American Concrete Institute

Lowering Carbon Footprint of Concrete Construction Using Fiber Reinforcement Technology

Novel Developments in the Use of Advanced Fiber Reinforced Concretes, Part 1 of 2

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As the knowledge, testing and experience of using synthetic macrofiber reinforced concrete continues to grow for use in infrastructure projects, their successful use and benefits are now being realized through full scale and long term demonstration projects. However, many prospective engineers, architectural firms and clients are now requesting additional information as to the environmental impacts of using fibers in replacement of traditional reinforcement or as an added material in concrete to improve durability and useful service life.

The term sustainability is broadly used to indicate programs, initiatives and actions aimed at the preservation of a particular resource. However, it actually refers to four distinct areas: human, social, economic and environmental – known as the four pillars of sustainability

Sustainable Development

Building a more sustainable world

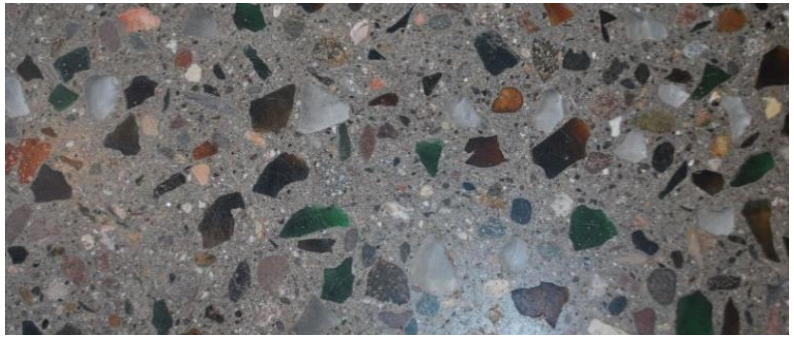
Capital investment of new infrastructure systems is environmentally and economically intensive. Today, governments are challenged to plan, build, and operate "sustainable" systems that – in addition to achieving the important goals of safety – support a variety of asset management, environmental stewardship, climate mitigation/adaptation, and resilient infrastructure objectives.

Synthetic macrofiber composites can be used to replace steel reinforcement or in conjunction with steel reinforcement to increase durability and extend service life. The contribution to sustainable construction through lowered environmental, social, and economic impacts is currently being documented.

Concrete as a Building Material

CONCRETE is already one of the most sustainable building material, compared to timber, steel, asphalt, etc:

- Lower embodied energy
- Using local materials
- Better life cycle / durability
- Thermal mass and energy efficiency
- Light reflectivity
- Minimized waste
- Customized properties



We can do even more with the use of fiber-reinforced concrete

The Future of FRC and 'Green' Construction

Fiber Reinforced Concrete (FRC) technology has advanced significantly over the past two decades:

- definitions for micro and macro fibers
- calculations for equivalent reinforcing options to conventional steel
- industry acceptance (UL, SDI, ACI, etc.)
- structural designs and software tools
- multi-million dollar research programs
- high profile projects and applications

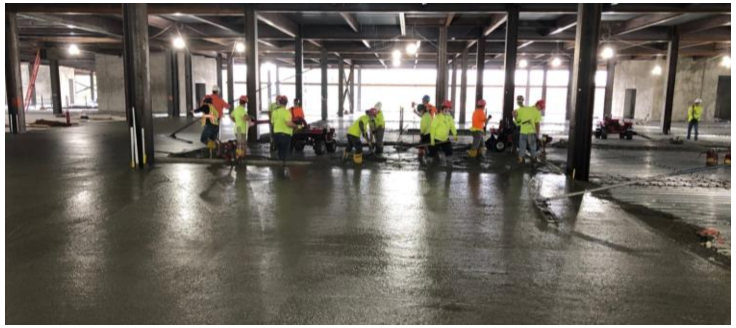
Many prospective clients and engineers are now asking:

"What are the environmental impacts and/or benefits of using FRC for concrete construction?"

The Journey to Sustainability with Fiber

- 25% of our existing infrastructure will be repaired or replaced between 2005-2030
- ~40% US emissions from building activities over lifetime
- One of largest contributors is concrete
- Decrease emissions by improving efficiency and innovating <u>material substitutions</u>



