



Enhancement of Electrical and Mechanical Properties of Modified Asphalt Concrete with Graphite Powder

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Abstract

A large number of additives are introduced in asphalt concrete mixtures in purpose of improving the properties of resistance, facing the increasing traffic and more severe climatic conditions. This will guarantee the good comfort for a longer exploitation time. In this article we used graphite powder as an unconventional additive, and then investigate its effect mainly on the electrical resistivity which is in context of our research work on conductive asphalt (with a resistivity around $10^6 \Omega \text{ m}$), As well as on its mechanical properties evaluated using the new Fenix test that gives many information of mechanical especially dissipated energy. A significant improvement was noticed in the reduction of resistivity by reaching $1.7 \times 10^6 \Omega \text{ m}$ and also greater resistance to cracking based on variation of dissipated energy as a result we concluded that introducing graphite powder with an appropriate amount enhance both mechanical and electrical properties asphalt concrete.

Keywords: Conductive Asphalt; Graphite Powder; Electrical Resistivity; Fenix Test; Cracking.

1. Introduction

Asphalt is the most used material in the world as a binder for wearing course in pavement structures, therefore, improving its performance has been the axe of several research works for a long time. In this context, research is being carried out to optimize formulations by various methods (Marshall, super pave), as well as to better characterize its mechanical characteristics by developing control tests. Research is also interested in adding additives.

The evolution of the viscoelastic character of asphalt concrete due to bitumen is often the most important thing to characterize. This makes the temperature a determining element on the mechanical behavior. In fact, At low temperatures in winter the bitumen hardens and becomes brittle, which promotes cracking, And at high temperatures in summer, its tendency to viscosity increases and favors permanent deformations such as rutting. For this reason, the requirements needed are the resistance to thermal cracking at low temperature and to permanent deformation at high temperature.

There are various types of additives (Polymer elastomer like rubber, Polymer plastomer, Fibers mineral fillers, resins, nanoparticles and others). The main purpose of using additions is to have superior stiffness at high service temperatures to reduce rutting and thrust but Lower stiffness and faster relaxation properties at low operating

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temperatures which will reduce thermal cracking. We want in fact a material that is less sensitive to changes in temperatures. The modification is made to get more resistance to permanent Deformation. Fatigue Cracking. Cracking at Low temperature. Moisture damage. Aging .and consequently a structure with less maintenance requirements as an economic gain.

Recently some non-structural properties are also studied like the possibility of energy harvesting from roads, the electromagnetic heating for deicing purposes and self-healing mechanism enhancement, smart monitoring of damage, the idea is to enhance sensibility of asphalt concrete to electrical current which is naturally a highly insulating material. This will make it possible to use this materials as a multifunctional for possible benefits in future (Figure 1), in fact, the electrically modified asphalt composites exhibit self-sensing ability to strain, defects, and temperature. Conductive asphalt-based composite would have a profound effect on pavement de-icing, damage testing, highway traffic monitoring and so on.

