Enhancing the Performance of Fiber-Reinforced Concrete by Using Two-Stage Mixing Approach

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Background

Use of Discrete Macro Fibers

- The use of fibers can be a way to improve sustainability of construction projects.
    - Improving mechanical performance.
    - Improving durability.
    - Reducing the material use.

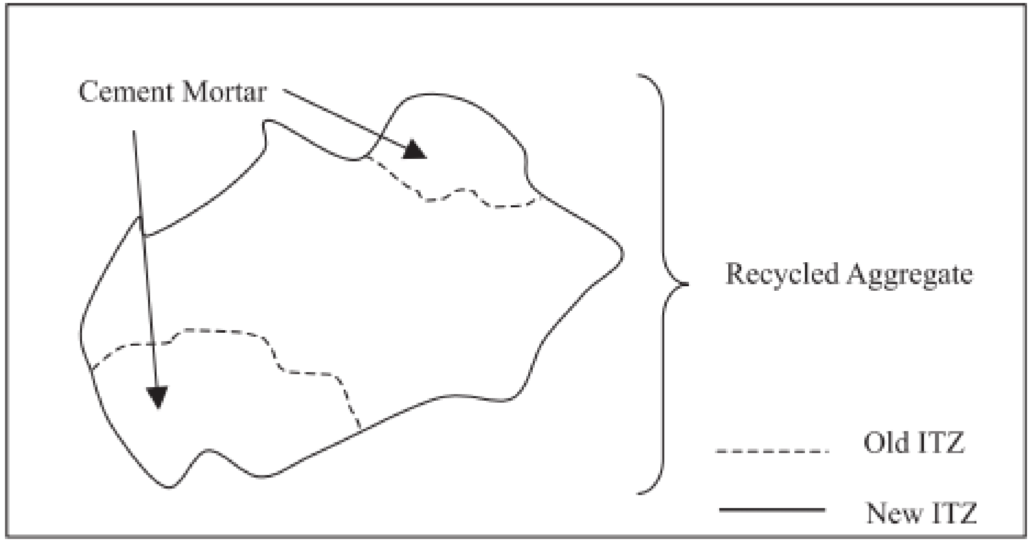
- Quality of the fiber-cementitious matrix interface has a considerable impact on the fiber reinforced concrete performance.

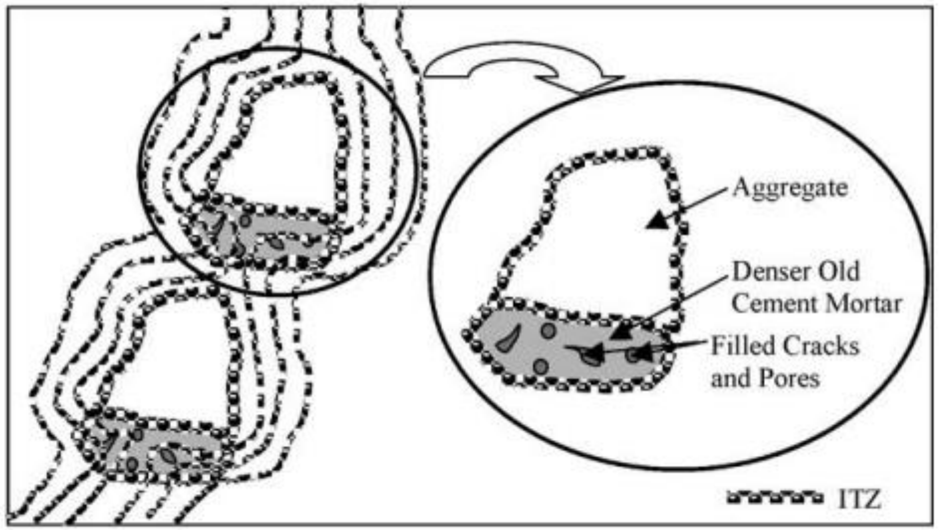
Polypropylene Fibers

Steel Fibers

Background

Two-Stage Mixing Approach



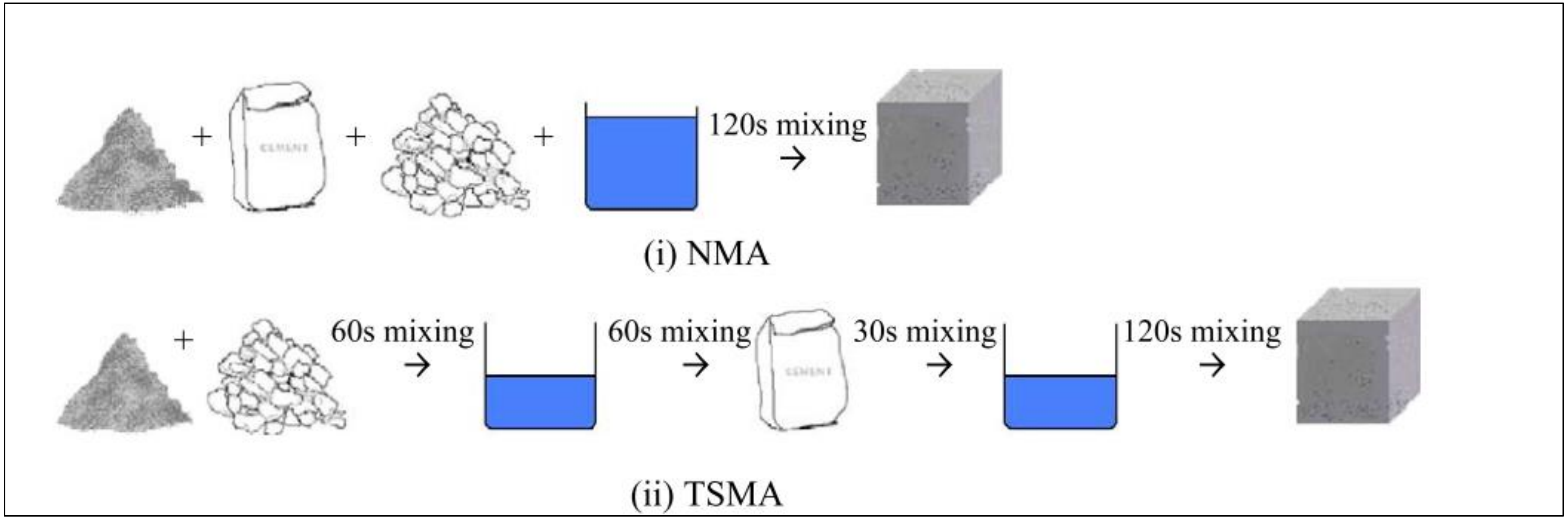


Tam, V. W., Gao, X. F., & Tam, C. M. (2005). Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. *Cement and concrete research*, *35*(6), 1195-1203.

Background

Two-Stage Mixing Approach

(i) normal mixing approach and (ii) two-stage mixing approach.