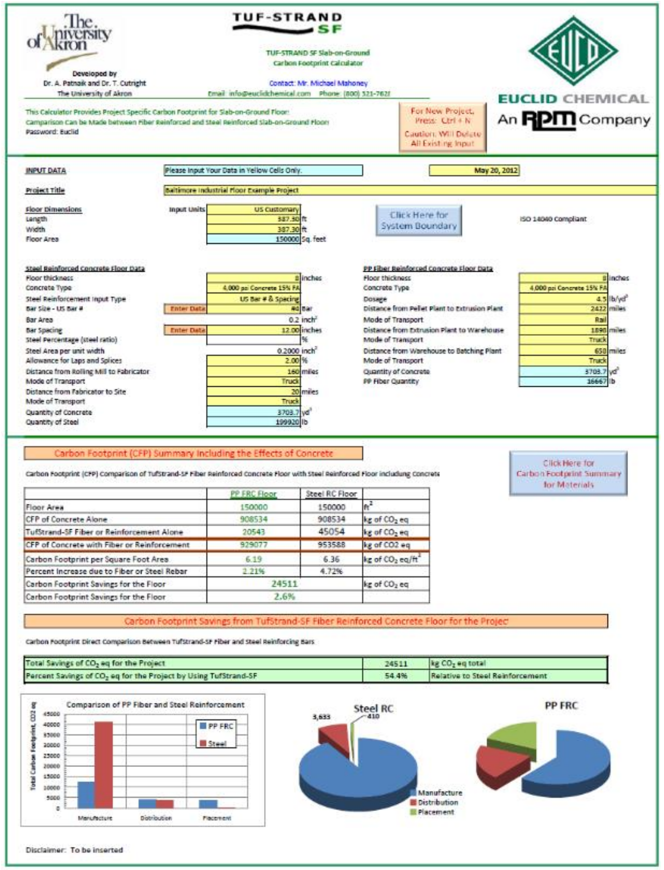


- Companies now developing Environmental Product Declarations for fibers
- Builds on the Carbon Footprint presentation from 2018 Las Vegas

CO2 and Sustainability

There is again renewed interest in reduction of carbon footprint and sustainable construction – coming from major companies and governments

There is no independent "Product Category Rule" for the development of an EPD on fibers at this time. There is discussion occurring at NRMCA and other organizations



- Previously developed work to calculate the GHG emissions reduction when comparing conventional steel to fiber for floor construction.
- Showed that macrofiber can reduce GHG of reinforcing by over 50%.

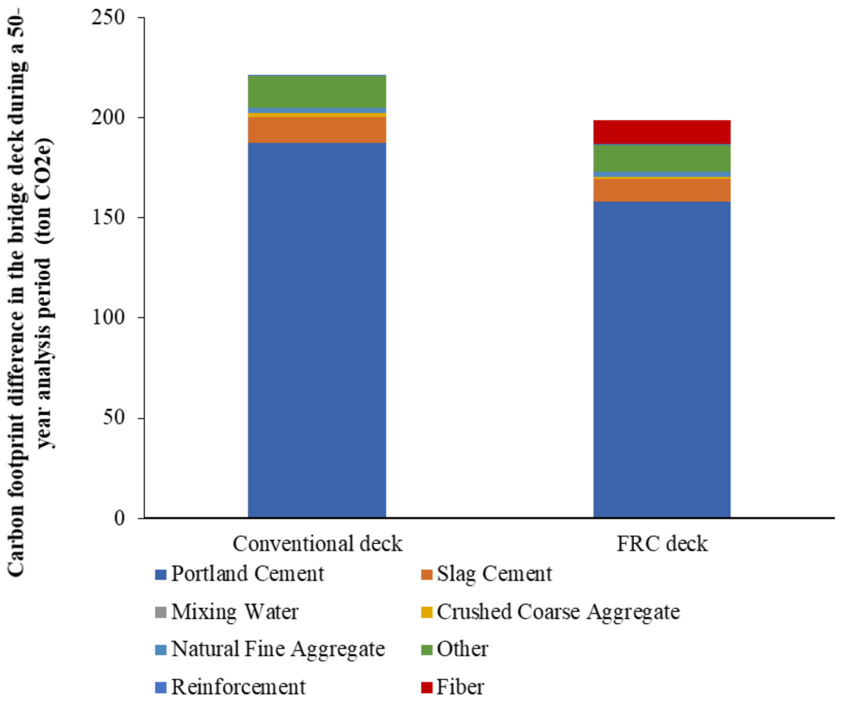
CARBON FOOTPRINT CALCULATOR

Local Expectations and Decisions

- Sometimes, the cost of adding fibers can appear as a detriment to the overall project, but….
- Would longer service life or faster and safer construction provide enough savings to offset the use of fibers and provide future resiliency?
  - Construction speed will be increased with less concrete and FRC
    - Value needs to be worked out through contractor and RM producer
  - Long term savings are not included (but should be!)
    - Less spalling and joint maintenance
    - Drying shrinkage crack control
    - Improved permeability, abrasion and impact resistance
    - Ductility and fatigue resistance

Service Life Increase

Embodied Carbon Emissions of Bridge Deck with Conventional Concrete and FRC



- In the conventional mix design, it was assumed that the concrete cover is fully removed and replaced by the same concrete made with similar mix design while the FRC scenario does not have any repair actions during the 50-year analysis period; Cover assumption: 3 in. (75 mm)

Environmental Product Declaration (EPD)

An Environmental Product Declaration (EPD) is defined by International Organization for Standardization 14025 as a Type III declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function”.