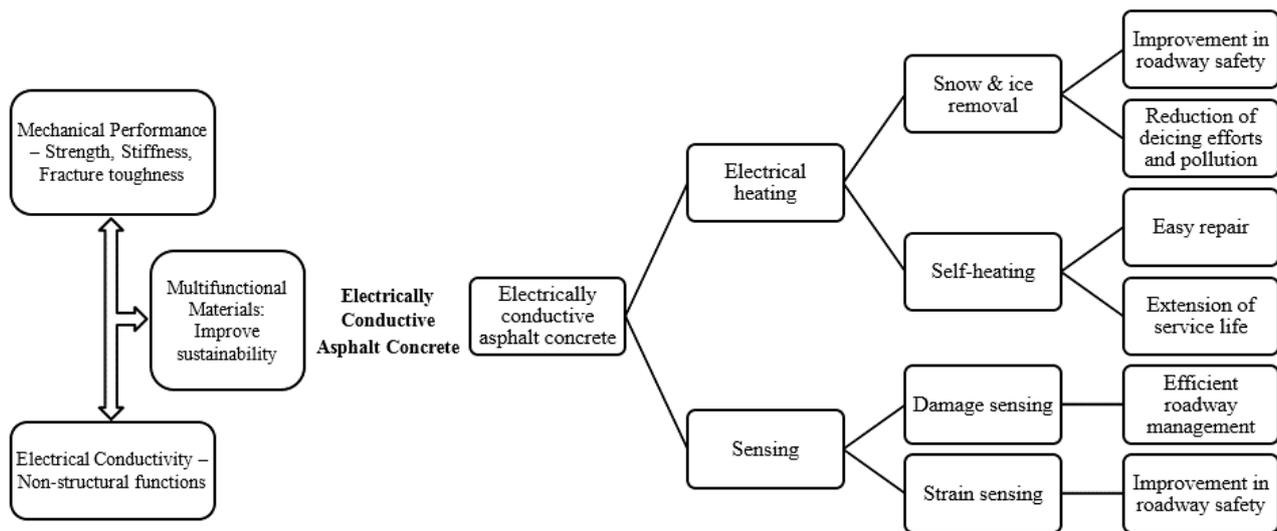


Figure 1. Electrically conductive asphalt as a Multifunctional materials with mechanical and electrical functions and its possible benefits

In recent years there has been a great deal of concern regarding this issue. Liu et al (2008) [1] investigated the act of graphite addition on the thermal, high temperature, high temperature and electrical properties of asphalt-based composites, concluding that graphite powder can decrease the electrical insulation increase the softening temperature of bituminous binders. Park et al. (2014) [2] studied the thermal conductivity of asphalt pavements with the addition of graphite powder as fillers with average particle size 150 μm . It was concluded that the duration for snowmelt is reduced to half with 20% of addition. Thus an increase in thermal conductivity. It has also been observed also an improvement of tensile strength and rutting resistance for modified asphalt using both graphite powder and carbon fibers. Wu et al. (2005) [3] observed a decrease of the electrical resistivity of graphite modified bituminous concrete. Park (2012) [4] conducted a study on the effect of varying types of graphite powders on the electrical conductivity in asphalt mastic and found that the electrical resistivity is affected considering the shape and the size of the graphite. In 2016, Wang et al. [5] studied the electrical and mechanical resistance of graphite mixes and to design asphalt concrete that conducts electricity without compromising the mechanical properties of asphalt concrete. The addition of graphite could increase the resistance to permanent deformation. Wu (2008) [6] Studied the rheological properties of bituminous binders with graphite powder as a filler. He noticed that the addition of graphite can significantly improve the electrical conductivity but impacts also the mechanical properties In fact, the operation causes an increase in viscosity. He concluded that an appropriate graphite content increases in complex shear modulus and decrease in phase angles. The rutting resistance of asphalts can also be significantly boosted by adding graphite. Temperature dependence and heating efficiency of an Electrically-conductive asphalt mastic is studied by Arabzadeh et al. [7], they concluded that with lower electrical resistivity, the asphalt concrete exhibits a better heat generation efficiency in context of anti-icing and deicing applications by melting ice and snow or preventing accumulation of snow and formation of ice on pavements.

In this study an unconventional additive will be used. Graphite powder with reference to the studies described below. The objective of this work is to characterize a modified asphalt concrete by graphite powder by inspecting an electrical property which is resistivity and also to evaluate its resistance to cracking by the Fenix test. With This direct tensile strength test based on the energy approach of the phenomenon, We determine the energy dissipated and see the effect of varying the graphite content, at the end, we state on the effectiveness of graphite powder in enhancing electrical and mechanical properties of the material.

