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CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Investigate engineering properties of modified open-graded asphalt mixtures

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Abstract: Open-Graded Friction Course mixture (OGFC) has a gap-graded aggregate that results in highly air voids. This structure provides higher permeability by allowing water to flow through it. Although these mixtures have good drainage properties, they exhibit poor strength with a short life span. Because of their poor performance, there is a lack to be used in pavement application. Attempts had made to increase mixture performance; one of these methods is by using fibers or polymers. The objective of the current study is to determine if modified OGFC mixes with different polymers and fibers have comparable performance. Polymers and fibers were used in OGFC mixes to evaluate their performance. Steel fiber, glass fibers, Polyvinyl chloride (PVC) and Phenol resin were investigated in this study. The modified mixtures were tested by indirect tensile strength, Marshall and permanent deformation tests. Results showed that fibers decrease rutting by 19% and they have more effective than polymers that decrease rutting by 7%, and glass fiber was found to be more effective with a 24% reduction in permanent deformation than other additives to enhance performance.

Subjects: Material Science; Materials Science; Civil, Environmental and Geotechnical Engineering

Keywords: open grade friction course; polymers; fibers; permanent deformation

1. Introduction

Special asphalt mixes designed with high porosity were introduced in 1950 in the United States, in order to improve drainage characteristics, reduce traffic noise and increase traffic safety (Joubert, 1992). These mixes improve surface drainage through improved friction by allow water to drain from the surface, which in turn reduce hydroplaning and traffic noise. These mixes utilized in



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Noor Moutaz Asmael is one of the faculty members of the college of engineering at Mustansiriyah university. The author interests in research about highway engineering, transportation planning, asphalt mixtures.

PUBLIC INTEREST STATEMENT

Open-Graded Friction Course mixture has a gap-graded aggregate which used to provide good drainage. These mixtures report unsatisfactory performance during service, in the literature, several attempts investigated to improve mixture performance. This study tries to use fibers and polymers to improve the performance of open-graded mixtures. The results indicate a good improvement could happen if the glass fiber or phenol polymer incorporated within it.

wearing layers in high-speed sites that have accidents in wet condition. Many states in the United States were reporting good performance when used OGFC modified with polymer and coarse gradation of aggregate. The Federal Highway Administration (FHWA) developed a mix design of OGFC in 1974. OGFC mixtures consist of an aggregate with an open grade, which was used to improve skid resistance; their gradation is coarser than a dense-graded mix, with this property, a problem of the drain down is occurring. These mixes exhibit poor strength and durability which made their performance questionable (Alvarez et al., 2006). These mixes require a modified binder by polymers or fibers to sustain suitable strength and to prevent drain down, accordingly, the cost will become higher (Faghri, Sadd, & Goncalves, 2002). The current study evaluates the performance of OGFC in the laboratory with different types of additives, and attempts to recommend the most successful additive to be used in OGFC mixture.

