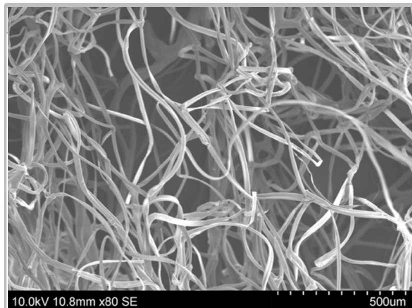

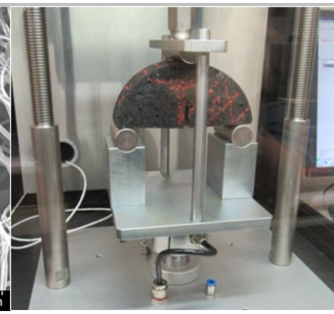
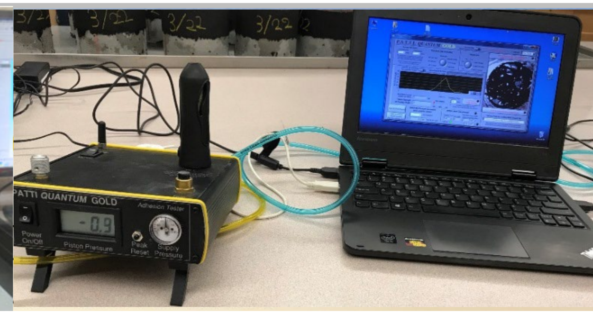


Sustainable Asphalt Mixes Containing Plant-Based Nanofibers

Presented by:

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MOUNTAIN-PLAINS CONSORTIUM

NDSU | UPPER GREAT PLAINS TRANSPORTATION INSTITUTE
TRANSPORTATION LEARNING NETWORK

March 7, 2023

A webinar hosted by:

SOUTHERN PLAINS TRANSPORTATION CENTER

Organization

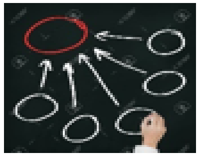
- INTRODUCTION and LITERATURE REVIEW

- OBJECTIVES

- MATERIALS and METHODOLOGY

- RESULTS

- CONCLUSIONS



Introduction

Asphalt Pavement Nationwide

- 94 % of paved roads in U.S. are Asphalt Concrete (AC).
- 27 million tons of asphalt binder per year
- 4,000 AC plants produce 500 to 600M tons of Hot Mix Asphalt (HMA) annually.
- Rising oil and gas prices and environmental concerns lead the pavement industry to use Green Pavement Technologies

<u>Examples</u>

- *Warm Mix Asphalt (WMA)*
- *Recycled Asphalt Pavement (RAP)*
- *Recycled Asphalt Shingles (RAS)*

Introduction

Components of asphalt mix

© http://www.pavementinteractive.org

Asphalt mix

=

© http://www.reesmans.com/aggregate/

Mineral aggregate

+

© http://www.vaasphalt.org/

Asphalt binder

Common Distresses

Cracks due to stripping

Pot-hole from stripping

Fatigue cracking

Thermal cracking

Rutting

Factors Affecting Distresses

- ✓ Asphalt binder type, content, chemical composition
- ✓ Physical, chemical, and mechanical properties of aggregate
- ✓ Asphalt binder-aggregate interaction
- ✓ Asphalt mix properties (VMA, VFA, Pb, %AV, distribution of air voids, interconnectivity of air voids, permeability, …)
- ✓ Construction conditions
- ✓ Traffic loading
- ✓ Weather/Freeze-thaw action

Granite
http://geologylearn.blogspot.com/2015/03/granite.html /Accessed July 2018

Quartzite
https://www.indiamart.com/proddetail/quartzite-4260206333.html /Accessed July 2018

Weather
http://www.sharonchoe.com/#/Accessed July 2018

Asphalt Binder
https://www.indiamart.com/proddetail/bitumen-11822717073.html/Accessed July 2018

Asphalt Mixes
http://www.australianasphaltcontracting.com/coldmix/
Accessed July 2018

Traffic loading
https://gulfnews.com/news/uae/transport/new-rules-for-heavy-trucks-in-dubai-starts-on-tuesday-1.2066289 /Accessed July 2018

Asphalt Binder

- Performance grading (AASHTO T 320, 2010)

PG 58-28

Average 7-day maximum pavement temp. ≤ **58 °C**

Minimum pavement temp. ≥ **-28 °C**

Waxes

Polymers

Fibers

Waste Rubber

RAP/RAS

Polyphosphoric Acid

Oxidizers

Introduction

Asphalt Binder Polymer Modification

Elastomers

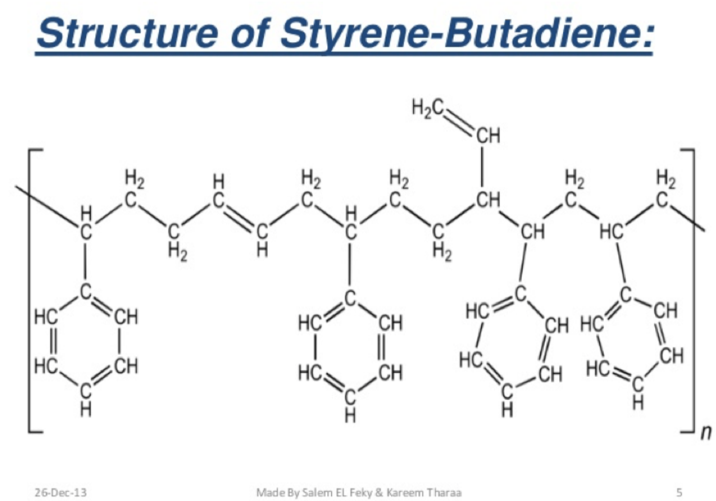
- Styrene-Butadiene Rubber – SBR
- Polyisoprene – Natural Rubber

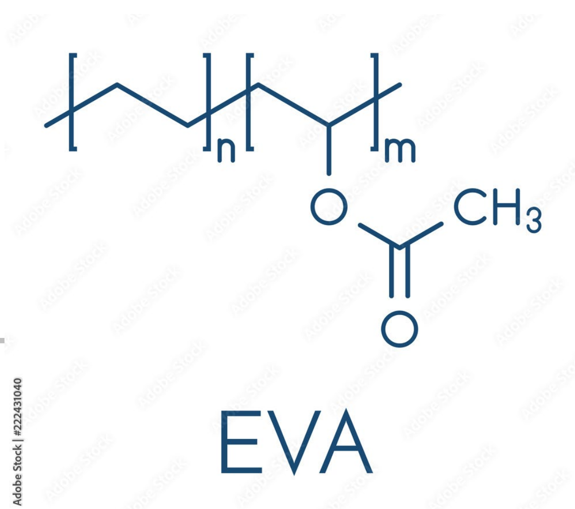
Thermoplastic Elastomers

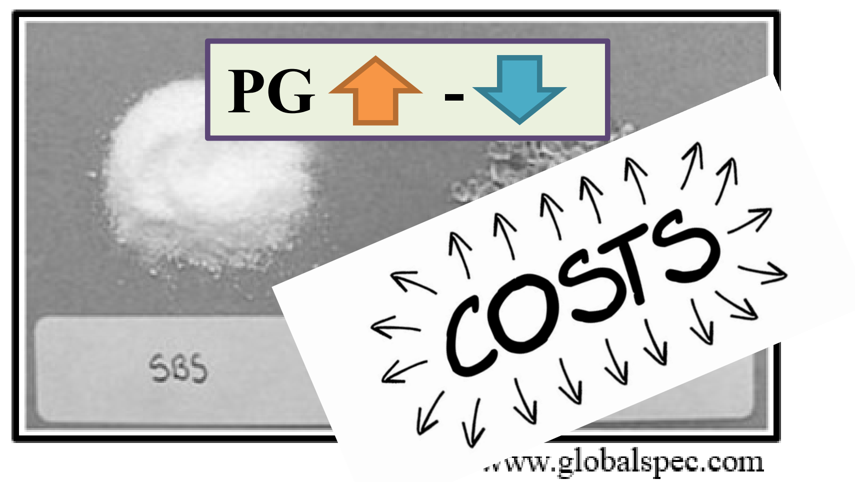
- Styrene-BD-Styrene block copolymer – SB-, SBS

Thermoplastic

- Ethylene vinyl acetate (EVA) resin



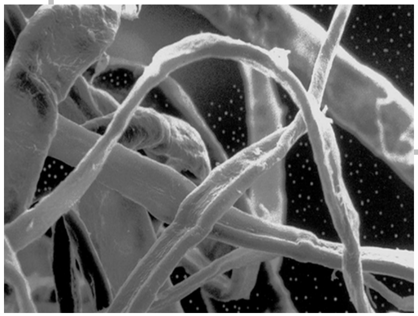




Use of Fibers in Asphalt Mix

Different fibers used in asphalt mix:

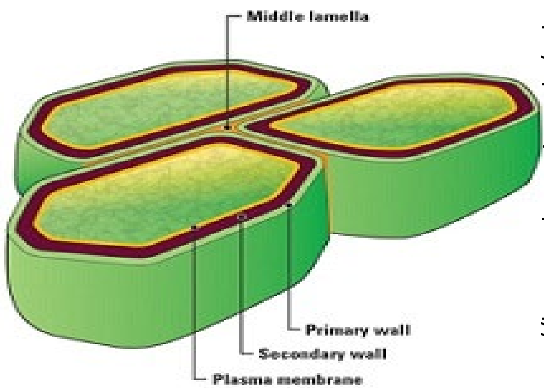
- Basalt fiber
- Polyester fiber
- Aramid fiber
- Asbestos fiber (Banned!)
- Carbon fiber
- Diatomite fiber
- …



Cellulose

Cellulose *The most abundant naturally-occurring bio-material*

- Abundant
- Cost-effective
- Reliable
- Renewable
- Environmentally Friendly
- Mechanical properties
    - Tensile Strength around 60 MPa
    - Young modulus around 3 GPa



