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Laboratory Evaluation of Fiber-Reinforced Asphalt Mixtures

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In This Presentation…

- Background and Problem Statement
- Research Goal and Objectives
- Materials and Experimental Plan
- Mix Design
- Performance Testing
- Summary and Conclusions

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Background and Problem Statement

Background

- Flexible pavements experie... di...sses :
  - Rutting
  - Crack...
- Lead t... ..., *and ultima...*

Fiber reinforced asphalt may lead longer service lives

Problem Statement

- Few studies compare the impact of different fiber types on the performance of HMA mixtures
  - Mahrez et al (2010) studied impact of one fiber type (Fiberglass) on cracking performance
  - Nejad et al (2014) studied impact of one fiber type (Carbon) on cracking and rutting
  - Davar et al (2017) studied one fiber type (Basalt) on low temperature cracking

1. Mahrez, A., & Karim, M. R. (2010). Fatigue characteristics of stone mastic asphalt mix reinforced with fiber glass. *International Journal of the Physical Sciences*, *5*(12), 1840-1847
2. Moghadas Nejad, F., Vadood, M., & Baeetabar, S. (2014). Investigating the mechanical properties of carbon fibre-reinforced asphalt concrete. *Road Materials and Pavement Design*, *15*(2), 465-475.
3. Davar, A., Tanzadeh, J., & Fadaee, O. (2017). Experimental evaluation of the basalt fibers and diatomite powder compound on enhanced fatigue life and tensile strength of hot mix asphalt at low temperatures. *Construction and Building Materials*, *153*, 238-246.

Problem Statement

- Literature used fiber dosage rates ≥ 0.3% of total mix weight → Little to no consideration of air voids
  - Kumar et al *(2016)* used dosage rate of 0.3% achieving 5% AVC
  - Chen et al *(2009)* used dosage rates of 0.25-0.4% achieving AVC > 8%
- Low dosage rates (<0.15% by total mix weight) are being recommended due to mix design issues

No consensus on performance of fiber-reinforced HMA at recommended dosage rates

1. Kumar, T. M., Ramesh, A., & Kumar, M. (2016). Evaluation of Rutting Characteristics in Stone Mastic Asphalt Mix When Added with Basalt Fiber. *i-Manager's Journal on Material Science*, *4*(3), 19.
2. Chen, H., Xu, Q., Chen, S., & Zhang, Z. (2009). Evaluation and design of fiber-reinforced asphalt mixtures. *Materials & Design*, *30*(7), 2595-2603.

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Research Goals and Objectives

Research Goals and Objectives

- **Goal:** Evaluate the impact of fibers on the design and performance of HMA mixtures
- The objectives of this study were:

1. Conduct HMA mix design using recommended dosage rate and different mixing methods
2. Assess the laboratory performance testing on different types of fiber-reinforced HMA and identify the impact of fiber type

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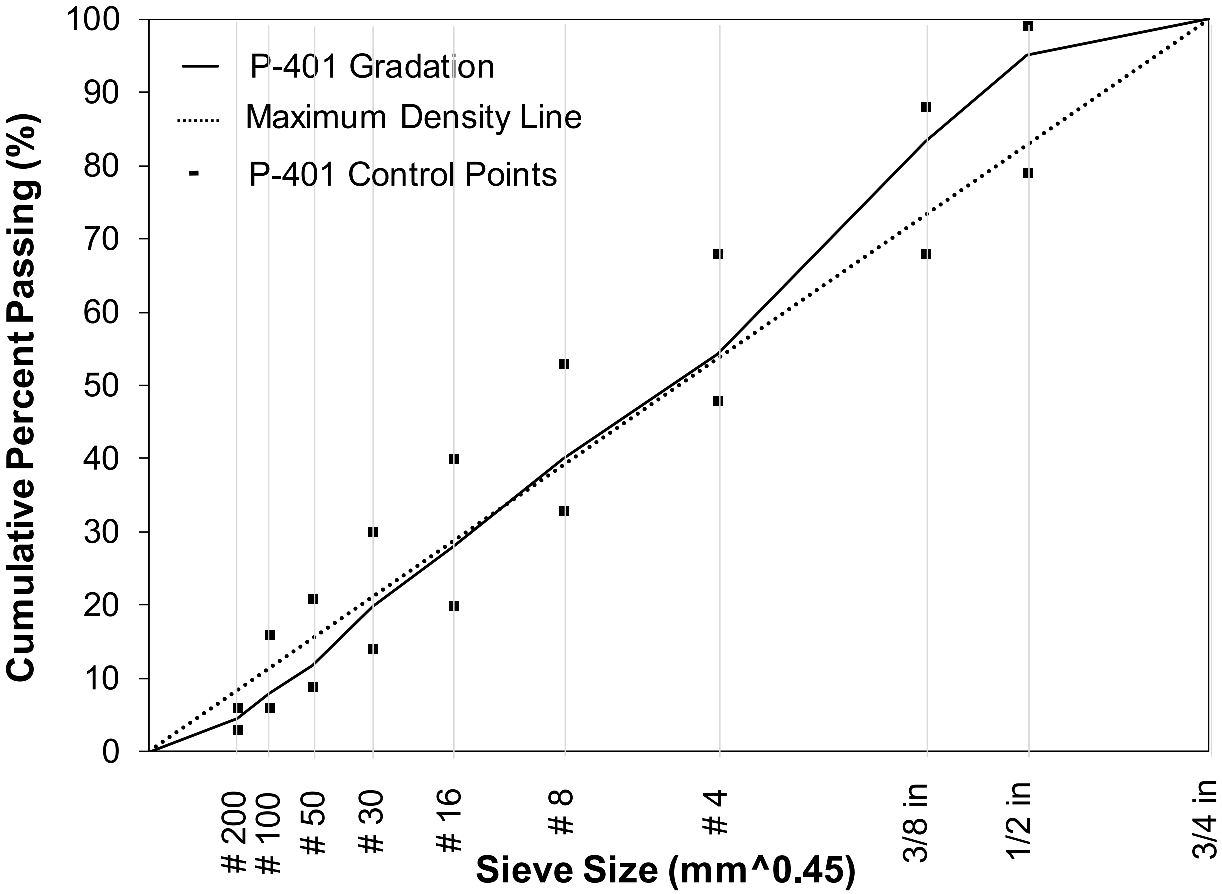
Materials and Experimental Plan

Materials

- Federal Aviation Administration (FAA) P-401 HMA Mix
  - 1/2 in (12.5 mm) NMAS
  - PG 76-22 Asphalt Binder
  - AVC: 3.5% ± 0.5%
    Minimum VMA: 15%



