Shrinkage Cracking Control of Concrete Using Non-Metallic Rebars and Meshes

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MIAMI

Plastic Shrinkage Cracking

- Has been studied over the last 60 years
- One of the earliest flaws in concrete
- Caused by restrained volumetric changes in the first 3-8 hours after casting
- Reduces concrete durability and structural service life

Fig. 1. *Plastic shrinkage crack*

Driving causes of plastic shrinkage

- Settlement of solid particles
- Bleeding
- Evaporation
- Capillary action
- Surface finishing

<u>But how to control it?</u>

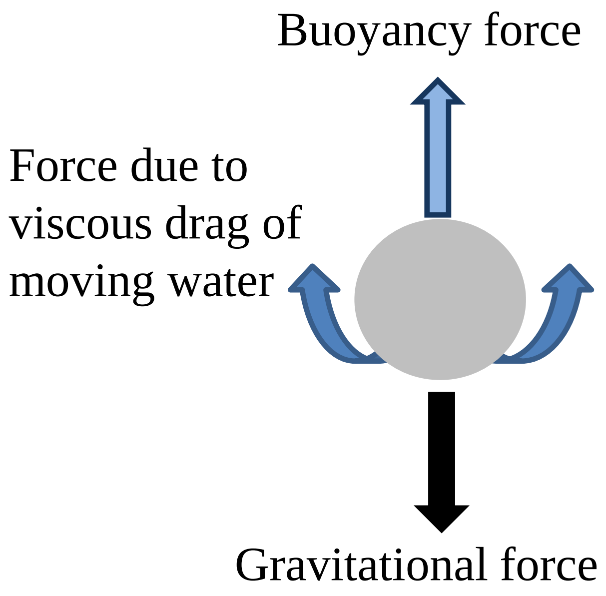

Fig. 2. *Major forces acting on a solid particle in fresh concrete*

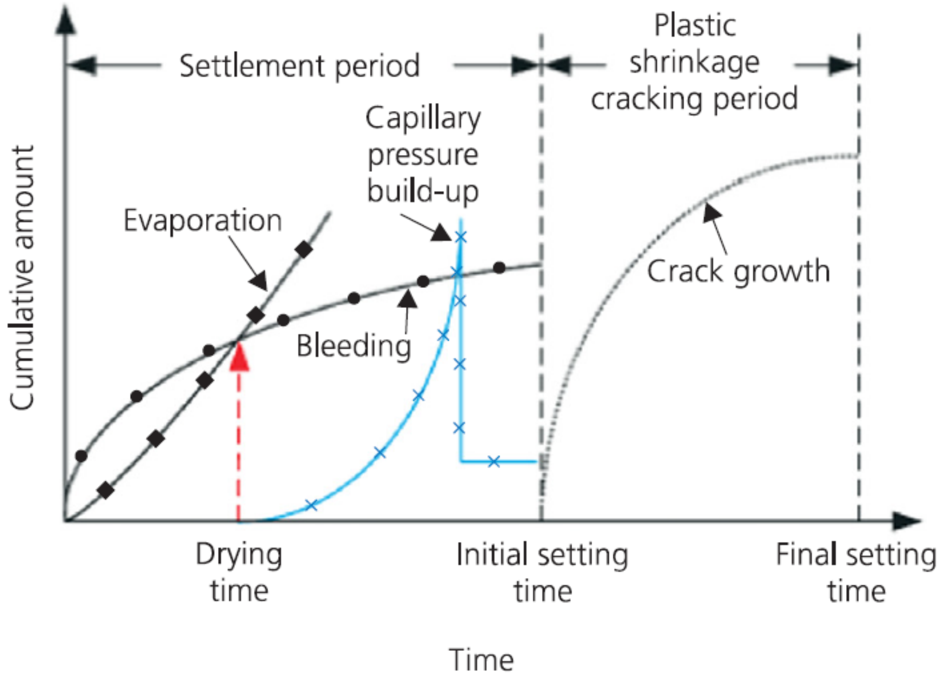

Fig. 3. *Sequence of events prior to and after cracking*

Material

Shrinkage cracking control

- Alternative concrete mixture
- Concrete surface sealers
- Curing techniques
- <u>Fiber Reinforced Polymer (FRP) reinforcement</u>