Nutrition Facts

8 servings per container
Serving size **2/3 cup (55g)**

Amount per serving	
Calories	**230**
	% Daily Value*
Total Fat 8g	**10%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**13%**
Dietary Fiber 4g	**14%**
Total Sugars 12g	
Includes 10g Added Sugars	**20%**
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 235mg	6%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

ENVIRONMENTAL IMPACTS

Declared Product:

1 3000PSI PU PL
Compressive strength: 3000 PSI at 28 days

Declared Unit: 1 m^3 of concrete

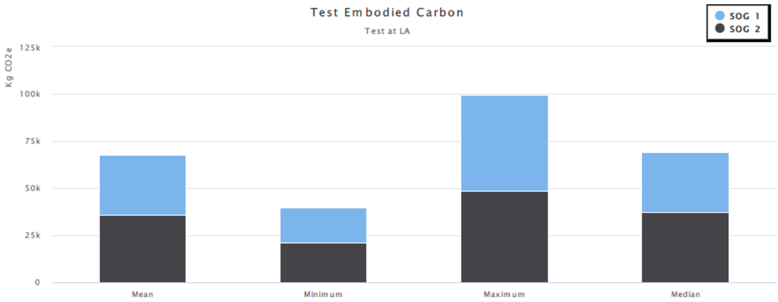
Global Warming Potential (kg CO_2-eq)	352
Ozone Depletion Potential (kg CFC-11-eq)	8.9E-6
Acidification Potential (kg SO_2-eq)	1.08
Eutrophication Potential (kg N-eq)	0.41
Photochemical Ozone Creation Potential (kg O_3-eq)	22.5
Abiotic Depletion, non-fossil (kg Sb-eq)	1.6E-6
Abiotic Depletion, fossil (MJ)	394
Total Waste Disposed (kg)	2.91
Consumption of Freshwater (m^3)	3.14

Product Components: natural aggregate (ASTM C33), Portland cement (ASTM C150), batch water (ASTM C1602), admixture (ASTM C494)

EMBODIED CARBON REPORT FOR: TEST

TEST

NATIONAL READY MIXED CONCRETE COMPANY



This project report was generated from National Ready Mix's database of environmental product declarations (EPDs). All EPDs were created with Climate Earth's EPD Generator and verified according to ISO standards and the product category rules for ready mix concrete.

Concrete performance requirements vary by application. Please contact National Ready Mix to discuss all your performance requirements for each mix design.

Results of analysis in table form:

Application	PSI	QTY	Mean		Minimum		Maximum		Median	
		(cyd)	Kg Co2e	%	Kg Co2e	%	Kg Co2e	%	Kg Co2e	%
SOG 1	4,000	100	32,319	48%	18,754	47%	51,292	51%	31,872	46%
SOG 2	5,000	100	35,509	52%	20,814	53%	48,334	49%	37,104	54%
		TOTAL	67,827		39,569		99,625		68,976	

Environmental Product Declarations

Product Category Rules (PCR)

- Defines the product category
- Establishes data collection type, boundaries and procedures via LCA
- Establishes reporting thresholds
- Requires open consultation of external stakeholders
- Register PCR through Program Operator

Conduct a Lifecycle Assessment (LCA)

- Evaluate impacts through cradle to gate life cycle assessment
- Follow requirements set by PCR and ISO 14040

- Multiple steps to complete an EPD.
  - Product Category Rules must be defined.
  - There presently is not a PCR for fiber used in concrete.

    - growing list of companies with fiber EPD's though

- Use of PCR EN 15804 (Sustainability Of Construction Works - Environmental Product Declarations - Core Rules For The Product Category Of Construction Products) and ISO 14025

- An LCA evaluates many parameters usually over a one-year time period.
  - Energy, water, waste, etc.

Fiber EPD Development

- After the collection of the data and format into ISO protocol, the data is third-party reviewed.
- Environmental impacts are taken from databases following ISO rules

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw Material Supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	Deconstruction Demoliton	Transport	Waste Processing	Disposal	Reuse Recovery Recycling Potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
			Scenario		Scenario							Scenario				
X	X	X	MND	MND	MND	MND	MNR	MNR	MNR	MND	MND	MND	MND	MND	MND	MND

X = INCLUDED IN LCA; MND = MODULE NOT DECLARED; MNR = MODULE NOT REPORTED

Verify LCA
- Conduct a review of LCA by third party
- Verify assumptions and conformance to PCR

Create Environmental Product Declaration (EPD)
- Translate the LCA data into environmental impacts
- Follow ISO
- Include company and product information

- Data collection necessary for fiber EPD (A1 through A3).
- Customer will define transportation to ready mix plant or job site - already in our fiber calculator

Environmental Product Declarations cont.