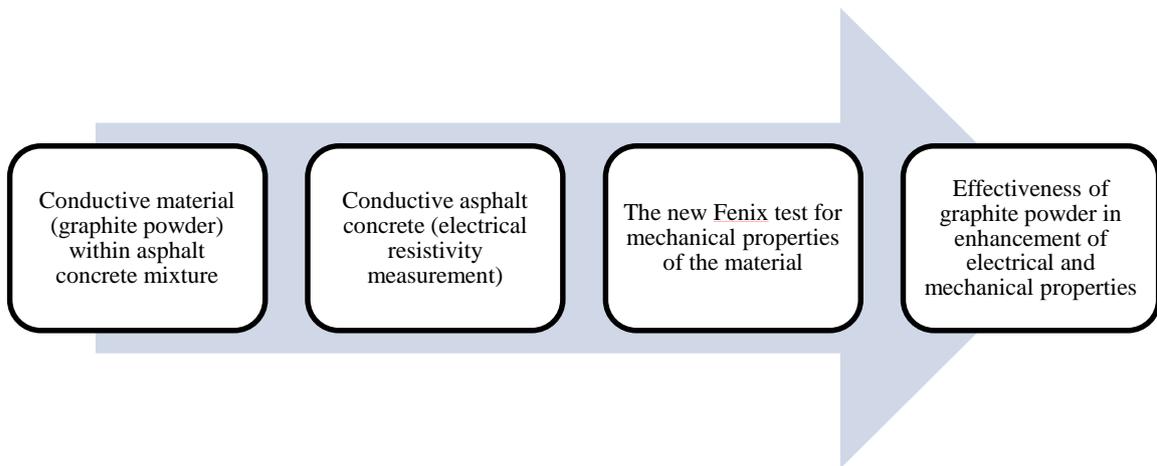


Figure 2. The research methodology

2. Research Methodology

2.1. Materials Electrical Resistivity of Asphalt Concrete

The 0/14 asphalt concrete specimens were prepared following Marshall’s method for electrical resistivity measurements, and Fenix test. The granular skeleton contains crushed granular fractions 0/3, 3/8 and 8/15 with fractions respecting the sieve gradation presented in Figure 3. The hydrocarbon binder used is the 40/50 pure bitumen with a TBA temperature of 52° C and a penetrability of 41 and a density of 1.3 g/cm³.

Graphite is a light, flexible, malleable and compressible material with high thermal and electrical conductivity and heat resistance, it also has the advantage of being inert and non-toxic. The graphite used is of a density of 1.80 g/cm³ with an electrical resistance of 1.4 Ω (Figure 4).

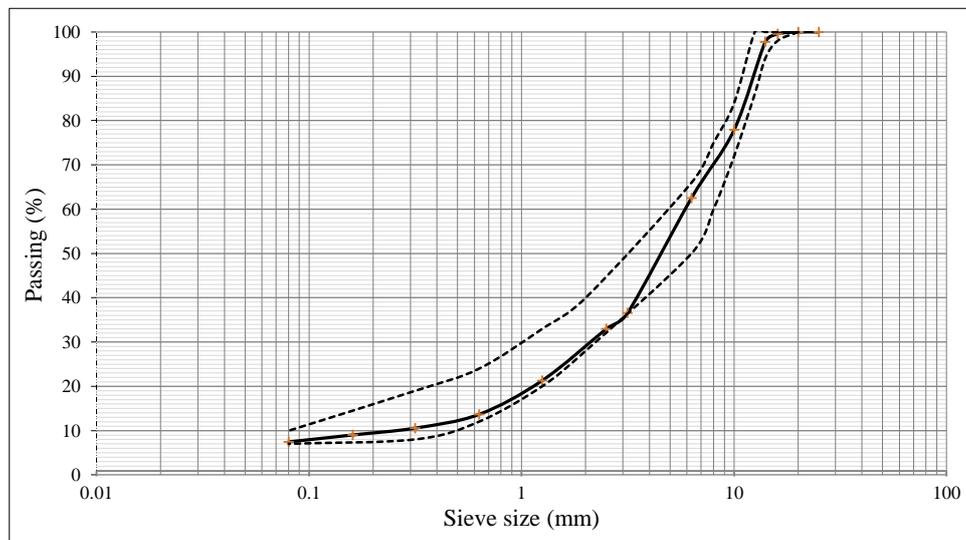


Figure 3. Sieve gradation of the granular mixture



Figure 4. Graphite powder

2.2. Electrical Measurement

The principle of electrical resistivity measurement is to determine the electrical resistance electric of the element at first by the law of Ohm:

$$R = \frac{U}{I} \tag{1}$$

where R is electrical resistance (Ω), U is tension (V) and I is current intensity (A).

For this purpose the specimen must be placed between two metal electrodes ensuring a good contact at the interface. An electric current is applied and then the difference in potential between the two electrodes as shown in the figure below (Figure 4). Then we multiply this value by a geometric coefficient to get the resistivity as the following:

$$\rho = R \times A / L \tag{2}$$

where ρ is the electrical resistivity (Ω.m), A is the section area of the sample (m²), and L is the length of the sample (m).