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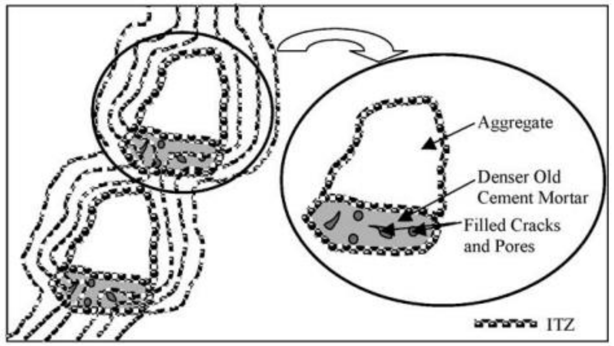
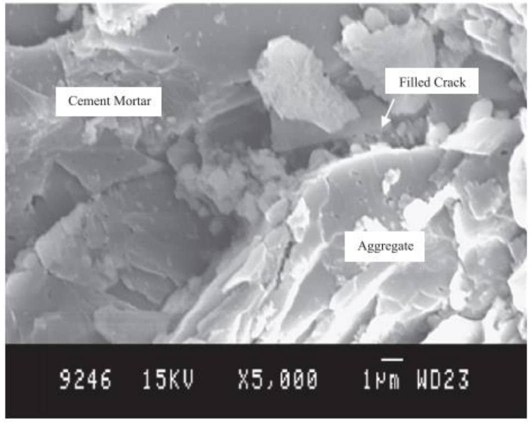
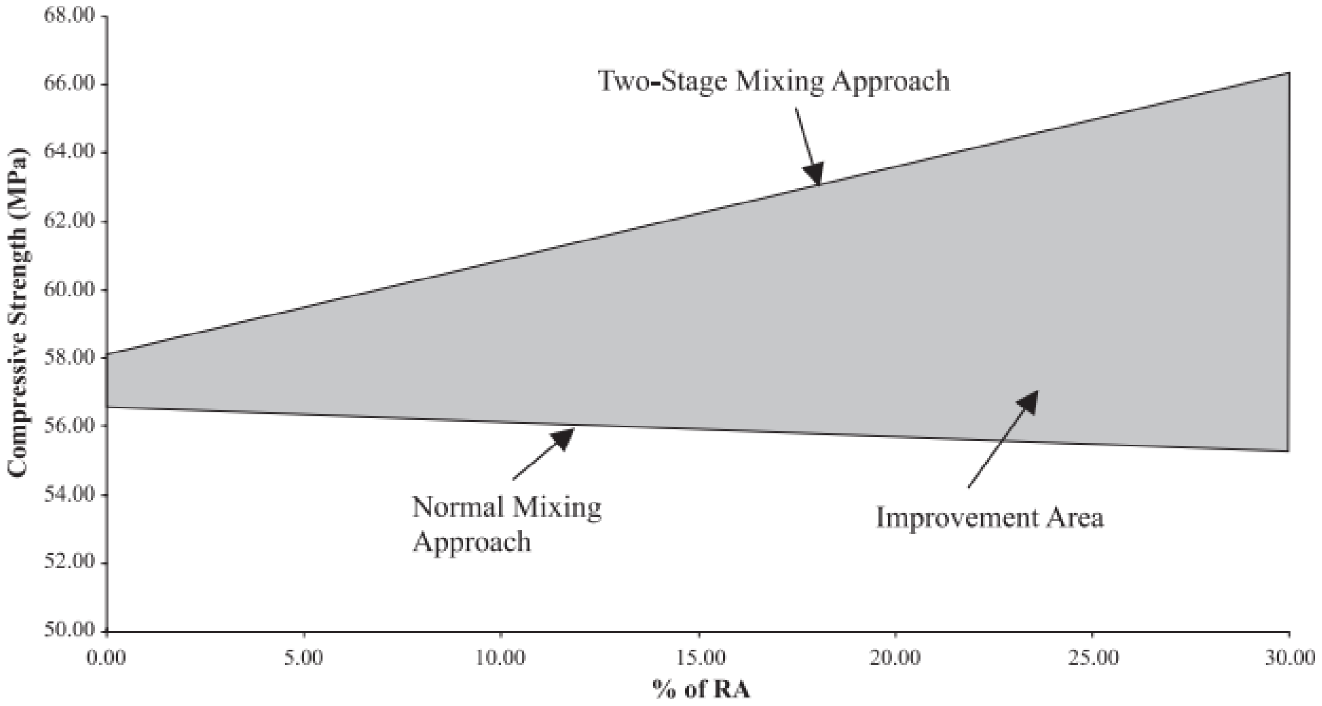
Background

Two-Stage Mixing Approach







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Background

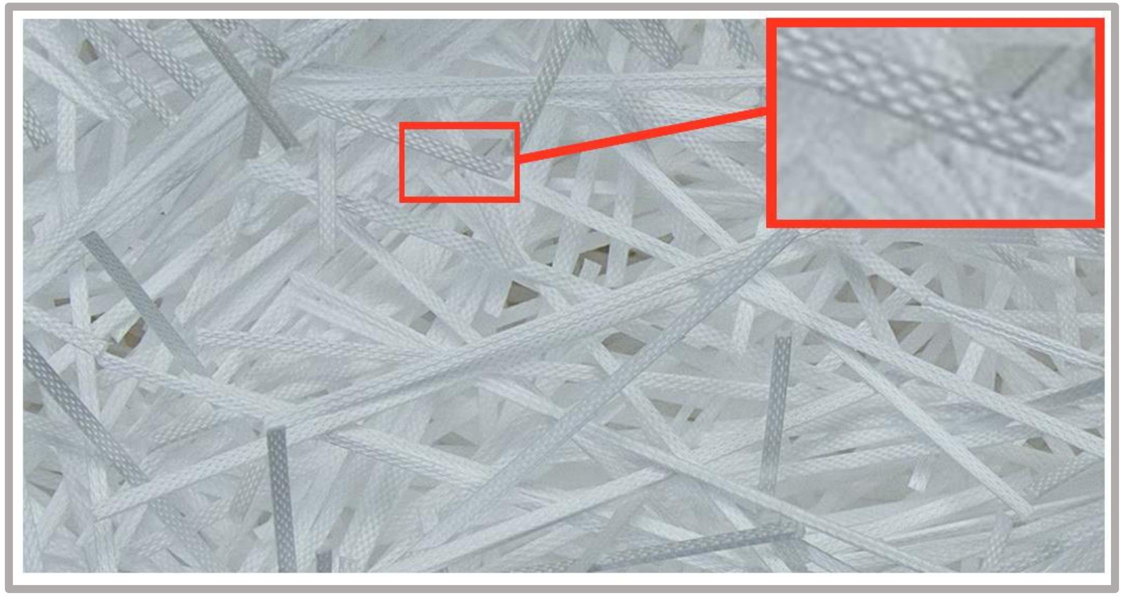
Two-Stage Mixing Approach

- Following studies:
  - Different recycled aggregate types
  - Supplementary cementitious materials
  - Modified mixing methods
  - etc.