2. Background

Early investigation of porous asphalt was reported in studies by Thelen and Fielding (Diniz, 1980; Thelen & Fielding Howe, 1978). Punith et al. (Punith, Suresha, Raju, Bose, & Veeraragavan, 2011) studied the properties of open grade asphalt mixtures, polymers like (reclaimed polyethylene, crumb rubber) and cellulose fibers were used to modify asphalt binder. The results indicated that the addition of polymers improve abrasion and mixture properties of open grade mixtures and the addition of fiber or polymer reduce drain down of open grade mixtures. Zhong, Sun, & Tang (2018) stated that epoxy porous asphalt can increase skid resistance and reduce the noise. Arrieta, Graciano, Vega-Posada, Álvarez, & Gómez (2017) measured the permeability flow of open grade mixtures by estimating total air voids and water-accessible AV. This performed using laboratory tests such as, X-ray and image analyses. The results indicated that there is a difference between measured total air void and water-accessible AV contents. Kandhal & Mallick (1999) evaluated several mix designs of open grade friction course mixes modified with polymers and fibers, and they recommended a mix design procedure for OGFC mixes. Shafabakhsh & Tanakizadeh (2016) stated that modified asphalt mixtures had higher mechanical properties than the control mixtures. Mrawira & Jiménez-Acuña (2008) evaluated OGFC mixes by performing laboratory investigation to determine the engineering properties of these mixes. The results indicated that mixes with 2% lime was more beneficial than the use of 0.5% cellulose fiber. Small changes on percent retained on sieve (4.75 mm), have significant affect rut resistance and resilient modulus. Tsai, Harvey, & Monismith (2012) evaluated the mix design adopted by the National Center for Asphalt Technology (NCAT) to made necessary revisions. Their results showed that, the most factors affected the drain down and cantabro performance is binder type. An OGFC mix design was proposed based on volumetric design and performance. Ibrahim, Katman, Karim, Koting, & Mashaan (2014) investigated open-graded friction course mix to find the relationship between rubber size, rubber content, binder content and their effect on select optimum binder content. Test results approved that the optimum binder of OGFC affected by crumb rubber particle size. Faghri et al. (2002) studied OGFC mixes using polymers and fibers. Their results showed that when using fibers, reduction in permeability and a small improvement in strength were occurred, while when using polymers, air voids, strength, and permeability were increased. They recommended using a polymer to increase strength and permeability characteristics of OGFC mixtures. Gemayel & Mamlouk (1988) found that open grade mixes have a half value of tensile strength of dense asphalt mixes, and these mixes were highly sensitive to temperature. Arshad, Masri, Ahmad, & Samsudin (2017) studied the addition of Nanosilica to modify binder cement, to increase stiffness porous mix performance and to resist rutting. The Dynamic standard penetration (SPT) test is used to investigate the addition of Nanosilica on porous mix performance. From the results, it is indicated that the addition of Nanosilica will increase dynamic modulus by 50%. Setyawan, Sumarsono, & Widyastuti (2017) investigated porous asphalt by using two types of aggregate, the ones is natural gravel and the other is volcanic gravel. They concluded that the type of aggregate affects the optimum binder content. In addition, these mixtures can be used on low traffic load road because they have lower stability and strength. Hamedy & Esmaeeli (2017) investigated the OGFC mixtures containing pumice aggregate. They concluded that the porous surface of this type of aggregate

increased the absorbed asphalt and also increased optimum binder content. In addition, the incorporation of pumice aggregate improved the mechanical properties of OGFC mixtures.

3. Materials

Materials used in OGFC mixtures were included aggregates, asphalt binders, and additives. Additives included polymers and fibers. The materials used in this study were locally available and selected from the currently used materials in road construction in Iraq.

3.1. Asphalt cement

Asphalt binder with a penetration grade (40–50) was used in this study; it was widely used in road construction in Iraq and it obtained from Dourah refinery. Physical properties of asphalt used shown in Table (1).

3.2. Aggregate

Crushed aggregate of one type was used, which was brought from Al-Taji quarry, this type of aggregate is widely used in road construction in Iraq. Physical properties of aggregate are shown in Table (2). Suitable aggregate gradation selected based on the Federal Highway Administration (FHWA) specification as shown in Table (3) and Figure (1).

3.3. Mineral filler

The filler is a nonplastic material which passing sieve No. 200. The open grade asphalt mixtures were prepared using ordinary portland cement. The physical properties of this type of filler were demonstrated in Table (4).

3.4. Additives

Generally, additives are used in open grade asphalt mixtures to prevent drain down, to maintain a uniform mix, and to increase durability and strength of OGFC mixes. Two additives were used in this study, including fibers and polymers. Two types of fibers were utilized in OGFC mixtures, which were steel and glass fibers and two proportions of fibers (0.2% and 0.4%) by weight of total mixes were used. Their physical properties are shown in Table (5) for each glass and steel fiber. Two types of polymers were also investigated; Polyvinyl chloride (PVC) and Phenol resin with two percentages (2% and 4%) by weight of binder. Physical properties of polymers are shown in Tables (6) and (7).