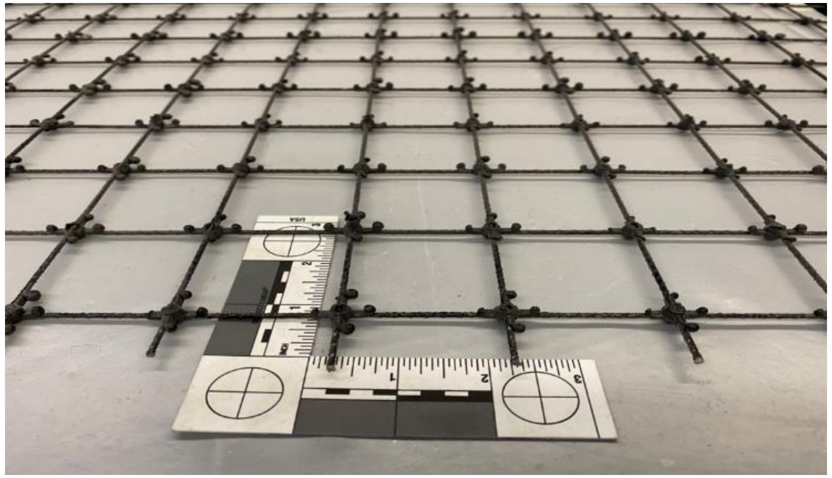

Fig. 4. *FRP Mesh*

Fig. 5. *FRP bars*

Why FRP?

What is a sustainable material?

- Last longer
- Require lower energy
- Emit less carbon dioxide

Environmental impact of FRP

- Increase service life of structure
- Decrease CO2 emissions
- Lower energy consumption

Reference	Type of FRP	FRP Re-placement % to Steel Rebars	Environmental Impact Category	Reduction % in the Environmental impact due to using FRP rebars
Garg and Shrivastava, (2019)	GFRP	100%	Global Warming (CO_2 emissions)	43%
Garg and Shrivastava, (2019)	GFRP	100%	Energy Consumption	47%
Garg and Shrivastava, (2019)	BFRP	100%	Global Warming (CO_2 emissions)	40%
Garg and Shrivastava, (2019)	BFRP	100%	Energy Consumption	50%
Garg and Shrivastava, (2019)	CFRP	100%	Global Warming (CO_2 emissions)	39%
Garg and Shrivastava, (2019)	CFRP	100%	Energy Consumption	32%
Van Loon et al. (2019)	E-glass	46%	Shadow Cost	28%
Van Loon et al. (2019)	Flax	46%	Shadow Cost	39%
Van Loon et al. (2019)	Kenaf	39%	Shadow Cost	36%
Inman et al. (2017)	BFRP	100%	Global Warming (CO_2 emissions)	62%
Inman et al. (2017)	BFRP	100%	Ozone Depletion	21%
Inman et al. (2017)	BFRP	100%	Human Toxicity	78%

Table. 1. *Comparison of LCA results of replacement of the conventional steel reinforcement by FRP composites*

Plastic Shrinkage Cracking Test

Modified ASTM C1579

- Based on guidelines of ASTM C1579 and AC521
- Evaluate FRP as secondary reinforcement
- To compare of FRP and steel for controlling shrinkage cracks