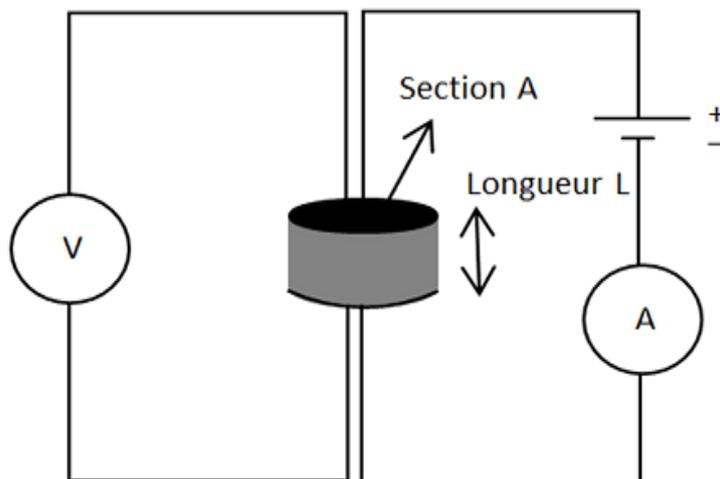


Figure 1. Measurement principle of electrical resistivity

The electrical resistance measurements were carried out by a two probe method using a resistance tester, a megohmmeter with 5 ranges 500–10000 V (Figure 6). Aluminum sheets are placed on both sides of the specimens during compaction to be sure of a good contact between the electrodes of the resistivity apparatus and the specimen as shown on the Figure 7. The asphalt specimen is placed between two copper electrodes exerting a small pressure to ensure that both sides of the test specimens are in good contact with these electrodes. The value of resistance is given after applying a voltage that can vary from the smallest 500 V to the highest 10000V. The electrical resistance measurement is shown in the Figure 8. Once the resistance given by the megohmmeter, we multiply this value by a geometric coefficient to get the resistivity (Equation 2).



Figure 6. Resistance tester-megohmmeter



Figure 7. Marshall specimen with aluminum foil on the faces

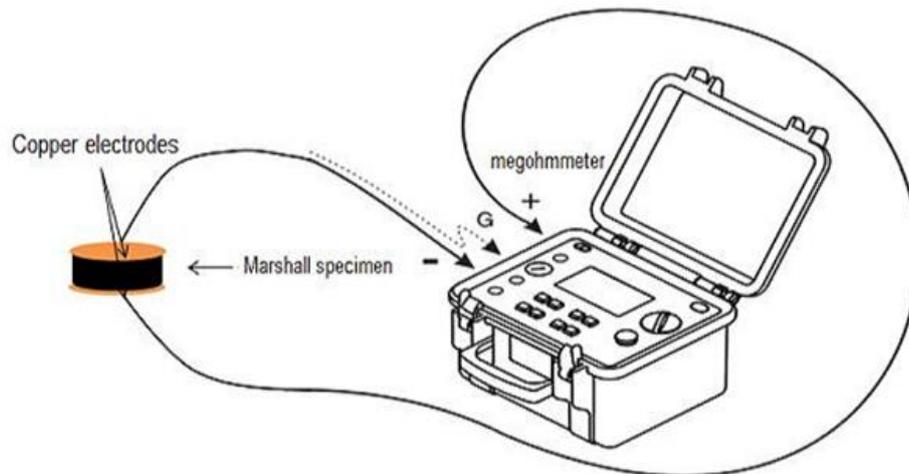


Figure 8. Electrical resistance measurement with a megohmmeter

2.3. Fenix Test

The effect of graphite powder on the mechanical properties of the material is evaluated with The Fenix test. It is a new test that has been developed at the Roads Lab of the Technical University of Catalonia to mainly simulate the cracking mechanism when a tensile stress normal to the crack plane (Mode I) which is generally the most dominant case often encountered on roadways (Valdés et al, 2009) [8] as well as other mechanical properties. With Fenix test, we get the energy dissipated during the simulated cracking process, which is a combination of all the energies released during deformation and cracking. The Evaluating of this energy is revealed to be an effective way to measure the cracking resistance of asphalt concrete mixes. The test consists on applying under direct traction a force in form of an imposed constant displacement 1 mm/min in a specific temperature 25°C due to the high sensitivity of the test to the variation of temperatures). The crack will propagate from a notch made in the middle flat side of the semi-cylindrical specimen prepared by Marshall method 63.5 height / 101.6 mm diameter (Figure 9) (COD test -Crack Tip Opening Displacement). Fenix samples are attached to two steel plates (with a thixotropic adhesive mortar containing epoxy resins). The plates are attached to a loading platen by ball joints so that they can rotate freely.

