Evaluation Of Porous Asphalt Mixtures Stabilized By Cellulose Fibers

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Abstract: Open graded friction course (OGFC) or porous asphalt is an open-graded Hot mixed asphalt (HMA) mixture with interior voids which provides improved surface drainage during rainfall. In addition to maximizing the skid resistance during rainfall, the OGFC offers many advantages compared to other dense-graded surfaces such as reducing vehicle splatter and spray behind vehicles, enhancing visibility of pavement markings, reducing nighttime surface flashiness in wet weather. The combination of open-grading for aggregates, low fillers, and high asphalt contents can lead to an increase in the proportion of drain down that draining the asphalt binder from a mix during transportation and lay down. The leading countries in paving by OGFC have chosen mineral fibers over organic fibers because of the fear that organic fibers (cellulose) would absorb water and lead to moisture problems in the field and decrease the stability of mixtures. The study required preparing OGFC mixes with both cellulose and mineral fibers and performing many Performance measuring tests and found out the optimum content of cellulose fiber in OGFC. Results indicated that cellulose fibers performed as mineral fibers in OGFC mixes and better than mineral fibers if a cement dust additives added to cellulose fibers.

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1 Introduction

Porous asphalt or open-graded asphalt friction course (OGFC) is an open-graded Hot mixed asphalt (HMA) mixture with interior voids which provides improved surface drainage during rainfall. The rainwater cleared out vertically through the porous asphalt course to an impermeable underlying layer and then laterally to the daylighted edge of the OGFC or infiltrated through bedding layer and base to the natural soil below. OGFCs typically need a gap-grading for aggregates, a low content of fillers and asphalt content slightly higher than that for dense-graded mixes. The combination of gap-grading for aggregates, low fillers and high asphalt contents can lead to an increase in the proportion of draindown that is the draining of the asphalt binder from a mix during transportation and lay down, Usually mineral fiber added at 0.4% of total mix weight to prevent the occurrence of this phenomenon. By searching in the experiences of the leading Countries that paving by OGFC,[1]mentions that there are fears about using organic fibers (cellulose) due to moisture damage. The main objectives of the proposed research are determine the validity and the efficiency of using cellulose fibers as additives to OGFC mixtures instead of mineral fibers and determine the optimum cellulose fiber content in OGFC mixture which give the best values of stability, flow, air voids and porosity and make the benefit of using cellulose fibers which produced from rice, cotton and wheat straws and bagasse.

2 Experimental work

In the first stage 12 types of tests were performed on the materials used to insure its validity, eight tests on aggregates (los angles abrasion, water absorption, apparent specific gravity, proportion of clay lumps and friable particles, bulk specific gravity, flakiness index, shape index and selection of design gradation that achieve the condition of stone-on-stone contact) and four tests on asphalt binder (Ductility, Softening point, penetration and viscosity). In the second and third stage the optimum asphalt content (O.A.C) and the optimum cellulose content (O.C.C) were determined. In the last stage a six types of tests were performed to compare and evaluate the porous asphalt mixtures stabilized by cellulose fibers with the other porous asphalt mixtures that stabilized by mineral fibers.

3 Materials

In This study, the materials used in preparing mixtures were open graded all-in aggregates of course and fine aggregate, asphalt binder (AC 60/70), slag wool fibers as mineral fibers, cellulose fiber as organic fiber and cement dust as additive to cellulose fiber.

3.1 Aggregates

Table (1) shows the properties of the used aggregates according to the results of tests conducted in the main laboratory of Housing and Building National Research Center (HBRC) - Building Materials Research and Quality Control Institute (BMI). Table (2) shows aggregates design gradation and gradation limits for OGFC according to (NAPA 115 - 2003)[2].

3.2 Asphalt binder

Table (3) shows the properties of the used binder according to the results of tests conducted in the main laboratory of General Authority for Roads, Bridges and Land Transport and Composite Materials laboratory of Housing and Building National Research Center (HBRC) - Building Materials Research and Quality Control Institute (BMI).