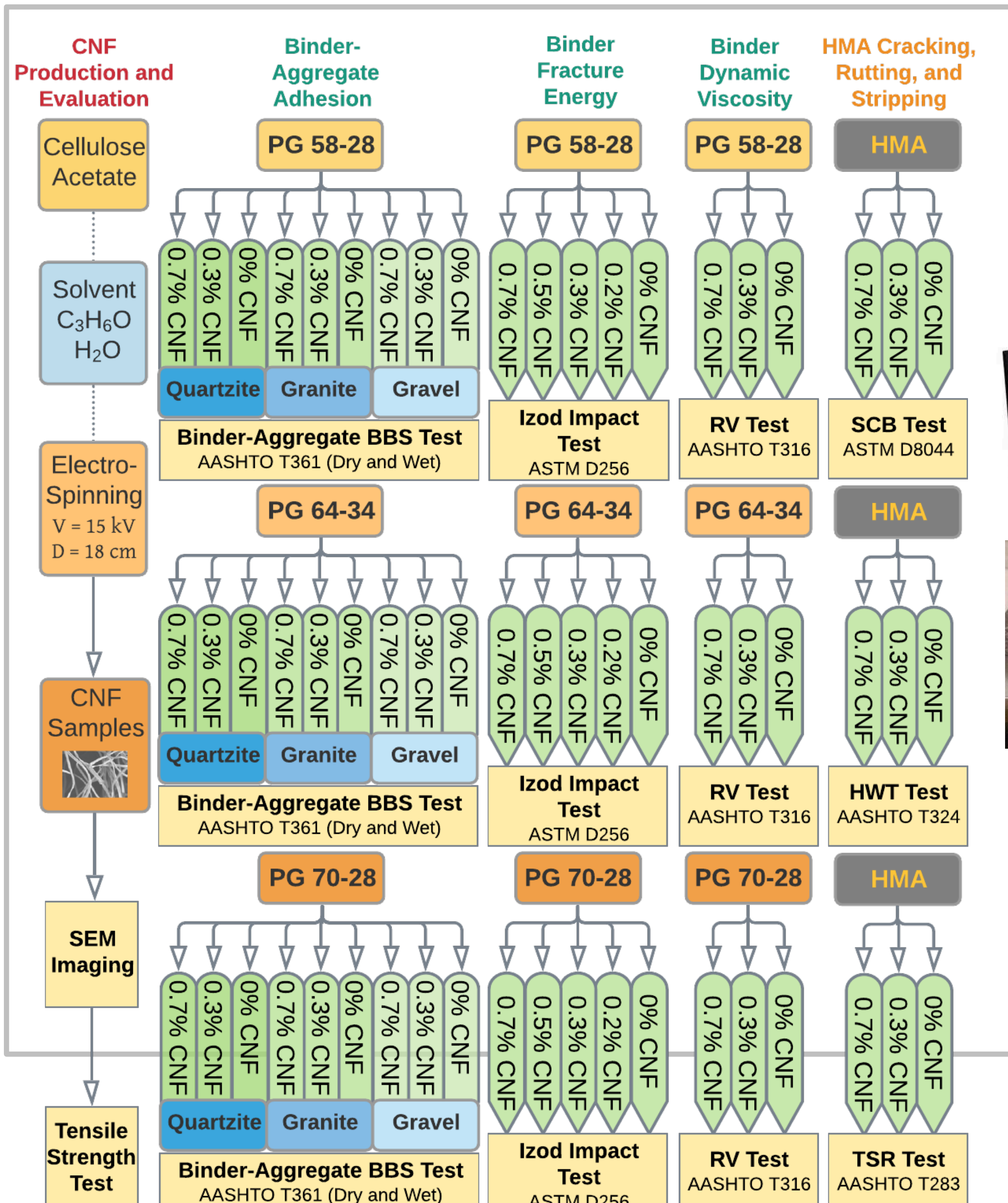
http://butane.chem.uiuc.edu/pshapley/GenChem2/B10/3.html

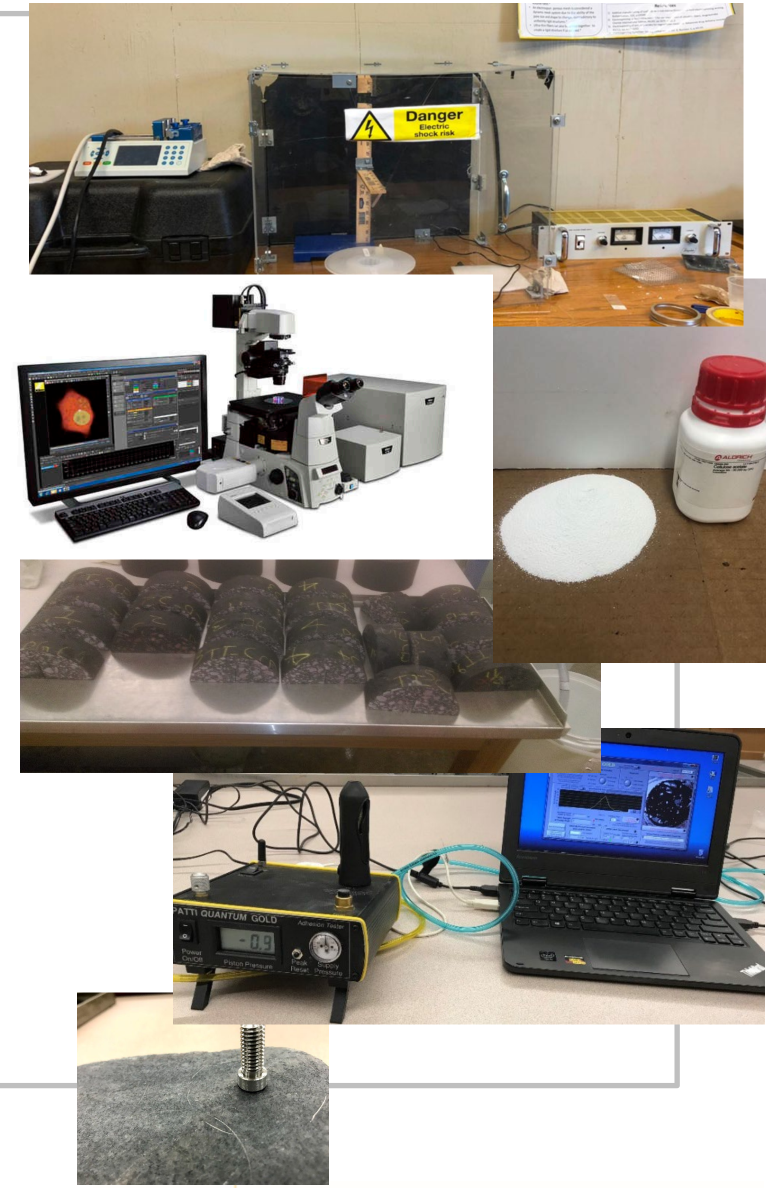
Convert to Nano-Fiber

Objectives

1. Produce CNF in the laboratory using electrospinning technique and characterize the properties of CNF.
2. Investigate the effect of incorporating 0, 0.2, 0.3, 0.5 and 0.7% CNF (by the weight of binder) in three types of asphalt binders, namely PG 58-28, PG 64-34, and PG 70-28, on their fracture energies at low temperature by conducting Izod impact tests;
3. Evaluate the effect of CNF used in different amounts on dynamic viscosity of binders;
4. Evaluate the effect of incorporating 0, 0.3, and 0.7% CNF (by the weight of asphalt binder) in three types of asphalt binders, namely PG 58-28, PG 64-34, and PG 70-28 on their adhesion and moisture-induced damage potentials with different aggregates, namely granite, quartzite, and gravel by conducting Binder Bond Strength (BBS) test;
5. Characterize the effect of incorporating 0, 0.3, and 0.7% CNF (by the weight of asphalt binder) on the resistance of asphalt mixes to cracking, rutting, and moisture-induced damage by conducting SCB, HWT, and TSR tests, respectively.

Study Plan





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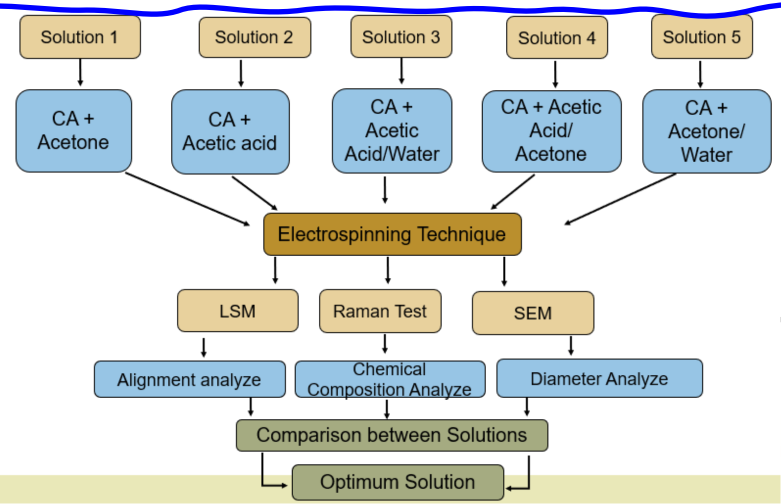
Materials

Cellulose Nano-Fiber (CNF)

Solution Preparation

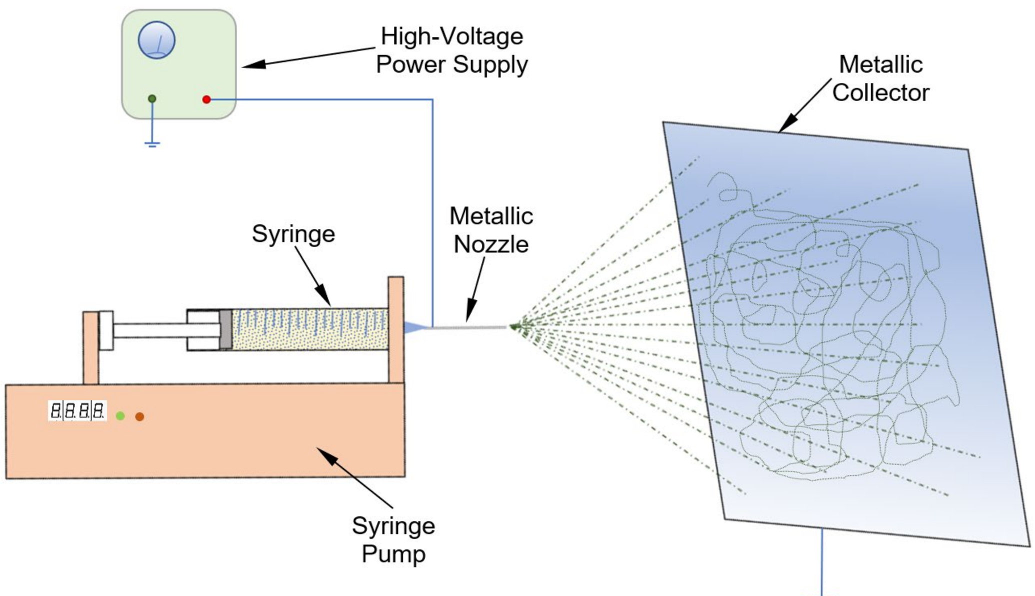
Solution	Polymer Type	Solvent Type	Concentration of Polymer by Weight (%)	Ratio of Solvent (%)	Total Weight (g)
1	Cellulose Acetate	Acetone	15	100	25
2	Cellulose Acetate	Acetic Acid	13	100	25
3	Cellulose Acetate	Acetic Acid/Water	17	75/25	25
4	Cellulose Acetate	Acetic Acid/Acetone	13	75/25	25
5	Cellulose Acetate	Acetone/Water	17	88/12	25

