 2 of OGFC at 2×25 and 2×50 marshal compaction efforts

As mentioned before, the compaction effort affects the convergence of particles in the mix. As the compaction effort is increased, the convergence of aggregate particles in porous pavements is promoted. As a result, the cross section area of paths of connected air voids is decreased.

Vertical permeability:

The effect of compaction effort on the permeability of OGFC was also investigated. In fact, permeability is the most term which is affected by compaction effort and the densification of OGFC leads to permeability decreasing. Rolling is done using a minimum of four (4) passes of a static tandem steel wheel roller having a minimum weight of 8 tons to smooth the surface and to seat the stones in the mix so that it doesn't consolidate under traffic nor ravel. The finished pavement must have 16 to 20 percent air void content (80 to 84 percent density).

For both mix 1 and mix 2 of OGFC, six specimens with both 2×25 and 2×50 of marshal blows of compaction were investigated in term of vertical permeability. In case of 2×25 marshal blows, the average coefficient of vertical permeability for mix 1 and mix 2 of OGFC were 0.00713 with a range between 0.00703 to 0.00727 and 0.00391 with a range between 0.00357 to 0.00421 respectively. In case of 2×50 marshal blows, the average coefficient of vertical permeability for mix 1 and mix 2 of OGFC were 0.00698 with a range between 0.00660 to 0.00731 and 0.00285 with a range between 0.00274 to 0.00296 respectively as shown in figure (5).

It is clear from previous investigation that there was a direct relation between the percentage of connected air voids and the coefficient of permeability. As a result, the coefficient of permeability of mix 1 was more than that of mix 2 for both 2×25 and 2×50 blows compaction efforts. In the other hand, the relation between connected air voids percentage and permeability of porous pavements is not linear and should be focused.

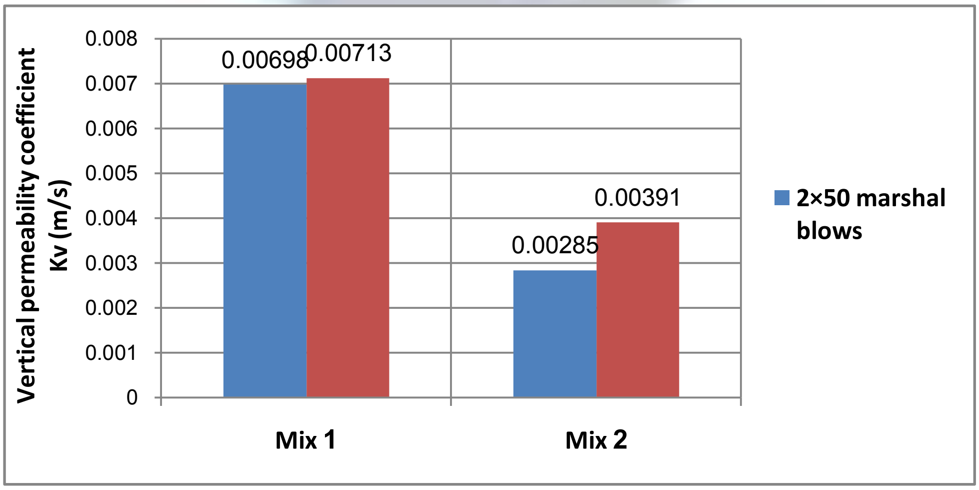

Figure (5) Average vertical permeability coefficient values of Mix 1 and Mix 2 of OGFC at 2×25 and 2×50 marshal compaction efforts

The average coefficient of vertical permeability was increased from 0.00698 to 0.00713 and from 0.00285 to 0.00391 for mix 1 and mix 2 respectively when the compaction effort was decreased from 2×50 marshal blows to 2×25 marshal blows. The over compaction of porous pavement decreases the infiltration rate of porous asphalt. [15] In the other hand, the effect of compaction effort on permeability was more in mix 2 than mix 1. In fact, the larger fine particles in mix 2 promotes voids clogging during compaction. When the coefficient of permeability at 2×25marshal blow was divided on that at 2×50marshal blows, the percentages were 102% and 137% for both mix 1 and mix 2 respectively. The large amount of mastic material within mix needs additional compaction effort to allow spreading through the coarse aggregate. Finally, the porous asphalt pavement layer should not be fully compacted to obtain maximum density.

CONCLUSIONS

1- the focusing on the effect of compaction effort on the properties of OGFC added an important indication about its behavior under different compaction effort.
2- it is indicated that when designing of porous asphalt mixes, it is important to optimize constituent materials as the long term performance of porous asphalt does not include any densification due to traffic moving on the pavement.
3- the permeability is decreased with increasing the compaction effort.
4- the effect of compaction effort is varied according to the change in aggregate gradation; M.A.S and percent passing sieve no.4 and also change in binder content.
5- The porous mixes with larger M.A.S needs to lesser compaction effort.
6- The little increasing in air voids of porous asphalt leads to a large increasing in its permeability.
7- the porous mixes with high fine materials are more susceptible to densification in the future than that with low fine materials.
8- Compaction effort of 2×50 marshal blows is the most suitable one to compact porous asphalt specimen.

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