3.3 Slag wool fiber (Mineral fiber)

Table (4) shows the properties of the used Slag wool fibers as the producer's data sheet USG Co.

3.4 Cellulose fiber (Organic fiber)

Table (5) shows the properties of the used Cellulose fibers as the producer data sheet (Cairo Cell. Co).

3.5 Porous asphalt mixtures

Table (7) shows a nine porous asphalt mixtures types that conducted to several tests to measure the performance of each one to evaluate the mixtures that stabilized by cellulose and cellulose/cement dust to make a comparison with those mixtures stabilized by slag wool fibers

Table (1) Properties of Aggregates used

Properties	Course	Fine	Egyptian Standards
Clay lumps and friable particles (%)	1.20	1.50	Up to 5%
L.A. abrasion (%)	25.60	_	Up to 40%
Water Absorption (%)	2.10	2.50	Up to 5%
Apparent Specific Gravity (t/m3)	2.53	2.48	_
Bulk Specific Gravity (t/m3)	1.60	1.40	_
Flakiness Index (%)	8.50	_	Up to 10%
Shape Index (%)	7.30	_	Up to 10%

Table (2) Aggregates Gradation (All-in)

Sieve (mm)	Gradation %passing	Specification Limits
19	100.0	100
12.5	95.0	85-100
9.5	65.0	55-75
4.75	15.0	12-25
2.36	7.0	5-10
1.18	4.5	--
0.6	4.1	--
0.3	3.5	--
0.15	3.2	--
0.075	3.0	2-4

Table (3) Properties of Asphalt binder used

	Ductility (cm)	Softening point (°C)	Penetration (0.1mm)	Viscosity (Poises)	Sp. gravity (t/m3)
AC(60/70)	110	52	62	10	1.02
EG.Std.	At least 90	45-55	60 - 70	At least 3.2	--

Table (4) Properties of mineral fiber used as data sheet from producer

Slag wool fiber	Melting point (°C)	Average fiber diameter (µm)	Fiber length (in)	Recycled content (%)	Specific gravity (gm/cc)	tensile strength (psi)
USG Co.	1204	4.1	0.035-1.25	90%	2.7-2.9	80000
Cost (L.E/kg)	7.0					

Table (5) Properties of mineral fiber used as data sheet from producer

Sample code	Fiber type	Fiber length (mm)	Cellulose content (%)	Specific gravity (gm/l)
K600A	Wood pulp	0.063-0.5	98.2%	150 - 200
Cost (L.E/kg)	2.5			

Table (7) The nine porous asphalt mixtures

code	Description	Function	Obj.
Mix 1	4.0% AC 60/70 + 0.4% Slag wool fiber	Determine O.A.C of Control Mix	Control Mix
Mix 2	5.0% AC 60/70 + 0.4% Slag wool fiber		
Mix 3	6.0% AC 60/70 + 0.4% Slag wool fiber		
Mix 4	7.0% AC 60/70 + 0.4% Slag wool fiber		
Mix 5	O.A.C% AC 60/70 + 0.3% Cellulose fiber	Determine O.C.C of Comparison Mixes	Comp.Mix.1
Mix 6	O.A.C% AC 60/70 + 0.4% Cellulose fiber		
Mix 7	O.A.C% AC 60/70 + 0.5% Cellulose fiber		
Mix 8	O.A.C% AC 60/70 + 0.6% Cellulose fiber		
Mix 9	O.A.C% AC 60/70 + O.C.C% + 0.3% Cement dust	Comparison Mix	Comp.Mix.2

4 Experimental works and results

4.1 Optimum asphalt content (O.A.C)

A four porous asphalt mixtures with the materials selected in the previous stage and different asphalt contents (4.0%, 5.0%, 6.0%, 7.0%) and 0.4% slag wool fiber had been prepared and conducted to Marshall design mix method (AASHTO T245) [3] to determinate mixtures properties according to (AASHTO T209)[4] and tested them by Marshall apparatus to obtain stability and flow, then a result comparison was made to found the optimum asphalt content (O.A.C)that was 5.5%which provide maximum stability and reasonable flow, actual specific gravity and % air voids. Table (8) shows the properties of O.A.C Mixture with slag wool fiber and figures (1,2,3 and 4) shows the relations between percentage of asphalt and the following items are plotted:(Stability, Flow, Unit weight, Percentage of air voids)