Objective

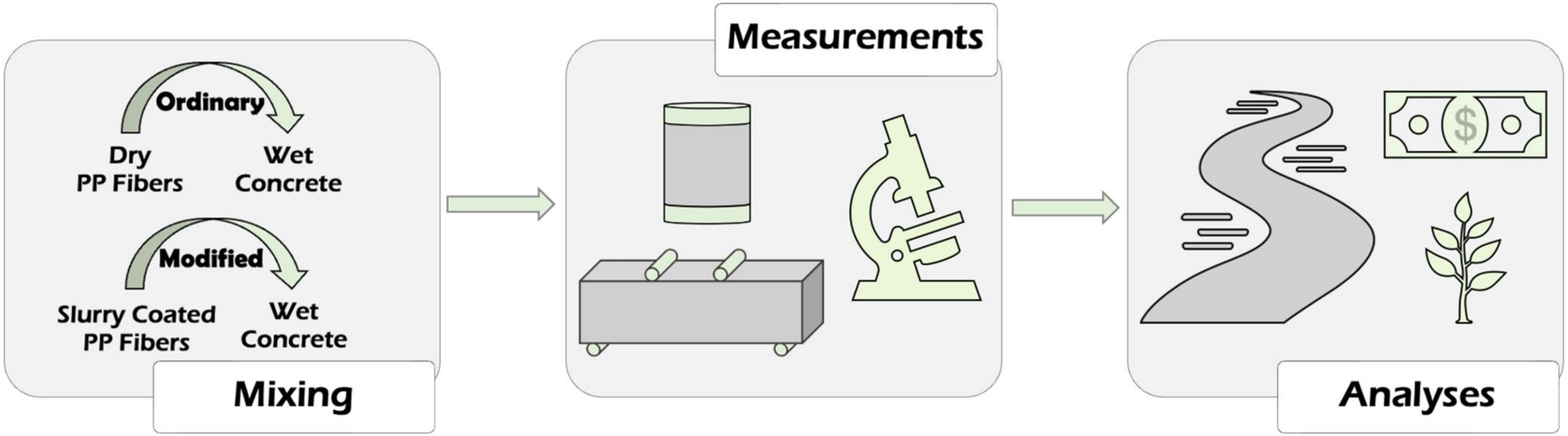
- Two-stage mixing approach has been implemented to improve the interface between the fibers and cementitious matrix.

GOAL: To fill the notches and coat the fibers with a cementitious matrix tailored to improve the pull - out resistance of fibers.



Embossed Polypropylene Fibers

Evaluation of the Effectiveness



Mixtures, Specimens& Tests

Materials	Control	SF-0-Std & SF-0-Mod	SF-2-Std & SF-2-Mod	SF-4-Std & SF-4-Mod
Cement	350.0	350.0	343.0	336.0
Silica Fume	-	-	7.0	14.0
CSt: No I	542.3	537.2	536.7	535.9
CSt: No II	451	446.8	446.4	445.7
Crushed Sand	634.6	628.6	628.0	627.0
Natural Sand	180.8	179.1	178.9	178.7
Water	210.0	210.0	210.0	210.0
Superplasticiser	1.1	1.4	1.5	1.6
PP Fiber	-	4.55	4.55	4.55

PP Fiber = 0.5%vol.

<u>Specimens</u>

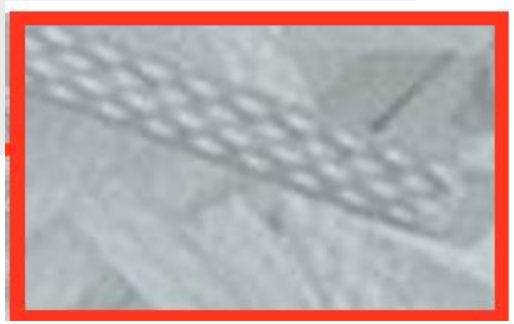
- 5 Cylinders (10x20 cm)
- 5 Beams (10x10x35 cm)

<u>Tests</u>

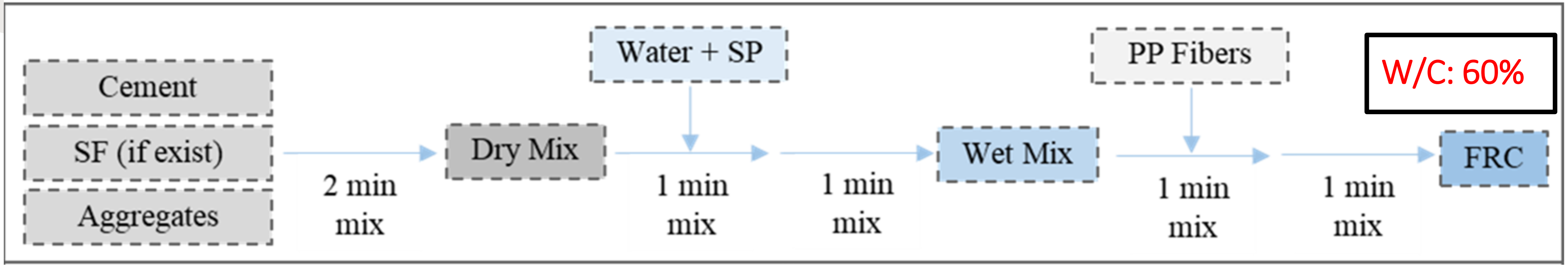
- Modulus of Elasticity (ASTM C469)
- Compressive Strength (ASTM C39)
- 4 Point Bending Test (ASTM C1609)

Mixing Methods

AIM: To fill the notches and coat the fibers with a cementitious matrix tailored to improve the pull - out resistance of fibers.