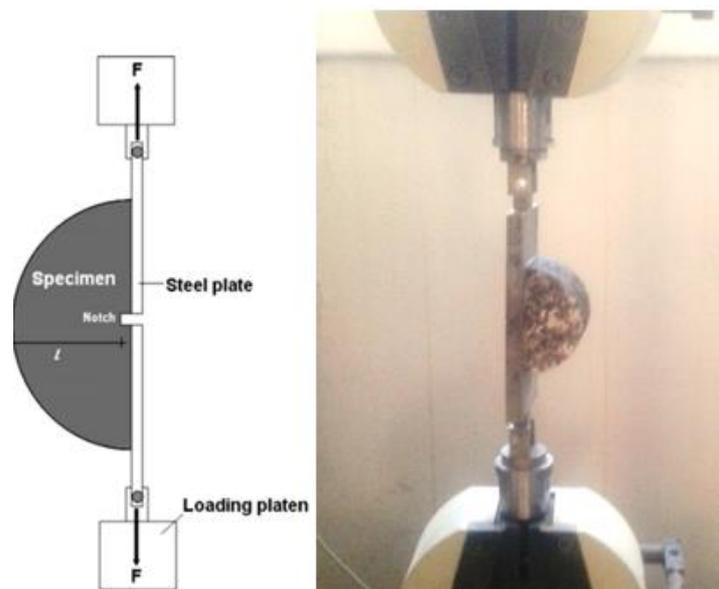


Figure 2. Fenix test

The load and displacement data are used to dress a load-displacement curve (Figure 10) from which we determine the mechanical parameters that are involved in the cracking process of the material [9].

In our study we are interested in:

- Displacement at 50% of the post-peak load, Δ_{mdp} , which is an indication of the ductility of the material.
- The Fracture energy (GF) which is defined as the ratio between the work done during the cracking process and

the fracture surface as the following;

$$G_f = \frac{W_D}{hl} \tag{3}$$

where G_f is the dissipated energy during test application (J/m^2), W_D is the dissipated work during test application ($kN.mm$), h is the specimen thickness (m) and l is the initial ligament length (m). Dissipated work during test application (W_D) is calculated as the following:

$$W_D = \int_0^{\Delta R} F du \tag{4}$$

where F is the applied load (kN) and u is displacement (mm).

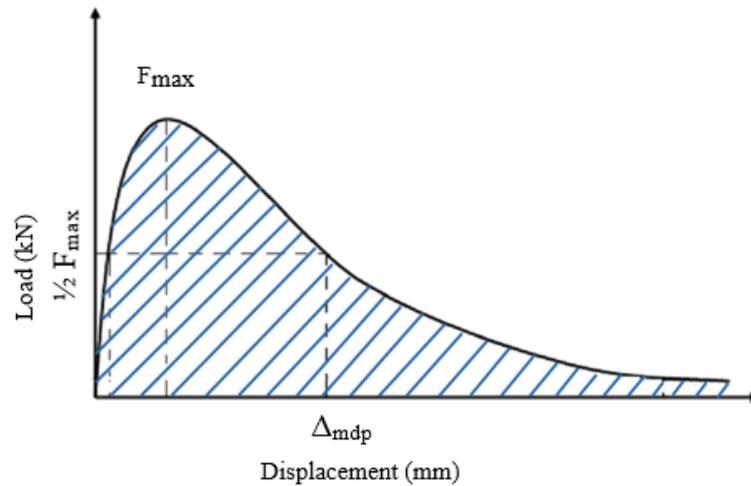


Figure 3. Typical load displacement curve

3. Results and Discussion

3.1. Materials Electrical Resistivity of Asphalt Concrete

The phase transition of resistance in a material from the insulating state to the conductive state occurs when conductive inclusions are introduced among an insulating matrix. In fact, Conductive composites can be achieved by adding a conductive filler to the insulating matrix. For a random distribution of this filler, a conducting network will form at a specified loading (conductive charges), known as the percolation threshold (p_c). When the filler loading reaches p_c , the conductivity of the composite rises suddenly and the graph of conductivity versus loading takes the characteristic S-shape, demonstrating the three characteristic regimes: insulating, percolating and conductive (Figure 11) [10-13]. It is also observed in several research works on conductive asphalt “as mentioned in the introduction section (background)” in these works the electrical resistivity of the material decreases slightly with the added content, reaching a critical value, called the percolation threshold marked by a strong decrease of the resistivity.