Table 1. Properties of Asphalt Binder

Property	Unit	ASTM Specification	Description
Penetration	1/10 mm	D5	46
Absolute Viscosity	Poise	D2171	2090
Kinematics Viscosity	C St.	D2170	380
Ductility	Cm.	D 113	>100
Softening Point	C°	D 36	55
Specific Gravity	Kg/m ³	D 70	1.04
Flash Point	C°	D 92	335

Table 2. Properties of aggregate

Property	Coarse	Fine
Bulk specific gravity	2.518	2.615
Apparent specific gravity	2.553	2.662
Percent water absorption	0.556	0.68

Table 3. Aggregate gradation of open grade friction course

Sieve size	FHWA Gradation	Selected Gradation
19 mm	—	—
12.mm	100	100
9.5 mm	95 – 100	95
4.75 mm	30-50	45
2.36 mm	5-15	10
0.075 mm	2-5	5

Figure 1. Aggregate gradation.

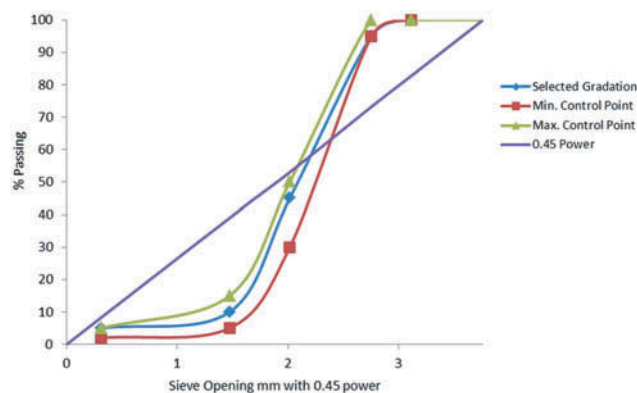


Table 4. Filler properties

Property	Description
Specific Gravity	3.11
Passing sieve No.200	95

Table 5. Properties of fibers

Properties of Glass fiber						
Property	Length (mm)	Density (gm/cm ³)	Tensile Strength (GPa)	Melting Point (°C)	Elastic Modulus (GPa)	Elongation %
Glass Fiber	12	2.65	3200	600	72	4.1
Properties of Steel fiber						
Property	Length (mm)	Density (gm/cm ³)	Tensile Strength (N/mm ²)		Elastic Modulus (GPa)	
Steel Fiber	50	7.8	1000		2*10 ⁵	

4. Porous asphalt mix design

Mix design of OGFC should withstand binder drain down, maintain the proper amount of minimum air void and provide sufficient resistance to degradation. Four percent of asphalt content from 5% to 6.5% was selected to determine optimum design binder content. Marshall specimens were

Table 6. Properties of phenol resin

Property	Resin Form	Color	Specific Gravity (gm/cm ³)	Reaction Temperature (C°)	Hardening Process
Phenol	Solid (powder)	Orange	1.11	90- 130C°	Hardening when adds HMTA with heating

Table 7. Properties of PVC polymer

Property	Form	Color	Specific Gravity (gm/cm ³)	Elastic Modulus (MPa)	Flexural strength (Psi)
PVC	Solid (powder)	White	1.3	2000	10,500

prepared with these asphalt contents, and compacted for 50 numbers of blows. The mix design was conducted according to ASTM (D 7064) (ASTM, 2018). Optimum design binder content was selected based on design criteria in ASTM (D 7064) (ASTM, 2018), which is the optimum has to be selected based on minimum air void 18%, maximum drain down equal to 0.3% and abrasion loss less than 20%. The Bulk specific gravity of OGFC compacted mixtures were determined according to AASHTO T331 (AASHTO, 2011) and the theoretical maximum specific gravity was determined according to AASHTO T209 (AASHTO, 2011). Volumetric properties of OGFC compacted specimens were then estimated.

