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Insights into the Pull-Off Strength of Polymer Concrete and the Effect of Nanomodification

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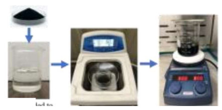
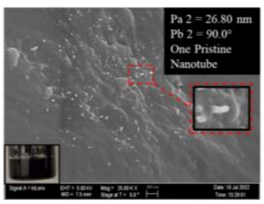
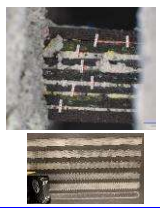
GALLOGLY COLLEGE OF ENGINEERING
SCHOOL OF CIVIL ENGINEERING AND ENVIRONMENTAL SCIENCE
The UNIVERSITY of OKLAHOMA

Innovative Materials & Methods *for* Emerging Research in Structural Engineering







Ali Akbarpour	PhD	Current
Sijan Adhikari	MS	Current
Trent Rogers	UG	Current
Alexandra Liever	UG+MS	Grad'23
Stephanie Castillo	UG	2022
Esther Nanziri Kayondo	UG	2022-23
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Outline

- BACKGROUND
- HYPOTHESIS and OBJECTIVES
- MATERIALS & METHODS
- RESULTS & DISCUSSION
- CONCLUSIONS & FUTURE WORK

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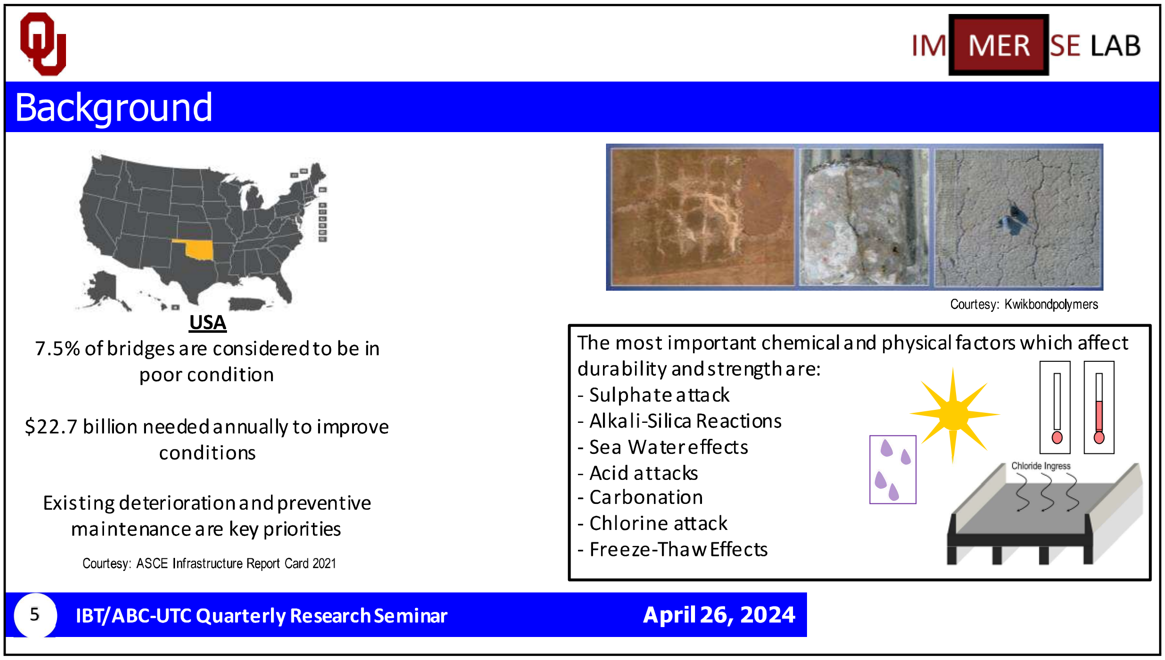
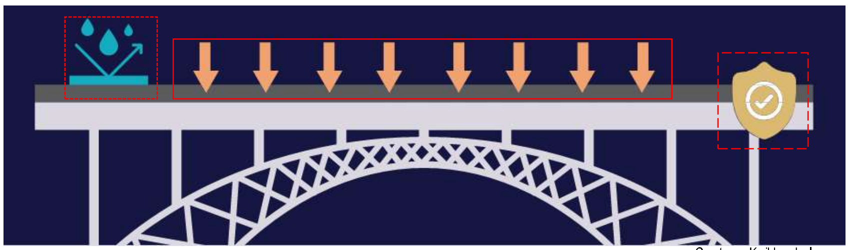
BACKGROUND