Materials

Carbon

Basalt

+

PPA

Fiberglass

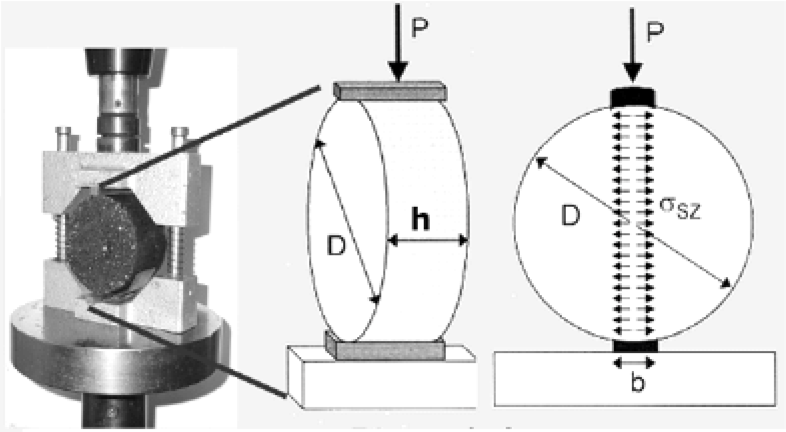
Materials

Fiber Property	Fiberglass	Basalt	Carbon	Polyolefin/ Aramid (PPA)
Specific Gravity	2.7	2.8	1.80	0.91/1.44
Tensile Strength (MPa)	2000	2500	4137	483/3000
Length (mm)	12	9	6	19
Acid/Alkali Resistance	Inactive	inactive	inactive	inactive
Decomposition Temperature (^{o}C)	>815	>1500	500	157/>450
Melting Temperature (^{o}C)	1121	250	1200	350
Maximum Recommended Dosage Rate*	0.16%	0.16%	0.16%	0.05%

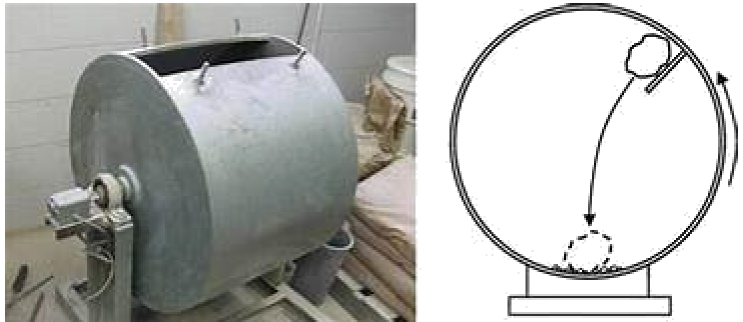
Experimental Plan

DCM (|E*|)

Asphalt Pavement Analyzer (APA)



Indirect Tensile Strength (ITS)

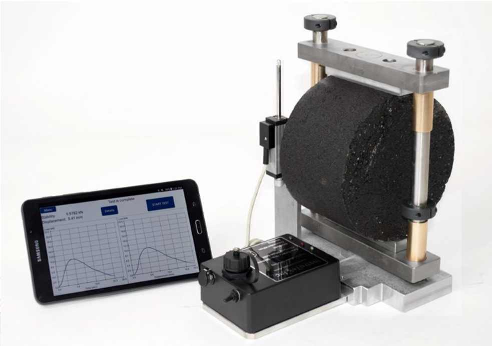


(a) (b)

Cantabro Test (Raveling)

(a) (b) (c)

Flow Number (FN)



IDEAL-CT

Experimental Plan

Test	Testing Temperature	Number of samples
Mix Design (ASTM D3203/D3203M)	325 °F (163 °C) Mixing 315 °F (157 °C) Compaction	60 (30 Gmb and 30 Gmm)
Asphalt Pavement Analyzer (APA) (AASHTO T340)	64 °C	30 (6 samples per fiber + 6 for control)
Dynamic Complex Modulus (DCM) (AASHTO T342)	4, 21, 37, & 54 °C	15 (3 samples per fiber + 3 for control)
Flow Number (FN) (AASHTO T378)	54 °C	15 (3 samples per fiber + 3 for control)
Indirect Tensile Strength Cracking Index (IDEAL-CT) (ASTM D8225)	25 °C	15 (3 samples per fiber + 3 for control)
Indirect Tensile Strength (ITS) (ASTM D6931)	25 °C	15 (3 samples per fiber + 3 for control)
Cantabro Durability Test (AASHTO TP 108)	25 °C	15 (3 samples per fiber + 3 for control)
Total:		165 Samples

Mixing Procedures and Mix Design

Mix Design

- Two different mixing procedure exist to replicate plant production:

Dry Met | **ds Method**

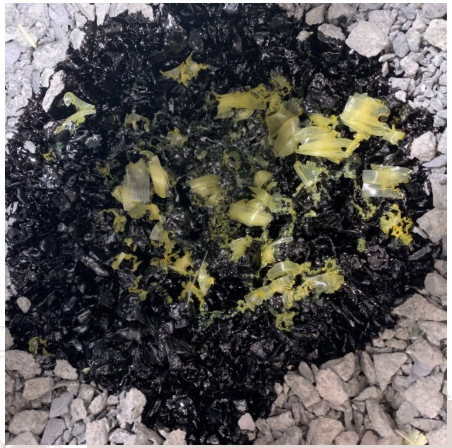
These methods were used on Fiberglass, Carbon and Basalt

- **Mix fiber with aggrega 1.5**
- **Pour binder into the m pot and mix for 1.5 min**
- **__Total Mixing:__ 3 min**

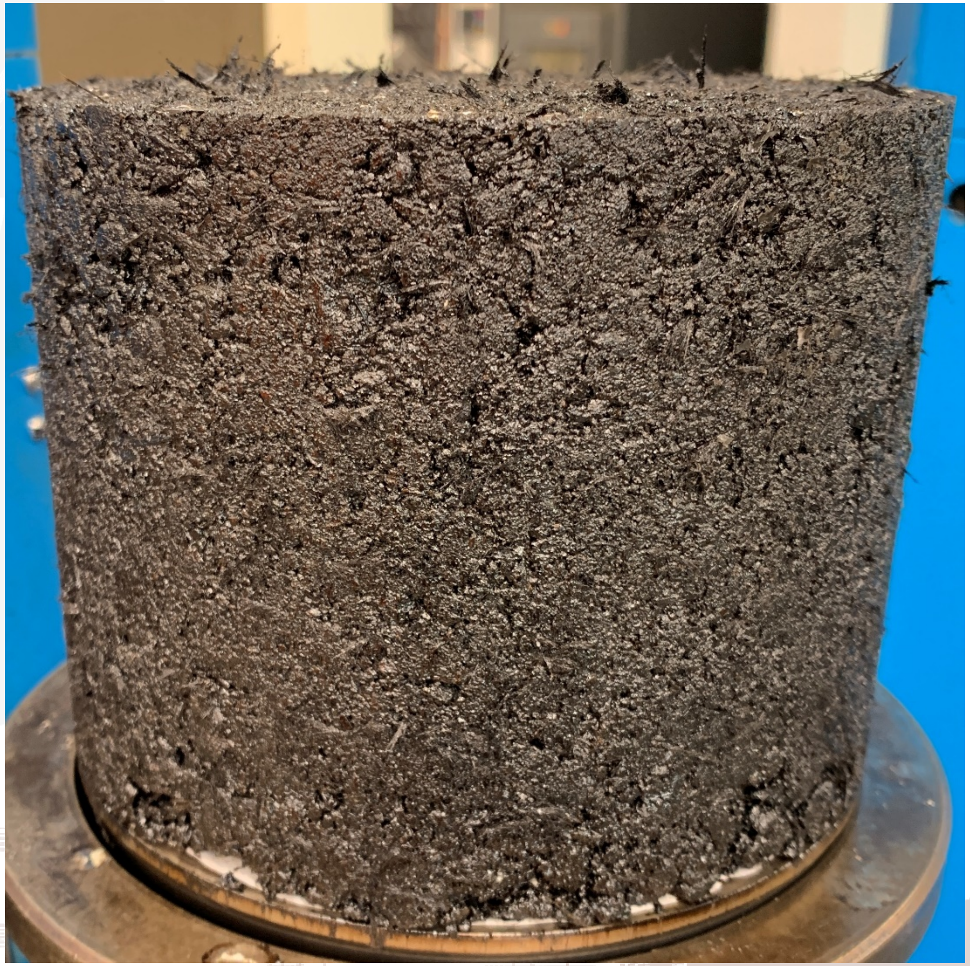
- **Add fiber every 15 sec (4 times)**
- **__Total Mixing:__ 3 min**

