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Illinois Asphalt Pavement Association

Scholarship Research Report

Self-Healing Asphalt Concrete

Prepared for the IAPA Scholarship Committee

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Abstract

Asphalt Concrete has consistently remained one of the most used materials for roads. It is solid, durable, and cheap. However, Asphalt Concrete is vulnerable to cracks. If the cracks are not healed when they are small, water can seep through and increase the sizes of the cracks which make things even worse. Over the years, scientists and engineers around the globe have experimented with various healing agents to perfect the self-healing process. This research paper explores the various new findings for self-healing concrete like induction heat method and carbon-based materials.

Introduction

Asphalt concrete is the most common material used in roads in many countries around the world. In the USA, more than 90% of roads are surfaced with asphalt concrete (1). Asphalt concrete is economical and safe that is why it is used widely in roads and highways. Roads can quickly be paved and finished with asphalt concrete. Asphalt concrete is also a better alternative to other kind of pavements like concrete pavement, as Asphalt concrete pavement provides a better rider quality experience for drivers compared to others. With all these useful characteristics of Asphalt concrete pavement, there are some drawbacks that come with it. Pavement behavior and performance is highly variable due to many factors, such as pavement structural design, climate, traffic, materials, subgrade, and construction quality. These factors contribute to changes in pavement performance. Asphalt concrete pavement is flexible (1). Therefore, this type of pavement is prone to plastic deformations and potholes which lessen the service life of asphalt concrete. Several studies over the past several years were conducted to increase the service life of asphalt concrete by adding different types of reinforcements. These methods were proven to help asphalt concrete to self-heal and improve its performance.

Fatigue Behavior of Asphalt Concrete

Asphalt concrete has a self-healing behavior; however, the rate of damage is much larger than the rate of healing (2). That means that the pavement will have a finite life span. Microcapsule-induced self-healing materials are materials that contain microcapsules filled with healing agents that can repair damage (3). This method can act as a self-healing first-aid system in the material because it can sense failure and repair the failure by itself. Since Asphalt concrete pavement is used a lot on roads, the pavement can fail due to fatigue because of the huge continuous loads that it endures from vehicles. Pavement subjected to continuous stresses that are less than the ultimate tensile strength will eventually crack. And in many cases water can seep into the cracks. Freezing and thawing will make the cracks even bigger. Cracks will cause the pavement to lose its strength. To restore that strength, rejuvenators are used which are core materials of the microcapsules (2). Rejuvenators will leak out which releases a liquid that will adhere to the broken asphalt and accelerate the healing process (2). The cracks are still fresh, at that moment, which does not affect the strength of pavement as much as aging cracks. Then the strength of the asphalt concrete at the cracks are recovered with time. Tests have shown that the healing of Asphalt concrete with integrated microcapsules can be accelerated with an increase of temperature and self-healing time. These tests calculated the Maximum Tensile Stress and strains of the microcapsule pavement to find its stiffness. Equation 1 shows the flexural stiffness modulus (MPa) where it is the ratio of the tensile strength to the tensile strain.

$$S = \frac{\sigma_t}{\epsilon_t}$$

Equation 1. (2)

Tests carried on two asphalt concrete specimens one with 3% microcapsules and the other without microcapsules are shown in Figure 1.

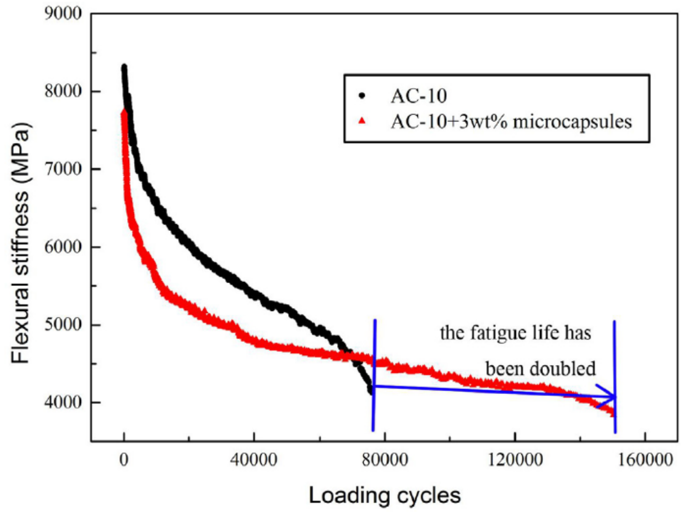

Figure 1. Flexure Stiffness of two asphalt concrete specimens. (2)