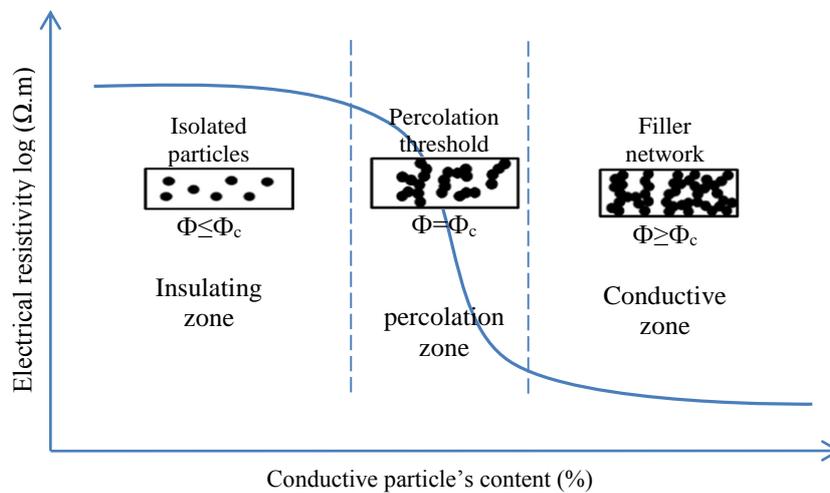


Figure 11. Electrical phase transition of an insulating material

The effect of the addition of graphite (0%; 5%; 12%; 17%; 20%; 23%; 26%) on the electrical resistivity of the mixture is shown in Figure 12. Note the percolation threshold is reached around 20% graphite, when the electrical resistivity goes from $1.5 \times 10^{11} \Omega \text{ m}$ to $1.7 \times 10^6 \Omega \text{ m}$.

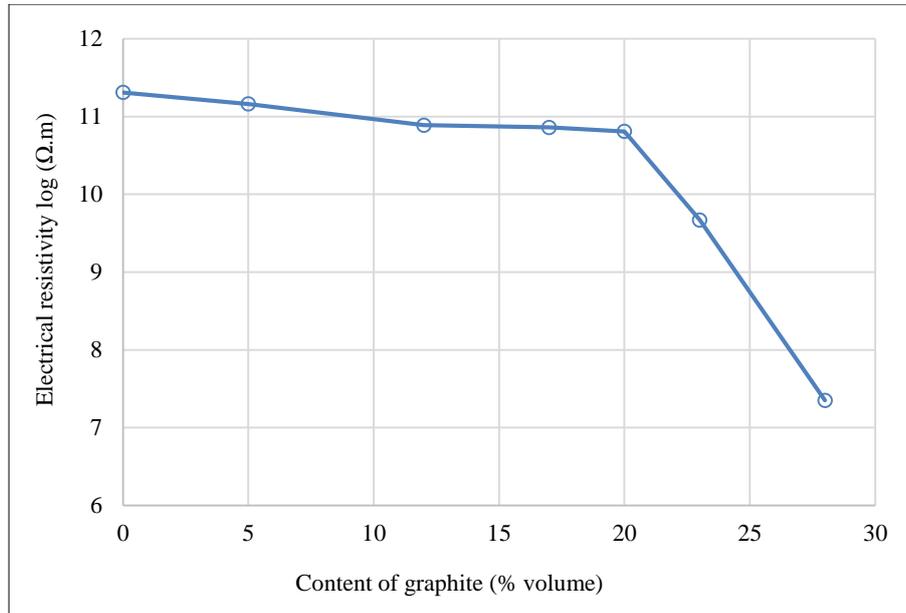


Figure 12. Electrical resistivity as function of graphite content

3.2. Fenix Test Results

Figure 13 shows the load values recorded during Fenix test as a function of displacement at a temperature of 25°C. the curves correspond to specimens with graphite content cited below to see the effect of graphite powder content on the resistance to cracking. The increased initial slope and the sharp drop in the post-peak curve observed in the samples shows greater stiffness and brittleness.

In our study we are particularly focused in the displacement at 50% of the post-peak load (Δ_{mdp}) that is proportional to the ductility of the mixture and the fracture energy (G_F) which represents the work done during the cracking process divided by the fracture area.