4.2 Optimum cellulose fiber content (O.C.C)

A four porous asphalt mixtures with the materials selected and the optimum asphalt content (5.5%) and various cellulose fiber contents (0.3%, 0.4%, 0.5%, 0.6%) were prepared and conducted to Marshall design mix method to found the optimum Cellulose content (O.C.C) that was 0.4%. Table (9) shows the properties of the O.C.C Mixture and figures (5,6,7 and 8) shows the relations between percentage of asphalt and the following items are plotted: (Stability, Flow, Unit weight, Percentage of air voids).

4.3 Properties of cellulose/cement dust mixture

A one porous asphalt mixture with the materials selected and the optimum asphalt content (5.5%), the optimum cellulose fiber content (0.4%) and (0.3%) cement dust was prepared and conducted to Marshall design mix method to determinate mixture properties and tested them by Marshall apparatus shown in figure (9) to obtain stability number and flow as shown in table (10).

4.4 Loss of stability

The loss of stability percent was used as an indicator to mix durability under different conditions. Tables (11) present the results of loss of stability test performed on the investigated mixtures. Figure (10) shows the loss of stability percents versus immersion time for the three mixtures (control mix, comp. mix1 and comp.mix2).

4.5 Draindown

As the main function of fiber additives to porous asphalt mixtures is to reduce the percent of binder draindown which increases in porous asphalt mixture due to the open grading of aggregates and the decrease of fillers content. The procedures according to (AASHTO T305)[5] was followed to determine the percent of binder draindown of the mixtures shown in figure (11). The results shown in table (12) and figure (12) that shows the comparison between the main three mixtures.

4.6 % Air voids

Air voids percentage of every mixture is a main element in the process of optimum content determination, So the air voids percentage calculated for mixtures according to (AASHTO T269)[6] to dictate the effect of asphalt content on the density and air voids of the specimen. Table (13) shows the Actual and apparent specific gravity and %air voids results and figure (13) shows the comparison between the main three mixtures' %air voids results. Based on these results it can be concluded that the use of cement dust at (0.3%) with cellulose fiber additives (0.4%) present the lower proportion of air voids.

4.7 Permeability coefficient

Permeability is the main function of porous asphalt mixtures, as it indicates the ability of porous asphalt mixtures to discharge the falling water to a drainage system. The permeability coefficient test was carried out according to (ASTM PS129)[7] on the main three mixtures samples (4 inch in diameter and 2 inch in thickness) to compare the porosity of each mixture under water falling conditions. Table (14) shows permeability test results and figure (14) shows the comparison of this results.

4.8 Moisture sensitivity (Indirect Tensile Strength Ratio)

To defeat all suspicions about moisture damage by using cellulose fiber additives instead of mineral fiber, one of the important moisture sensitivity tests as the indirect tensile strength ratio test was carried out on the main three mixtures according to (AASHTO T283)[8] to compare the results and determine the moisture sensitivity of each mixture. Table (15) shows TSR test results and figure (15) shows the comparison of this results.

4.9 Rut depth resistance

The determination of rutting susceptibility was the last performance test in this research. A one slab - figure (16)- of 330 mm width, 440 mm length and50 mm thickness according to (LTG2015)[9] was prepared for each mixture and conducted to the test after socked 24 hr in 60°c water bath under wheel load of 700 N according to (AASHTO T340)[10]. The rut depth results shown in table (16) and figure (18) shows the comparison of mixtures results.

