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Electrical and mechanical behaviors of conductor asphalt concrete by the addition of steel fibers

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Abstract – Conductive asphalt has the potential to satisfy different multifunctional applications. The behavior and the electrical and mechanical properties of this asphalt concrete have been modified using conductive additives, which can improve the durability of the asphalt mix and the service life of the pavement system. Among these additives are steel fibers. The results obtained indicate that the direct tensile strength of bituminous mix, the resistance to cracking, the energy, and the ductility modulus are increased with an increase in the percentage of steel fibers. Electrical resistivity decreased with the addition of steel fibers. So it is concluded that tensile strength increases reversibly with increasing electrical resistivity.

Keywords – Conductive Asphalt Concrete, Steel Fibers, Electrical Resistivity, Dissipated Energy And Ductility Modulus.

I. Introduction

Asphalt concrete is a composite material consisting mainly of bitumen as a binder and aggregates. It is used as a material for road construction thanks to the good adhesion that exists between the binder and the aggregates [1, 2].

Due to the intensive use of asphalt for the construction of flexible pavements and its ride comfort, this material has become essential for research [3,4].

Conductive bituminous mixes provide a methodology for designing bituminous mixes that ensure both good mechanical and electrical properties [5].

In order to transmit the electrical conductivity in the bituminous mix by adding different additives in the bitumen or the bituminous mix [6].

Previous research has studied various conductive fibers such as steel fibers [6–8], carbon fibers [7–9], wool [10,11], carbon [12] and graphite powder [7,9,11].

For our work, we study the effect of steel fiber on the performance of bituminous mixes, evaluate the electrical conductivity, and make a correlation between the mechanical and electrical properties. Asphalt mix performance was evaluated using electrical and mechanical tests such as Finex direct tensile test and electrical resistivity test.

The addition of fibers to the bituminous coating ensures their stability and their mechanical resistance [13–16], increases its dynamic modulus, this behavior to fatigue and ductility [13].

An adequate amount of fibers modifies the properties of asphalt and modifies the viscoelasticity of the bitumen [13, 17].

In addition, fibers have been observed to improve moisture sensitivity and compressive strength in bituminous mixes [18–20].

In addition, fiber additives have been considered as a positive reinforcement material for bituminous mix [3].

Fibers have been included in asphalt mixes to improve resistance to cracking and rutting [8, 21–24], prevent drainage in porous asphalt and stone matrix asphalt [21], and enable multifunctional applications [11,12, 25, 26].

According to additional research [5, 27], fiber-reinforced bituminous mixes exhibit strong resistance to fatigue cracking, moisture cracking, flexural cracking, and reflective cracking.

It has been demonstrated in numerous studies on the electrical conductivity of conductive bituminous mixes that the conductivity is inversely related to the amount of added fibers [5, 28].

The goals of this research are:

Making electrically conductive bituminous mixes with progressive reduction in resistivity.

Study the effect of steel fiber on the mechanical and electrical properties of bituminous mixes.

II. Materials and Method

1. Materials

The class (0/14) semi-grained bituminous mix was produced using the Marshall design method.

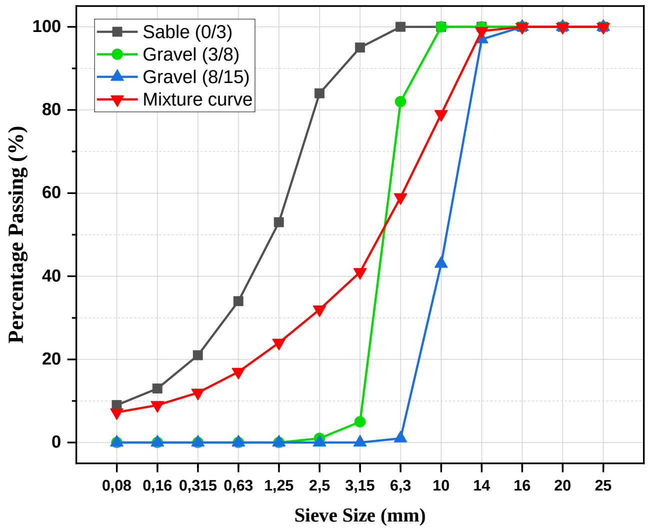

Fig. 1. Gradation Curve

Table 1. Blending Percentages

Binder and Aggregate	Percentages (%)
(0 / 3)	35
(3 / 8)	23
(8 / 15)	38
Filler	4
Asphalt	6,22

The properties of bitumen are: penetration (P): 43 (1/10) mm; ring and ball temperature (TRB): 52 °C.