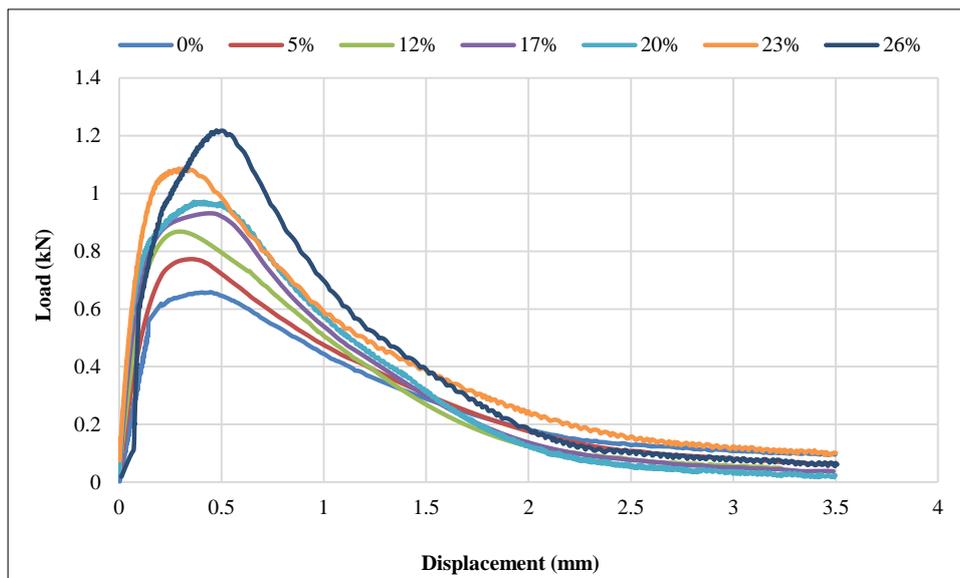


Figure 13. Load–displacement output curves from Fenix test

3.3. Displacement at 50% of Post-Peak Load ($d_{0.5PostFmax}$)

As presented in section 2, the 50% displacement of the post-peak load is proportional to the ductility of the mixture. As can be seen in Figure 14, the addition of graphite decreases these values, so the material becomes more

brittle. Nevertheless, the decrease is not important enough to become prejudicial, indeed even with 20% the value remains at the order of 77% which is not significant.

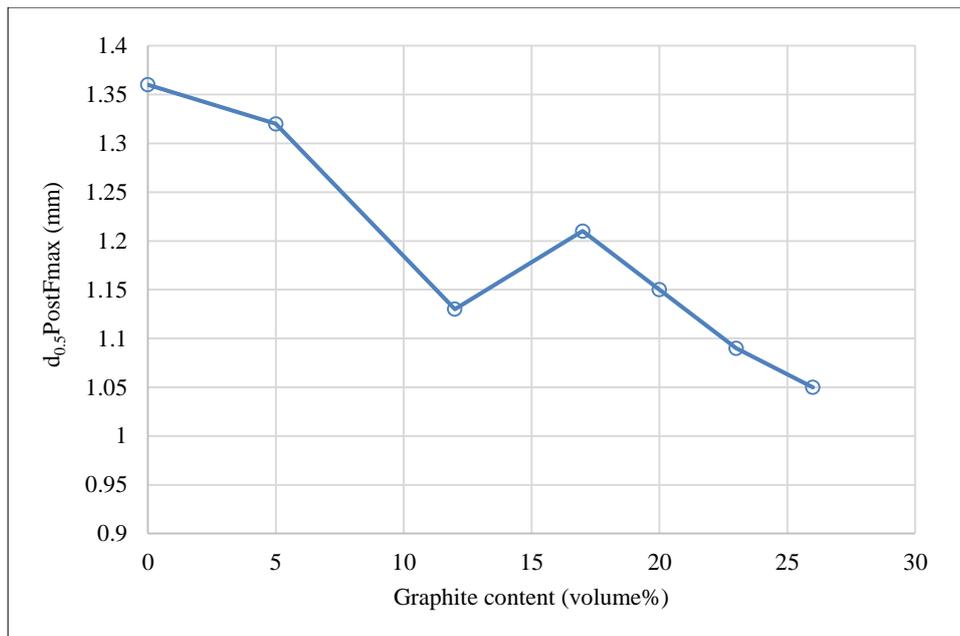


Figure 4. 50% of post-peak load displacement

3.4. Fracture Energy (G_F)

In order to produce a rupture, a sufficient energy stored in the material during the test (traction) must be transmitted to the made crack (the notch) to activate the rupture mechanism (Charmet 1997) [14]. Several rupture criteria are proposed (Irwin 1957) [15], (Griffith 1921) [16]. The criterion of Griffith proposes a limit value of rate of energy restitution, called resistance to cracking (G_c). There will then be a starting when G reaches G_c which represents the energy necessary for the creation of new free surfaces at the bottom of the crack.