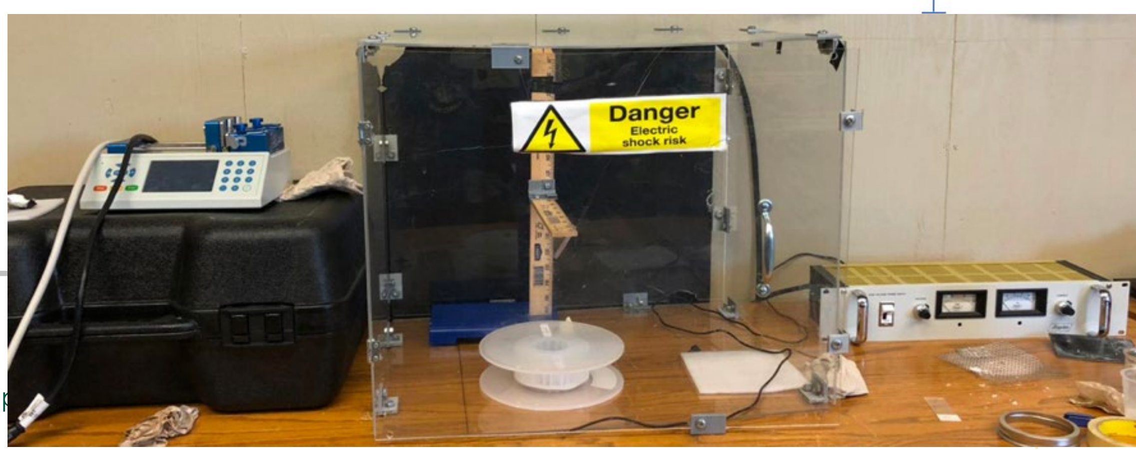


Materials and Methods

Cellulose Nano-Fiber (CNF)

Electrospinning

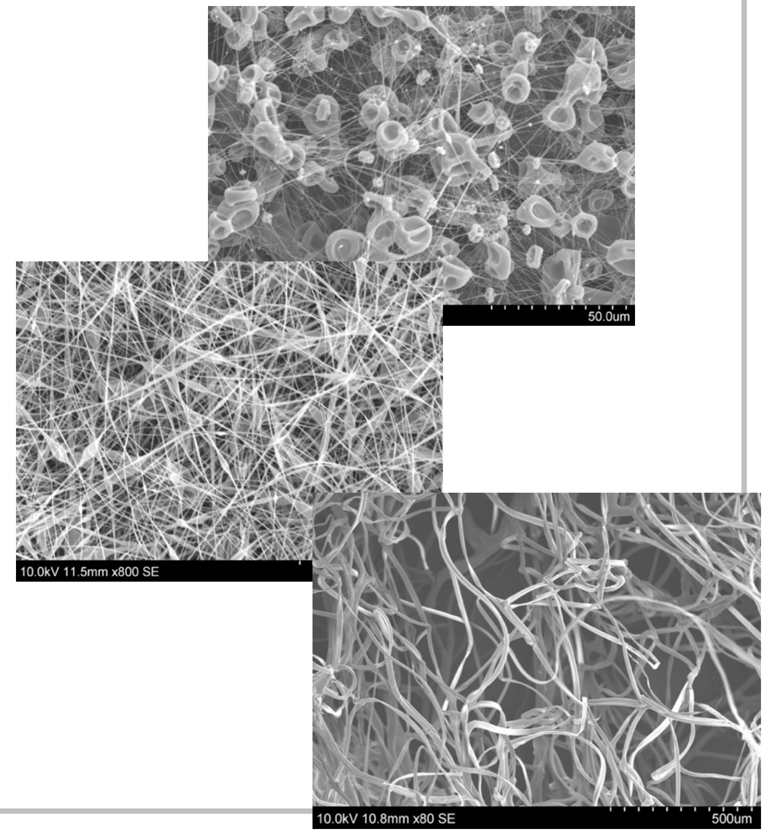




Materials and Methods

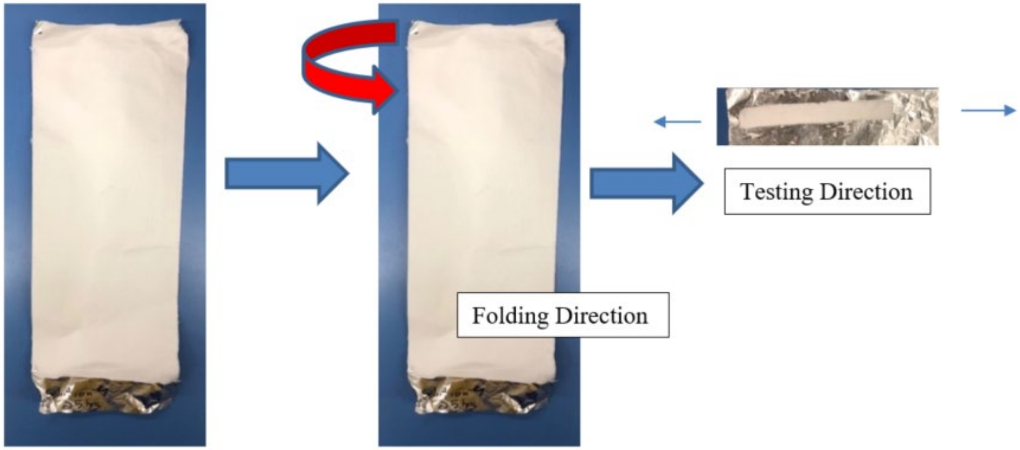
Cellulose Nano-Fiber (CNF)

Scanning Electron Microscopy (SEM)



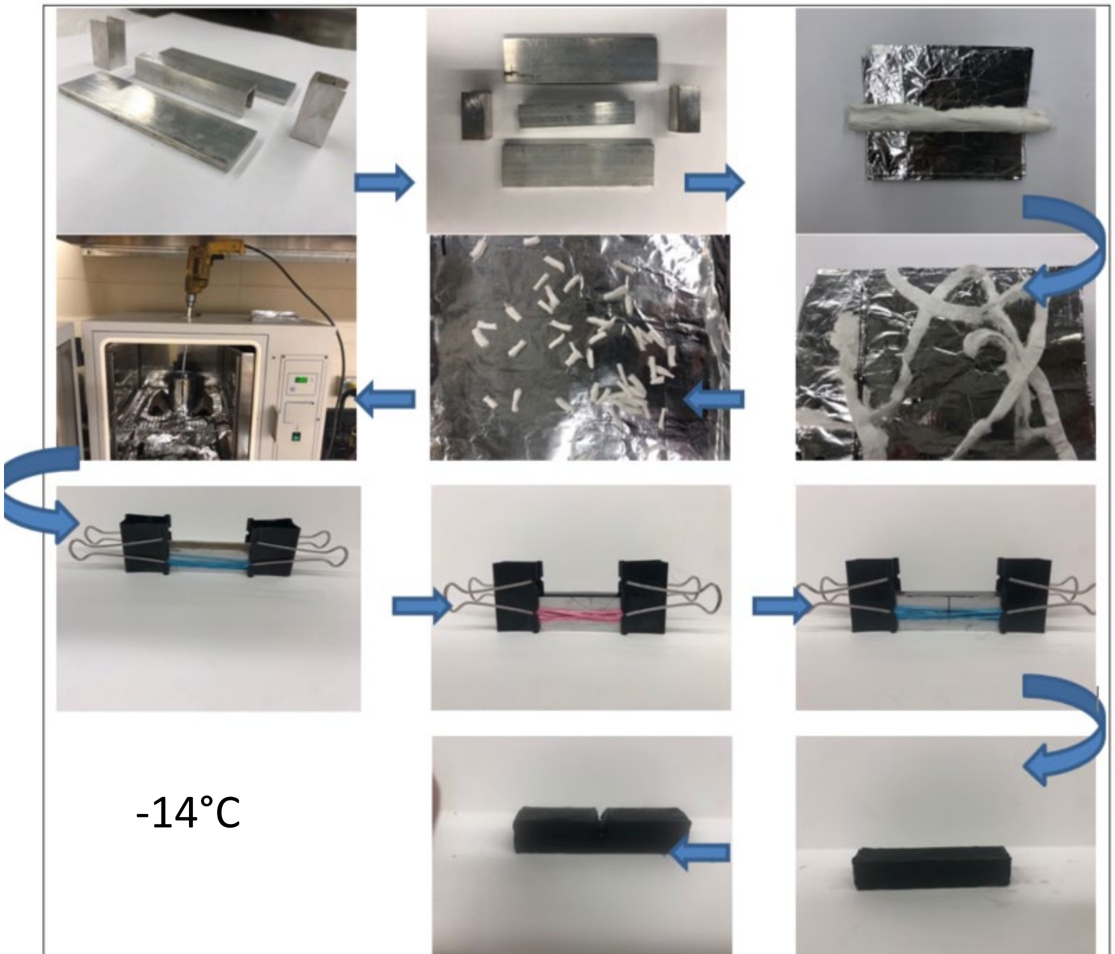
Cellulose Nano-Fiber (CNF)

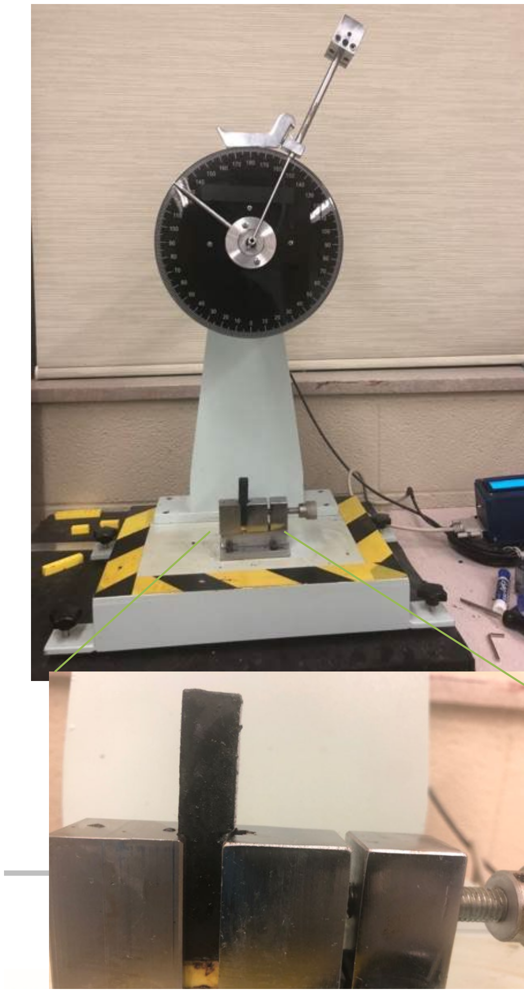
Tensile Test



Cellulose Nano-Fiber (CNF)-Modified Binder Test

Izod Pendulum Impact Resistance Test (ASTM D256)