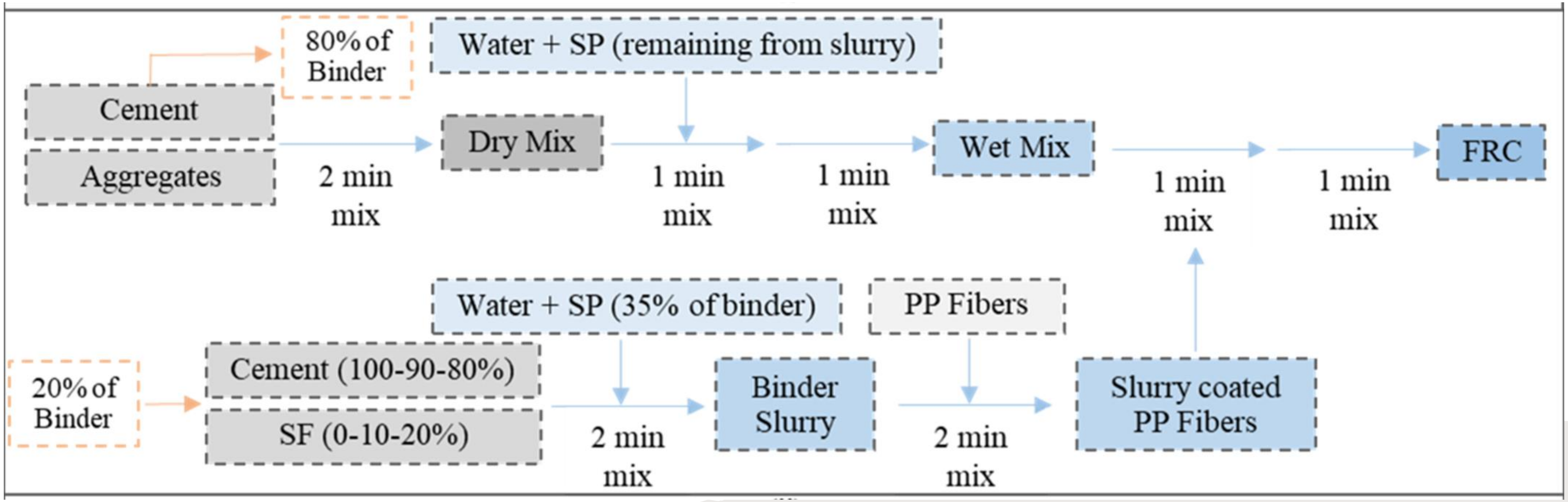
STANDARD MIXING



Pan Mixer

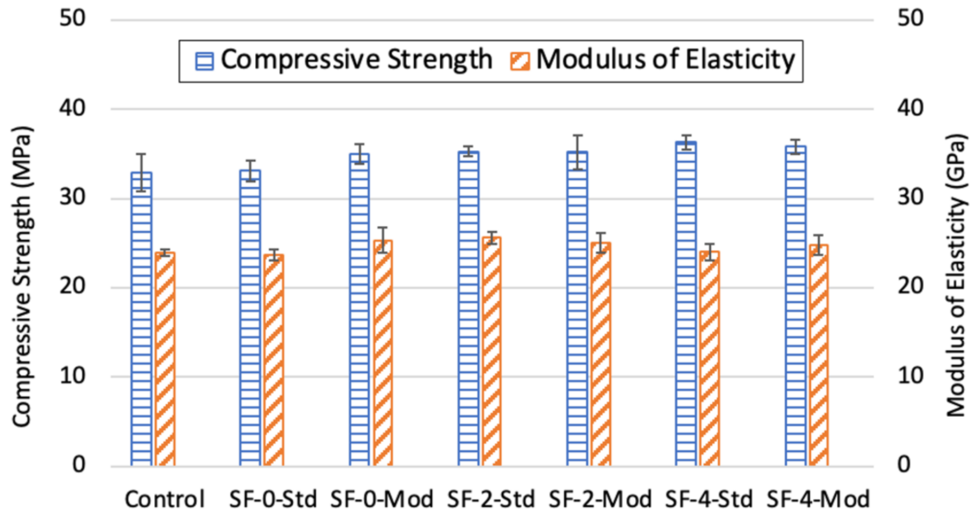
MODIFIED MIXING

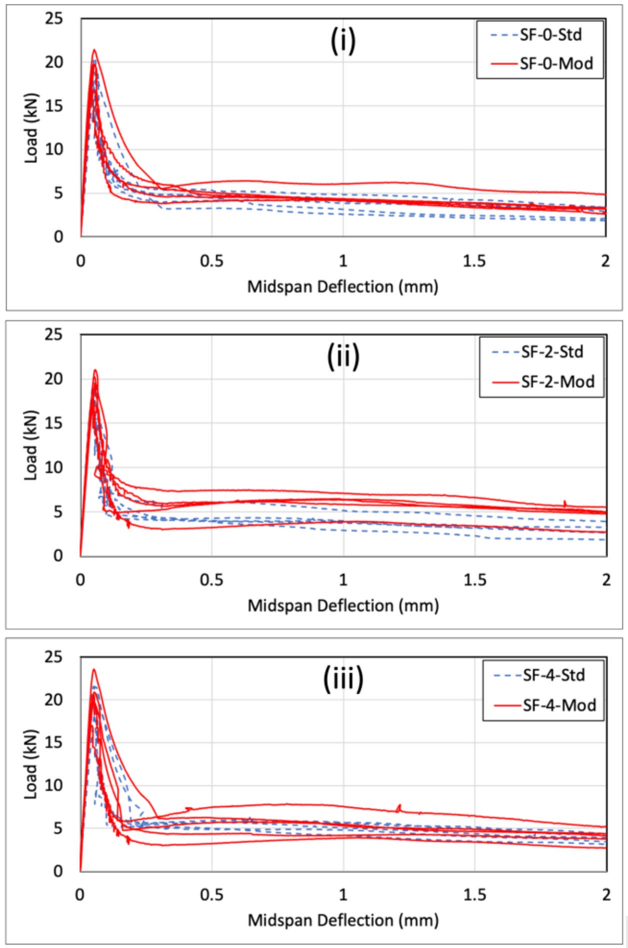
Mortar Mixer

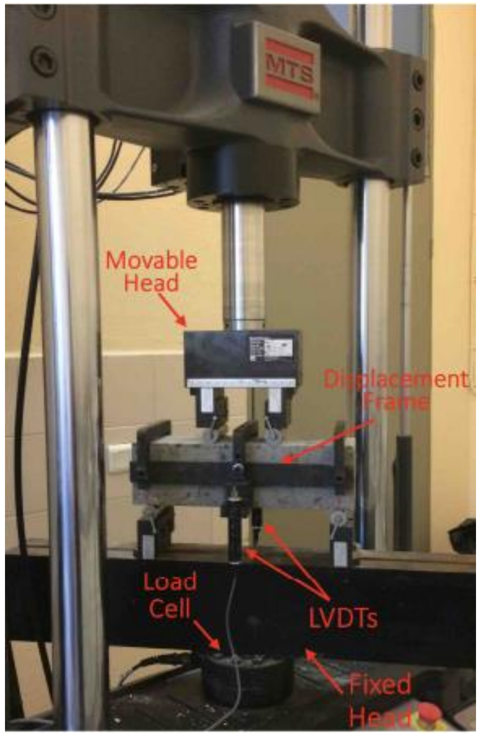


Test Results

Compressive Strength, Modulus of Elasticity, and Flexural Performance





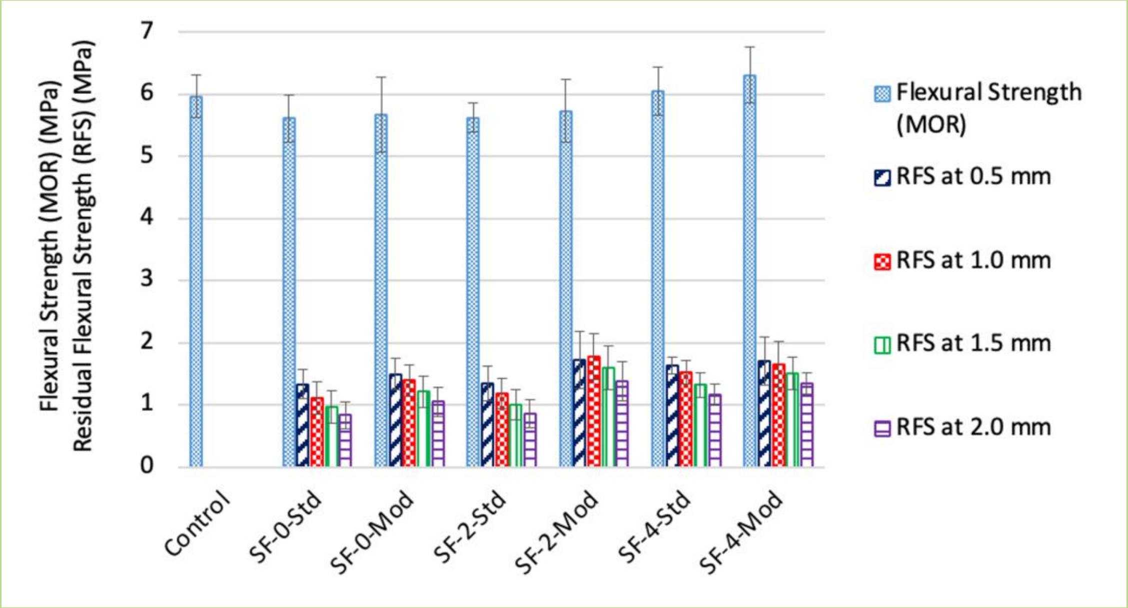


Blue Dashed Lines: Standard Mixing

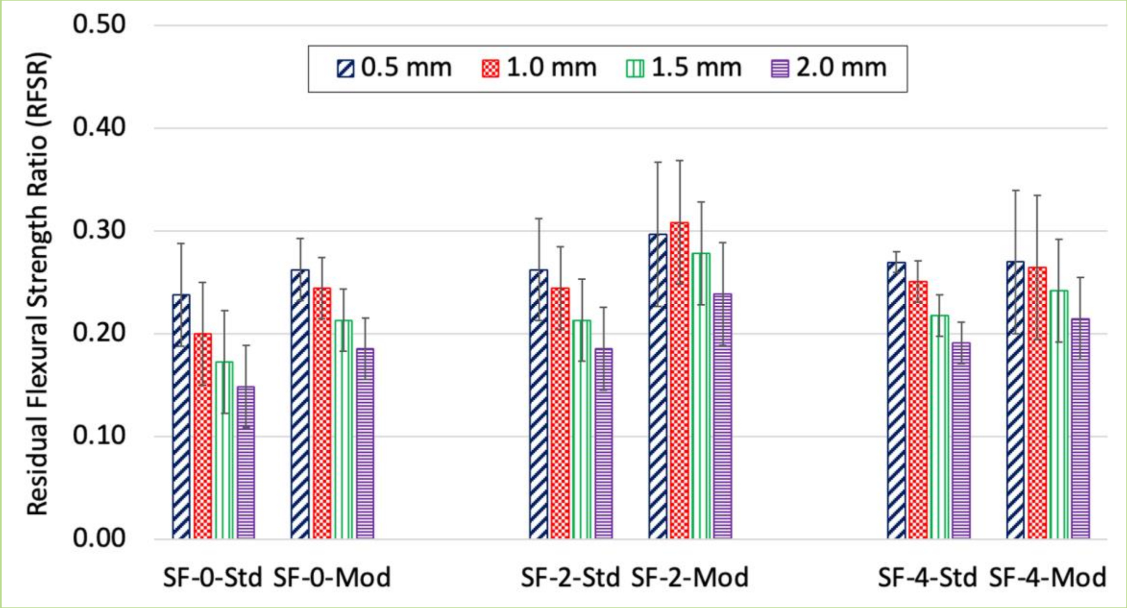
Red Continuous Lines: Modified Mixing

Test Results

Flexural Performance



RFSR = RFS / MOR

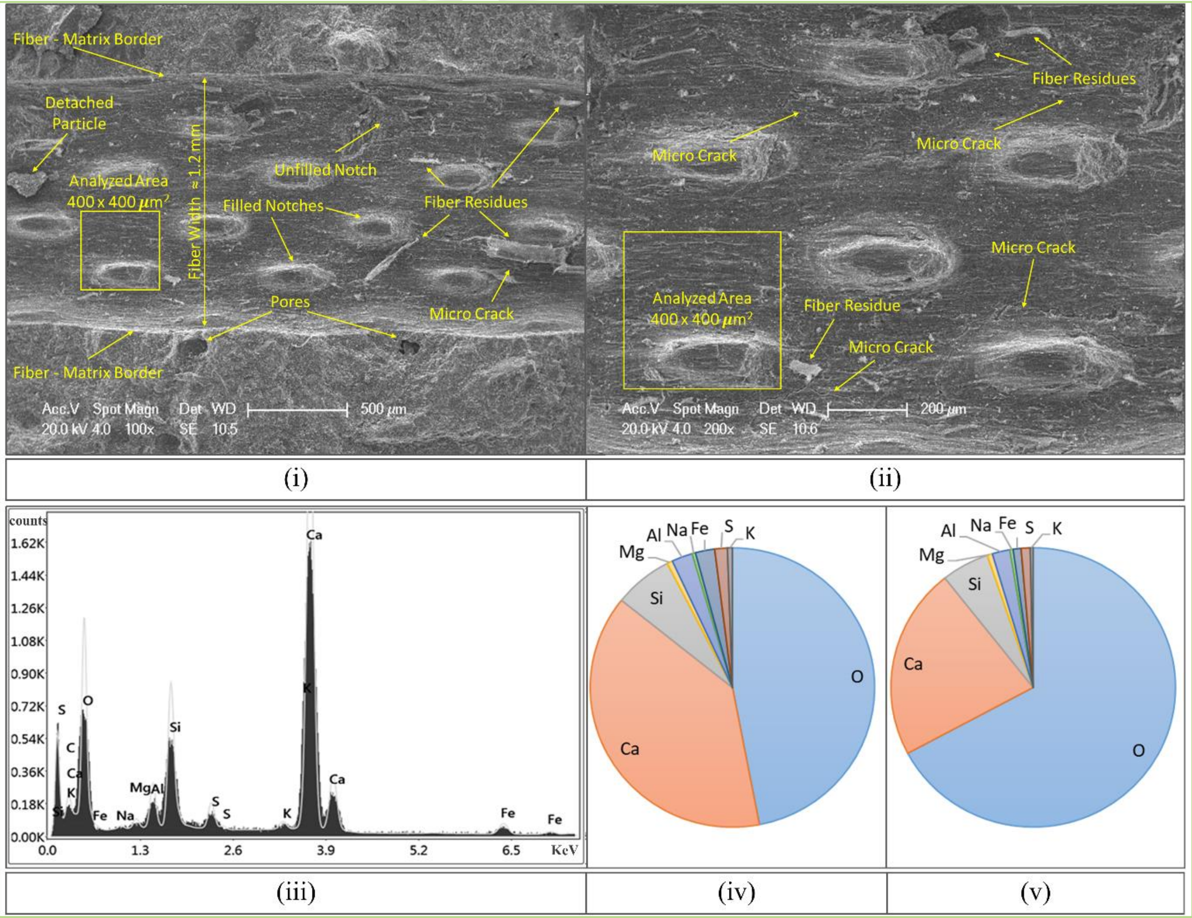


Modified Mixing Approach

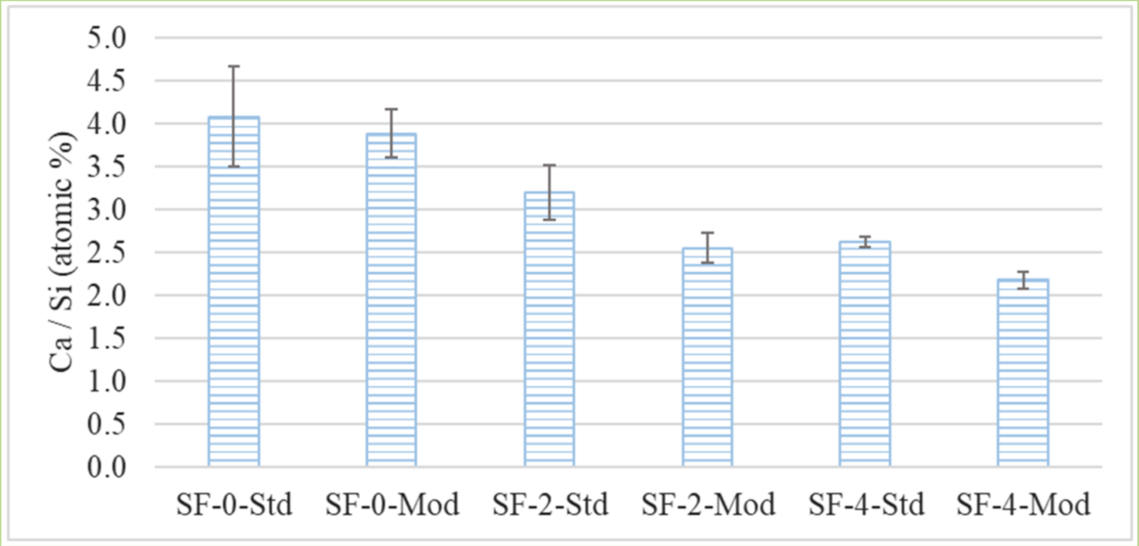