- **External sulfate attack:** most common type of distress and typically occurs where water containing dissolved sulfate penetrates the concrete
- **Sources:** seawater, oxidation of sulfide minerals in clay adjacent to the concrete (sulfuric acid formation), and bacterial action in sewers (sulfur dioxide then sulfuric acid formation)
- **Consequences:** include extensive cracking and expansion, overall loss of concrete strength and section

Background

Role of Polymer concretes in preservation treatments



Courtesy: Kwikbondpolymers

Minimize penetration of water, oxygen, chlorides and deicing salts

Protective barrier on top of concrete bridge deck

Improve deck performance and service life

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Background

Role of Polymer Concretes in preservation treatments Relevant to Accelerated Bridge Construction

- Rapid cure & light weight
- Minimizes traffic disruption
- Small thickness 0.375 – 1.5 inch
- Dead load increase of approximately 5 to 18 lb/ft^2
- Wear resistant
- Skid resistant



Courtesy: Kwikbondpolymers

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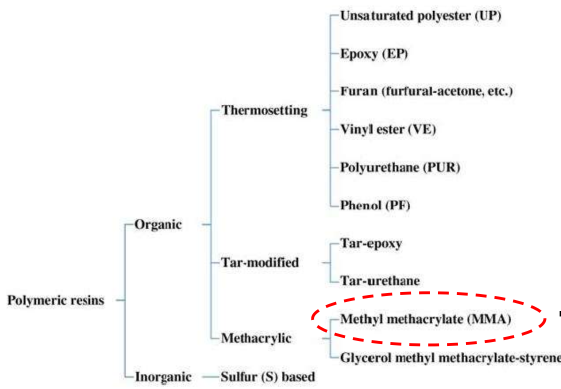
Background

What is a Polymer concrete?



+ Curing Agent or Initiator +

Silica or Basalt aggregates

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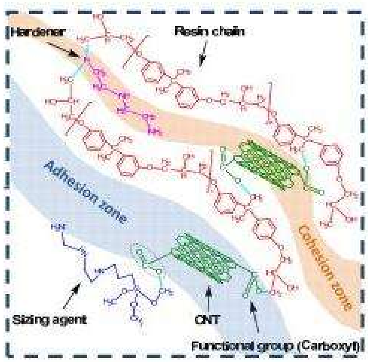
Background

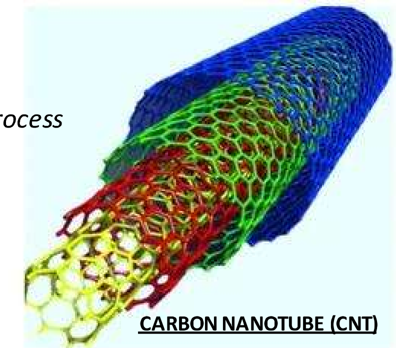
Nanomodification in Polymer concrete



Genedy, M., Daghash, S., Soliman, E., & Taha, M. M. R. (2015). Improving fatigue performance of GFRP composite using carbon nanotubes. *Fibers*, *3*(1), 13-29.

Adding nano size filler materials in polymer concrete has shown to improve

- *Ductility*
- *Fracture Toughness*
- *Improve Polymerization process*



CARBON NANOTUBE (CNT)

Zeeshan, A., Shehzad, N., Atif, M., Ellahi, R., & Sait, S. M. (2022). Electromagnetic flow of SWCNT/MWCNT suspensions in two immiscible water-and engine-oil-based newtonian fluids through porous media. Symmetry, 14(2), 406.

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Hypothesis and Objectives

Hypothesis

Due to their known **mechanical effects and chemical changes** on polymer systems, it is hypothesized that incorporation of **Carbon Nanotubes (CNTs)** may improve bond performance of polymer concrete with underlying concrete substrate by developing **chemical compounds** and **crosslinking agents** that are suitable for **adhesion and durability** of polymer concrete overlay systems

Objectives

To assess the performance of **ASTM 1583 pull off strength** of polymer concrete incorporated with **Carbon Nanotubes** with concrete substrate in **good condition** and with concrete substrate exposed to **sulphate exposure** and report on the **interface** characteristics

