Asphalt bitumen modified with carbon nanotubes

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ABSTRACT

Carbon nanotubes (CNTs) were introduced into asphalt bitumen to investigate the effect on (1) strength, (2) viscoelasticity, and (3) exposure to microwave radiation. (1) Shear storage and shear loss moduli increased with addition of nanotubes. (2) The phase lag between stress and strain that qualifies the viscoelasticity of the bitumen was found to decrease with addition of carbon nanotubes, through a sweep of frequencies ranging from 0.5 to 5 Hz. (3) It is a well-studied phenomenon that carbon nanotubes heat upon exposure to microwave radiation. In our study focused on future repair processes, microwaves were directed towards a CNT-bitumen composite film. The temperature of the bitumen increased as a function of exposure time, and as a function of increase in weight percent CNT.

Keywords: asphalt, bitumen, carbon nanotube, composite

1 INTRODUCTION

Researchers have extensively investigated nano-additives in many composite systems [1-7] but limited research has been performed on CNT-bitumen composites. In the realm of asphalt, previous work has focused on the effect of CNTs in asphalt concrete [8] (bitumen with aggregate) but not on the effect of the bitumen alone. We have introduced carbon nanotubes into asphalt bitumen (paving asphalt with no stone or sand aggregate) to investigate the effect on (1) strength, (2) viscoelasticity, and (3) exposure to microwave radiation.

2 METHOD

Conductivity grade carbon nanotubes (1/3 single-walled CNTs, 1/3 double-walled CNTs, 1/3 multi-walled CNTs; Carbon Nanotechnologies Inc.) were shear-mixed into asphalt bitumen (PG64-22, Wright Asphalt) at 200 r.p.m. and 150°C. CNT-bitumen composites of 0.1, 0.5, 1 and 3 weight percentages were tested and compared to conventional asphalt, along with asphalt with other common existing modifiers (SBS co-block polymer [PG70-22S, Wright Asphalt] and SBS with tire rubber [PG76-22TR, Wright Asphalt]), except in the case of the microwave experiment.

2.1 Method for testing strength

Dynamic mechanical analysis (DMA) was used in shear mode at 0.5, 1, 2 and 5 Hertz frequencies and at room temperature to measure the shear storage modulus and the shear loss modulus of the composite. A sinusoidal stress was applied to the material and the resulting strain was measured, allowing the shear complex modulus to be determined. The shear complex modulus can be decomposed as per Equation 1. [9]

$$G = G' + iG'' \tag{1}$$

G' is the shear storage modulus and G" is the shear loss modulus. The storage modulus of a viscoelastic material is a measure of the stored energy, which itself is a representation of the elastic portion of the modulus. The loss modulus of the same material is a measure of the energy dissipated as heat, and represents the viscous portion of the modulus.

2.2 Method for testing viscoelasticity

DMA was used (sinusoidal applied stress in shear mode to measure the phase lag (δ) of the viscoelastic CNT-bitumen composites. Viscoelastic materials demonstrate both viscous and elastic characteristics under a deforming stress. Viscous materials strain linearly with time under a stress. Elastic materials strain instantaneously under a stress, and recover to the original state upon removal of the stress. A viscoelastic material will experience a phase lag between 0° (perfectly elastic) and 90° (perfectly viscous). The tangent of the phase lag value (the phase angle) of a material on that spectrum reveals the nature of the viscoelasticity [9]. The tangent of the phase lag is related to the ratio of the loss and storage moduli, as per Equation 2.

$$\tan(\delta) = \frac{G''}{G'} \tag{2}$$

2.3 Method for testing exposure to microwaves

Films (2.5 mm) of CNT-bitumen composites were cast in a mold. Microwaves (50 & 80 watts) were directed towards a CNT-bitumen film as per Figure 1. For reference, a typical household microwave oven is 900-1100 watts, non-directed.