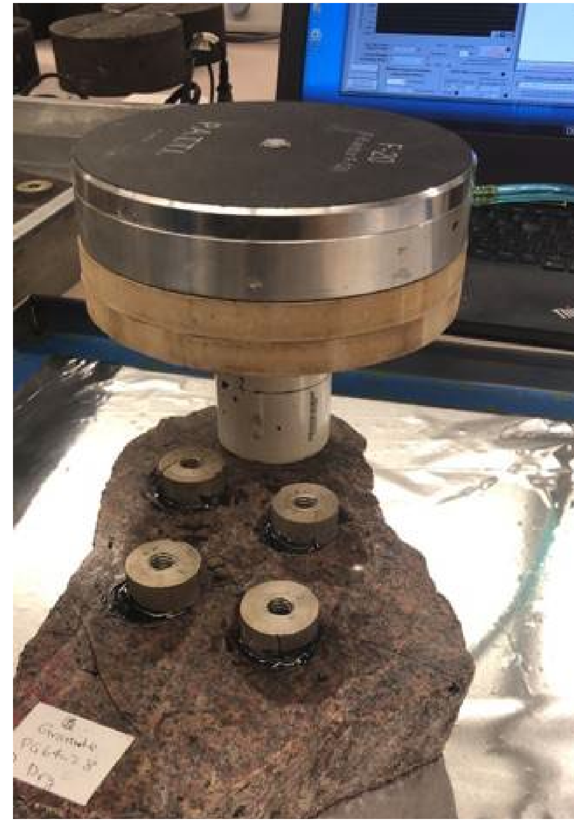


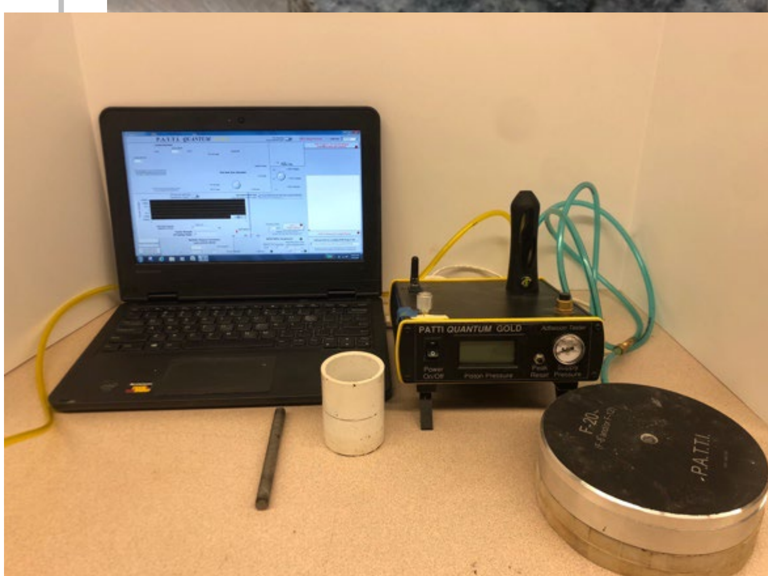
$$E_{cor.} = MgL\left(\cos\beta - \cos\alpha\right) - E_{TC}$$

Materials and Methods

Binder Adhesion

Binder Bond Strength Test (AASHTO T 361)





Aggregates

Quartzite aggregate
Sioux Falls, SD
November, 2018

Granite aggregate
Brookings, SD
November, 2018

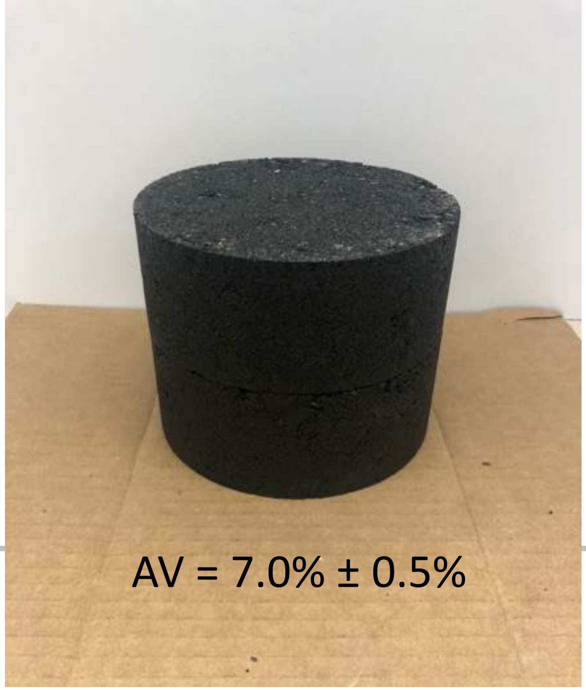
Gravel
Brookings, SD
December 2018

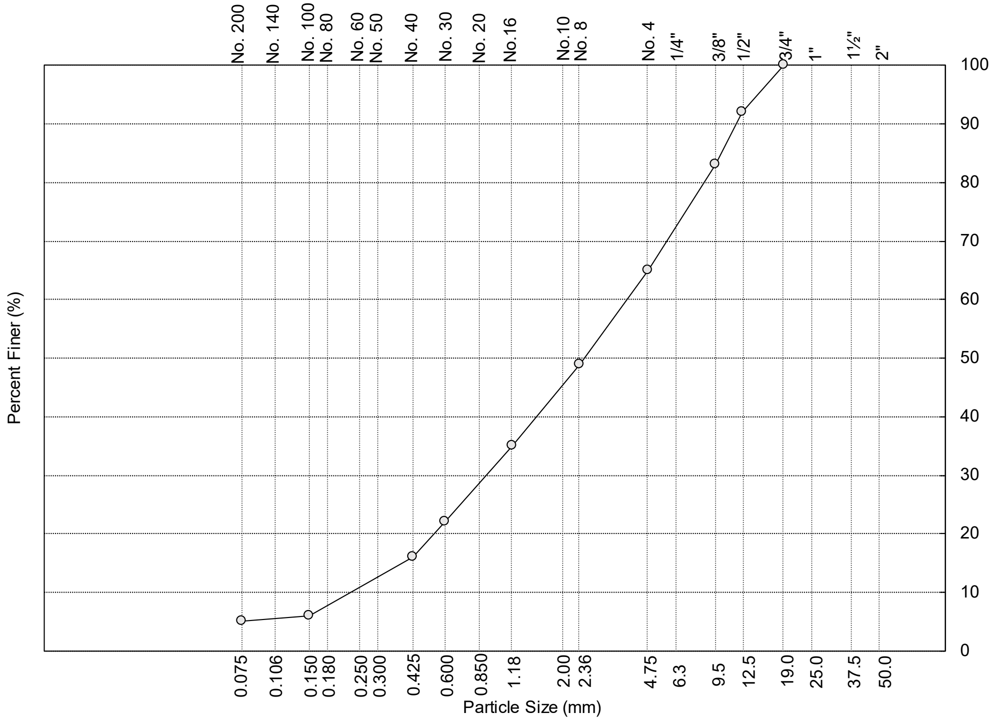
Materials and Methods

Asphalt Mix Preparation

Asphalt Mix Type	Asphalt Binder Grade	Virgin AC† (%)	Replaced AC† (%)	Additive Type: RAP (%)	Additive Type: Lime (%)	Additive Type: WMA (%)	%VMA‡ Required+ >14	%VFA§ Required+ 70 – 80	DP* Required+ 0.6 – 1.2
HMA	PG 58-28	4.8	1.0	20	-	-	14.5	72.4	1.0

+ *AASHTO M 323 volumetric mix design requirement*
† *Asphalt Content*
‡ *Voids in Mineral Aggregates*
§ *Voids Filled with Asphalt*
* *Dust Proportion*





Asphalt Mix Tests

Semicircular Bend Test (ASTM D8044)

Compacted samples

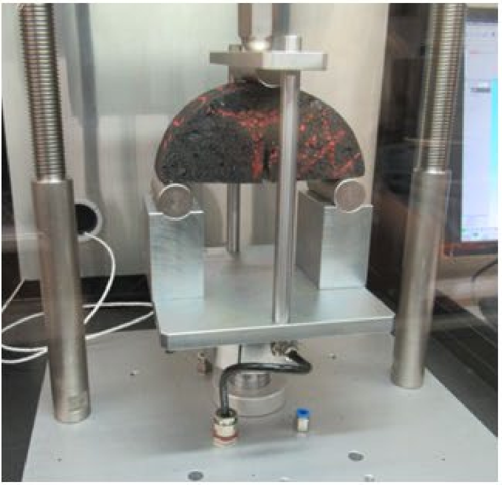
Saw used to prepare semicircular specimens

Semicircular specimens

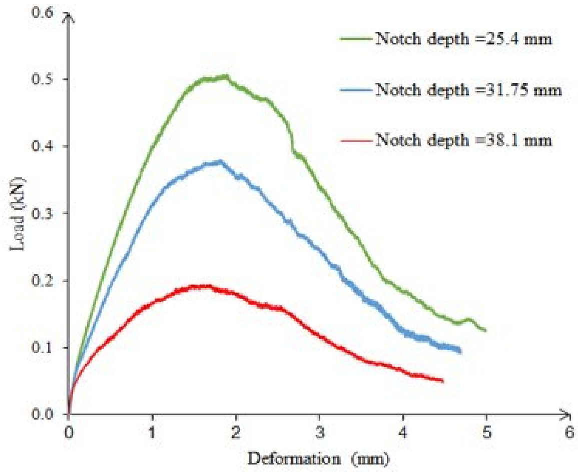
Height of compacted sample in SCB test = 120 mm (4 ¾")
Height of the compacted sample in TSR test = 95 mm (3 ¾")
Diameter of the compacted sample = 150 mm (6")
Target thickness of the SCB sample = 58.5 mm (2.3")
Notch sizes in the SCB test = 25.4 mm, 31.75 mm, 38.1 mm (1" ; 1 ¼"; 1 ½")

Asphalt Mix Tests

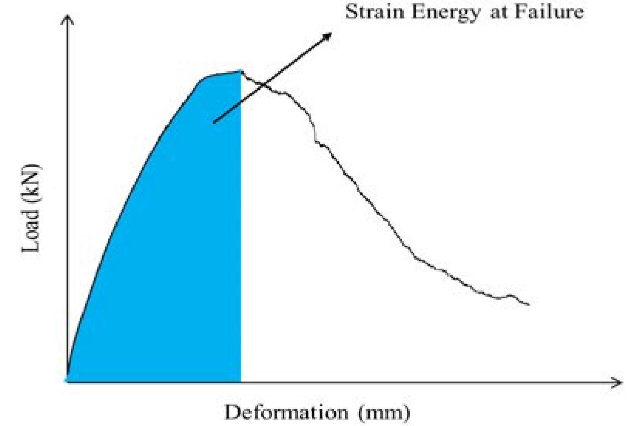
Semicircular Bend Test (ASTM D8044)