Mix Design

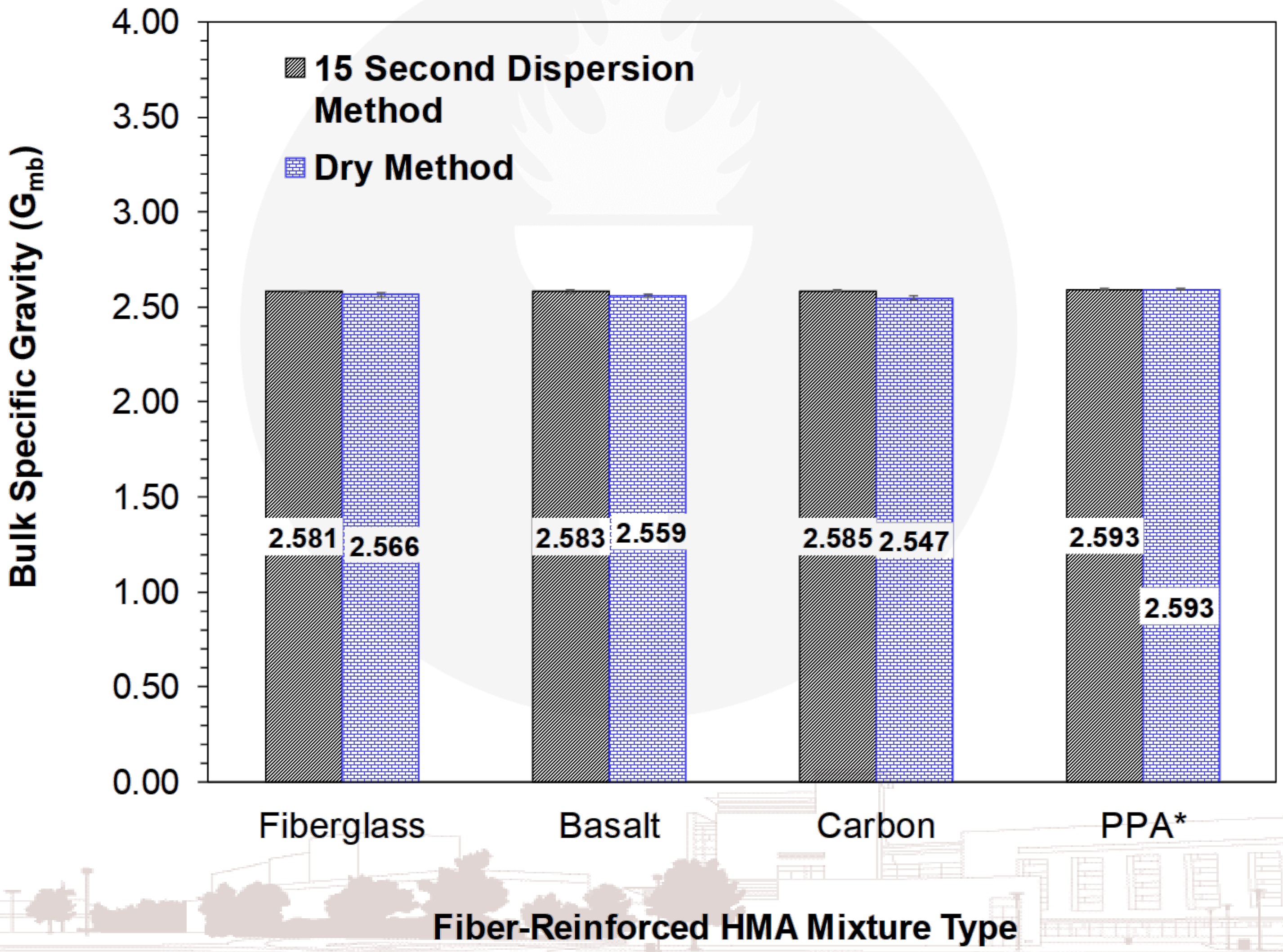
- PPA was introduced according manufacturer's process
  1. 1/3 of Aggregate Blend
  2. 1/2 Aramid fiber
  3. 1/3 of Aggregate Blend
  4. 1/2 Aramid fiber
  5. 1/3 of Aggregate Blend
  6. Add binder
  7. Add Polyolefin to the binder
  8. Mix for 1.5 min