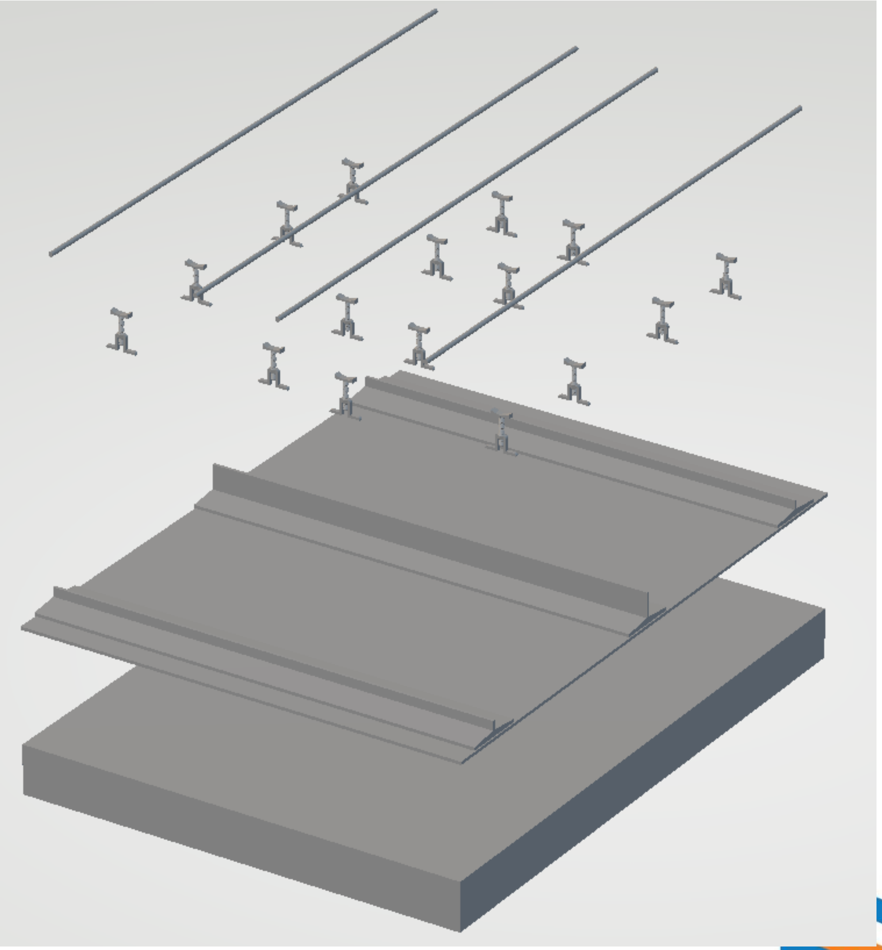

Fig. 6. *Specimen, riser and restraints, reinforcement, and chairs*

Plastic Shrinkage Cracking Test

Mold

Each specimen contains <u>2 sections</u>

1. FRP

2. Steel

Wind tunnel

- To obtain a laminar wind flow
- Accelerate evaporation and provide a severe condition

Fig. 7. *Mold and reinforcement configuration*

Fig. 8. *Wind Tunnel Design*

Influential parameters

- Environmental variables (wind speed, RH, ambient temperature)
- Material characteristics (reinforcement and concrete)
- Restraint conditions (at both ends)
- Stress concentration (riser)
- Clear concrete cover (0.75 in.)
- Base roughness (steel plate)
- Workmanship