--> 30% increase in RFSR

Test Results

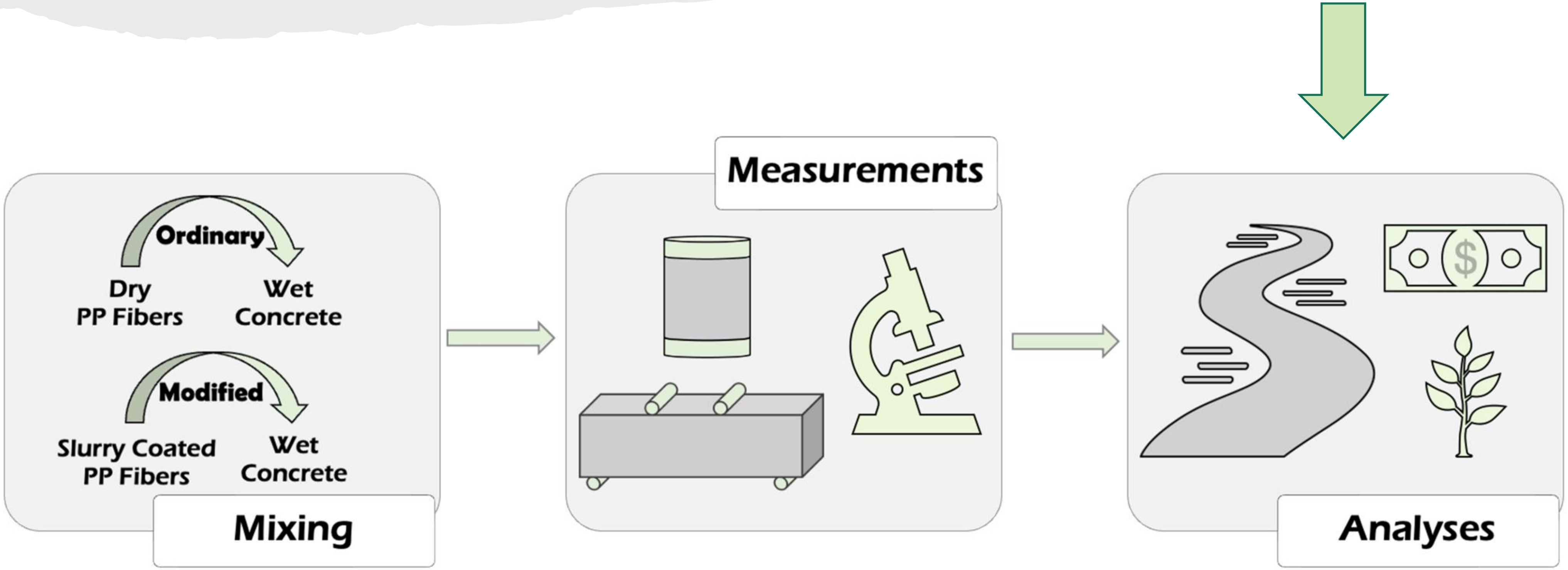
Microstructural Analyses



Ca/Si ↘ C – S – H ↗ $Ca(OH)_2$ & Ettringite ↘



Overview



Ordinary
Dry PP Fibers
Wet Concrete
Modified
Slurry Coated PP Fibers
Wet Concrete
Mixing
Measurements
Analyses

Analyses

Pavement Structural Design

Traffic, Environment & Soil Parameters

Design Life (year)	30
Annual Daily Truck Traffic (ADTT)	1000
Annual Growth Rate (%)	2
Traffic in the Dominant Direction (%)	50
Day Time Traffic (%)	50
Night Time Traffic (%)	50
Temperature Differential (Day) (°C)	10
Temperature Differential (Day) (°C)	10
Modulus of (Subgrade + Base) Reaction (MPa/m)	100

Traffic Spectrum

(ACPA – StreetPave / Major Arterial)

Single Axle Load (kN)	Frequency (%)	Tandem Axle Load (kN)	Frequency (%)
151.2	0.10	266.9	0.15
142.3	0.29	249.1	0.28
133.4	0.35	231.3	0.46
124.5	0.95	213.5	0.79
115.6	1.88	195.7	0.91
106.8	2.22	177.9	5.28
97.9	5.16	160.1	20.31
89.0	22.28	142.3	28.45
80.1	36.37	124.5	24.88
71.2	30.41	106.8	18.48

Design Method: Indian Road Congress (IRC) Method (IRC 58, 2015)

$$\text{MOR'} = \text{MOR} * (1 + \text{residual flexural strength ratio})$$

Roesler, J. R., Bordelon, A. C., Ioannides, A., Beyer, M., & Wang, D. (2008). Design and concrete material requirements for ultra-thin whitetopping.