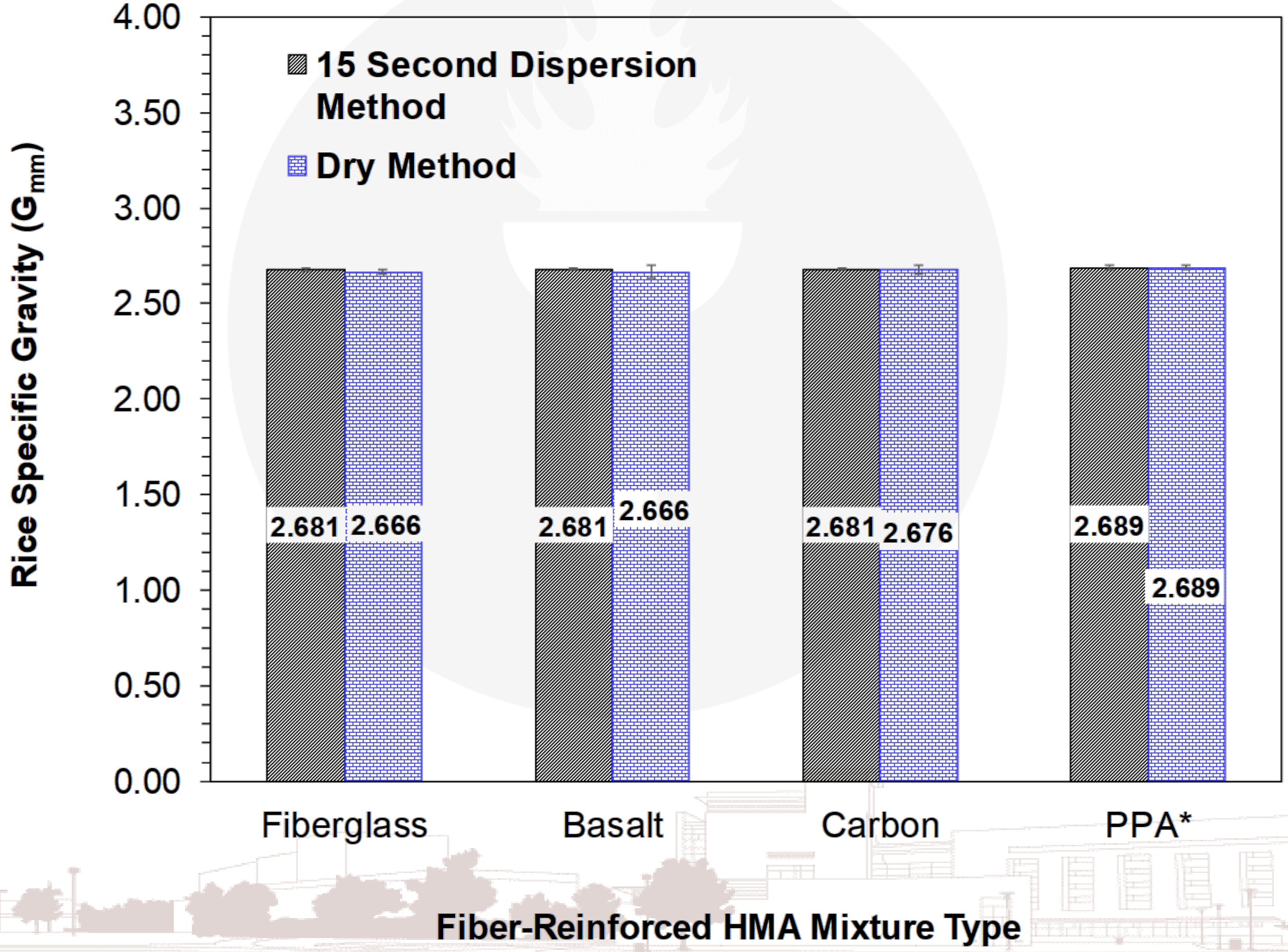
Mix Design



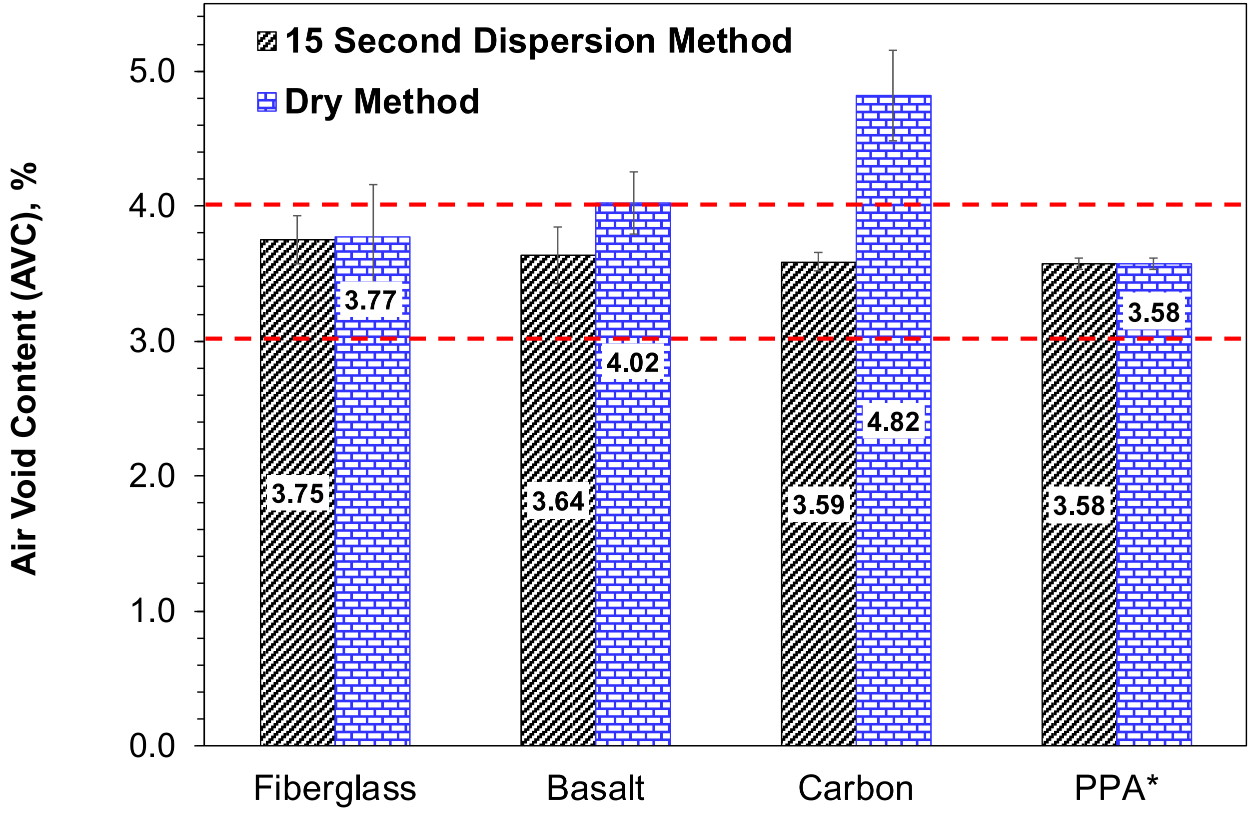
Bulk Specific Gravity (G_{mb})