The variation of the fracture energy, illustrated in Figure 15, quantifies the work required for the initiation and propagation of cracks. Higher energy implies greater resistance to cracking. We can see on the curve a clear increase in energy with the addition of graphite reaching a maximum value for a percentage of 20% and then decreasing. Which means an improvement over crack resistance.

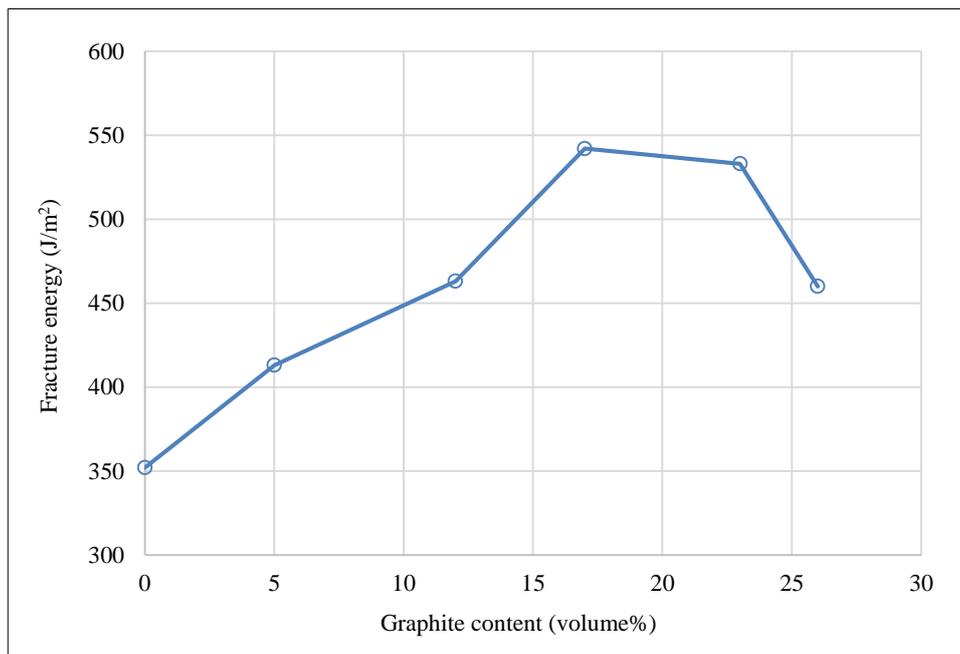


Figure 5. Fracture energy with graphite content

4. Conclusion

In This study we investigated the effect of graphite powder as a non-traditional addition on the properties of the electrical conduction of asphalt to show the possible improvement of electrical conduction which is a part of our research on conductive asphalt. The mechanical properties of cracking resistance were also investigated with the new Fenix test based on the variation of the energy dissipated and the 50% post peak displacement with different amounts of graphite.

The resistivity measurements revealed that replacing a traditional filler part with graphite powder improves the conduction from 1.5×10^{11} to $1.7 \times 10^6 \Omega \text{ m}$, so graphite has been shown to be effective for conduction. Displacement at 50% of Post-Peak Load decreases with the addition of graphite so the material becomes less ductile however, the decrease is not substantial enough to become too fragile, indeed even with 20% the value remains around 77% of that of the control specimen.

The variation of the dissipated energy reveals a clear increase until reaching a maximum value for a percentage of 20%. This reflects an improvement of the mechanical behavior towards cracking. It is concluded that the graphite addition offers non-structural properties as well as structural properties which aligns with current research on multifunctional materials.

5. Declarations

5.1. Author Contributions

Conceptualization, Z.Z., G.B. and A.O.; methodology, G.B. and A.O.; software, G.B. and A.O.; validation, G.B. and A.O.; formal analysis, Z.Z., G.B. and A.O.; investigation, Z.Z., G.B. and A.O.; resources, Z.Z., G.B. and A.O.; data curation, Z.Z., G.B. and A.O.; writing—original draft preparation, Z.Z.; writing—review and editing, Z.Z.; visualization, Z.Z., G.B. and A.O.; project administration, G.B. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article

5.3. Funding and Acknowledgements

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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