5. Modified porous asphalt mix design

Open grade mixtures were modified with additives like polymers and fibers. Two polymers included Polyvinyl chloride (PVC) and Phenol resin and two fibers included steel and glass were used in this study. Modified asphalt mixtures were prepared by the Marshall method, 50 blows were applied to each face, and specimens were prepared at the optimum binder content obtained previously. For preparing modified mixtures, initially, the fiber additives were mixed using the dry method by adding additives to the aggregate and mixed thoroughly, and then asphalt binder was poured on aggregate mix. While polymer additives was mixed by the wet method, which was prepared by blending polymer with asphalt binder first, then mixing modified bitumen with aggregate. During the preparation procedure of modified asphalt with phenol resin, HMTA was added to phenol resin with heating and mixing thoroughly for 5 min with asphalt cement in order to obtain a homogenous mixture.

6. Experimental tests

Several tests are conducted on OGFC mixtures to obtain their properties which as follows.

6.1. Drain down test

One of the design requirements of OGFC is resistance to drain down. Drain down is the segregation of material from the mixture during handling, transport and field production. Higher binder content used in OGFC mixtures will lead to drain down of the binder during transport and placement of mixture. ASTM specifies limited the drain down value to 0.3% as a limit to accept the mixture. The drain down test was conducted on the loose uncompacted OGFC mixture. The mixture was sited in a wire basket on a plate of a known weight and it was placed in oven for 1 h at a temperature equal to the field production temperature which was equal to 150 °C in our case. At the end of time, the drain down of binder on the plate is calculated. The test was conducted according to ASTM D6390 (ASTM, 2018), the drain down value was estimated based on the following equation:

$$\text{Drain down \%} = ((D - C)) / ((B - A)) * 100 \quad (1)$$

6.2. Marshall test

Bituminous Marshall mixtures were tested for resistance to plastic flow by applying load using Marshall apparatus on lateral surface of specimens according to ASTM D6927 (ASTM, 2018). After the treatment of specimens in water bath for 30 min at 60 °C temperature, Marshall stability and flow values were measured. The specimens were compressed at a constant rate of (50.8 mm/min) until failure was occurred. The maximum values of load and flow in failure situations were recorded. Marshall Quotient (MQ) of compacted samples was then estimated which was equal to Marshall stability divided on Marshall flow.

6.3. Indirect tensile test

The behavior of specimens under tension was studied; this behavior was related to the possibility of cracking. The indirect tension test was performed to estimate the tensile strength of bituminous materials. The specimen of 101.6 mm in diameter, 63.5 mm in thickness was used and compressed diametrically at a loading rate of (0.2 in/min), this configuration created a tension zone on specimen diameter. The test procedure was conducted according to ASTM D3967 (ASTM, 2018), at 25 °C temperature.

6.4. Cantabro test

OGFC mixtures must have adequate durability, which is related to the quantity and quality of asphalt mixture, to ensure this property is satisfied, cantabro test was conducted according to ASTM D 7064 (ASTM, 2018). This test evaluates the ability of asphalt mixture to withstand degradation, by estimating the percentage of loss in mixtures, abrasion loss of unaged OGFC asphalt mixtures will be determined using los angeles machine. The OGFC specimens were placed in this machine without steel balls, and operated at a speed of 300 revolutions per minute at 25 °C test temperature. At the end of the test, the weight loss of specimens was estimated and used to know the ability of mixtures to disintegration. Small losses give an indication of the strong bond between asphalt and aggregate particle.