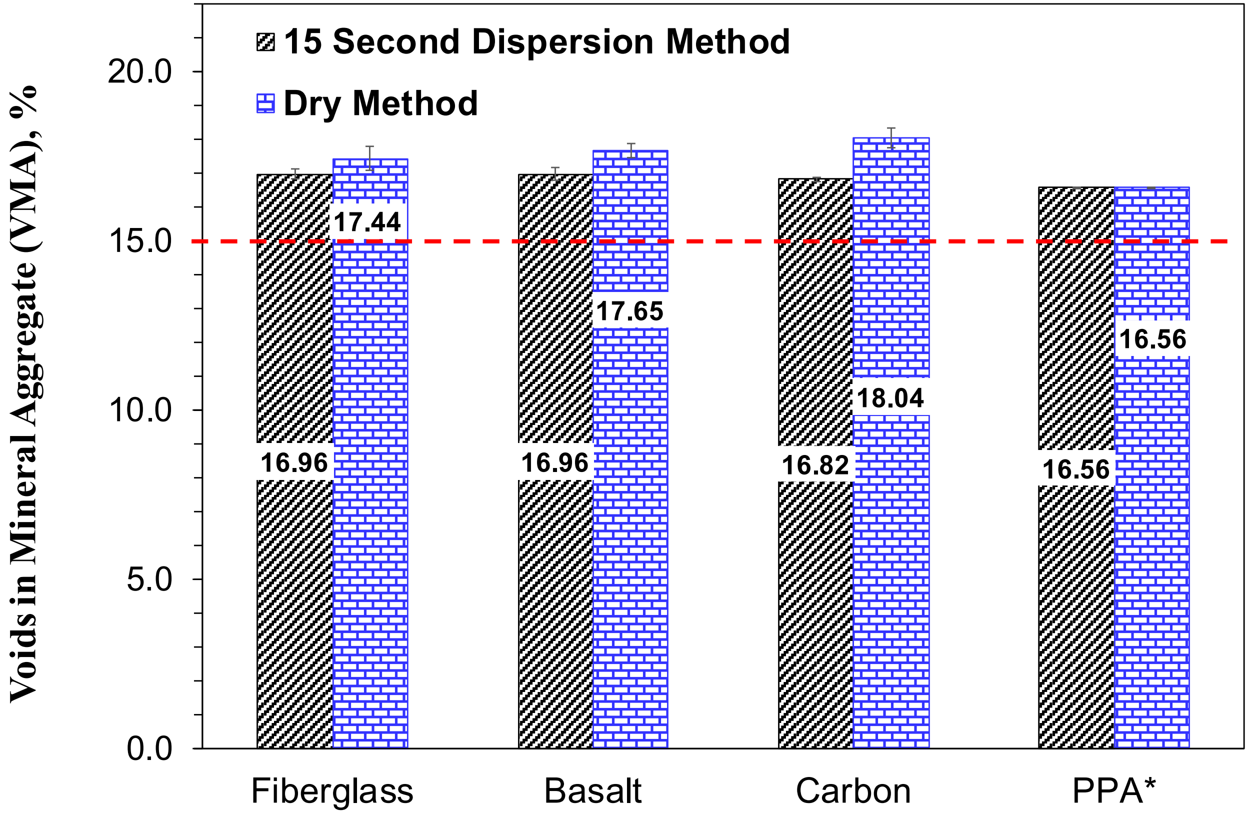


Rice Specific Gravity (G_{mm})



Mix Design Volumetrics





Target Air Voids: 3.5% ± 0.5%

Minimum VMA: 15%

Mix Design

Fiber Type	Avg. G_{mb}	Avg. G_{mm}	Air Voids (%)	VMA (%)	Binder Cont. (%)
Control (No Fiber)	2.584	2.681	3.64	16.86	5.3
Fiberglass	2.581	2.681	3.75	16.96	5.3
Carbon	2.585	2.681	3.59	16.82	5.3
Basalt	2.583	2.681	3.64	16.87	5.3
PPA	2.593	2.689	3.58	16.56	5.3

Target Air Voids % = 3.5% ± 0.5
Min. VMA: 15%

All samples prepared following the
15 Seconds Method

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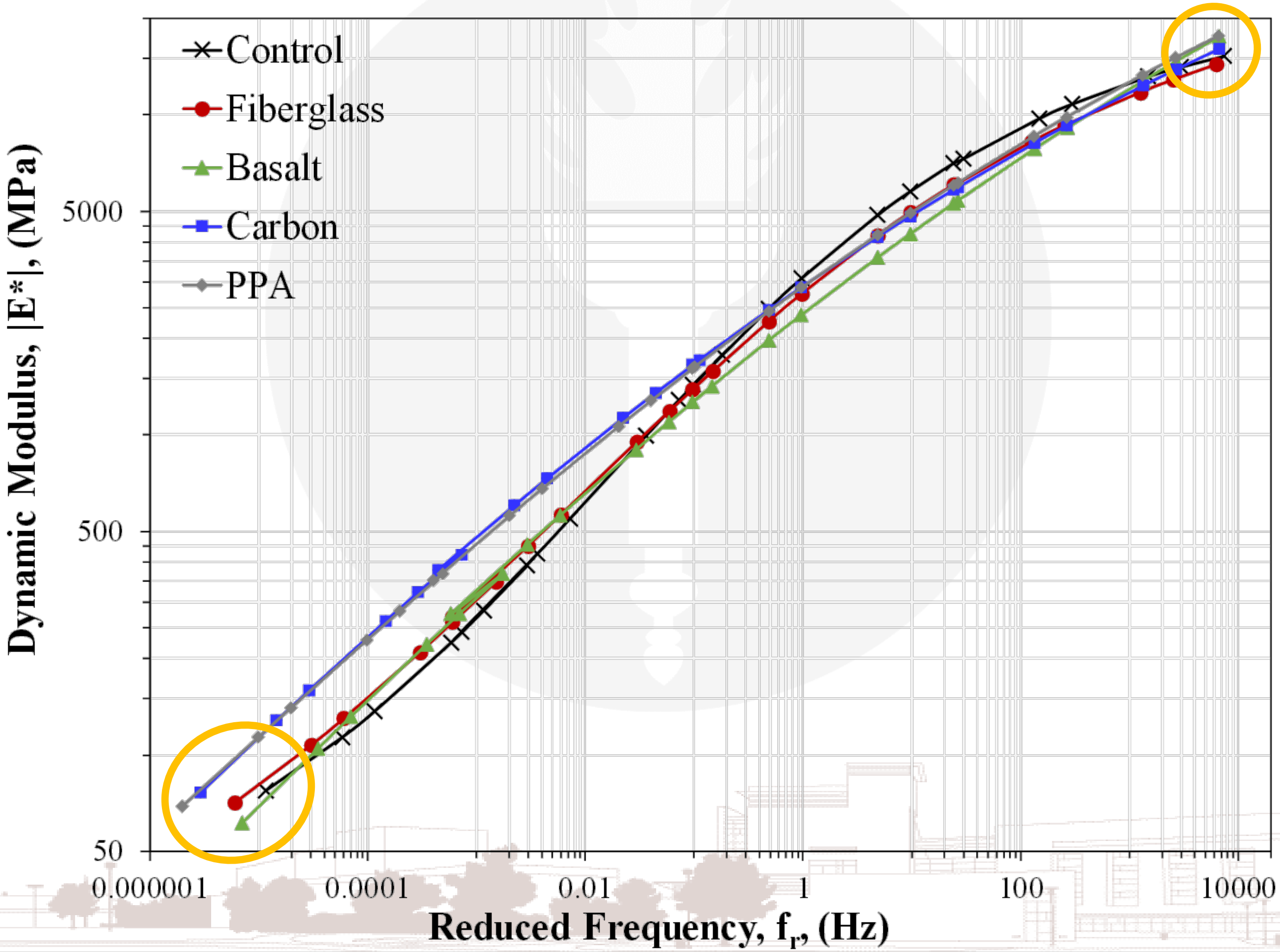
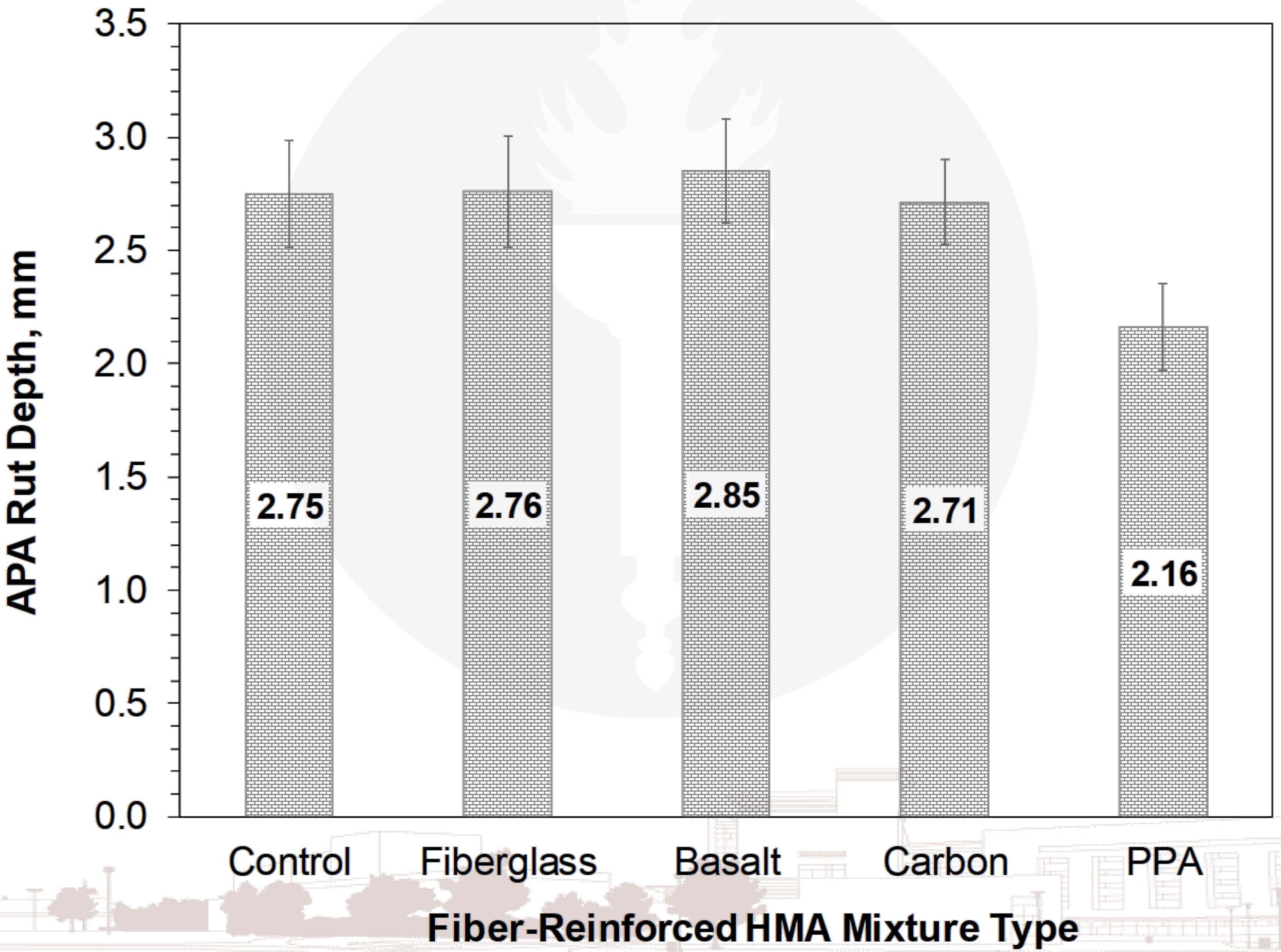
Laboratory Performance Testing