SCB testing by AMPT



Load-deformation curves for different notch depth of SCB specimens



Critical strain energy release rate

$$J_c = \frac{-1}{b}(dU/da)$$

where,

J_c = critical strain energy release rate (kJ/m^2);

b = sample thickness (m);

a = notch depth (m);

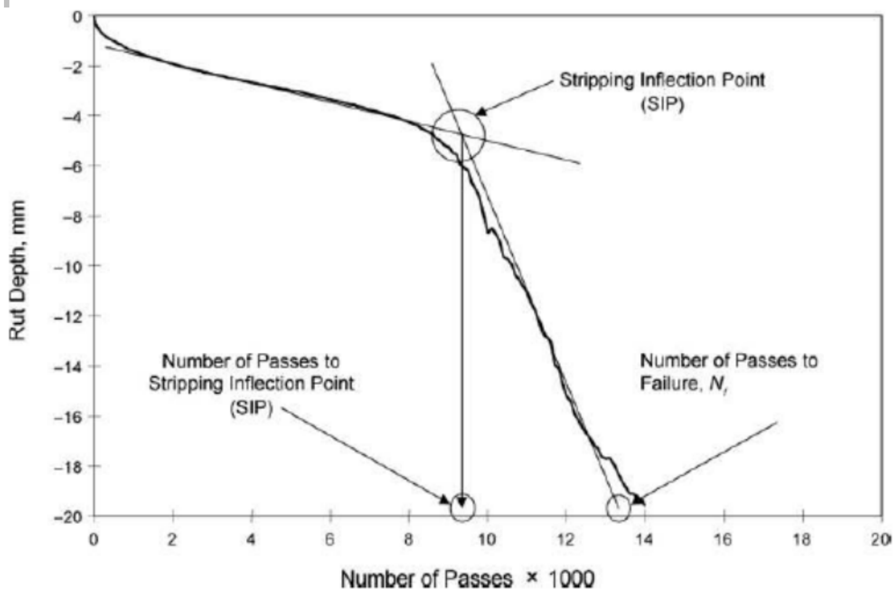
U = strain energy to failure (kJ); and

dU/da = change of strain energy with notch depth.

Materials and Methods

Asphalt Mix Tests

Hamburg Wheel Tracking (AASHTO T 324)



(Feener et al., 2021)

Asphalt Mix Tests

Tensile Strength Ratio (AASHTO T 283)

Failed TSR specimen

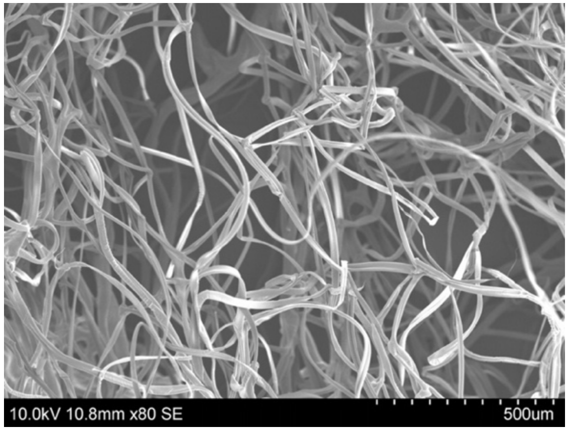
Failure surface of the dry sample and moisture-conditioned sample

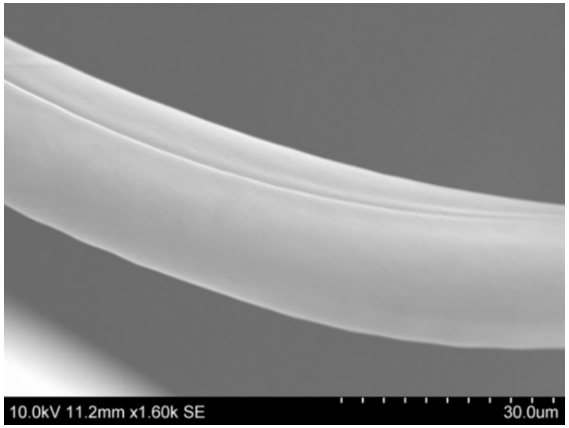
$$S_t = (2000\,P)/(\pi\, t\, D)$$

where,
S_t = tensile stress, kPa,
P = maximum load, N
t = specimen thickness, mm,
D = specimen diameter, mm
TSR = St (moisture-conditioned)/St (dry)

CNF Characteristics

SEM Imaging

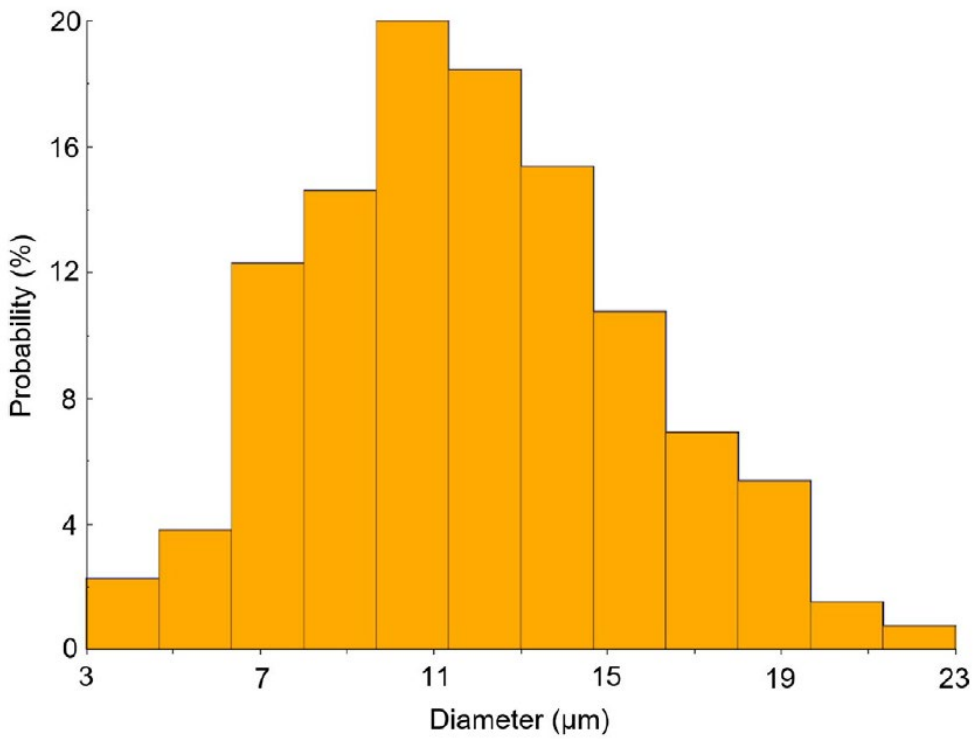




88 volumetric parts acetone

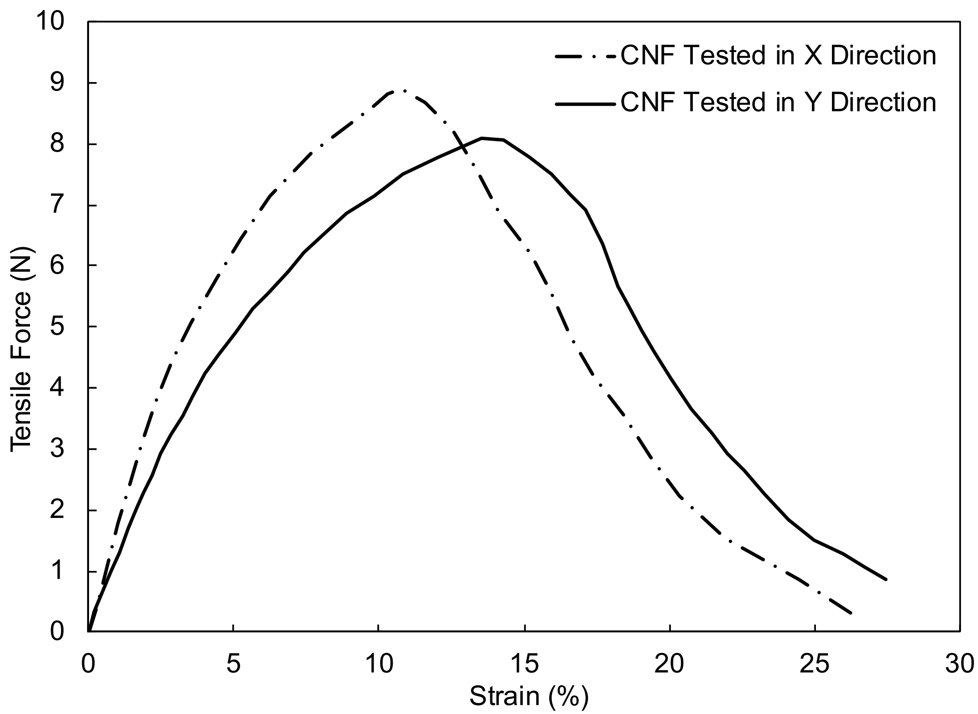
12 volumetric parts distilled water

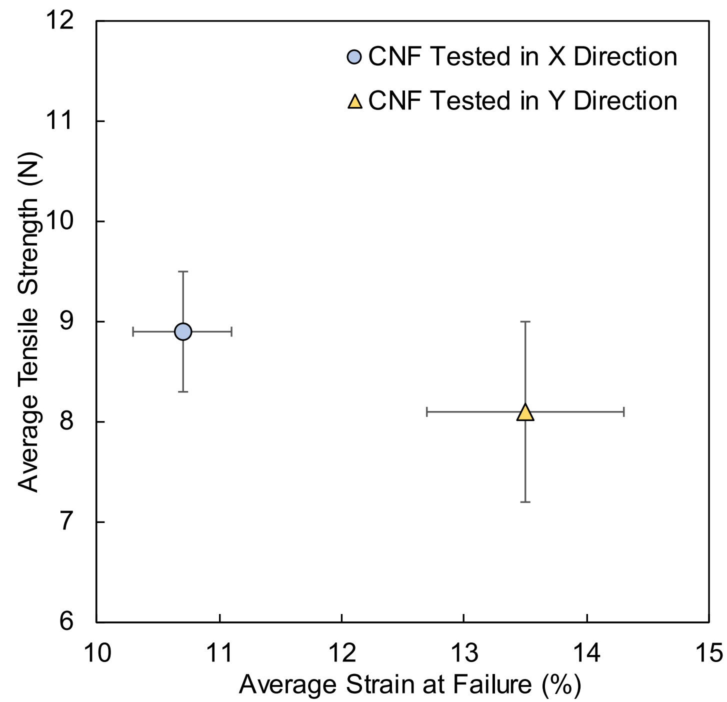
17% CA (by weight)