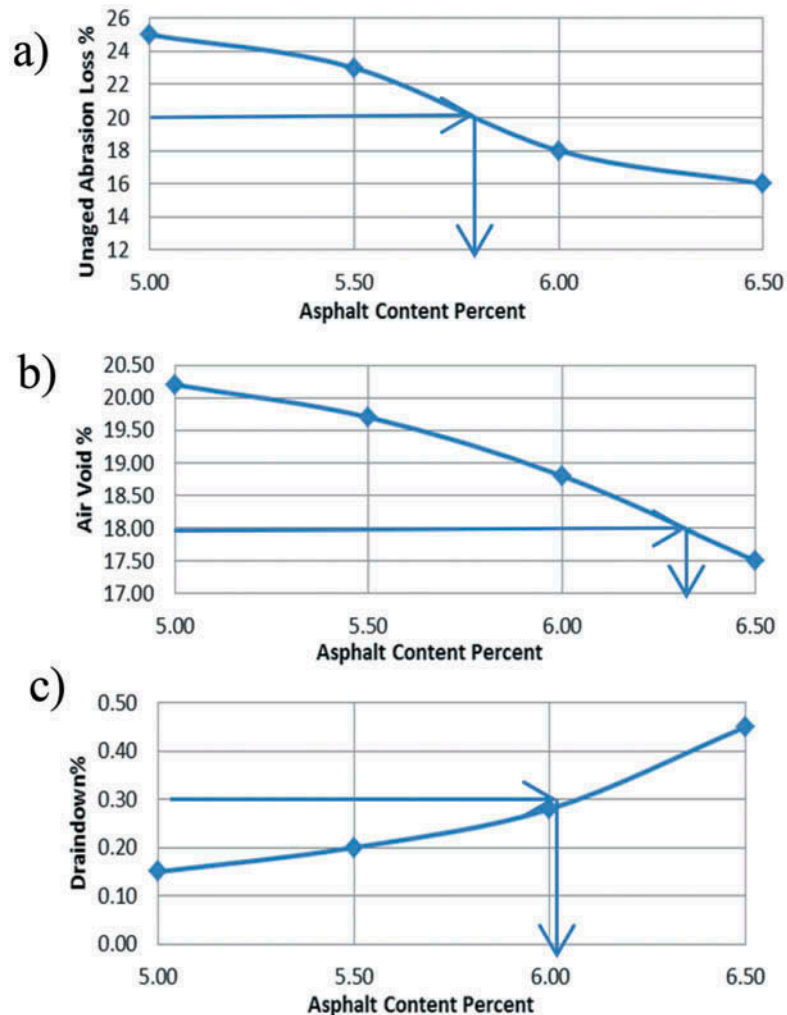
6.5. Wheel track test

OGFC asphalt mixture slabs were prepared for this test according to the ASTM D8079 (ASTM, 2018), their dimension was about 400 mm in length and 300 mm in width by 50 mm in height. These slabs were compacted by roller compactor at design binder content. A wheel-tracking machine was used to estimate the rut depth of OGFC asphalt mixture. The test gives information on the rate of rut depth through moving 700 ± 10 N concentrated loads on OGFC slab, the load wheel is in a fixed position that is moving forwards and backwards with a constant frequency of (26.5 ± 1.0) cycle per 60 s. Slab samples were tested at a temperature of 40 °C. LVDT transducer was used to monitor the rate of permanent deformation in the center of the sample; the test was running until 10,000 cycles is reached.

7. Results and discussion

Results of OGFC Marshall compacted specimens were shown in Figure (2), design binder content should be selected based on these results. It should satisfy the requirement of ASTM D7064 (ASTM, 2018) where the loss in Cantabro test should be less than 20%. This value will limit the minimum binder content in mixtures, the binder content can be calculated using the graph below, by intersecting 20% losses and plot down, which equaled to 5.8%. In addition, air void content should be higher than 18% and drain down should be no more than 0.3%, these values limited the maximum binder content used in open grade mixtures. The maximum binder content could be calculated from the graphs, by intersecting these criteria and plot down, which equalled to 6.3%, 6.05%, respectively. These 3% of binder content was selected based on the above criteria and the mean value was used as design binder content, which will be equal to 6.05%.