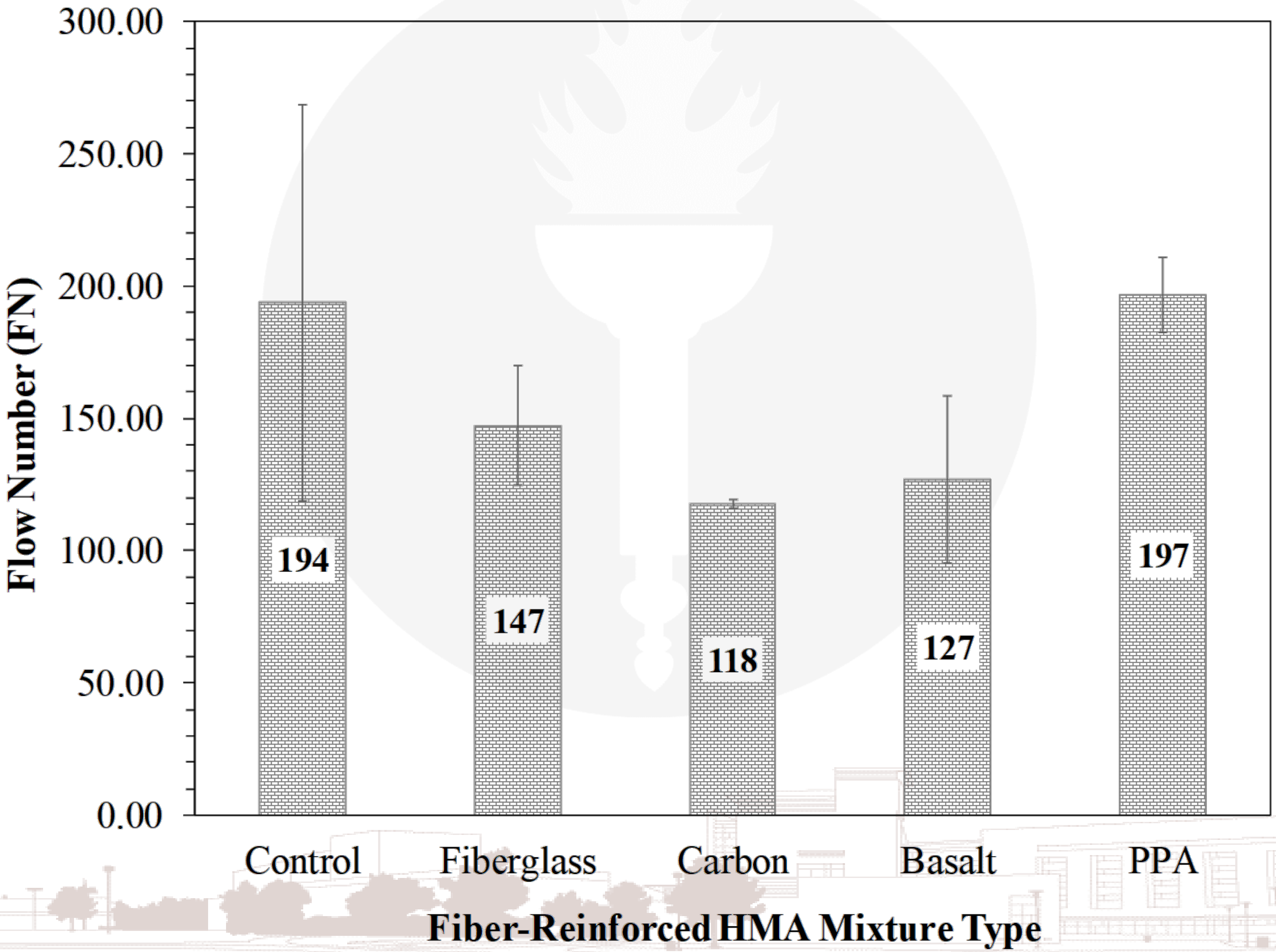
Dynamic Complex Modulus (DCM)



Asphalt Pavement Analyzer (APA)



Flow Number (FN)