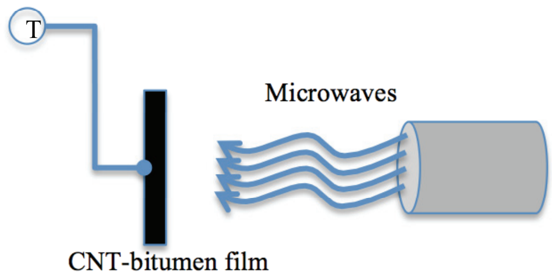

Figure 1: Test setup for CNT-bitumen composites reaction to microwaves

A thermocouple was attached to the posterior of the composite film to measure temperature. The motivation behind the work is that a CNT-bitumen composite can be laid and repaired more efficiently. [10-11]

3 RESULTS AND DISCUSSION

Modifying asphalt bitumen with carbon nanotubes has a demonstrable effect on the strenght, viscosity, and response to microwave radiation.

3.1 Effect on strength

A trend was experimentally observed of increasing moduli, both storage and loss, with increase in weight percent carbon nanotubes. Figure 2 is a graph of the storage moduli of the CNT-bitumen composites as a function of test frequency.

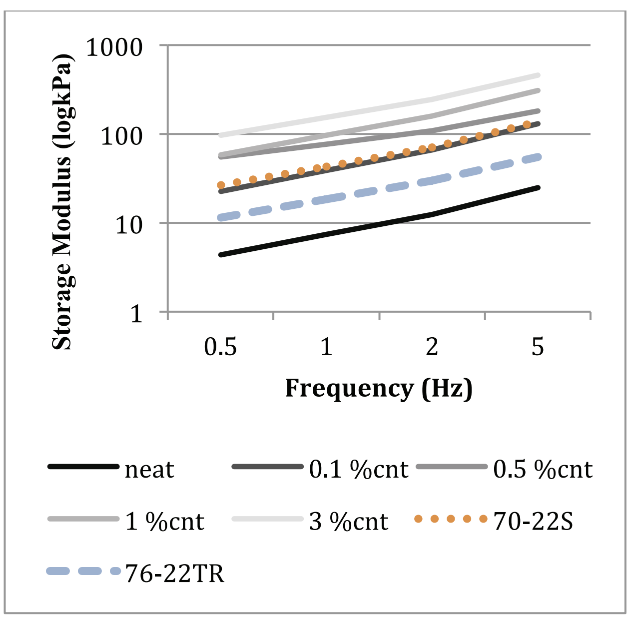

Figure 2: Storage modulus vs. Frequency

Figure 3 is a graph of the loss moduli of the CNT-bitumen composites as a function of test frequency.