Figure 2. OGFC Marshall Asphalt Mixtures Properties: a, unaged abrasion loss; b, air void; c, drain down.



OGFC mixture without any additives represented as a control mix and it was compared with all other modified mixtures for all tests. Stability, MQ, and flow values of modified OGFC mixtures were shown from Figures (3–5). From these Figures, it can be seen that all additives increased stability and decreased flow when compared to the unmodified OGFC mixture (control mix), but steel fiber and phenol resin had more effect on Marshall test results. Adding steel fiber at 0.2% and 0.4% will increase Marshall stability value to 167%, 185%, respectively. Adding glass fiber in OGFC mixtures will cause Marshall stability to increase 13% at 0.2%, then another addition will cause decrease stability value. Flow values will decrease when using fiber additives in OGFC mixtures. For OGFC mixtures modified with polymers, stability value will increase to 18.8%, 20.2%, when add 2% and 4% of phenol resin, respectively. While when the addition equal 2% of PVC, stability will increase to 119%, then after another addition of PVC, it will decrease stability value and the increase will be just equal to 47%.

Figure (6) shows the results of indirect tensile strength, it is indicated that glass fiber is more effective than steel fiber in tensile strength. The Addition of 0.2% of glass fiber will cause an increase of tensile strength by 214%, while steel fiber will increase the strength to 135%. The Addition of 0.4% of glass fiber will increase the tensile strength to 187% and steel fiber cause an increase in tensile strength to 174% than control mix. This is because the tensile strength of glass fiber is more than steel fiber and accordingly will increase the strength of the mixture. The results are consistent with results of Manoj Shukla et al. (Shukla, Tiwari, & Sitaramanjaneyulu, 2014). It is

Figure 3. Flow Values of Modified OGFC Mixtures.

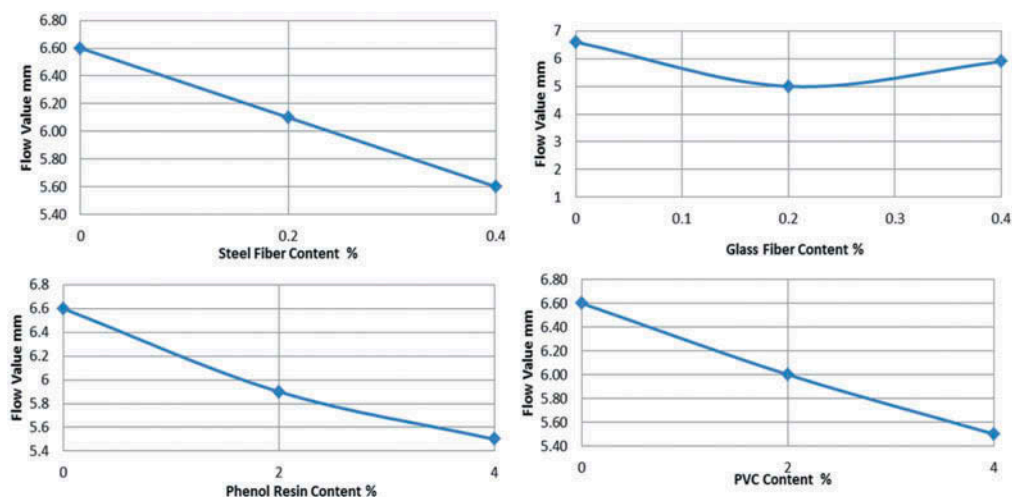


Figure 4. Stability Values of Modified OGFC Mixtures.