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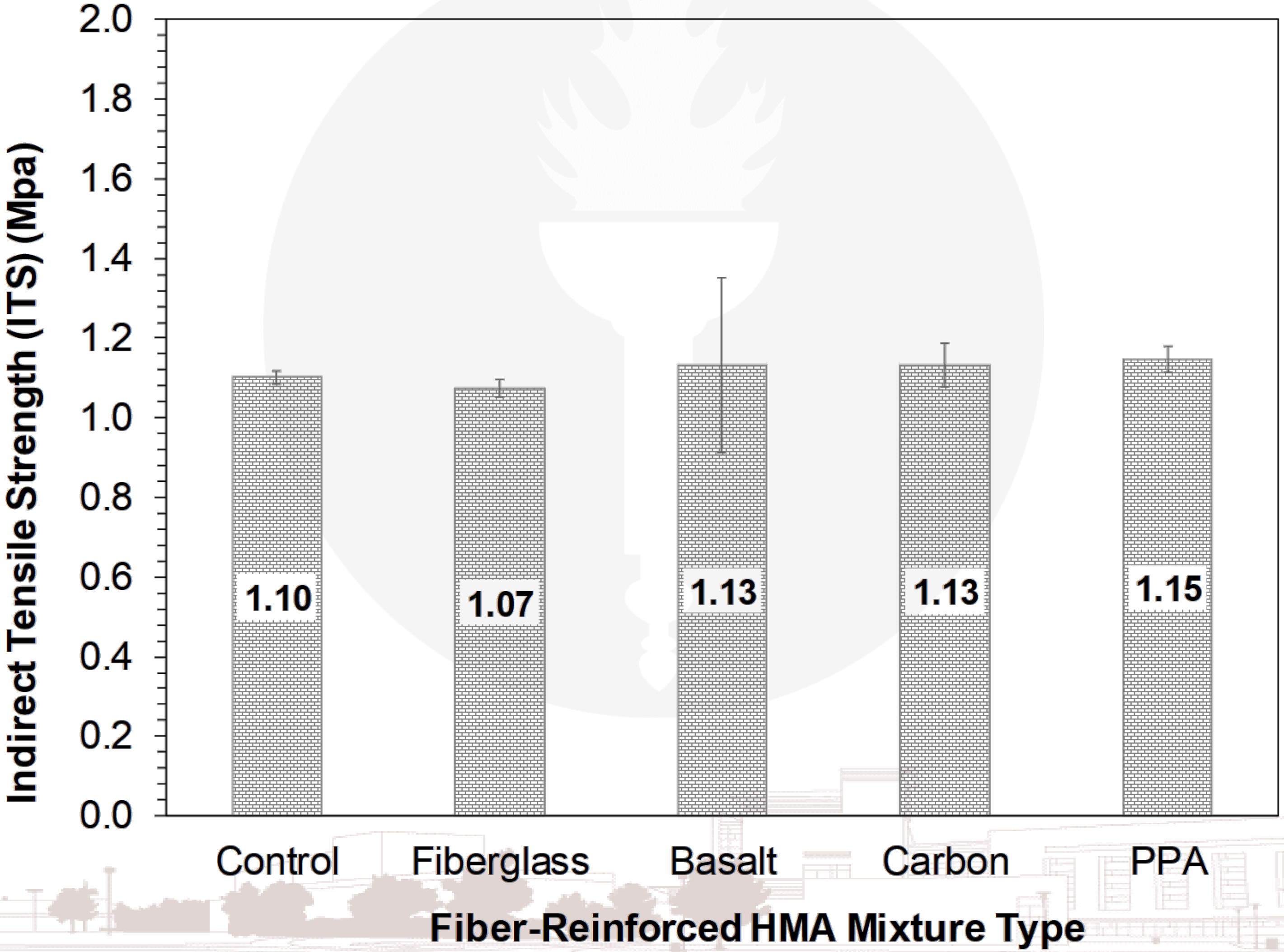
Indirect Tensile Strength (ITS)