Figure 1 shows that the life span has doubled with the incorporation of microcapsules. It can be noticed though that the initial flexural stiffness of the asphalt with microcapsules decreased by around 7% from the asphalt mixture without microcapsules. However, the difference is minor, and it can be due to that a small portion of microcapsules that is ruptured during compaction. Figure 2 shows the behavior of flexural strength after healing for both samples. It can be seen that the sample with 3% microcapsules decreases more than the original sample at the beginning, however, the decrease slows down as the loading time increase. This is the opposite behavior of the original sample where it decreases rapidly as the loading time increases.

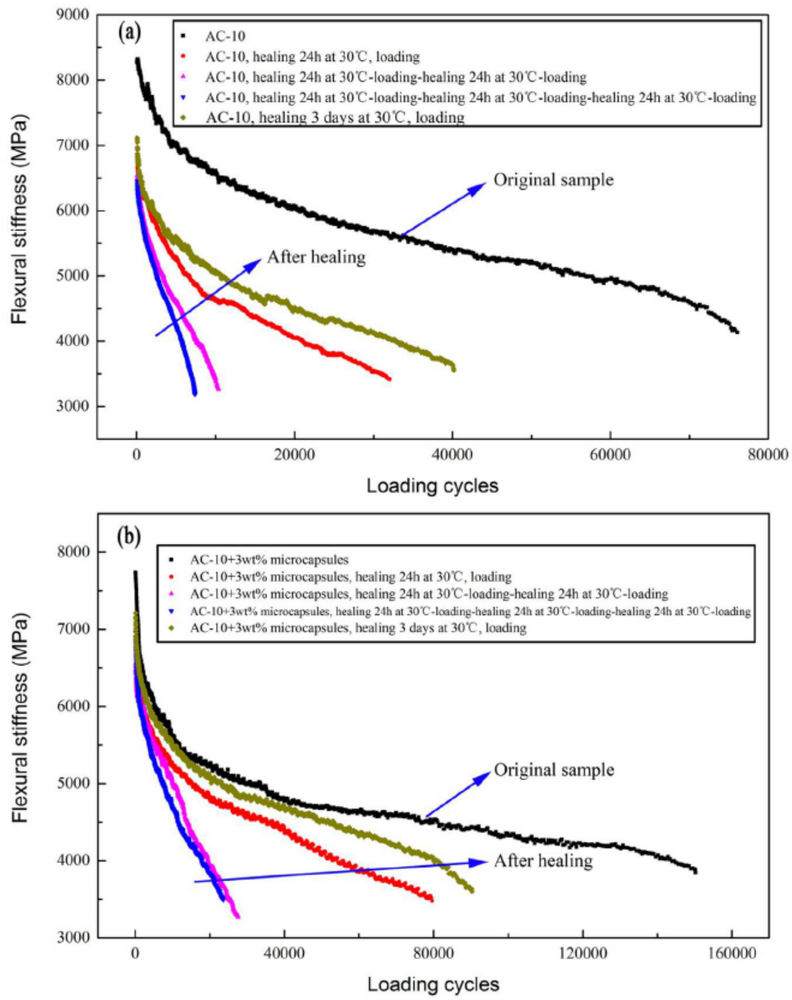

Figure 2. Flexural strength of Asphalt Concrete Samples After Healing. (2)

These behaviors can be attributed to the rejuvenators. As they are ruptured and released from the microcapsules, they soften the asphalt binder which results in a lower stiffness modulus. Therefore, the addition of 3% microcapsules in the asphalt concrete mix can double the fatigue life of the asphalt. This indicates that microcapsules play an important role in improving the healing process of asphalt concrete and increasing its lifespan.