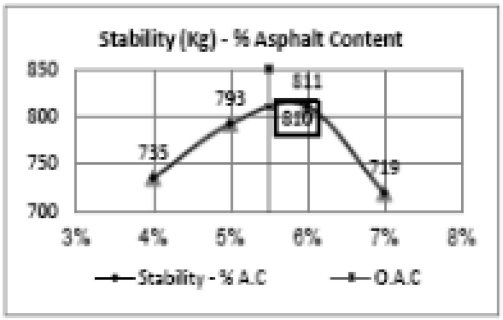

Figure (1) The stability for porous asphalt mixtures

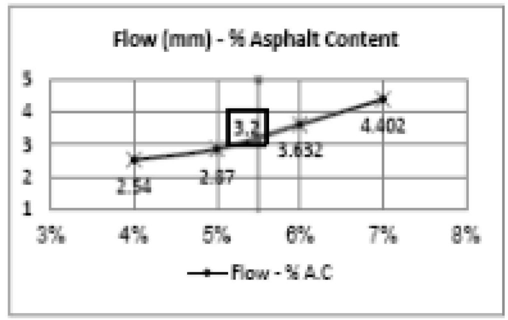

Figure (2) The flow for porous asphalt mixtures

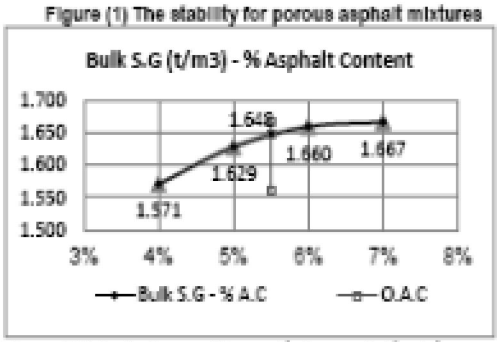

Figure (3) The bulk specific gravity for asphalt mixtures

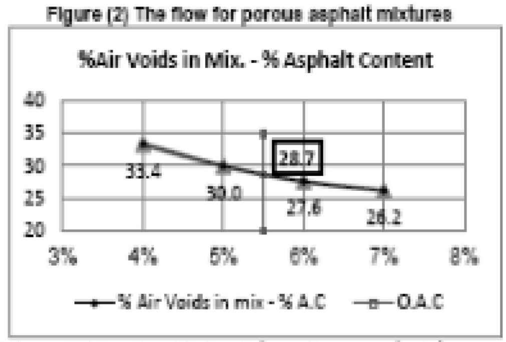

Figure (4) The air voids in mixtures for asphalt mixtures

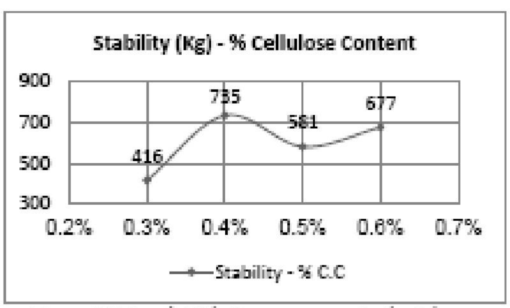

Figure (5) The stability for porous asphalt mixtures

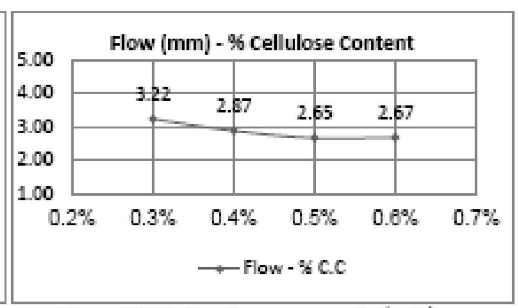

Figure (6) The flow for porous asphalt mixtures

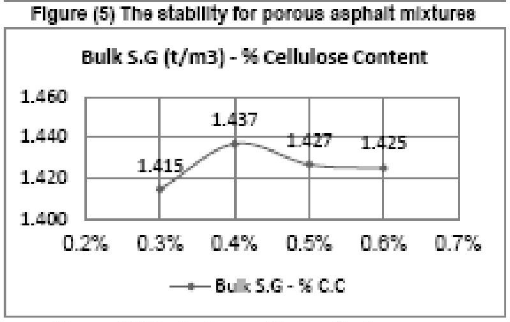

Figure (7) The bulk specific gravity for porous asphalt mixtures

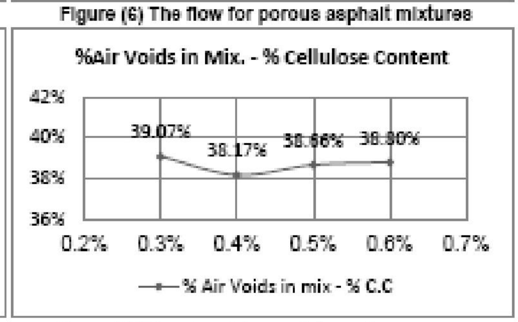

Figure (8) The air voids in mixtures for porous asphalt mixtures

Table (8) roperties of O.A.C mixture with mineral fiber

Properties	Results	(NAPA,2003) Requirements for OGFC
Stability (kg)	810	> 500 kg
Flow (mm)	3.2	2 - 6 mm
Marshall stiffness (kg/mm)	253.125	> 200 kg/mm
% Air voids	28.7	> 18%
Bulk S.G (g/cc)	1.648	---