Verify EPD

- Conduct a comprehensive audit of the EPD by a third party

Register EPD

- Publish EPD in public repository
- Maintain EPD updates at scheduled intervals or due to significant changes

- Quantified life cycle environmental performance
- NOT a claim of environmental superiority
- A fair way to compare products

Third Party Example Concrete EPD - NRMCA

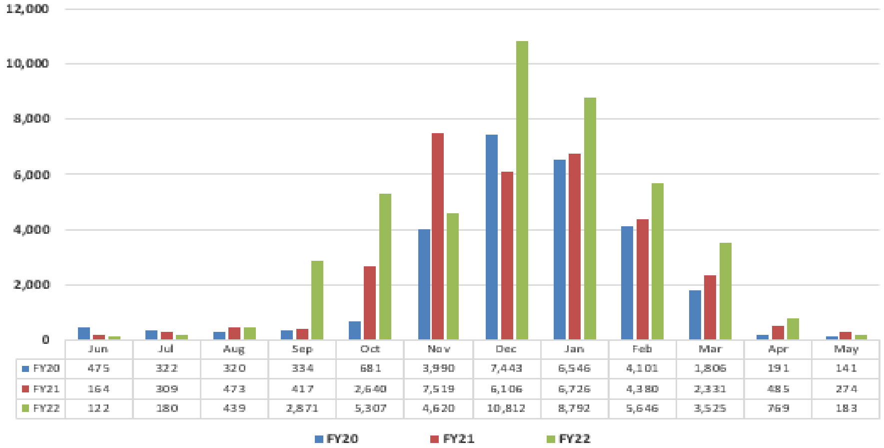
Service Area: Brentwood (340 mixes)

		Perf.	Impacts							
Mix Code	Plant	CS	TPE	CWB	CWW	GWP	ODP	AP	EP	POCP
	minimum	*2,000*	*2.155E+03*	*6.871E-02*	*4.504E-03*	*2.058E+02*	*3.634E-06*	*1.513E+00*	*8.143E-02*	*2.568E+01*
	maximum	*6,000*	*3.629E+03*	*7.287E-02*	*4.504E-03*	*4.819E+02*	*6.637E-06*	*3.466E+00*	*1.395E-01*	*4.745E+01*
325PC901	Brentwood	2,500	2.556E+03	6.871E-02	4.504E-03	3.058E+02	4.237E-06	2.174E+00	9.251E-02	3.072E+01
325PC902	Brentwood	2,500	2.552E+03	7.287E-02	4.504E-03	3.056E+02	4.249E-06	2.173E+00	9.197E-02	3.067E+01
325PC9D1	Brentwood	2,500	2.231E+03	6.871E-02	4.504E-03	2.529E+02	3.634E-06	1.786E+00	8.243E-02	2.572E+01
325PC9D2	Brentwood	2,500	2.225E+03	7.287E-02	4.504E-03	2.525E+02	3.638E-06	1.784E+00	8.143E-02	2.568E+01
325PC9Q1	Brentwood	2,500	2.161E+03	6.871E-02	4.504E-03	2.062E+02	4.591E-06	1.515E+00	1.004E-01	2.760E+01
325PC9Q2	Brentwood	2,500	2.155E+03	7.287E-02	4.504E-03	2.058E+02	4.571E-06	1.513E+00	9.997E-02	2.754E+01
325PG9C1	Brentwood	2,500	2.536E+03	6.871E-02	4.504E-03	3.047E+02	4.147E-06	2.170E+00	8.987E-02	3.063E+01
325PG9D1	Brentwood	2,500	2.311E+03	6.871E-02	4.504E-03	2.674E+02	3.760E-06	1.894E+00	8.401E-02	2.707E+01
325PG9Q1	Brentwood	2,500	2.344E+03	6.871E-02	4.504E-03	2.310E+02	5.036E-06	1.704E+00	1.109E-01	3.082E+01
325PG9Q2	Brentwood	2,500	2.345E+03	7.287E-02	4.504E-03	2.316E+02	5.064E-06	1.707E+00	1.106E-01	3.085E+01
330PC901	Brentwood	3,000	2.671E+03	6.871E-02	4.504E-03	3.246E+02	4.436E-06	2.313E+00	9.581E-02	3.251E+01

	Name	Abbreviation	Unit
Mix performance	28-day compressive strength	CS	psi
Mix impacts (per m³)	Total primary energy consumption	TPE	MJ
	Concrete water use (batch)	CWB	m^3
	Concrete water use (wash)	CWW	m^3
	Global warming potential	GWP	kg CO_2-eq
	Ozone depletion	ODP	kg CFC-11-eq
	Acidification	AP	kg SO_2-eq
	Eutrophication	EP	kg N-eq
	Photochemical ozone creation/smog	POCP	kg O_3-eq

- Industry Average EPDs provide only ½ point in LEED
- Product Specific EPDs can provide 1 point in LEED

LCA and Data Collection



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
FY20	475	322	320	334	681	3,990	7,443	6,546	4,101	1,806	191	141
FY21	164	309	473	417	2,640	7,519	6,106	6,726	4,380	2,331	485	274
FY22	122	180	439	2,871	5,307	4,620	10,812	8,792	5,646	3,525	769	183