Induction Heat Method

Fixing cracks and rehabilitation of pavement can be very costly. Therefore, emerging technologies have found new ways to increase the performance of pavement with less cost. As mentioned before, pavement has the ability to self-heal; however, it is impossible to take advantage of this characteristic with the continuous flow of traffic. New studies were conducted to find ways to accelerate self-healing through induction heating (4). The heat generated through induction heating can enhance the partial or complete healing of asphalt concrete (4). Induction heating is the process of heating an electrically conductive material electromagnetic induction (5). There has been a new study conducted to use a normal, metallic fiber embedded, aluminum fiber embedded asphalt concretes and applying a magnetic field on their surfaces (5). Induction heating can occur rapidly and without any contact. Several pavement samples have been tested to see the affect of using induction heating to self-healing. The asphalt mix with 5% aluminum exhibited a greater ultimate load at failure than the specimens with different amounts of steels fibers (5). Figure 3 shows the ultimate loads for different asphalt pavement samples before and after healing.

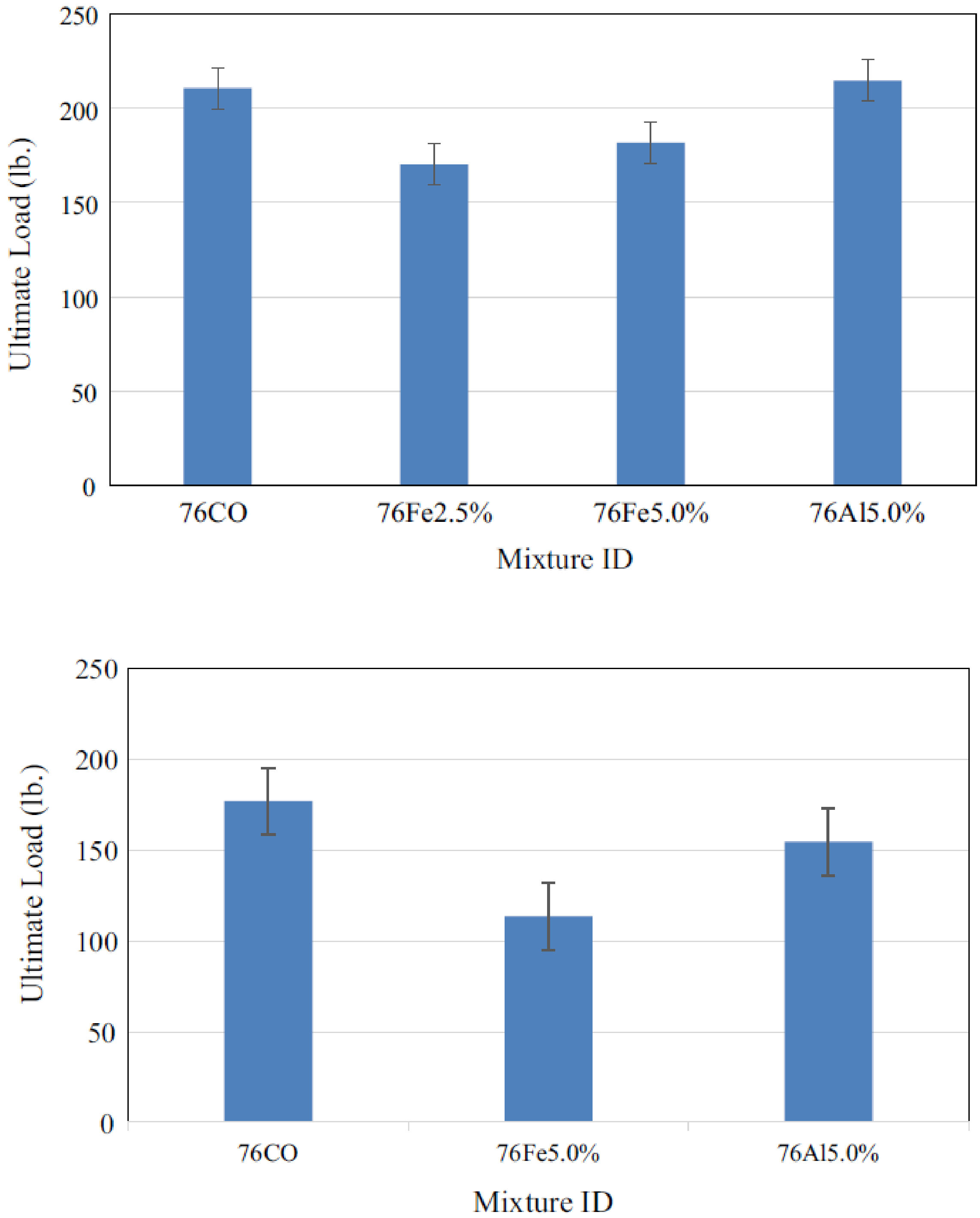

Figure 3. Ultimate Loads of Three Asphalt Concrete Specimens Before and After Healing. (5)

Tests have also shown that samples with steel fibers heated faster than aluminum. This is due to the poor conductivity of steel; therefore, there is more resistance. Sample with aluminum fibers needed around 30 minutes to heat up, while samples with steel fibers just needed 10 minutes to heat up (5). The test then measured the percentage of healing efficiency by finding the ratio of the ultimate load before healing and the ultimate load after healing. A healing efficiency of 100% means that a fracture failure is fully recovered after healing. The control mix showed the highest efficiency with 85% maximum healing efficiency. The healing efficiency for the aluminum and steel fiber samples were 72 and 62 %, respectively. Figure 4 shows the healing efficiencies for the different asphalt concrete pavements.