American Concrete Pavement Association. (2011). ACPA StreetPave Software.

Analyses

Pavement Structural Design

Mixture Name	Density (t/m^3)	MOE (MPa)	MOR (MPa)	RFS (MPa) (2mm)	MOR' (MPa)	Characteristic MOR' (90 days) (MPa)	Required Thickness (cm)	Thickness Reduction (%)	Thickness Reduction (%)
Control	2.37	23.9	5.96	-	5.96	4.59	22.9	-	-
SF-0-Std	2.36	23.7	5.61	0.83	6.44	4.96	21.7	5.2	-
SF-0-Mod	2.36	25.3	5.67	1.05	6.72	5.17	20.4	10.9	6.0
SF-2-Std	2.36	25.6	5.62	0.86	6.48	4.99	20.8	9.2	-
SF-2-Mod	2.36	25.0	5.73	1.38	7.11	5.47	19.7	14.0	5.3
SF-4-Std	2.35	24.0	6.05	1.16	7.21	5.55	19.9	13.1	-
SF-4-Mod	2.35	24.8	6.30	1.34	7.64	5.88	18.8	17.9	5.5

Analyses

Cost and Environmental Impact

Parameter	Cost ($ / kg product)	CO_2 emission ($kg\ CO_2$ - eq / kg product)
Cement	0.067 *	0.707 *
SF	0.400 *	0.024 ****
CSt: No I	0.006 *	0.004 **
CSt: No II	0.006 *	0.004 **
CS	0.006 *	0.004 **
NS	0.009 *	0.009 **
Water	0.001 *	0.0003 **
SP	0.600 *	1.880 **
PPF	6.000 *	3.430 ***
Steel Mesh	1.000 *	1.990 **

* Local suppliers (Turkey) (in July, 2022)

** Hammond and Jones (2008).

*** Korol et al. (2020).

**** Thilakarathna et al. (2020)

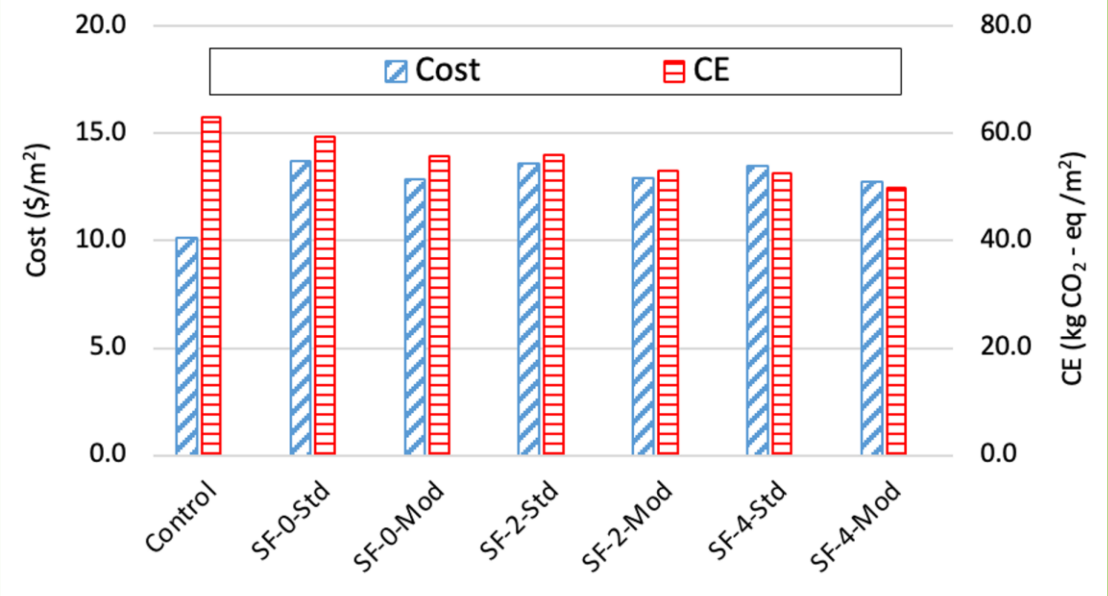
Cost and CE

Unit Concrete Volume > Unit Pavement Area

Fibers

--> 35% Increase in Cost

--> 16% Decrease in CO_2 Emission



Modified Mixing Methodology

--> 6% Decrease in Cost and CO_2 emission

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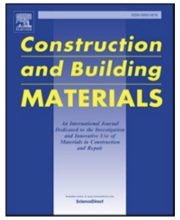

Implementation of two-stage mixing approach to improve the performance of fiber reinforced concrete for sustainable construction

Onur Ozturk *, Nilufer Ozyurt

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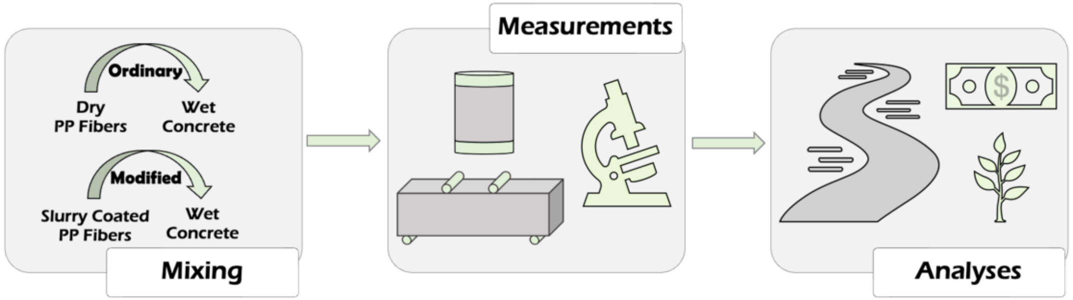

Thank you!

