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Electrical measurements' contribution to the non-destructive assessment of bituminous mixtures

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Abstract – A crucial method for enhancing the mechanical and electrical characteristics of the pavement body is the incorporation of additives into bituminous mixes. In this work, various laboratory test results, including those from the FENIX direct tensile test and the electrical resistivity test, are presented and interpreted. On the basis of conductive additives (graphite powder and steel fibers), we will also present comparative studies examining the mechanical and electrical properties of the bituminous mix. This comparison allows us to categorize the resulting materials as those that can respond to various multifunctional applications.

Keywords – Electrical Measurement, Asphalt Concrete, Conductive Additives, Electrical Resistivity, FENIX Test.

I. Introduction

Conductive asphalt exhibits the capacity to fulfill various multifunctional applications, including but not limited to the provision of heated pavements for the purpose of snow and ice removal, self-sensing capabilities, self-healing properties, and energy recovery [1-3]. The composition of the conductive bituminous mixture consists of bitumen, aggregates, and additives with electrical conductivity properties [4, 5]. Liu et al. [6] assert that the objective is to achieve optimal electrical properties while maintaining mechanical functionality.

A range of conductive fibers and powders have been subjected to testing by researchers in order to modify the properties of bituminous mixes and facilitate the transmission of electricity within them. The materials examined in previous studies encompass steel fibers [3, 7-9], carbon fibers [10, 11, 13, 14], wool steel [4], and graphite powder [1, 2]. According to a study by [3], fiber-reinforced asphalt mixes demonstrate favorable traits in terms of fatigue cracking resistance and flexural cracking resistance. The incorporation of fibers into bituminous mixes has been found to enhance their stability and mechanical strength [8, 9, 11, 12]. Furthermore, the addition of fibers has been shown to improve the dynamic modulus of these mixes, as well as their fatigue resistance and ductility behavior [11]. The incorporation of a sufficient quantity of fiber into the bituminous mixture results in the alteration of its characteristics, leading to an increase in the softening point and a decrease in penetration. The inclusion of fiber in the composition of bitumen has been found to alter its viscoelastic properties [11, 12, 15]. Moreover, the utilization of fibers has been regarded as a beneficial reinforcement component for bituminous mixes, as stated by [11].

Fibers have been incorporated into asphalt mixtures to mitigate drainage issues in porous asphalt mix and stone matrix asphalt mix, as demonstrated by [2]. Additionally, the inclusion of fibers has been found to enhance the resistance to rutting, as reported by [7]. The relationship between the conductivity of bituminous mixes and the presence of added fibers [3] and conductive powders [17] is directly proportional.

According to [18], the inclusion of graphite in a bituminous mix enhances its ability to self-sense tension and exert self-control over compressive stresses. The addition of carbon additives in the form of graphite powder has been shown to significantly enhance the conductive property [19]. According to [5], the fatigue resistance of the conductive bituminous mix containing graphite is greater when compared to that of the conventional bituminous mix.

According to [18], the inclusion of graphite in a material leads to an enhancement in thermal conductivity. Additionally, Park et al. [2] found that the incorporation of graphite also results in an increase in electrical conductivity. The incorporation of graphite, a conductor of electricity, into the bituminous mixture results in a significant reduction in rutting resistance, an increase in dynamic modulus, and enhanced resistance to indirect tensile cracking [20, 21].

II. Empirical investigation

A. *Materials*

Half-grained asphalt concrete of the 0/15 class was achieved using the Marshall design method. Based on various aggregate grain sizes, it is possible to calculate the proportions of the mixture that must be inserted in reference spindle 0/15. Table 1 displays the percentages that were attained.

Table 1. Mixture Percentages

Aggregates and Binder	(%)
8/15	35
3/8	20
0/4	35
Bitumen	6
Filler	4

The characteristics of bitumen include a softening point temperature (TRB) of 52°C and a penetration value at 25°C (P) of 43.5 (1/10) mm.

The steel fibers employed in this investigation exhibit dimensional variations, ranging from 8 mm to 12 mm in length and 2 mm in diameter. These fibers possess a tensile strength of 502 MPa, an electrical resistivity of $8x10^{-7}$ Ω. m, and Young's modulus of 1347 MPa. The dimensions of graphite powder, when manually ground, are equal to or smaller than $8x10^{1}$ µm. Sample preparation involved the utilization of cylindrical specimens measuring 60 mm in length and 100 mm in diameter for conducting the tests. The binder, steel fibers, aggregates, and graphite powder were heated at 150°C for two hours. The graphite powder, steel fibers, and aggregates were introduced into the heated vessel of a mixer and subjected to simultaneous mixing until they achieved uniform distribution and full coating with the binder.