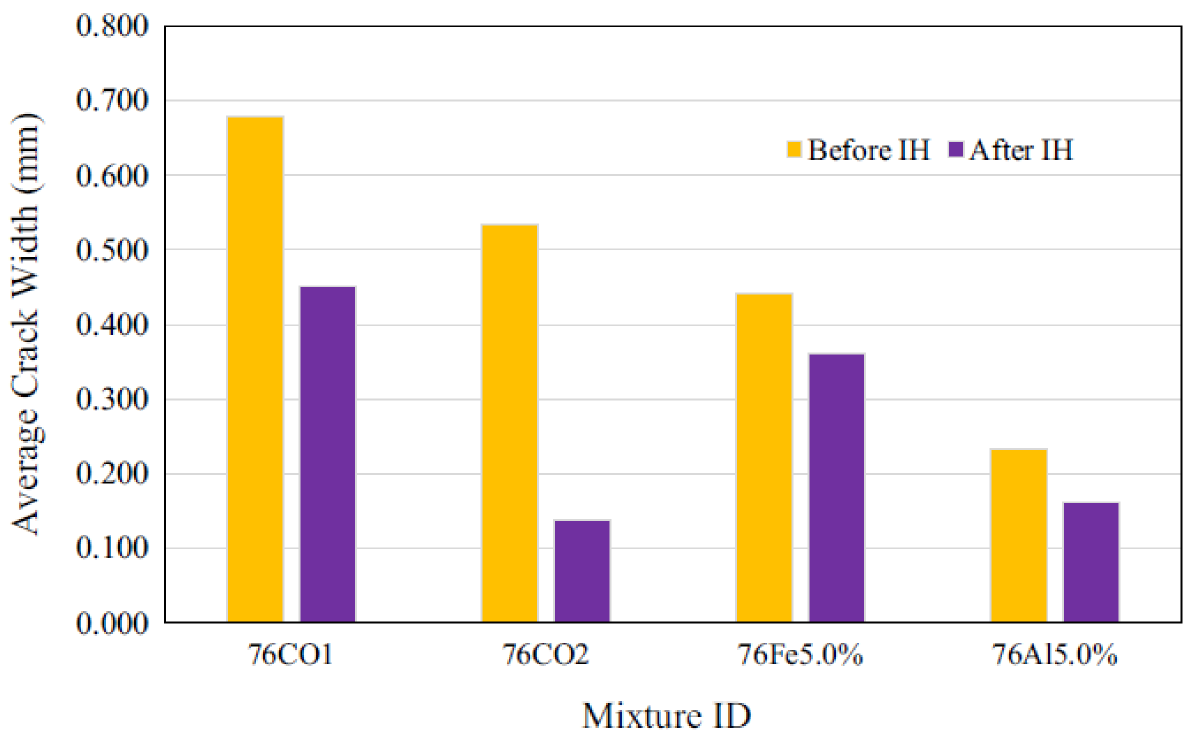

Figure 4. Crack Width of Different Asphalt Concrete Specimens Before and Induction Heating. (5)

These results prove that induction heating is a very useful, economical method to restore the strength of different mixes of asphalt concrete after a crack or failure.

Asphalt Concrete with Carbon-based Materials

There have been several studies made over the past decade to review and improve the performance of asphalt concrete. A study found out that adding fibers as a reinforcement in the asphalt concrete improved the characteristics and the performance of the pavement itself (6). The study also found out that longer, smooth steel fibers effectively improve the tensile strength of asphalt concrete. Furthermore, steel fibers enhance toughness of the asphalt concrete compared to other form of fibers. There have been other studies that looked into the effect of nylon and cellulose fibers on the performance of asphalt concrete; however, there are not many studies of the effectiveness of carbon-based materials have on the performance of asphalt concrete. Therefore, a study has looked into the positives of using carbon-based materials like carbon fiber (CF), carbon nanotubes (CNT), and graphite nanofiber (GNF) in asphalt (7). This study has used the induction heating method to test the self-healing capabilities of asphalt concrete specimens with and without carbon materials. The samples, also, go through the Marshall Stability test which measures the maximum load resisted by the bituminous material at a loading rate of 50.8 mm/minute at a temperature of 60 C. This test is important to select the asphalt binder that satisfies the minimum stability in the pavement. The Marshall stability of asphalt concrete was enhanced with the carbon materials like the CNT and GNF. The Marshall Stabilities were 25% and 28% higher for the CNT and GNF samples compared to the control asphalt mix. This is due to that adding the CNT and GNF filled the pores in the mix which led to a denser microstructure. Figure 5 shows the Marshal stability for the asphalt mix samples tested.