Tableau 2 : Aggregate Properties.

Aggregates	(0/3)	(3/8)	(8/15)
Density	2,71	2,71	2,71
Methylene Blue	0,75	/	/
Micro-Deval	/	/	13,71
Los Angeles	/	/	19,14
Electrical Resistivity (Ω .m)	> 10^{14}	> 10^{14}	> 10^{14}

Steel fibers used have a length of (0.7- 1) cm and a diameter of 0.1 mm (Fig 1), tensile strength 501 MPa, electrical resistivity: 7,1. 10^{-7} Ω.cm.

Fig. 1 Steel Fibers

2. Sample preparation

The tests were carried out using cylinder specimens that were 10 cm in diameter and 6 cm long (Fig. 2). For two hours, the binder, fillers, and steel fibers were heated to 150°C. The steel fibers and aggregates were simultaneously added to the heated mixer container, where they were mixed until the binder had been evenly distributed throughout and covered all of the steel fibers and aggregates.

In compaction molds, the mixture was compressed using 50 strokes on each side. Before testing, samples taken out of the molds were kept in the lab environment for 24 hours.

Fig. 2. Asphalt concrete specimens

Fenix direct tensile test specimens containing (0.2%, 0.4%, 0.6%, 0.8%, 1% and 1.2%) steel fiber by blend weight.

3. TEST METHODS

3.1. FINÉX TEST (DIRECT TENSILE TEST)

The test was carried out by a Finex device (Fig 3), Marshall test specimens were cut in half with a gap of 6 mm, fixed in fenix plates, we must apply a movement at constant speed (01 mm/min).

Fig. 3. Fenix test

The tensile strength of the specimens:

$$R = \frac{2F}{\pi\theta h} \text{.................................}(1)$$

With :

R: Tensile strengths (Pa),
F: applied vertical force (N),
θ: specimen's diameter (in m),
h: Height of the specimen (m).

The dissipated energy GD is calculated by:

$$G_D = \frac{W_D}{h.\theta} \text{...............................}(2)$$

With :

G_D: Energy dissipated during the test application (J/m2)
W_D: WORK dissipated (kN mm).

$$W_D = \int_0^{\Delta R} F.du \text{...............................}(3)$$

With :

F = Load (in kN).
u = Displacement (mm).
ΔR = Displacement at load Fmax.

II.3.2. ELECTRICAL RESISTIVITY TEST

A CHAUVIN ARNOUX digital megohmmeter was used to measure electrical resistance below 41.10^6 Ω and a multimeter was used to measure resistance above this value.

The two-probe method is used to measure this resistance. Two electrodes connected and placed at the two ends of the specimens.

Fig. 4. Electrical resistivity test

The electrodes were put under pressure to make sure they made good contact with the surface.

Ohm's second law [6] was used to determine electrical resistivity after measuring resistance:

$$\rho = \frac{RS}{h} \text{...............................}(4)$$

With :
ρ: Electrical resistance (Ω .m).
h: The height of the specimen (m).
S: The conductive surface of the electrode (m2).
R: The measured resistance (Ω).

III. RESULTS

III.1. Direct tensile strength of bituminous mix with steel fiber:

Fig.s 5, 6 and 7 present the results of tensile strength of bituminous mix, ductility modulus ane dissipated energy containing different percentage of steel fiber to the control respectively.

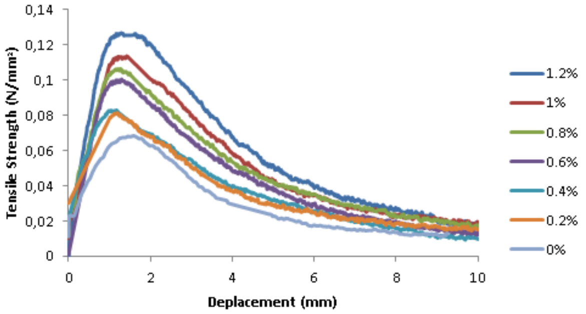

Fig. 5. Tensile strength R of asphalt concrete as measured by the displacement of various steel fiber content levels.