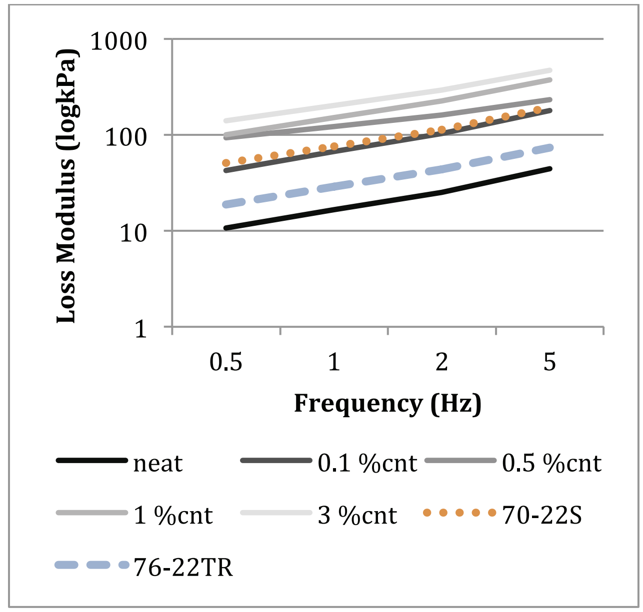

Figure 3: Loss modulus vs. Frequency

The storage and loss moduli of the composite increase with an increase in added carbon nanotubes. Indeed, an increase of an order of magnitude can be achieved with an increase of only 0.5 wt% nanotubes. Also, the reader should note that an addition of 0.1 wt% CNTs yields similar properties of PG70-22S, a polymer-modified asphalt. Addition of greater than 0.1 wt% nanotubes yields a stronger composite than conventional methods of modification, yet the asphalt remains work-able, a requirement for paving and other applications [12-14]. The carbon nanotubes in the asphalt bitumen act to reinforce the bitumen matrix, whilst still allowing for mobility of the hydrocarbon chains that make up asphalt.

3.2 Effect on viscoelasticity

The phase lag (δ) between stress and strain that qualifies the viscoelasticity of the bitumen was found to decrease with addition of carbon nanotubes, through a sweep of frequencies ranging from 0.5 to 5 Hz. As indicated by a decreasing $\tan(\delta)$, the CNT-asphalt composites trended towards more elastic behavior with an increase in nanotube loading, as illustrated in Figure 4.

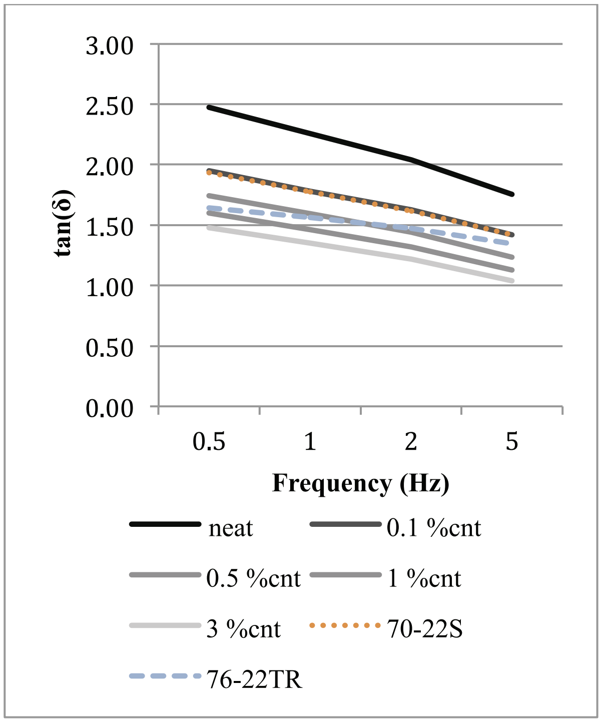

Figure 4: Phase angle vs. Frequency

3.3 Effect of microwave radiation exposure

It is a well-studied phenomenon that carbon nanotubes heat upon exposure to microwave radiation [15]. In our study focused on future repair processes, microwaves were directed towards a CNT-bitumen composite film. The microwaves interacted with and heated the nanotubes, and consequently, the localized bitumen. The temperature of the bitumen increased as a function of increase in wt% CNT, which can be seen in Figures 5 and 6.

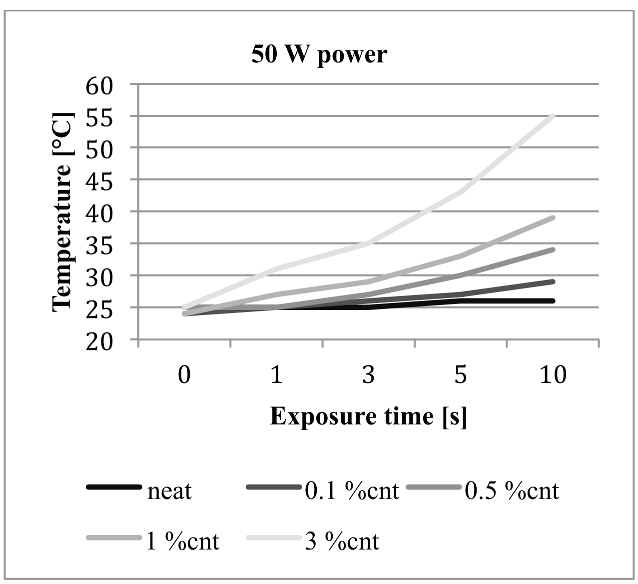

Figure 5: Temperature vs. Exposure time (50 watts)