CNF Characteristics

Tensile Strength

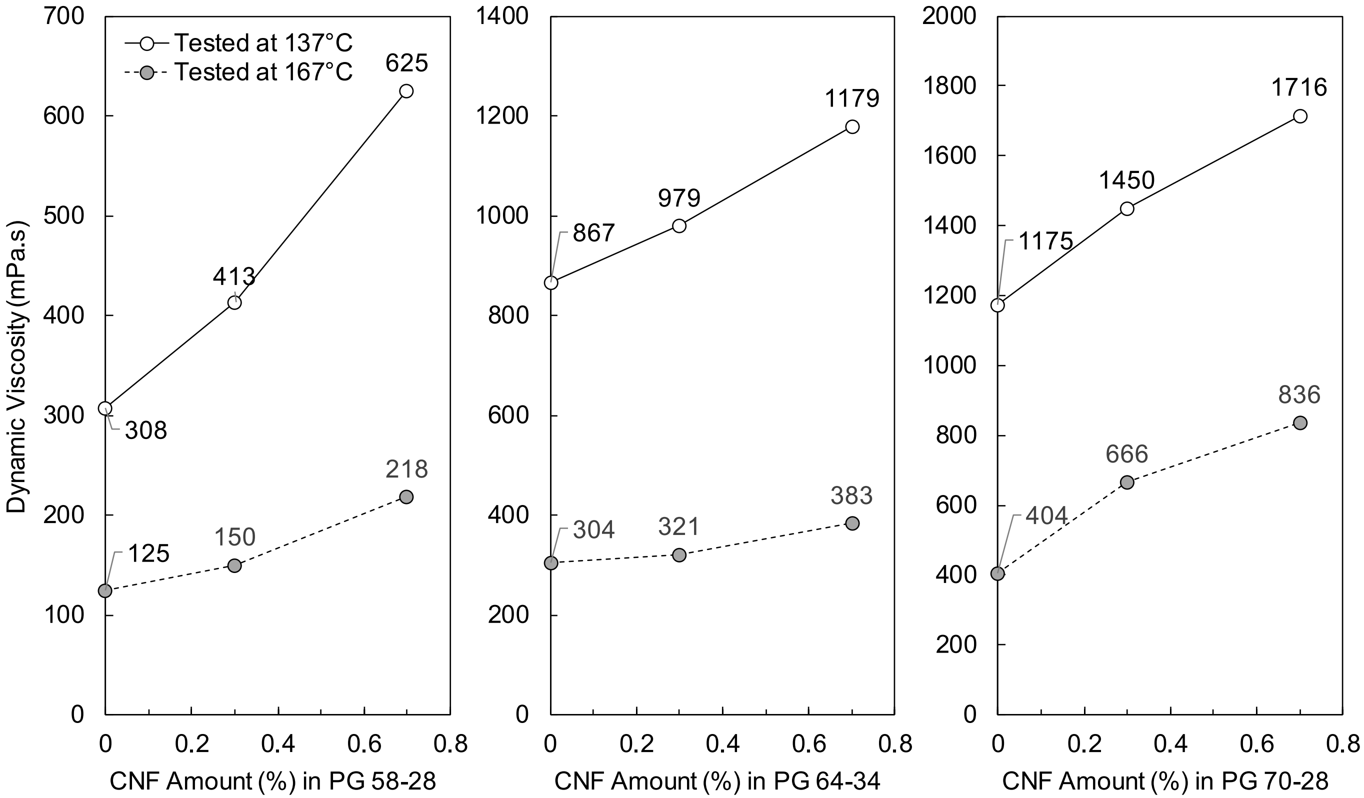




Results and Discussion

Asphalt Binder

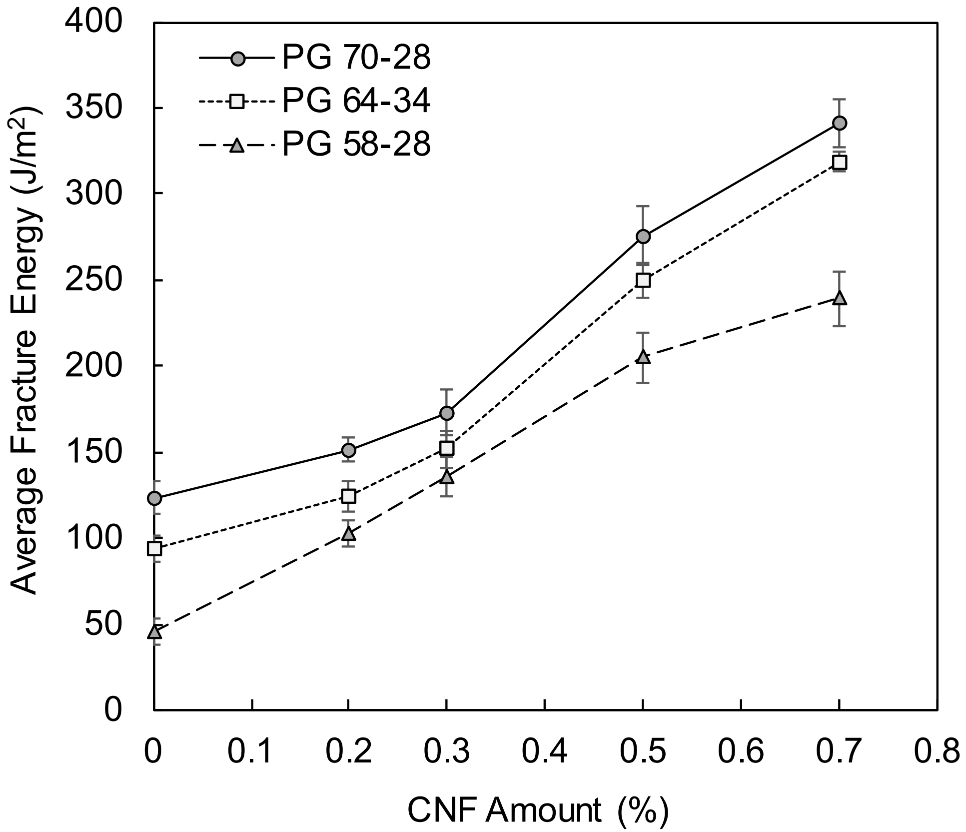
Dynamic Viscosity

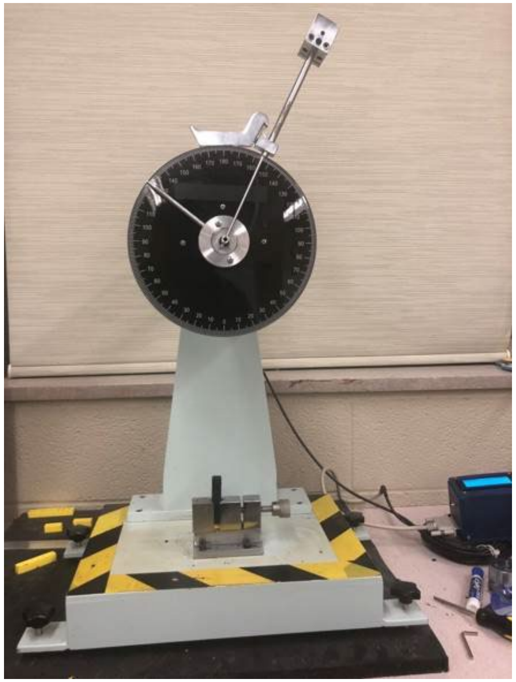


Results and Discussion

Asphalt Binder

Fracture Energy

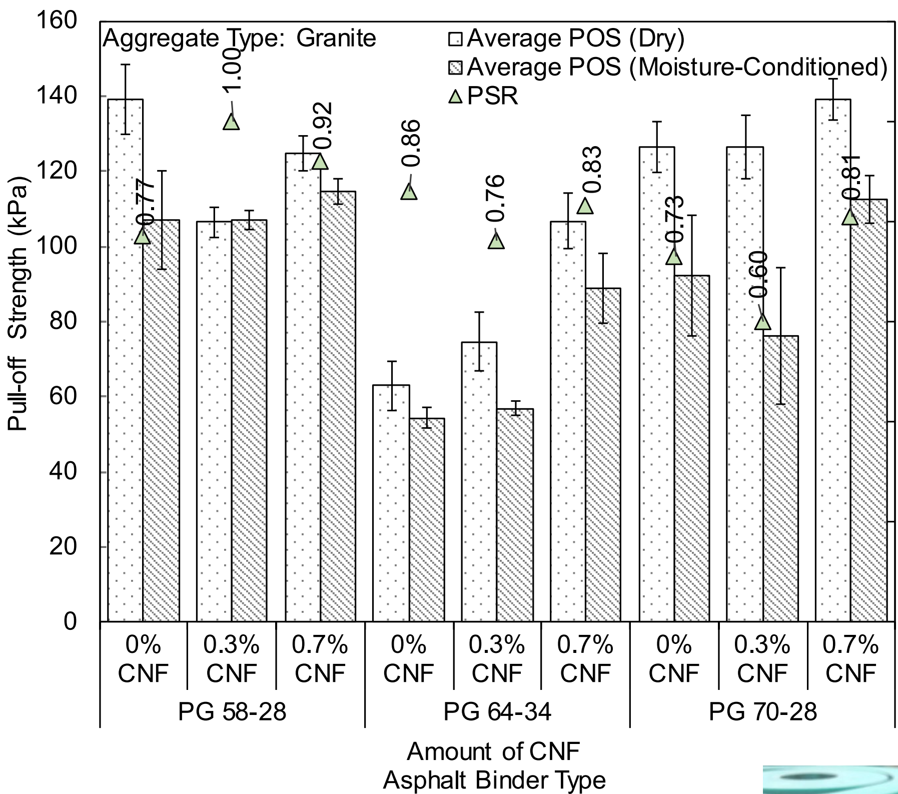


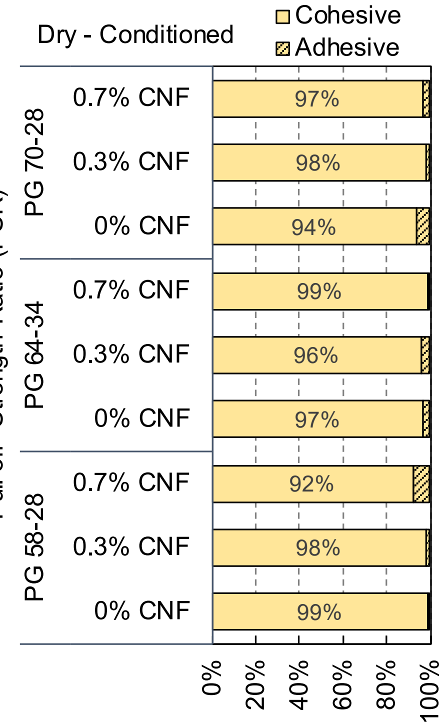