MATERIALS AND METHODS

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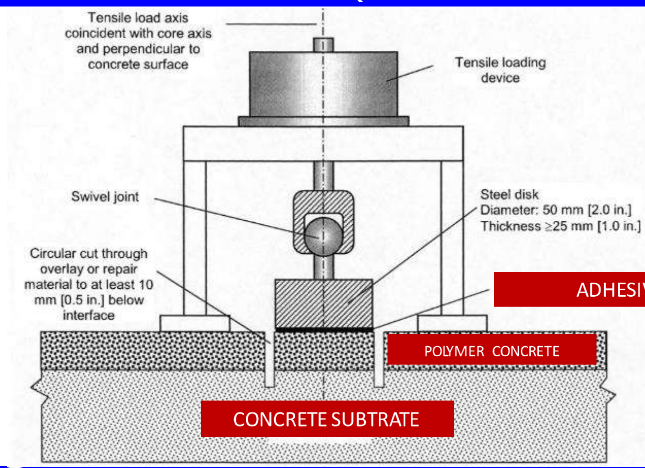
Materials & Methods (Pull-off Test – ASTM 1583)

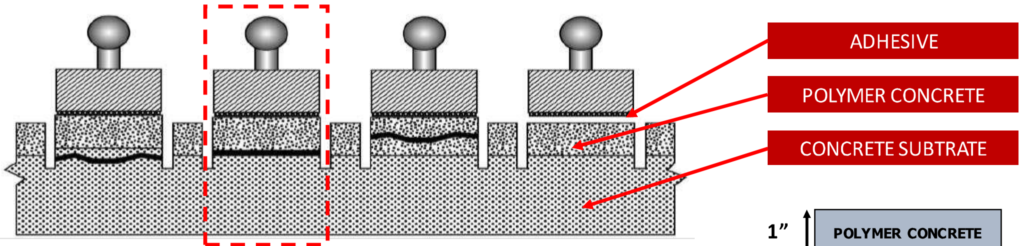


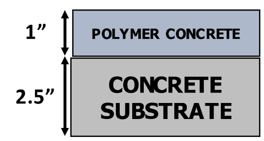
Designation: C 1583 – 04

Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)[1]

Courtesy: ASTM C1583-04

Materials & Methods (Pull-off Test – ASTM 1583)





$$\textbf{Bond or Tensile Strength}\,(psi) = \frac{\textbf{Tensile Load}\,(lbf)}{\textbf{Area of test specimen}\,(in^2)}$$

Courtesy: ASTM C1583-04

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Materials & Methods (Concrete and Polymer Concrete Mix Designs)

Substrate preparation:

Substrate fabrication

Portland Cementitious Concrete Mix

Material	Units	PCC
Superplasticizer		3.5
Water	kg/m^3	137
Portland Cement		455
Aggregate		910

Materials & Methods (Nanomaterial Dispersion)

Polymer concrete preparation:

Polymer Concrete Mix

Material	Units	PolC
T-17 Polymer Concrete Powder	kg/m^3	2000
T-17 Polymer Concrete Resin		250

Types	CNTs wt%
Neat	0
0.25Pristine	0.25
0.5Pristine	0.5
0.25COOH	0.25
0.5COOH	0.5
$0.25NH_2$	0.25
$0.5NH_2$	0.5

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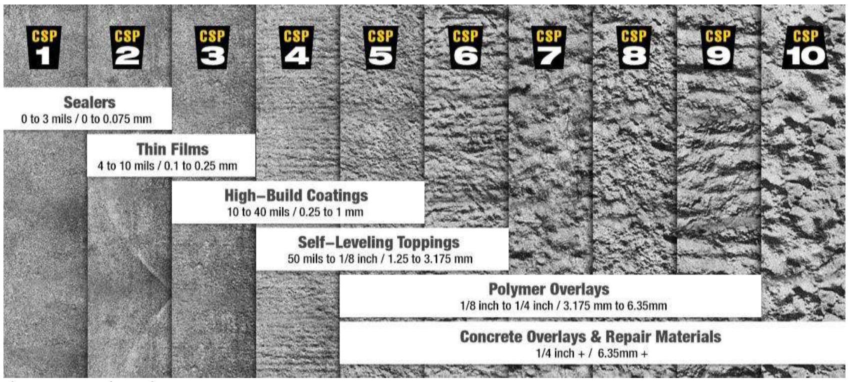
Materials & Methods (Surface Preparation)

CONCRETE SURFACE PREPARATION (CSP)



Courtesy: ICRI, Graco.com

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Materials & Methods (Surface Preparation)