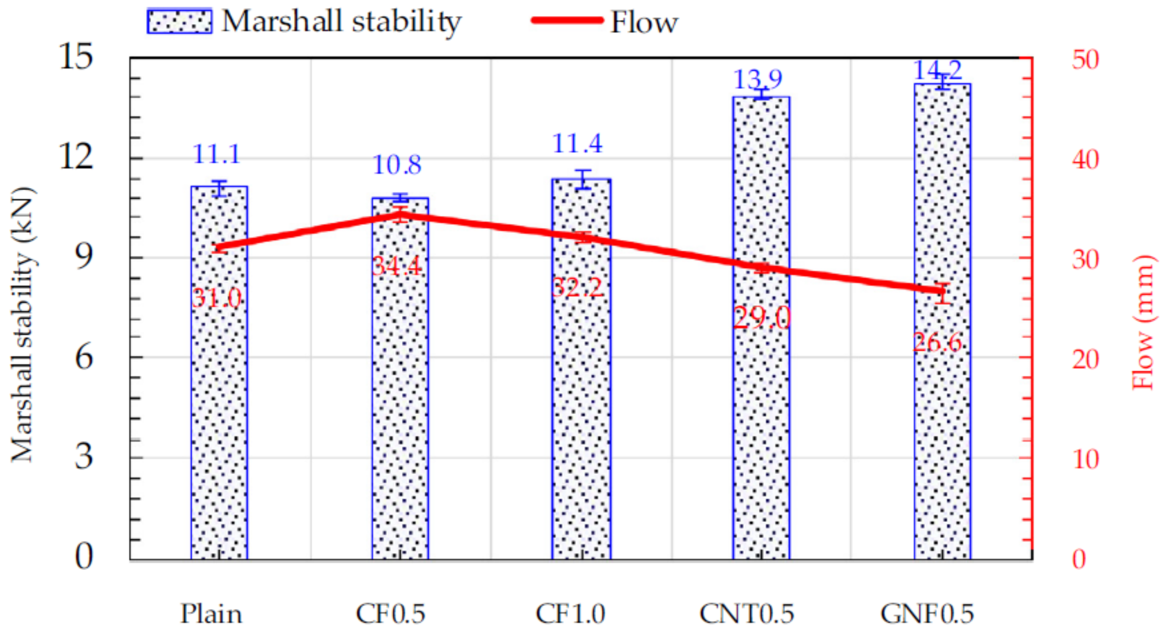

Figure 5. Marshall Stability of Five Asphalt Mix Samples. (7)

The test found out that the CNT and GNF carbon-based mixes had a lower air void content compare to the control mix and the CF mix. The CF mix according to the test did not disperse well leaving pores filled by air in the mix. Therefore, the carbon nanomaterials are more effective in filling the voids in the asphalt concrete. Figure 6 shows the air void content in asphalt concrete.

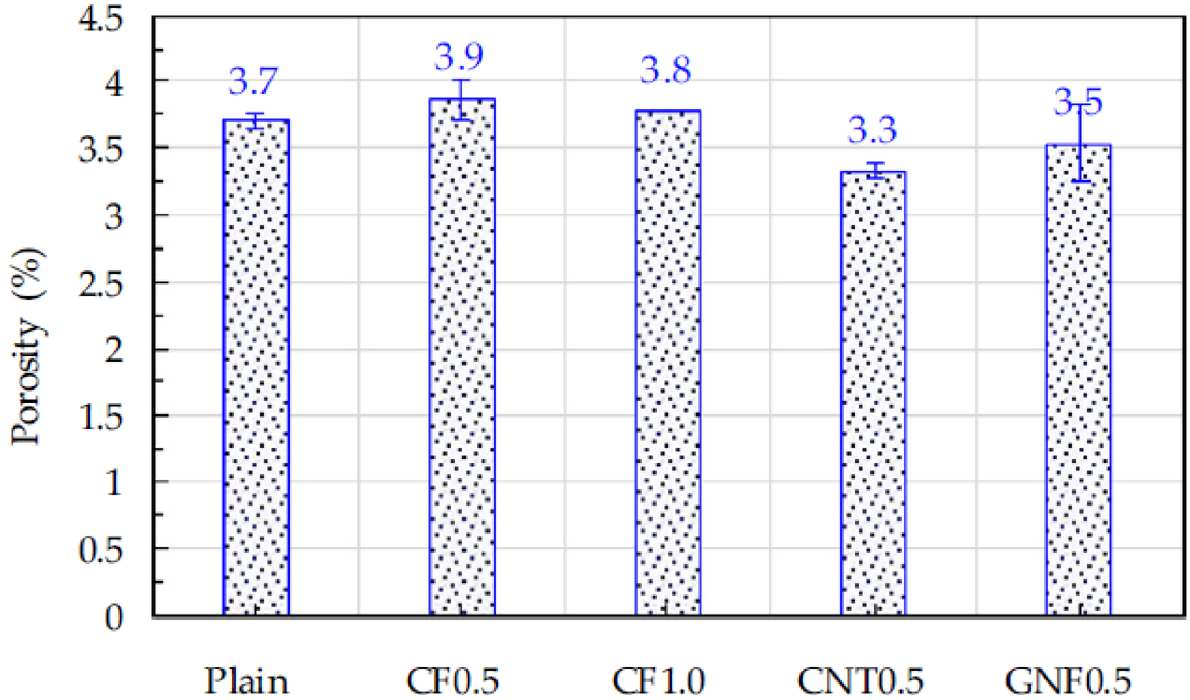

Figure 7. Porosity of Five Asphalt Mixes. (7)

The tensile strength of the CNT and the GNF samples were enhanced. However, the CF mix did not show improvements in its tensile test when compared to the control mix. This shows that the improvements in the tensile strength of carbon-based materials when compared to steel fibers is limited due to the difficulty in mixing these materials. The difficulty in mixing can be attributed to the tendency of carbon materials to be tangled. Figure 8 shows the indirect tensile strength of the test samples.