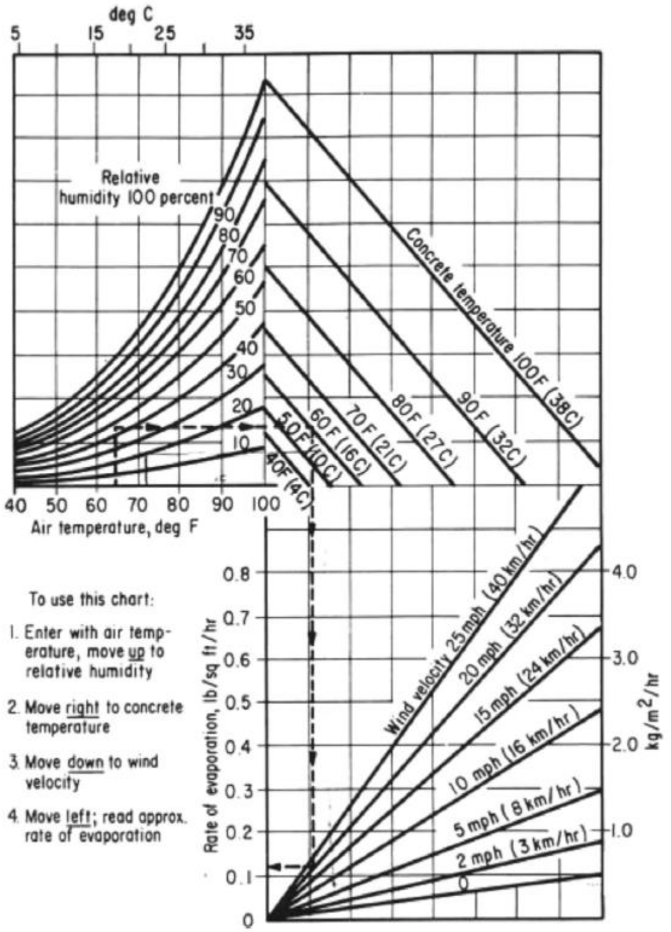

Fig. 9. *Nomograph for estimating rate of evaporation*

Parameters measurements

Environmental variables

- Wind speed measured at midspan using an anemometer
- RH and ambient temperature measured using a thermometer in the wind tunnel

Measurement	Temperature (inside the wind tunnel) [˚F]	RH (inside the tunnel) [%]	Wind Speed (at Mid span) [m/s]
1	72.2	66.0	4.4
2	71.6	61.0	4.6
3	72.2	62.0	4.4
4	72.9	59.0	4.6
5	72.9	59.0	4.5
6	72.4	60.0	4.6
7	73.3	62.0	4.7
8	73.6	59.0	4.6
9	73.3	60.0	4.5
10	72.9	59.5	4.5
11	72.5	60.0	4.5
12	72.9	62.0	4.8
13	72.9	60.0	4.6
14	72.9	60.0	4.5
15	72.9	60.0	4.5
16	72	60.0	4.5
Average	72.7	60.6	4.5

Table. 2. *Environmental variables measurement*

Material characteristics

- FRP
  1. Tensile properties (ASTM D7957 and D7205)
  2. Surface enhancement (surface roughness)
  3. Bond strength (ASTM D7957 and D7913)

- Concrete
  1. Compressive and tensile strength
  2. Time of setting (ASTM C403)
  3. Concrete temperature (implementing sensors in concrete)
  4. Rate of evaporation

Specimen ID		**Tensile Force** P_{Max}		**Nominal Area** A_{nom}		**Ultimate Strength** $F^{tu}{}_{nom}$		**Modulus of Elasticity** E_{nom}		**Ultimate Strain** ε_{tnom}
		KN	**Kips**	mm^2	in^2	**Mpa**	**Ksi**	**GPa**	**Msi**	**%**
A-35L1 TNS 01		72.06	16.20			1015.4	147.3	53.4	7.75	1.9
A-35L1 TNS 02		71.42	16.10			1006.4	146	54.2	7.86	1.86
A-35L1 TNS 03		74.30	16.70	71	0.11	1046.9	151.8	51.1	7.41	2.05
A-35L1 TNS 04		73.72	16.60			1038.8	150.7	52.4	7.61	1.98
A-35L1 TNS 05		72.06	16.20			1015.4	147.3	53.3	7.73	1.91
	Average	**72.71**	**16.36**			**1024.6**	**148.6**	**52.9**	**7.67**	**1.94**
		1.23	0.27			17.32	2.49	1.18	0.17	0.08
	CV%	1.69	1.65			1.69	1.67	2.24	2.23	3.87
Garanteed Tensile Load		69.02	15.55							

Table. 3. *FRP bar tensile properties*

Evaluate Cracking Control

Crack Measurements

- Depth
- Width
- Length
- Area

Crack reduction ratio is computed to evaluate FRP performance:

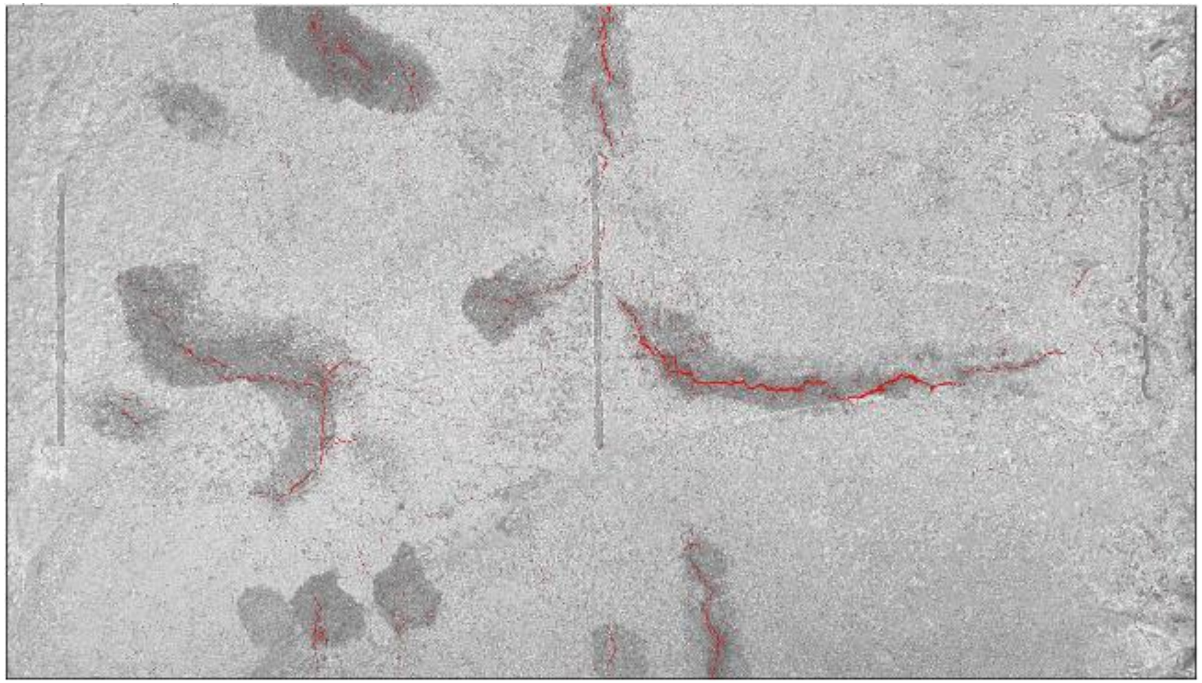

Fig. 10. *Processed image of concrete surface*

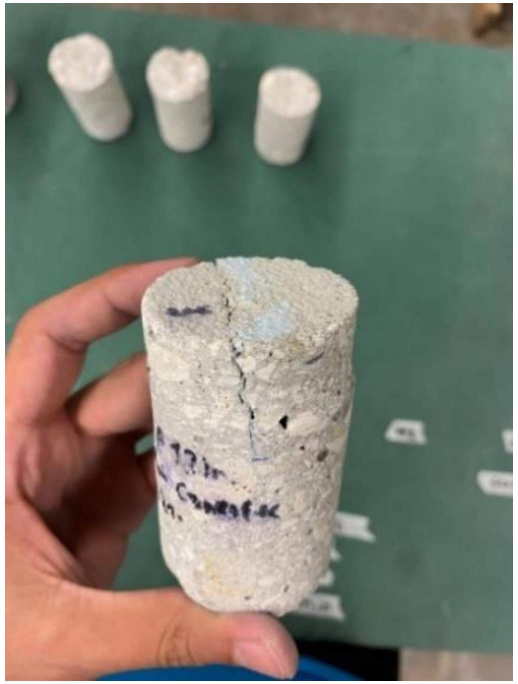

Fig. 11. *Concrete core*

$$CRR = [1 - \frac{Average\ Crack\ Width\ of\ section\ reinforced\ with\ FRP}{Average\ Crack\ Width\ of\ section\ reinforced\ with\ steel}]$$

Conclusions (expected)

1- Provide experimental evidence to show efficiency of FRP to control plastic shrinkage cracks

2- Establish feasible equivalency between FRP and steel

3- Minimum FRP reinforcement as secondary reinforcement (temperature and shrinkage reinforcement)

4- A standard test method to evaluate FRP as secondary reinforcement

Thank U