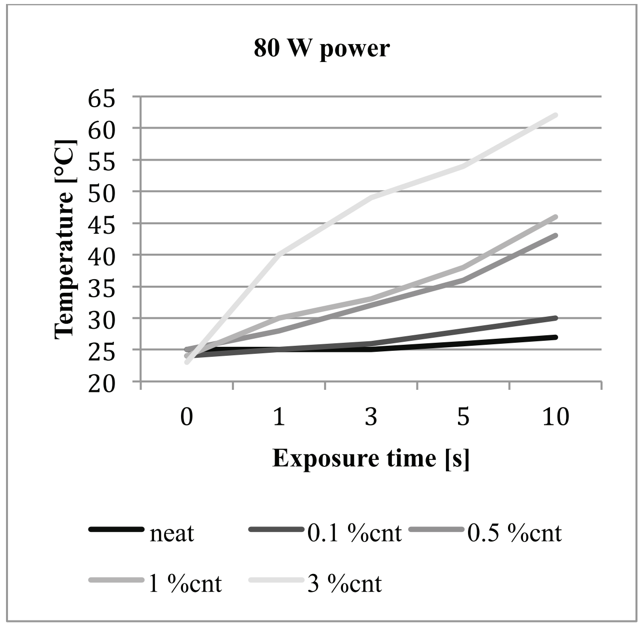

Figure 6: Temperature vs. Exposure time (80 watts)

Additionally, the temperature of the asphalt composites increased as a function of exposure time. This is revealed in Figure 7.

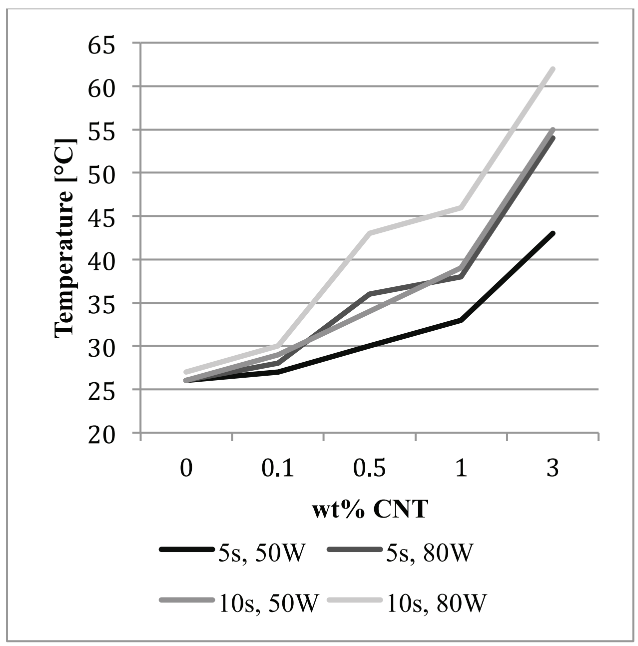

Figure 7: Temperature vs. weight percent CNT

4 CONCLUSION

We expect that continued research on nanotube-modified bitumen without aggregate will lead to a more fundamental understanding of the behavior of the composite material. As nanotechnology moves forward into the realm of transportation, including energy harvesting, health monitoring and energy transportation, and as nano-bitumen finds uses in unconventional spaces such as pit liners for hydraulic fracturing, sealants and coatings, our present work will aid to the understanding of the material characteristics of the nano-modified bitumen system.

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