The compaction molds were utilized to compress the mixture by applying 50 strokes on each side. Prior to conducting the experiments, the specimens extracted from the molds were subjected to a controlled laboratory setting for a duration of 24 hours. Different amounts of graphite powder (1.0%, 3.0%, 5.0%, 10.0%, 15.0%, 20.0%, 25.0%, and 30.0% by volume of bitumen) and steel fiber (0.20%, 0.40%, 0.60%, 0.80%, 1.00%, and 1.20% by blend weight) were used to make the FENIX direct tensile test specimens.

B. *Test methods*

Direct tensile test (FENIX test): The test was conducted using a FENIX device (Fig. 2). The specimens used in the Marshall test were divided into two sections, with a separation distance of 6 mm, and securely affixed to FINEX plates. It is imperative to implement a displacement at a consistent velocity of 0.1 millimeters per minute. The traction force and vertical displacement were recorded by the data acquisition system.

Fig. 2 Photo of the FENIX Test

Following the tests, Bitencourt et al. [22, 23] calculated the tensile strength of the samples using the following equation:

$$R = \frac{2F}{\pi\theta h}$$

Where 'R' is tensile strength (Pa), 'F' is the total vertical load applied (N), 'θ' is the diameter of the specimen (m), and 'h' is the height of the specimen (m).

III. ELECTRICAL RESISTIVITY TEST

In the present investigation, the electrical resistance was assessed at a level below 40.10^6 Ω utilizing a CHAUVIN ARNOUX megohmmeter, while measurements above this threshold were conducted using a multimeter. Two copper plate electrodes were connected and positioned at the opposite ends of the cylindrical specimens.

Fig. 1 The two-point method to measure electrical resistance

By applying Ohm's second law after measuring the resistance, Bouazza et al. (2018) were able to determine the electrical resistivity:

$$\rho = \frac{RS}{h}$$

Where is ρ electrical resistance (Ω.m), h is the specimen's height (m), S is the electrode's conductive surface (m^2), and R is the measured resistance (Ω).

IV. FINDINGS AND ANALYSIS

A. COMPARISON OF THE BITUMINOUS MIXES' MECHANICAL CHARACTERISTICS

Fig. 3 shows how the ductility and modulus of the additives (graphite powder and steel fiber) affect the variation in energy dissipated.

According to this graph, the dissipated energy for a bituminous mix based on graphite powder decreases as the ductility modulus increases. On the other hand, as steel fibers are added, the modulus of ductility rises, increasing the amount of dissipated energy.

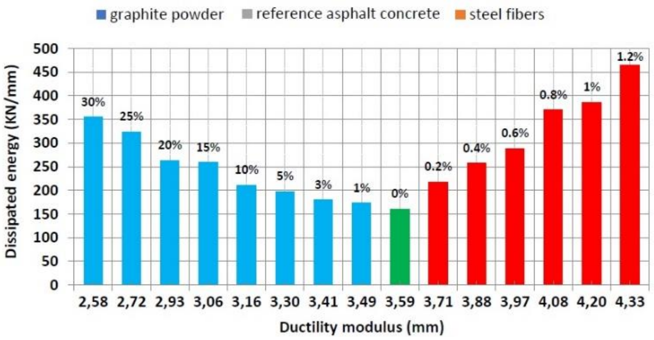

Fig. 3 energy dissipation's variation in relation to ductility modulus

Ductility and rigidity are key properties in bituminous mixes used in various applications, including road construction. Ductility is a measure of a material's ability to deform plastically before fracturing, and it is often a desirable property in bituminous mixes to withstand stresses and strains without cracking. Rigidity, on the other hand, is associated with a material's stiffness and resistance to deformation. As a result, the substance becomes more fragile. which will make it less ductile. The incorporation of steel fibers into bitumen enhances the bond strength between the two materials. This increased bond strength leads to an elevation in the ductility modulus, which in turn results in higher dissipated energy. Consequently, the presence of steel fibers effectively mitigates the formation of cracks and microcracks.

V. CONCLUSION

In this paper, we present the results of the electrical resistivity test and the direct traction test, from which we draw the following conclusions:

• Adding steel fibers to bituminous mixtures is a useful way to increase their tensile strength, energy dissipation, and ductility modulus.

• The direct tensile strength and the dissipated energy increase as the percentage of graphite increases; however, the modulus of ductility decreases.

• The results demonstrate that the bituminous mix performs better mechanically and is less likely to crack when it contains the recommended amount of steel fiber additives (1%).

• Steel fibers or graphite powder could be added to the bituminous mix to increase its electrical conductivity.

• However, in experimental runs, steel fibers are much more effective than graphite powders at achieving the desired conductivity.

• Better electrical performance is attained for the recommended amount of steel fibers (1%), where electrical resistivity is reduced to a minimum and the bituminous mixture becomes more conductive. Additionally, electrical conductivity is improved with 30% graphite (it remains in phase transition). Tensile strength and dissipated energy are improved, but ductility is decreased.

• By using numerical simulation, we added 39% graphite to the modified mix to give it the desired conductivity. We therefore draw the conclusion that a bituminous mix with steel fibers has better mechanical and electrical properties.

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