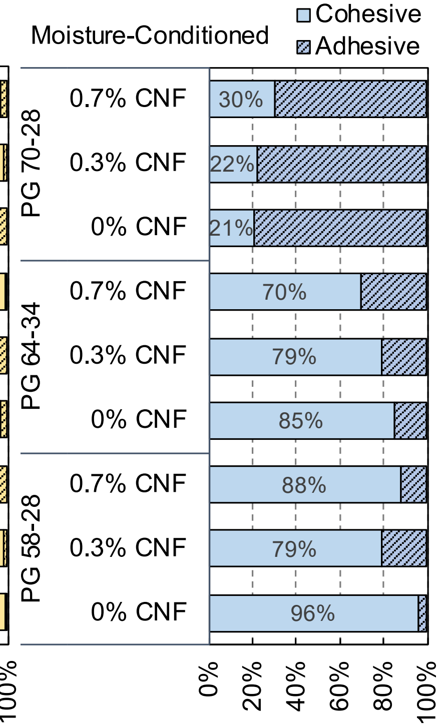
Results and Discussion

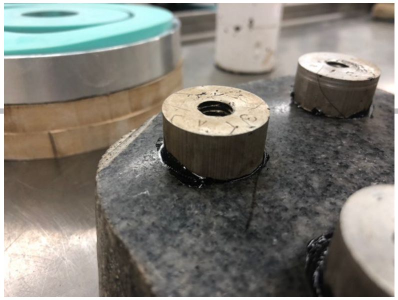
Asphalt Binder Adhesion

Adhesion to Granite



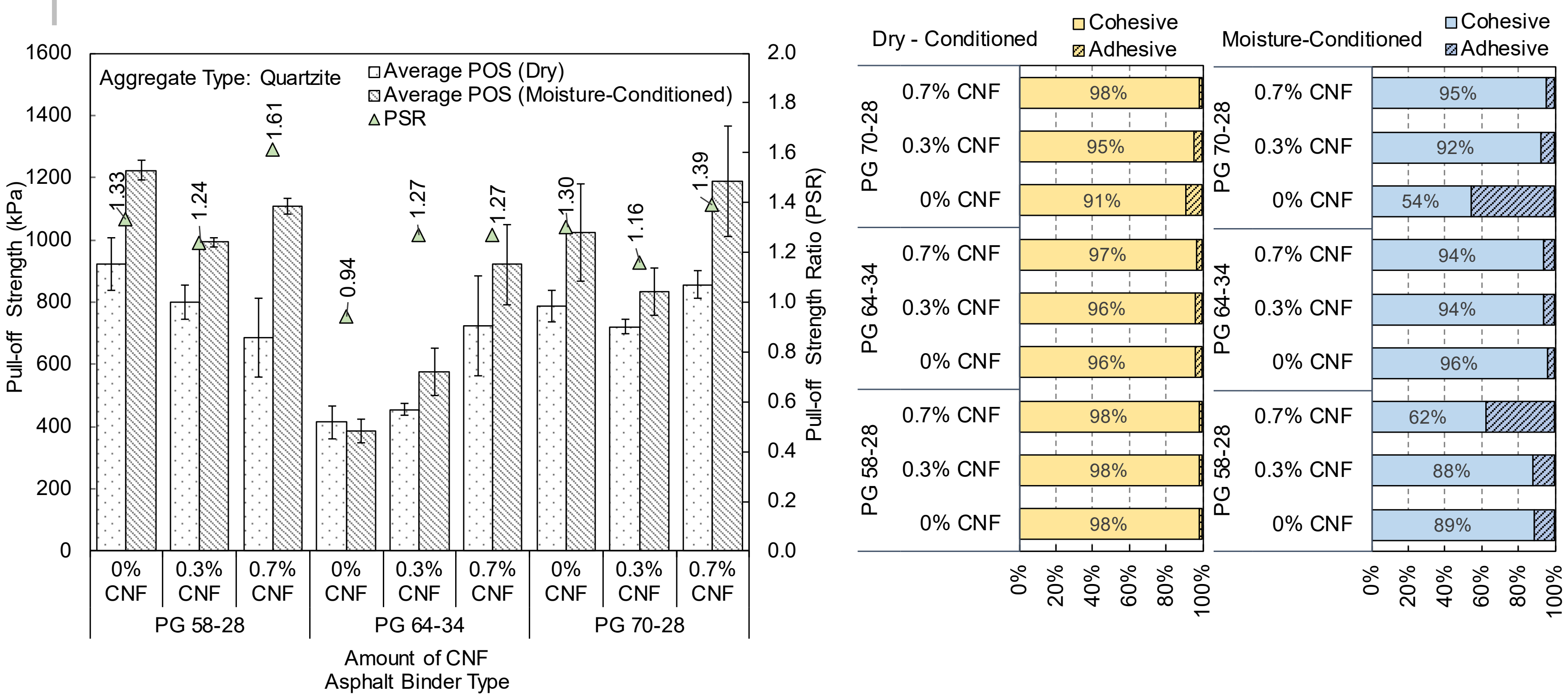






Asphalt Binder Adhesion

Adhesion to Quartzite



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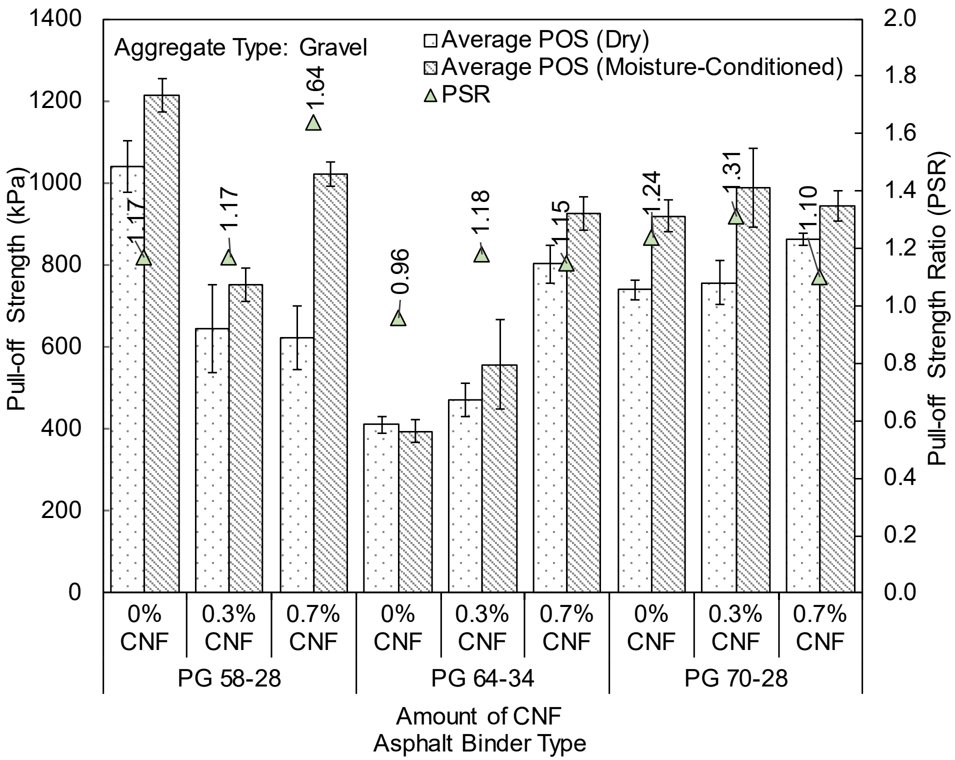
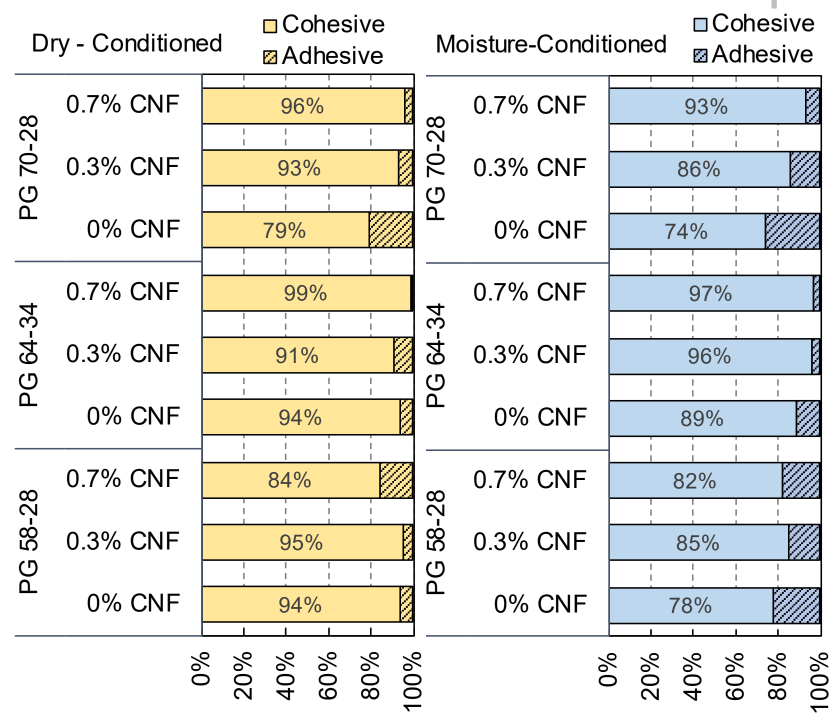
Asphalt Binder Adhesion

