Exploiting the synergetic effects of graphene and carbon nanotubes on the mechanical properties of bitumen composites

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Results and Discussion

1. Synergetic effects of hybrid graphene and CNT and Micro-structure

- Inhibited the occurrence of self-stacking and agglomeration
- Increased the contact area
- Maximizing the stress transfer
- Formation 1D-2D interconnections

2. Rheological properties

- The R value was increased by 895% and 716%, and the Jnr value was decreased by 95.7% and 89.5%
- At -24 °C, the fracture deflection and fracture energy were increased by 197.6% and 220.2%, respectively.
- The Tc and ΔT values were decreased by 94.7% and 25.4%, respectively.

3. Low temperature behavior

- Graphene (2D) and CNTs (1D) were combined to form 1D-2D hybrid structures that acted synergistically on the mechanical properties of bitumen composites.
- Incorporating 2D-graphene and 1D-CNTs in bitumen could prevent graphene sheets stacking and CNTs aggregation.
- Hybrid graphene and CNT can significantly improve rheological properties, such as the stiffness, rutting resistance, and permanent deformation resistance at high and intermediate-temperatures, as well as the low-temperature cracking resistance of the bitumen composites.

Conclusion

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Fig. 1. Flowchart of the experimental procedures.

Fig. 2. (a) Bitumen/Graphene/CNT composite, (b) Interaction mechanism, (c) Dispersion of graphene, (d) Dispersion of CNTs.

Fig. 3. SEM morphology: (a) Bitumen, (b) B+1 wt.% CNT, (c) and (d) B+1 wt.% Graphene+0.8 wt.% CNT.

Fig. 4. AFM images: (a) Bitumen, (b) B+1 wt.% CNT, (c) B+1 wt.% Graphene+0.8 wt.% CNT, (d) B+1 wt.% Graphene.

Fig. 5. Master curves of (a) complex modulus and (b) phase angles.

Fig. 6. Evolution in G* on d.

Fig. 7. Jnr and R at (a) 1.6 kPa and (d) 3.2 kPa stress level.

Fig. 8. The (flax) stress-strain curves at (a) -18 °C and (b) -24 °C.

Fig. 9. The fracture energy.

Fig. 10. DSC test results.