Table (9) Properties of O.C.C mixture

Properties	Results	(NAPA,2003) Requirements for OGFC
Stability (kg)	735	> 500 kg
Flow (mm)	2.87	2 - 6 mm
Marshall stiffness (kg/mm)	256.09	> 200 kg/mm
% Air voids	38.17	> 18%
Bulk S.G (g/cc)	1.437	---

Table (10) Properties of Cellulose/Cement Dust Mixture

Properties	Results	(NAPA,2003) Requirements for OGFC
Stability (kg)	837	> 500 kg
Flow (mm)	2.04	2 - 6 mm
Marshall stiffness (kg/mm)	410.3	> 200 kg/mm
% Air voids	22.13	> 18%
Bulk S.G (g/cc)	1.82	---

Figure (9) Marshall test

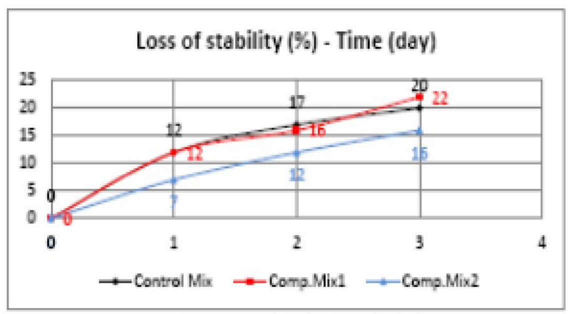

Figure (10) Loss of stability percent with time

Table (11) Loss of stability test results (%)

Time (day)	Control Mix.	Comp. Mix.1	Comp. Mix.2
1	12	12	7
2	17	16	12
3	20	22	16

Figure (11) Wire basket with the specimen

Table (12) Draindown test results (%)

Weights (g) / Mixes	Empty wired basket	Wired basket + Sample	Empty container	Container + Drained Sample	% Drain down
Control Mix.	243.00	3843.00	363.00	366.24	0.09
Comp. Mix.1	243.00	3843.00	363.00	366.60	0.10
Comp. Mix.2	243.00	3843.00	363.00	365.16	0.06