Necessary Data to develop LCA

- 12 month “actual data”
- All inbound raw materials tracked
- Total poundage of all fibers produced
- Electricity, water and gas usage
- Safety records and waste material
- Pallets, plastic and other consumable materials

Verified EPD's

- Consultant prepared LCA
- Third Party verified (NRMCA)
- Cradle to Gate production
    - Data provided by production facility (Type III - not industry generic)
- Separate for micro and macrofibers

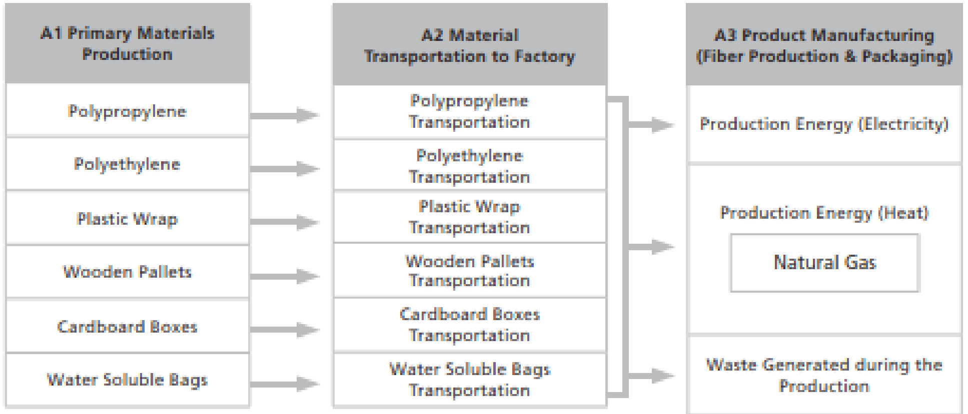


Table 5. LCA Results for Tuf-Strand SF Product

Life Cycle Category Indicators and Inventory Metrics				
Core Mandatory Impact Indicator	**Abbreviation**	**Unit**	**Meth**	[illegible]
Global warming potential	GWP	kg CO_2e	TRACI	[illegible]
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	TRAC	[illegible]
Acidification potential of soil and water sources	AP	kg SO_2e	TRAC	[illegible]
Eutrophication potential	EP	kg Ne	TRA	[illegible]
Formation potential of tropospheric ozone	SFP	kg O_3e	TRA	[illegible]
Abiotic depletion potential (ADPfossil) for fossil	ADPf	MJ, NCV	CML-IA	[illegible]
Abiotic depletion potential (ADPelements)	ADPe	kg Sbe	CML-I	[illegible]
Use of Primary Resources				
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	CED V1.10 NCV	[illegible]
Renewable primary energy carrier used as material	RPRM	MJ, NCV	LCI Indicator	0.00205
Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	CED V1.10 NCV	91.28805
Renewable primary energy carrier used as material	NRPRM	MJ, NCV	LCI Indicator	2.27619
Secondary Material, Secondary Fuel and Recovered Energy				
Secondary material	SM	kg	LCI Indicator	0.00000
Renewable secondary fuel	RSF	MJ, NCV	LCI Indicator	0.00000
Non-renewable secondary fuel	NRSF	MJ, NCV	LCI Indicator	0.00000
Recovered energy	RE	MJ, NCV	LCI Indicator	0.00000
Mandatory Inventory Parameters				
Consumption of freshwater resources;	FW	m^3	LCI Indicator	0.02199
Indicators Describing Waste				
Hazardous waste disposed	HWD	kg	LCI Indicator	5.48E-05
Non-hazardous waste disposed	NHWD	kg	LCI Indicator	0.00380
High-level radioactive waste	HLRW	m^3	LCI Indicator	5.46E-06
Intermediate- and low-level radioactive waste	ILLRW	m^3	LCI Indicator	0.00000
Components for re-use	CRU	kg	LCI Indicator	0.00000
Materials for recycling	MR	kg	LCI Indicator	0.02176
Materials for energy recovery	MER	kg	LCI Indicator	0.00378
Recovered energy exported from the product system	EE	MJ, NCV	LCI Indicator	0.00000

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Comparisons to other products

ENVIRONMENTAL PRODUCT DECLARATION

According to ISO 14025 and ISO 21930:2017

STEEL REINFORCEMENT BAR

CONCRETE REINFORCING STEEL INSTITUTE

About the Concrete Reinforcing Steel Institute
Founded in 1924, the Concrete Reinforcing Steel Institute (CRSI) is a technical institute and Standards Developing Organization (SDO) that stands as the authoritative resource for information related to steel reinforced concrete construction. CRSI offers many industry-trusted technical publications, standards documents, design aids, reference materials, and educational opportunities.

Membership Facts
Approximately 8 million tons of reinforcing steel (rebar) is manufactured per year using scrap steel in efficient manufacturing operations. It is estimated that the industry impacts over 75,000 people in steel transportation and placement.