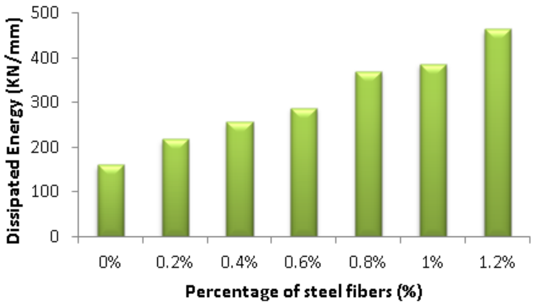

Fig. 6. Dissipated energy at various percentages of steel fibers.

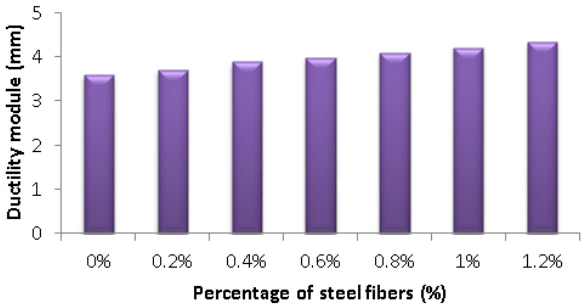

Fig. 7. Ductility module at various percentages of steel fibers

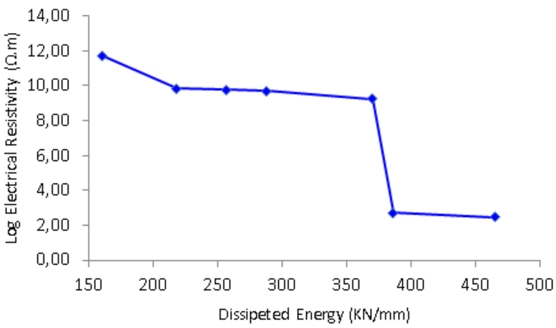

Fig. 8. Electrical Resistivity of Dissipated Energy of Different Steel Fiber Percentages in Asphalt Concrete.

IV. DISCUSSION

The results of the FENIX tests show that as the percentage of steel fibers is increased, the direct asphalt tensile strength, ductility modulus, and dissipated energy increase due to the higher tensile of the steel fibers themselves.

The steel fibers reflect the cracking resistance of bituminous mix.

Hence, steel fibers in the bituminous mix can form a three-dimensional reticular structure.

The mesh of the structure has a reinforcing effect in the mix, which increases the tensile strength of the asphalt mix.

The mixture with the highest energy value has a better cracking resistance, according to the results of the energy dissipated during cracking.

Fig. 8 illustrates the impact of steel fiber on the asphalt concrete's resistivity.

The resistivity of the specimens has three stages:

High resistivity stage, with a fiber content of less than 0.8%; transition stage, with 0.8% to 1% fiber; and low resistivity with percentages above 1%.

Specimens with less than 1% fibers exhibit insulating behavior, with resistances greater than 10^9 Ω m.

The transition phase (between 0.8% and 1% the steel fibers), the electrical resistivity of the specimens suffered a sharp drop (percolation) from 10^9 Ω m to 10^2 Ω m.

According to the percolation theory. The distribution of steel fibers in the coated bituminous specimens is as follows:

A small reduction in resistivity compared to the control is observed when 5% of the fibers are added to the mixture. This is because the fibers are distributed throughout and do not penetrate in contact.

As more fibers are added to the concrete asphalt, they begin to come into contact and a gradual decrease in resistivity.

If the steel fiber content reaches more than 0.8% (percolation threshold), the first conductor are formed in the specimens.

When the content of the fibers is more than 1%, the fibers come into contact in all directions and form conductive passages, corresponding to a very low value of electrical resistivity to which by adding more of steel fibers does not reduce the electrical resistivity of the specimens anymore.

With the highest percentage of fibers added (1%) to the bituminous mixes, they have a higher cracking resistance and better mechanical performance.

V. CONCLUSION

The addition of 1% of steel fibers produces a conductive bituminous mix with good performance in terms of crack resistance. It clearly increases the tensile strength, the dissipated energy and the ductility of the bituminous mix.

The percolation threshold (sudden decrease in resistivity) is observed in test specimens of bituminous mix made from steel fibres.

The conductive bituminous mix with steel fibers has good mechanical and electrical performance

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