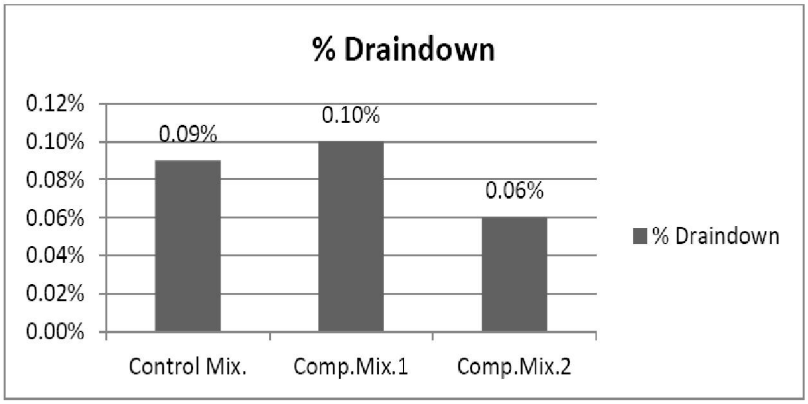

Figure (12) %Draindown of each mixture

Table (13) Properties of the main three mixtures

Mixes	Bulk S.G (g/cc)	Apparent S.G (g/cc)	% Air voids
Control Mix.	1.648	1.66	28.7
Comp. Mix.1	1.44	1.50	38.17
Comp. Mix.2	1.82	1.90	22.13

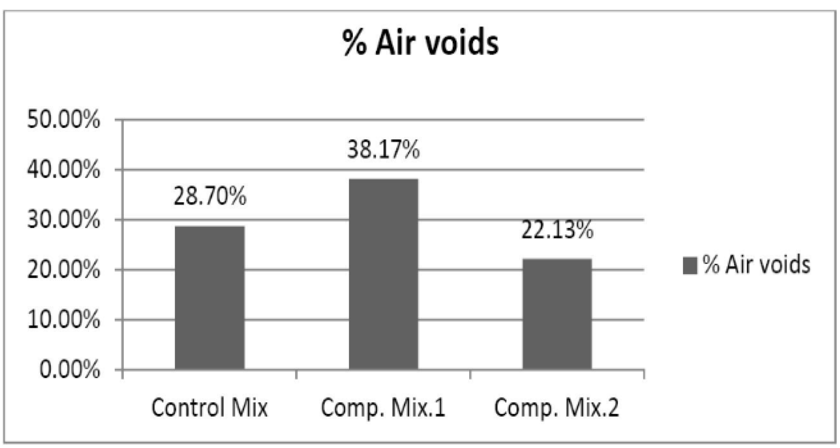

Figure (13) %Air voids of each mixture

Table (14) Permeability coefficients of the main three mixtures

Mixes	Sample height (cm)	Time (sec.)	Coefficient of permeability (K) (cm/sec)
Control Mix.	4.9	8	0.15
Comp. Mix.1	5.1	7	0.17
Comp. Mix.2	5.2	10	0.12

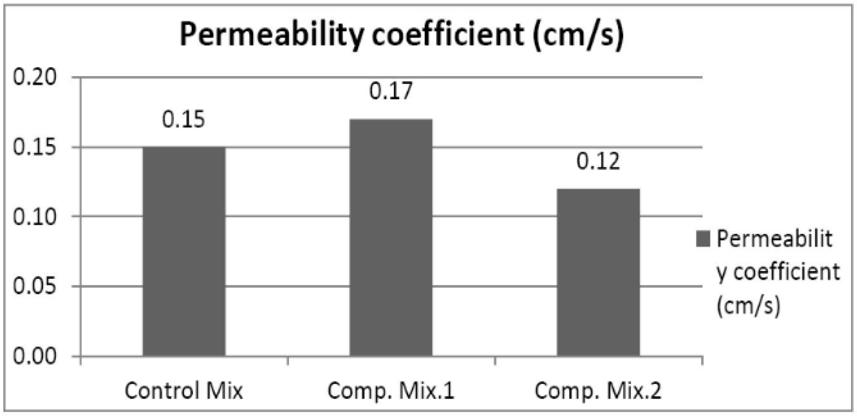

Figure (14) Permeability coefficient of each mixture

Table (15) Tensile strength of the main three mixtures

Mixes	Tensile failure load (N)		Dry T.S (Mpa)	Cond. T.S (Mpa)	TSR
	Dry	Conditioned			
Control Mix.	24986.55	24515.55	1.061	1.041	0.98
Comp. Mix.1	22466.70	24548.25	0.954	0.915	0.96
Comp. Mix.2	26894.10	26328.90	1.142	1.118	0.98