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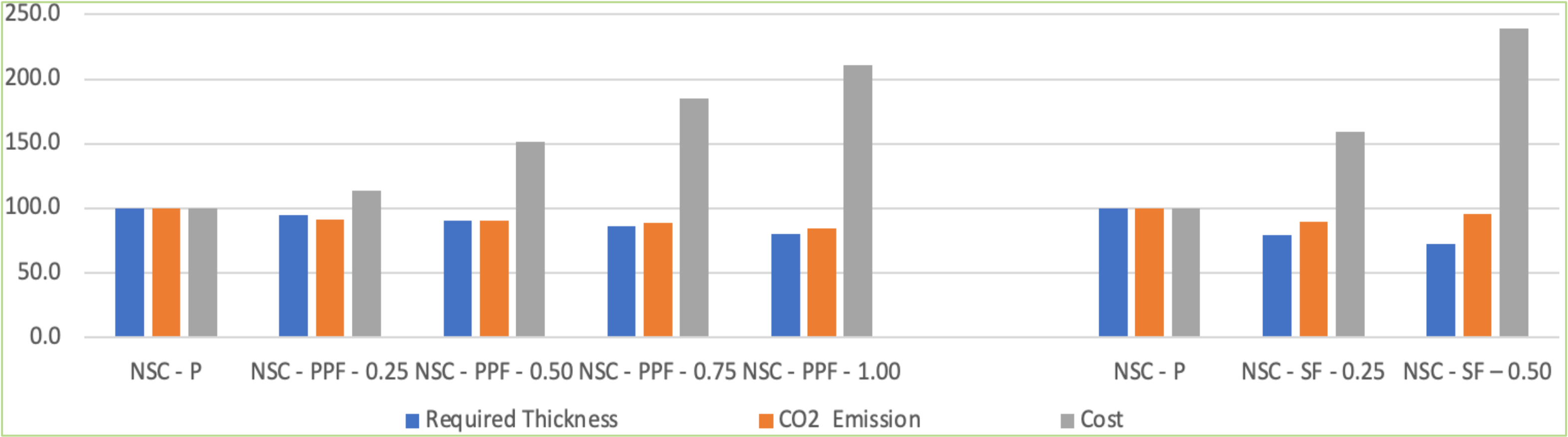
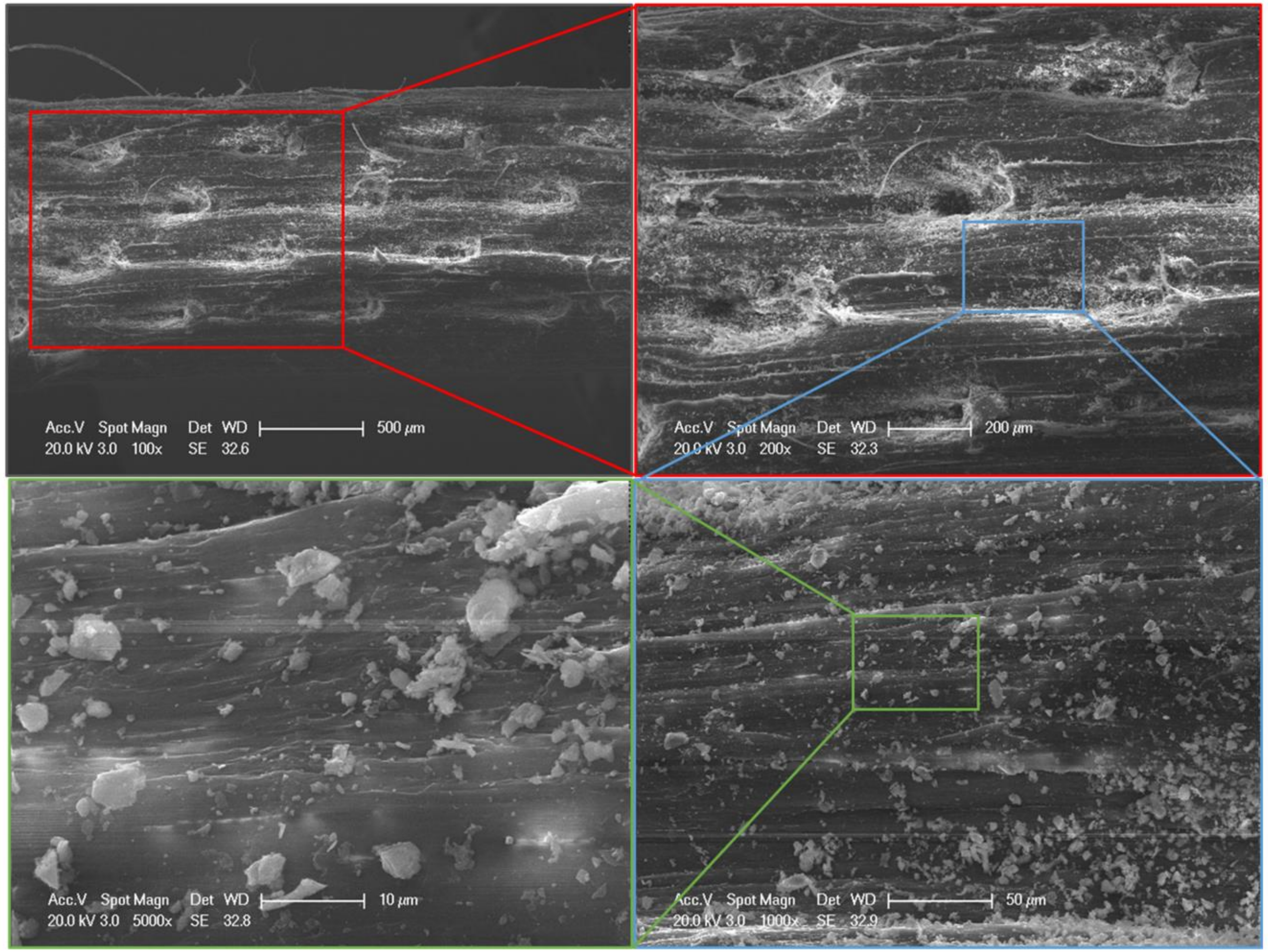
Background

Use of Discrete Macro Fibers



- Despite the increasing cost, fibers can reduce the environmental impact by reducing the structural dimensions (pavement thickness).
    - ➢ Type and amount of the fibers should be selected carefully.

Ozturk, O., & Ozyurt, N. (2022). Sustainability and cost-effectiveness of steel and polypropylene fiber reinforced concrete pavement mixtures. *Journal of Cleaner Production*, *363*, 132582.


Acc.V Spot Magn Det WD 500 μm
20.0 kV 3.0 100x SE 32.6
Acc.V Spot Magn Det WD 200 μm
20.0 kV 3.0 200x SE 32.3
Acc.V Spot Magn Det WD 10 μm
20.0 kV 3.0 5000x SE 32.8
Acc.V Spot Magn Det WD 50 μm
20.0 kV 3.0 1000x SE 32.9