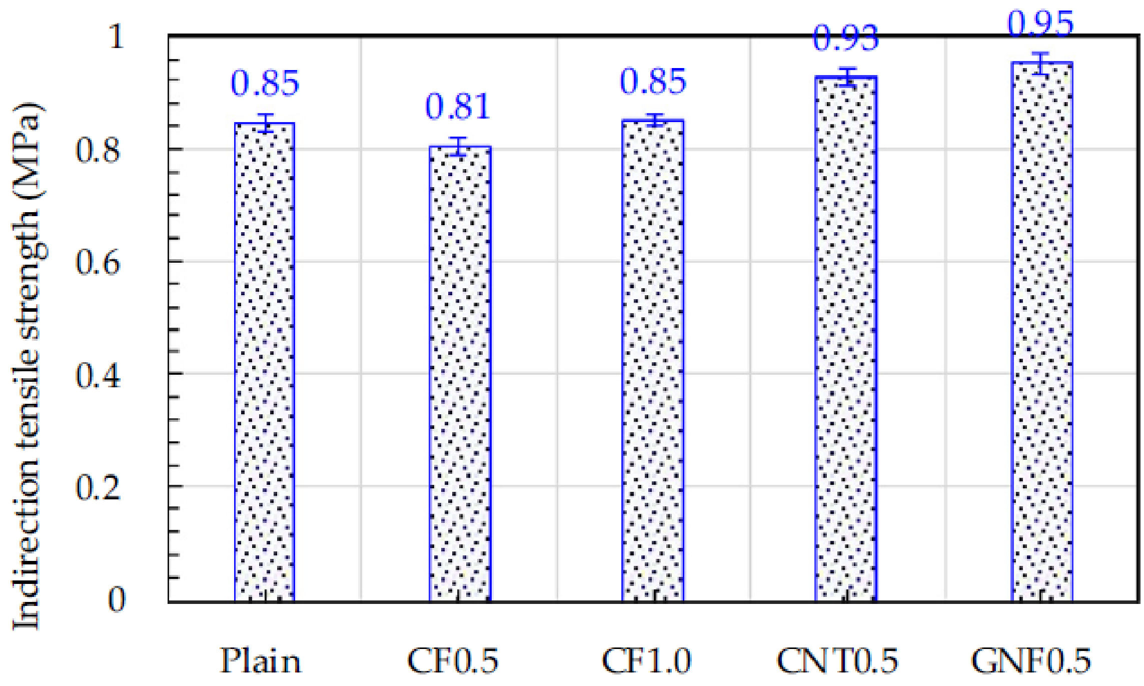

Figure 8. Indirect Tensile Strength of Five Asphalt Sample. (7)

The study has also showed that failing asphalt concrete was partially self-healed after adding the carbon-based materials and completing the induction heating method. GNF and CF samples provided the best healing of asphalt concrete with around 40% recovery to the original strength. These results have shown that carbon-based materials have potential to enhance self-healing and serve as a good alternative to other types of fibers to be used in asphalt concrete mixes.

Conclusion

Self-healing asphalt proved to have a lot of potential and could be a great option for countries around the world to make roads that will have a longer lifespan and save money as well in the future. By reducing premature aging of road surfaces, less amount of resources is used and no need for more traffic interruptions, which also increases road safety. However, the studies are still made on a smaller scale and more cost-efficient ways need to be explored to implement the self-healing technology on a global scale.

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