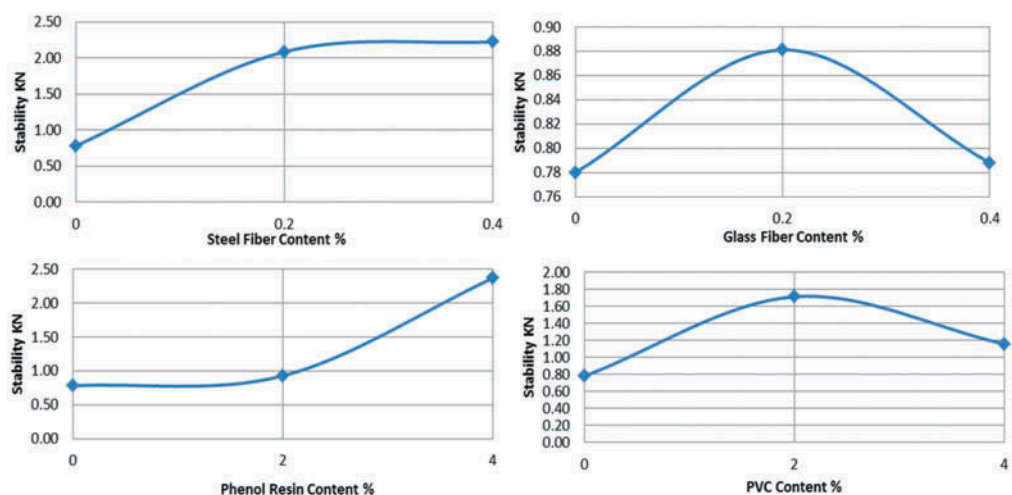


Figure 5. Marshall Quotient of OGFC Mixtures.

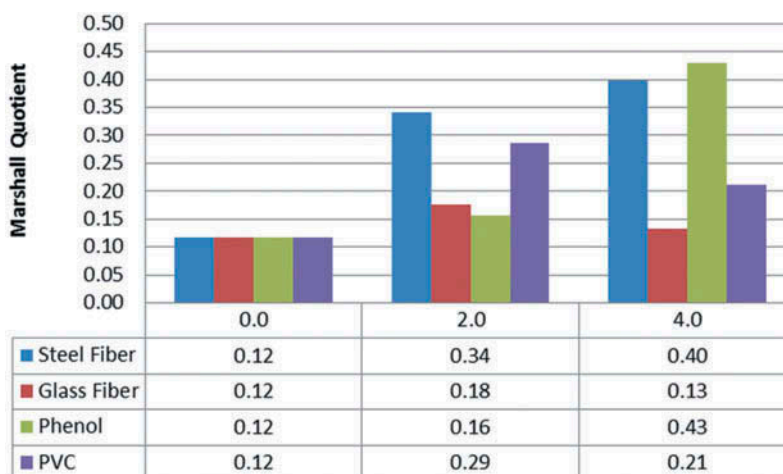


Figure 6. Tensile Strength of different Modified OGFC asphalt mixtures with: a) Fibers, b) Polymers.