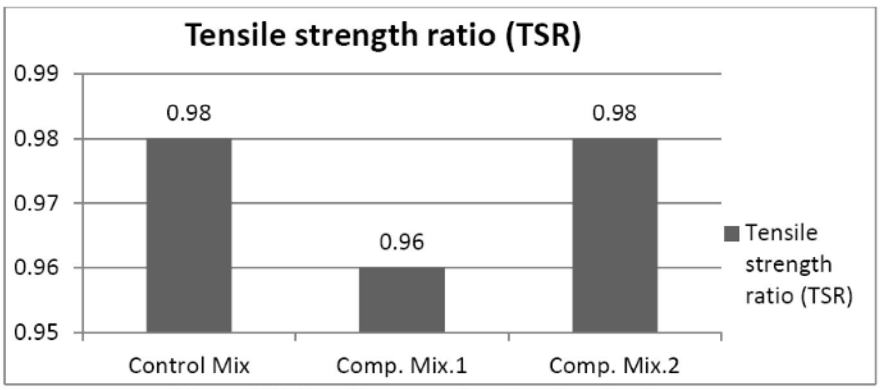

Figure (15) Tensile strength ratio of each mixture

Figure (16) Compacted slab

Figure (17) Slab under wheel load

Table (16) Rut depth in (mm) of the main three mixtures' slabs

Rut depth (mm)	Control Mix.	Comp.Mix.1	Comp.Mix.2
After 5000 cycles	6.2	7.2	5.8
After 10000 cycles	8.5	9.6	7.9

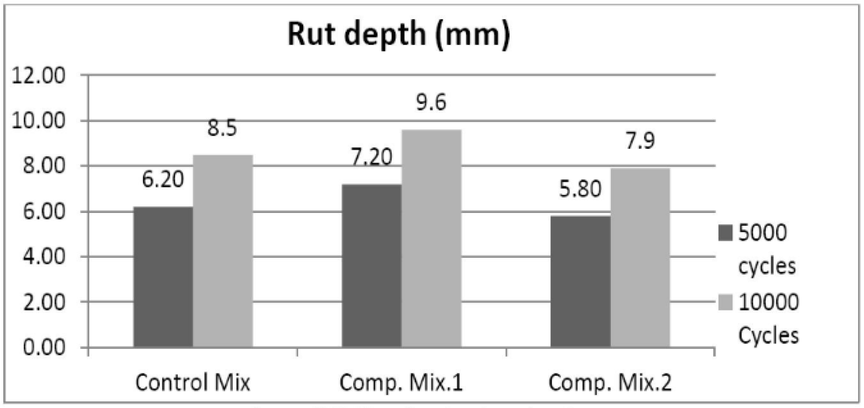

Figure (18) Rut depth of each mixture

5 Conclusions

Based on the results of experimental work and review of literaturesthe following points can be concluded:

1- Stabilizing the porous asphalt mixtures by cellulose fibers present almost the same performance of stabilizing by mineral fibers.

2- The porous asphalt mixtures stabilized by cellulose fiber + 0.3% cement dust present a performance higher than those that stabilized by mineral fibers.

3- The optimum cellulose fiber content is 0.4% of the mixture total weight.

4- Stabilizing of porous asphalt mixtures using cellulose fiber or cellulose/cement dust additives is more economic and greener than stabilizing by any other mineral fibers.

5- The proportion of binderdraindown in mixtures stabilized by cellulose fiber is almost the same in mixtures stabilized by mineral fiber. and by adding 0.3% cement dust to cellulose fiber %draindown decreased by 40%.

6- The moisture sensitivity in mixtures stabilized by cellulose fiber is almost the same in mixtures stabilized by mineral fiber, and by adding 0.3% cement dust to cellulose fiber present very low sensitivity of TSR 98%.

7- The rut value in mixtures stabilized by cellulose fiber is almost the same in mixtures stabilized by mineral fiber, and by adding 0.3% cement dust to cellulose fiber rut value decreased by 10%.

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3/15/2017