CRSI members include manufacturers, fabricators, material suppliers, and placers of steel reinforcing bars and related products as well as professionals who are involved in the research, design, and construction of steel reinforced concrete. CRSI members employ approximately 15,000 people in steel production and rebar fabrication at over 450 locations in 47 states throughout North America.

CRSI Concrete Reinforcing Steel Institute

Issue Date: September 20, 2022

Valid Until: September 19, 2027

Declaration Number: EPD 362

Declaration Number: EPD 362

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Other companies are now producing EPD's through various parties including ASTM, NRMCA, NSF, etc.

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Important Notes and Discussion Points

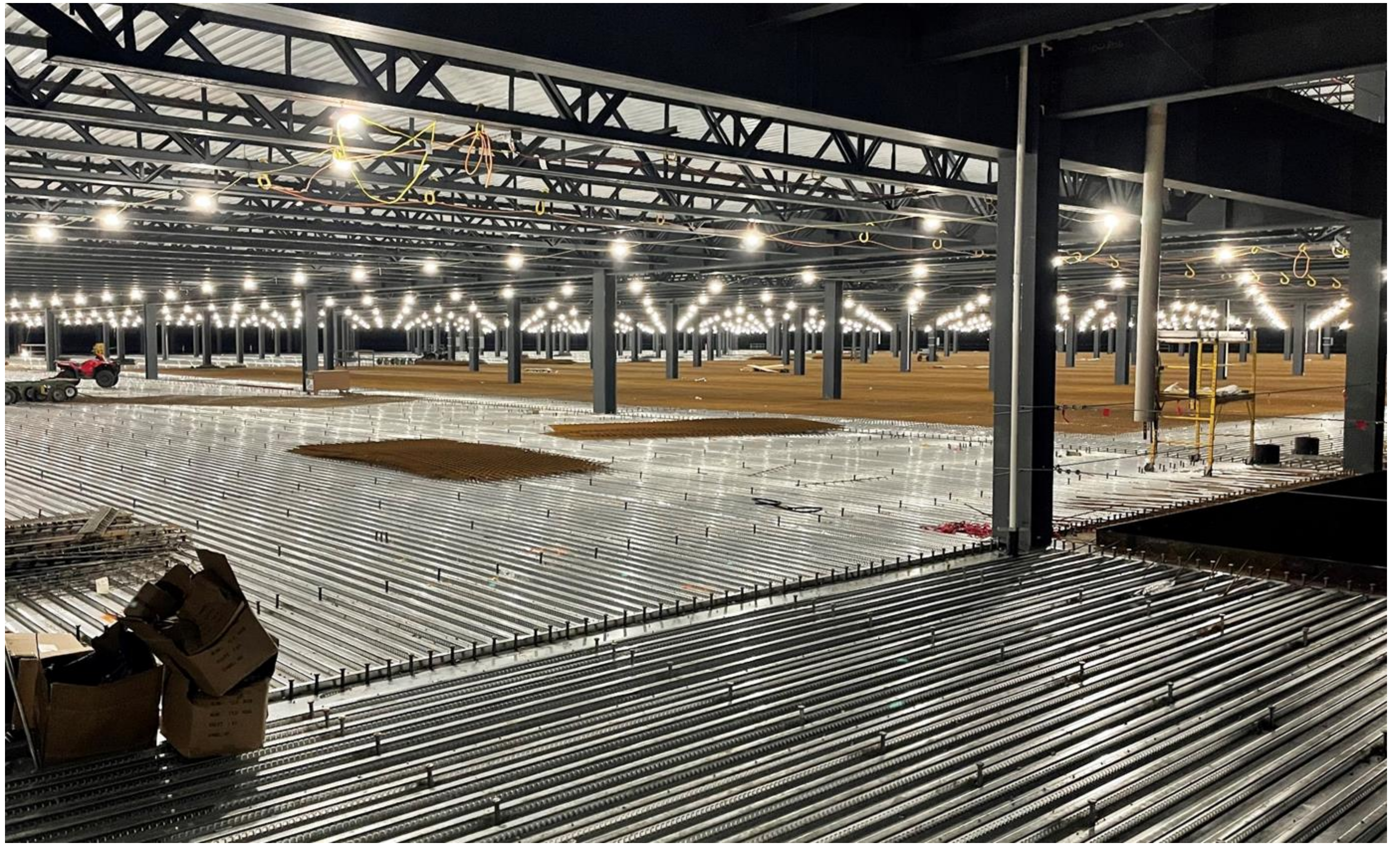
- **We can now quantify the savings in GWP of using fiber versus steel**
- **Discuss less cracking, cost equivalencies and safer construction sites**
- **Specifications, especially government funded projects, will soon require EPD's for product submissions**

Notes:

GWP is dimensionless units – kg/kg or lbs/lbs

Comparative data is now available

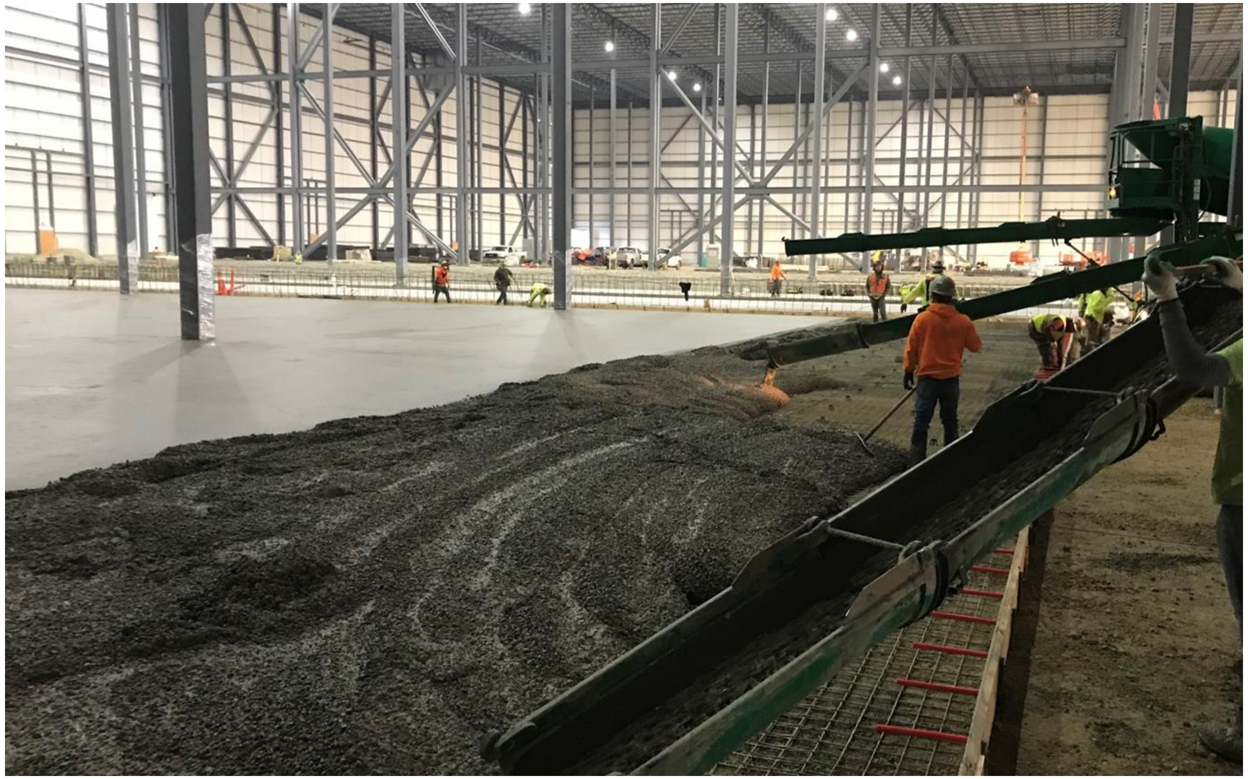
Example total EPD for FRC



GWP Values:

- Macrofiber "A"
    - 3.1 kg CO_2e/kg
- Steel rebar
    - 0.85 kg CO_2e/kg
- Concrete
    - 4500 psi mix, 20% FA
    - 401 kg CO_2e/m^3

Case Study Calculations



250,000 sq ft floor
8” thick

Specified Reinforcement:
#4 bar @ 12” c.c. mid depth (t&s)