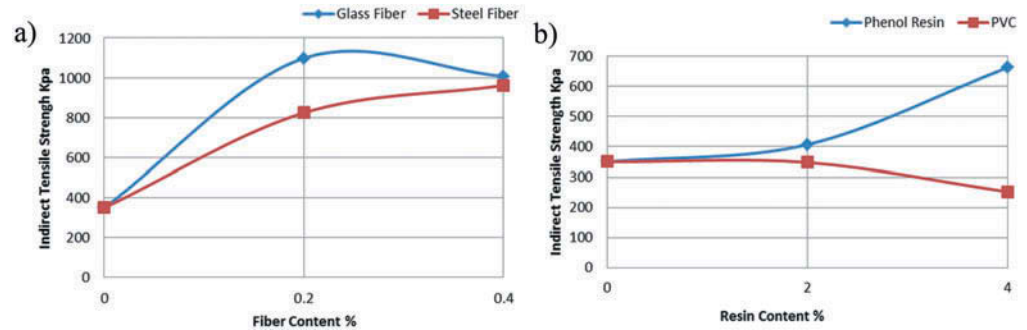
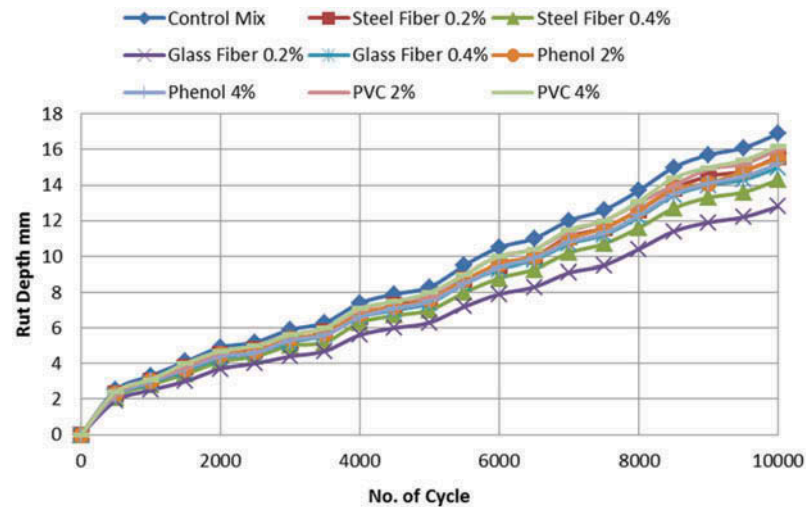


Figure 7. Permanent Deformation of Different modified OGFC asphalt mixtures.



observed that fiber additives had more effect on tensile strength than polymer additives. When polymers were added to the OGFC mixtures, it will cause a slight increase in tensile strength, phenol resin will increase in tensile strength by 16% when 2% of content is added, and when 4% of phenol is added it will cause a 89% increase. PVC polymer will cause a decrease in tensile strength, especially when the addition become 4%, it will cause a decrease about 28%. It can be indicated that addition of fibers is more effective than polymers in reduce cracking in OGFC mixtures.

From the result of the wheel track test as shown in Figure (7), it can be seen that when adding steel fibers, it will decrease permanent deformation by 7.6% and 15.3% at 0.2, 0.4% respectively. When adding glass fiber at 0.2% and 0.4%, it will decrease rut depth by 24% and 11%, respectively. The addition of phenol resin will decrease rut depth of about 8% and 10% for 2, 4%, respectively. While with the addition of PVC, it will decrease the rut depth by 5.3% and 4% for 2% and 4% than the control mix, respectively. From these results, it is observed that mixtures modified with fibers exhibit higher resistance to permanent deformation that indicate better mixture to resist rutting.

8. Conclusions

The present study tries to improve the engineering properties of open-graded asphalt mixtures performance by using additives. According to the experimental work, engineering properties were investigated by measuring stability, tensile strength and resistance to rutting. The results of the study concluded that the contribution of fibers in mix design will enhance material strength and

increase rut resistance, and it is proved that it is more beneficial than polymers to improve performance. The recommended dosage of glass fiber is 0.2% to get optimal performance for OGFC. The use of a small amount of glass fiber does not increase the cost of producing the mixture and also it plays a role of increasing the performance of the mixture. Fibers bind the mixture together, and this will increase the strength required to fracture the mixture sample. Additives are encouraged to be used with this type of mix because it reduces drain down and enhance mixture performance. Using PVC additive in this type of mix is undesirable because it gives an unsatisfactory performance. Also, using 4% of phenol additive will increase MQ to the maximum value and enhance mixture stability. It is observed that glass fiber is more beneficial than other additives in increase open-graded asphalt mixtures performance.

Nomenclatures

A	Mass of the empty wire basket
B	Mass of the wire basket and sample
C	Mass of the empty plate
D	Mass of the plate plus drained material

Abbreviations

FHWA	Federal Highway Administration
MQ	Marshall Quotient
OGFC	Open-Graded Friction Course
PVC	Polyvinyl chloride

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