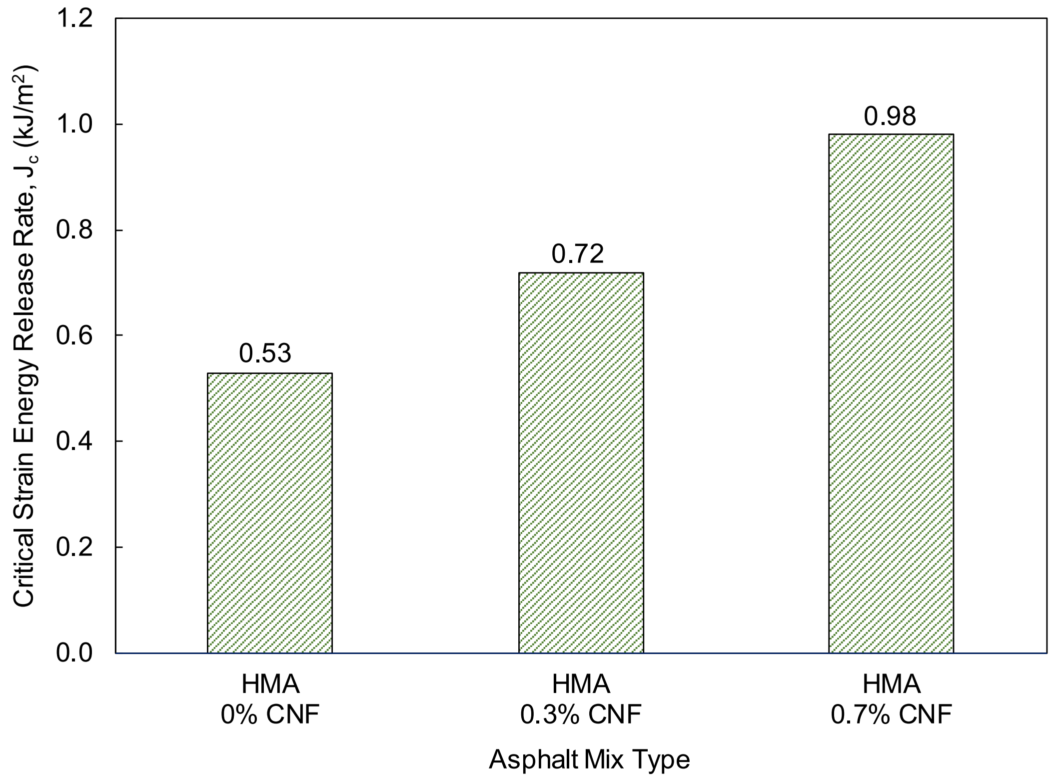
Adhesion to Gravel



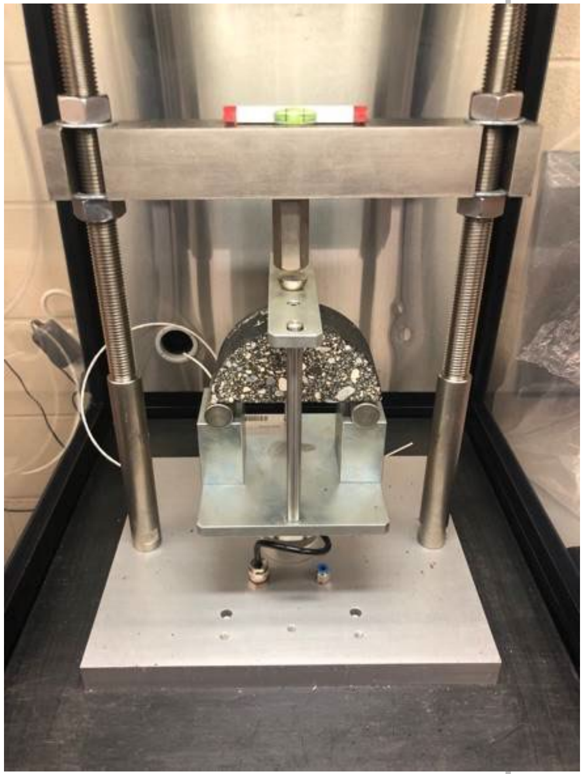


Asphalt Mix Characteristics

Resistance to Cracking

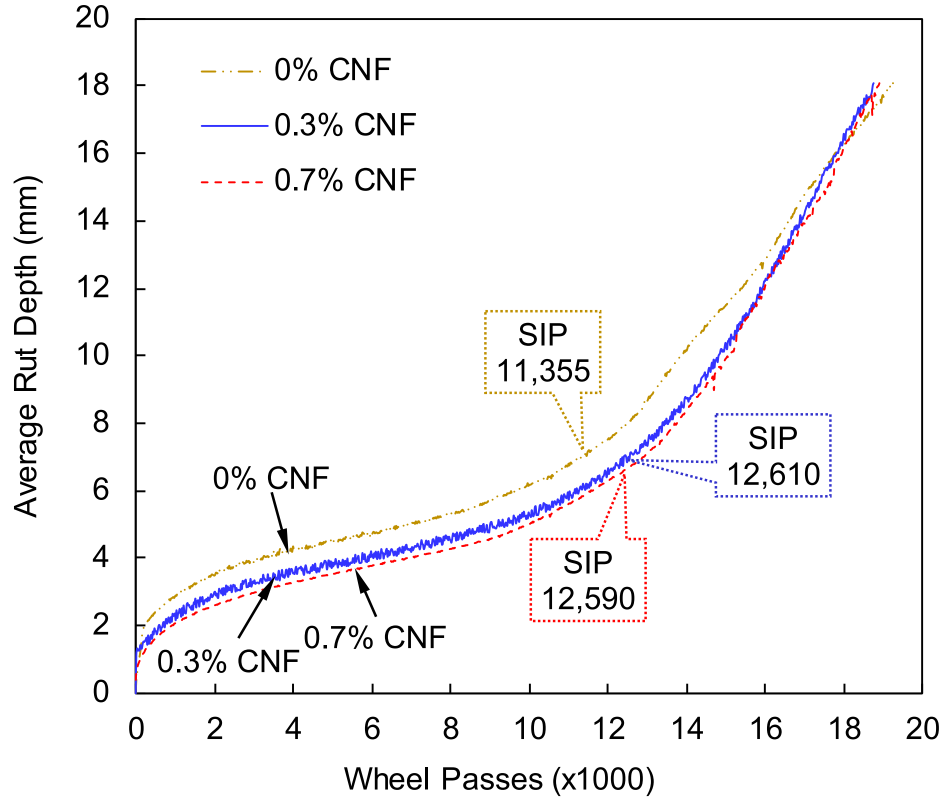


PG 58-28



Asphalt Mix Characteristics

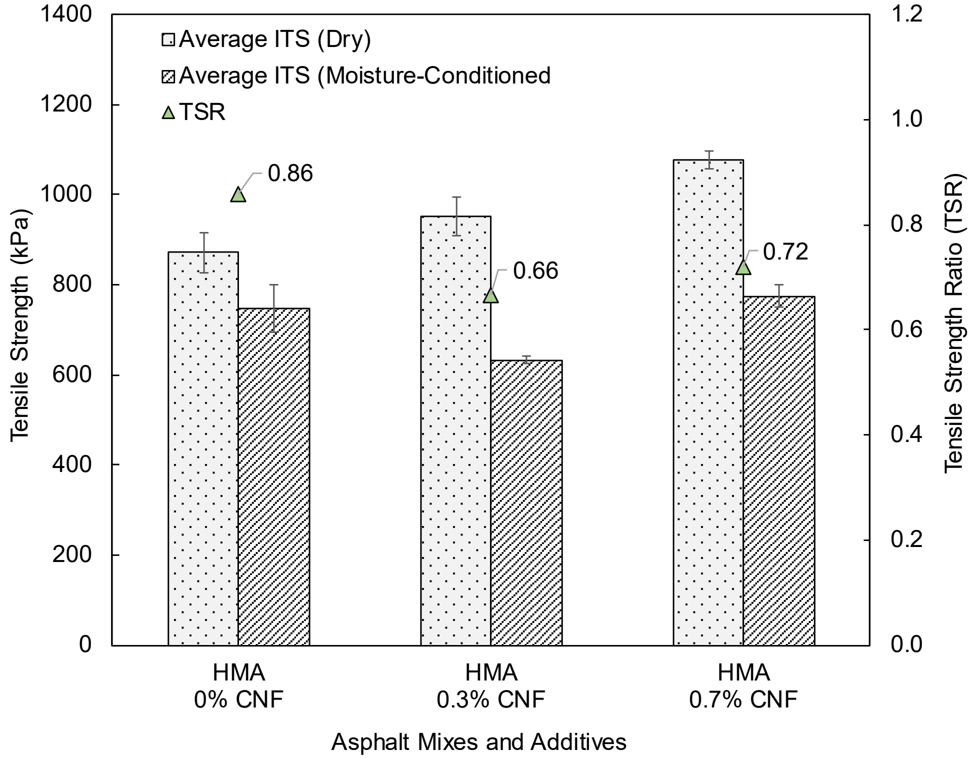
Resistance to Rutting/Stripping



PG 58-28

Asphalt Mix Characteristics

Resistance to Moisture-Induced Damage



PG 58-28

Conclusions

1. The electrospinning method was found to be a flexible, quick, scalable, and inexpensive method for production of CNF. The average diameter of the filaments was found to be 11.888 µm with a standard deviation of 2.939 µm.
2. The produced CNF was found to have tensile strength values which in average differed by 10% when tested in two perpendicular directions. The strain at failure measured at the direction with a higher tensile strength was in average by 3% less than that measured in the other direction.
3. Incorporation of CNF in asphalt binders was found to result in an increase in dynamic viscosity values of all tested binder blends. An increase in dynamic viscosity results in an increase in mixing and compaction temperatures. It is also expected to be indicative of an improved resistance to rutting.
4. The effect of addition of CNF to asphalt binders on increasing their viscosities was more pronounced at lower temperature for all binders (PG 58-28, PG 64-34, and PG 70-28) and more prominent in non-polymer-modified binder (PG 58-28).

Conclusions

5. Absorbed fracture energy determined by conducting Izod pendulum impact test was introduced as an innovative adoption of an existing test method for quick characterization of asphalt binders' resistance to cracking. It was found that the effect of addition of CNF to asphalt binders on absorbed fracture energy values was similar to that observed as a result of using polymer-modified binders.
6. The results of BBS tests indicated an overall improvement in adhesion of asphalt binders to tested aggregates as a result on incorporation of CNF in binder blends.
7. The resistance of asphalt mixes to cracking was found to significantly improve as a result of incorporation of CNF in the mixes.
8. Using CNF in asphalt mixes was found to effectively reduce the susceptibility of the mixes to rutting and moisture-induced damage.
9. The results of TSR tests conducted on asphalt mixes were found not to be in full agreement with HWT test results. While it showed an improvement in tensile strength values of the dry and moisture-conditioned samples of the mix as a result of using 0.7% CNF compared to that containing 0% CNF, still the one without CNF exhibited a higher TSR value. This was attributed to empirical nature of the TSR test which underlines the importance of using tests with a stronger mechanistic basis for screening new generation of asphalt mixes for moisture-induced damage.

Recommendations

- Study the effect of CNF on PG and MSCR grades of asphalt binders
- Study other variations of the electrospinning technique to explore the effects of different solvents, different concentrations of cellulose acetate, temperature, voltage, and tip-to-collector distance on the mechanical properties of the produced CNF
- In the case of terminal blending, the storage stability of CNF-modified asphalt binder is recommended to be studied
- A separate study is recommended to establish a solid basis for validating and interpreting the Izod test results in the context of characterization of cracking potential in asphalt mixes.

More information:

Ghabchi, R. and Castro, M.P.P., 2021. Effect of laboratory-produced cellulose nanofiber as an additive on performance of asphalt binders and mixes. *Construction and Building Materials*, 286, p.122922.

Acknowledgment

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Contributions of the Ingevity Co., Bowes Construction Co., Jebro Co., Flint Hills Co., and GCC Ready Mix Co. are highly appreciated.