Concrete f'_c = 4500 psi

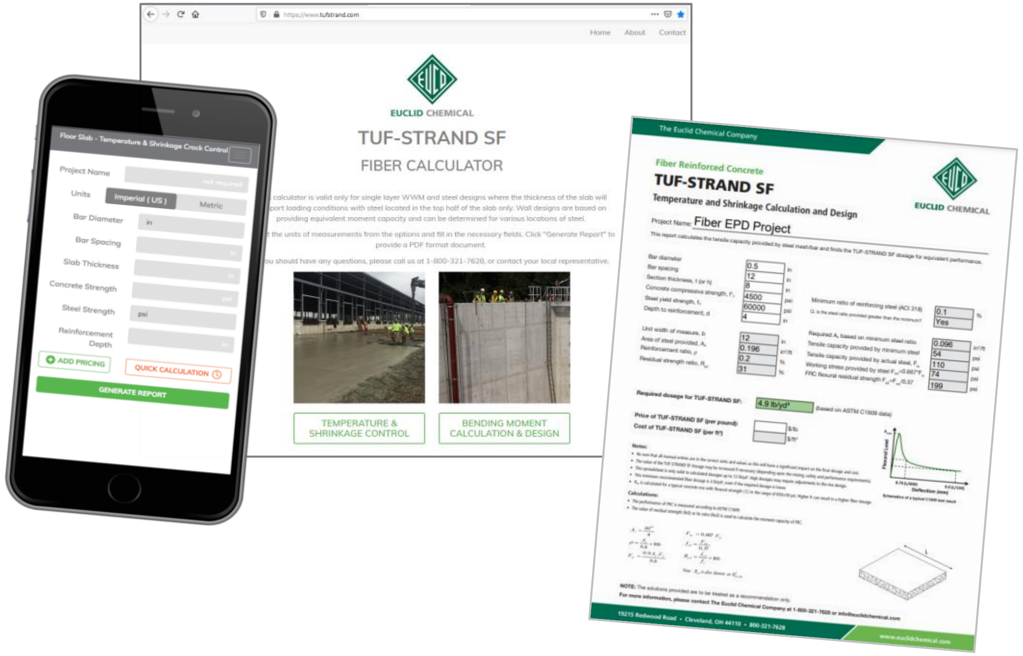
Volume = 6173 yd^3 of concrete

GWP Concrete	**1,884,836 kg**

Do the math…….

Reinforcing Steel Details

bar diameter	0.5	in
bar spacing	12	in
steel grade	60000	psi
Length of Steel Required	500000	ft
percentage for laps, splice, etc.	3	%
Length of Steel to Order	515000	ft
Steel density	490	lbs/ft3
Weight of steel required	344089	lbs



Macrofiber dosage to match = 5 pcy

TOTAL Fiber Req'd = 30,864 lbs

GWP Steel 132,702 kg

GWP Fiber 43,131 kg

Comparisons

Fiber 43131 kg
Steel 132702 kg

67% reduction in switching reinforcement options!

Note that these values do not include any site transport of reinforcing materials but fiber would already be included with delivery of the concrete while the 344,000 lbs of steel would need to arrive separately and require additional handling, storage and fabrication.

More details…..

concrete plus steel	2,022,251 kg CO2
concrete plus fiber	1,932,680 kg CO2

reduction in GWP by material substitution from steel to fiber **4.4% +**

STEEL COSTS

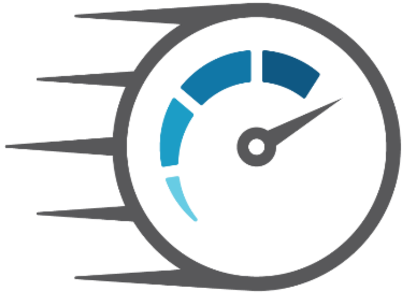
raw material	850	$/ton
installation	650	$/ton
TOTAL	1500	$/ton
Cost of Steel	$ 258,066.48	
Cost of steel per area	$ 1.03	$/ft2

FIBER COSTS

Cost of Fiber*	$ 5.00	$/lb
Total cost of fiber	$ 154,320.99	
Cost of fiber per area	$ 0.62	$/ft2

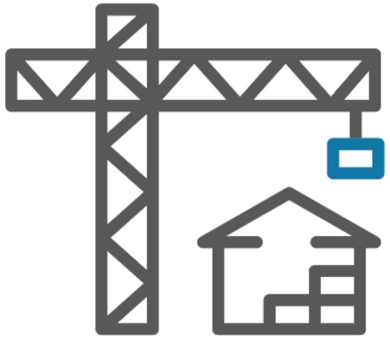
Based on 2023 costs for materials – substantial savings in real $$

Faster, Cheaper, Cleaner, Greener



No steel to deliver, cut, chair, install and inspect

With current steel prices plus install, fiber represents significant savings



Site impacts are reduced with less labor required and less material delivered needing storage

Quantifiable savings in CO_2 reduction and improvement in life cycle service life

What else is out there?

Over the past several years, there has been a renewed interest in the use of fiber reinforcement in concrete pavements for parking lots, white toppings, bridge decks and roadways. Various technical organizations such as the American Concrete Institute, American Concrete Pavement Association and the National Concrete Pavement Technology Center have developed new guidance and recommendations on how to properly select and use fiber types in concrete with new information available on long term serviceability and sustainable attributes available.

Conclusions

The use of concrete reinforcing fibers have been found to reduce CO_2 emissions by more than 50% compared to the corresponding steel reinforcing bars for the reinforcing portion of typical industrial floors and pavements.

Large reductions of CO_2eq are feasible by using fiber in place of steel reinforcing bars due to the large volume of reinforced concrete floors used worldwide

Other materials, such as chemical admixtures, advanced cements and supplemental cementitious materials can demonstrate additional significant reductions in overall upfront GWP values.

Sustainable Infrastructure Design can be accomplished using FRC which will significantly extend service life and offer much lower predictable operational energy.

Acknowledgements

Beton Consulting Engineers
Consultant and developer of LCA and EPD document

National Ready Mixed Concrete Association
EPD Review and Verification

In the end….

Concrete can be (and already is) green too.

The use of improved concrete mix designs, advancements in shrinkage technologies and fiber reinforcement can contribute to improving service life, durability and resilience while also contributing to the reduction of overall greenhouse gas emissions, or carbon footprint.

Thank you for your attention