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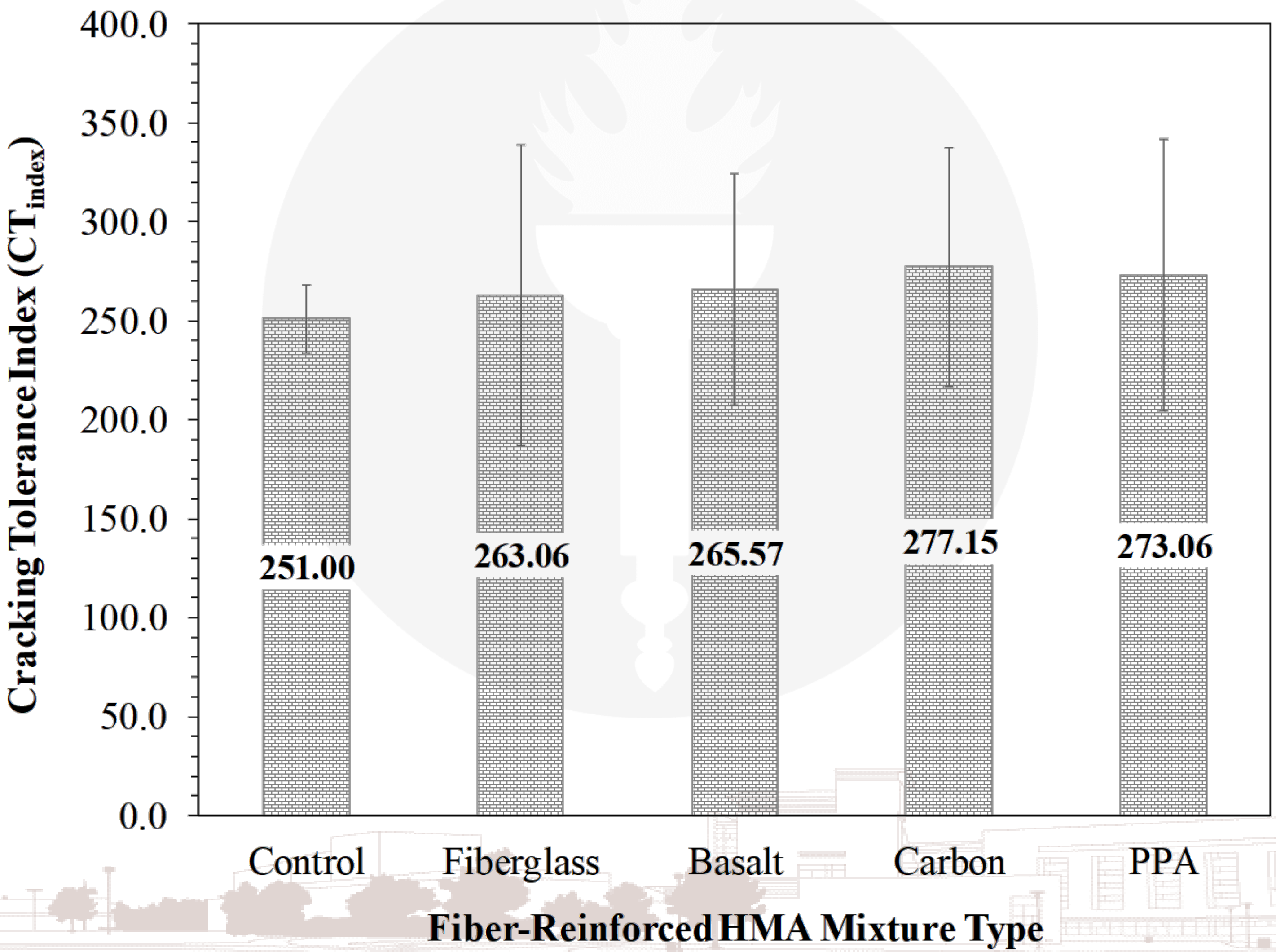
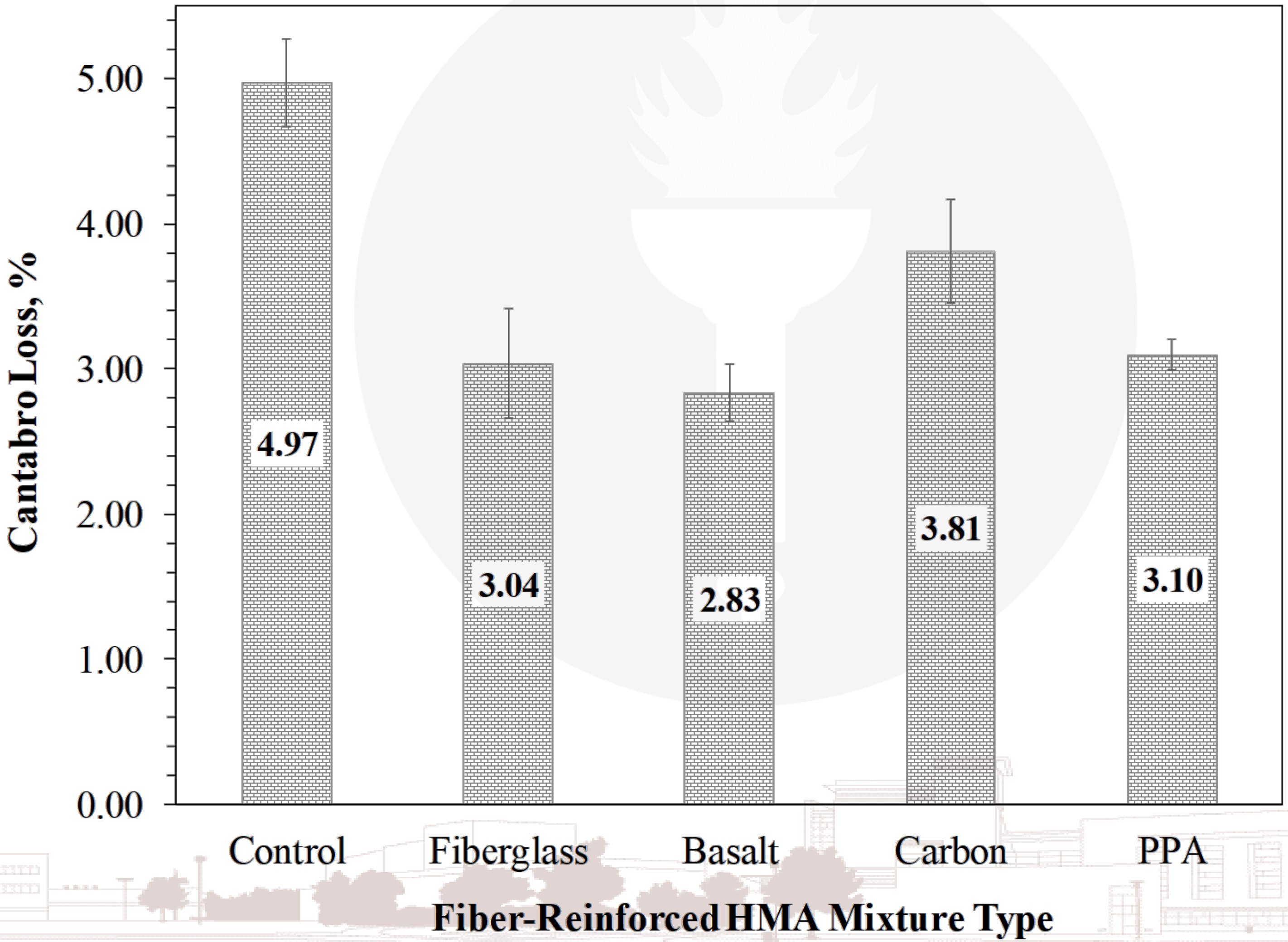
IDEAL-CT


400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Cracking Tolerance Index (CT_{index})
251.00
263.06
265.57
277.15
273.06
Control
Fiberglass
Basalt
Carbon
PPA
Fiber-Reinforced HMA Mixture Type

Cantabro Durability



Statistical Analysis

Analysis of Variance (ANOVA)

Mix Properties and Durability			
Test Measure	**F-Statistic (*p-value*)**	**Test Measure**	**F-Statistic (*p-value*)**
$\|E^*\|$ at 21.1°C-10 Hz	**5.835** ***(0.011)****	Cantabro Loss	**26.126** ***(0.000)****

Strength and Cracking Resistance			
Test Measure	**F-Statistic (*p-value*)**	**Test Measure**	**F-Statistic (*p-value*)**
ITS Values	0.329 (*0.852*)	CT_{index}	0.076 (*0.988*)

Rutting Susceptibility			
Test Measure	**F-Statistic (*p-value*)**	**Test Measure**	**F-Statistic (*p-value*)**
APA Rut Depth	**4.014** ***(0.006)****	Flow Number	2.021 (*0.175*)

Statistically significant at a confidence level of 95%

p-value <= 0.05 indicates a significant impact

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Summary and Conclusions

Summary and Conclusions

- The 15-second mixing procedure exhibited **greater consistency** and **less variability** in the mix design of fiber-reinforced HMA.
- No impact on optimum binder content was observed when using the 15-second mixing method at the recommended dosage rate
  - Higher binder content was necessary when using the dry mixing procedure
- At low frequencies (less than 10Hz), the Carbon and PPA-reinforced HMA mixtures had **greater** |E*| values than all other HMA mixtures.

Summary and Conclusions

- Fibers **improved** the durability of HMA mixtures. The basalt fiber type showed the best durability performance with a Cantabro loss value of 2.83%.
- PPA reinforced mixtures had **the highest** rutting resistance compared to the unreinforced and other fiber-reinforced HMA mixtures.
- ANOVA showed that there was a statistical impact on the **mix durability and rutting performance** due to fibers.
  - No impact was observed on the strength or cracking performance of HMA mixtures.

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Thank You!

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- Mahrez, A., & Karim, M. R. (2010). Fatigue characteristics of stone mastic asphalt mix reinforced with fiber glass. *International Journal of the Physical Sciences*, *5*(12), 1840-1847.

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- Moghadas Nejad, F., Vadood, M., & Baeetabar, S. (2014). Investigating the mechanical properties of carbon fibre-reinforced asphalt concrete. *Road Materials and Pavement Design*, *15*(2), 465-475.
- Kumar, T. M., Ramesh, A., & Kumar, M. (2016). Evaluation of Rutting Characteristics in Stone Mastic Asphalt Mix When Added with Basalt Fiber. *i-Manager's Journal on Material Science*, *4*(3), 19.