CONCRETE SUBSTRATE **BEFORE** SURFACE PREPARATION

CONCRETE SUBSTRATE **AFTER** SURFACE PREPARATION

POLYMER CONCRETE OVERLAY **BEFORE** SURFACE PREPARATION

POLYMER CONCRETE OVERLAY **AFTER** SURFACE PREPARATION

Be prepared to answer a question on how you achieved this CSP
Check https://www.graco.com/us/en/contractor/solutions/articles/concrete-surface-prep-part-3-grades-of-roughness.html

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Materials & Methods (Pull-off Test – ASTM 1583)

UNIVERSAL DRILLING MACHINE

HYDRAJAWS 2000

Materials & Methods (Sulphate attack cell)

Sulfate solution container

The pH was maintained equal to 3

- To understand the effect of polymer concrete modification with one of the chemical and physical factors which affect durability and strength that is sulphate attack
- Concrete substrates were subjected to sulfate attack for 210 days
- Periodic observations of the substrates were made to visualize extent of deterioration

Materials & Methods (Sulfate attack)

Ettringite

After 210 days

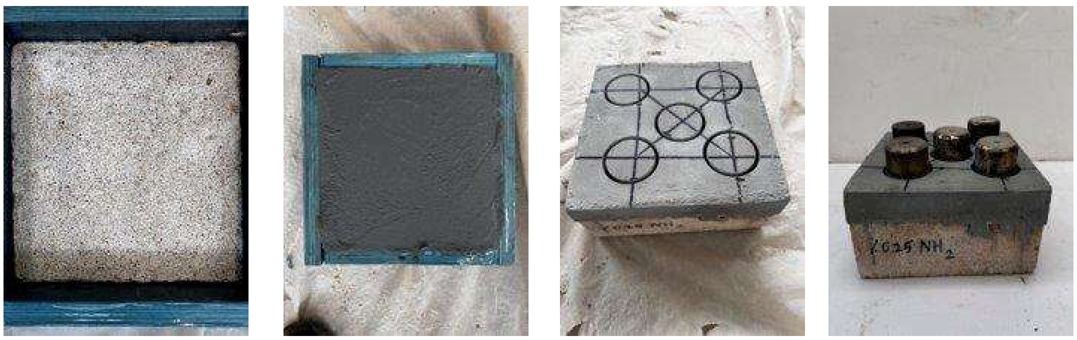
After surface preparation

After 28 days

After 140 days

Materials & Methods (Sulphate attack cell)

Process of preparation of sulphate exposed substrate for pull-off experiment



RESULTS AND DISCUSSION

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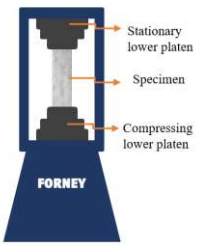
Results and Discussion (Mix Designs Evaluation – Compressive Strength)



ASTM C39

ASTM C579

Materials	Compressive strength (MPa)
Portland Cement Concrete	67.4 ± 1.1
Polymer Concrete	59.9 ± 0.9

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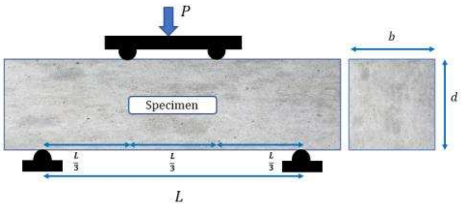
Results and Discussion (Mix Designs Evaluation – Modulus of Rupture)



Materials	Modulus of Rupture (MPa)
Portland Cement Concrete	7.8 ± 0.11
Polymer Concrete	23.7 ± 0.72

ASTM C78

ASTM C580

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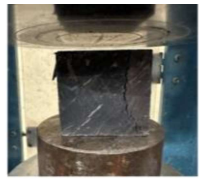
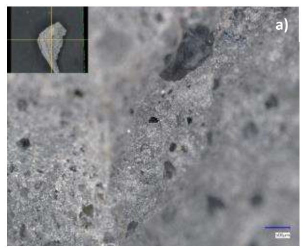
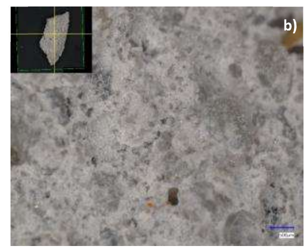
Results and Discussion (Nanomodification and Dispersion)

Dispersion Stabilization
Picture taken 48 hours after initial dispersion

Cubes under compression and fracture propagation







Fracture surface showing small dark particles spread across homogeneously

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Results and Discussion (Pull-off Test – ASTM 1583)

Failure in concrete substrate

Failure in interface of concrete substrate-polymer concrete

Failure in polymer concrete

Results and Discussion

Type	CNTs wt%
Neat	0

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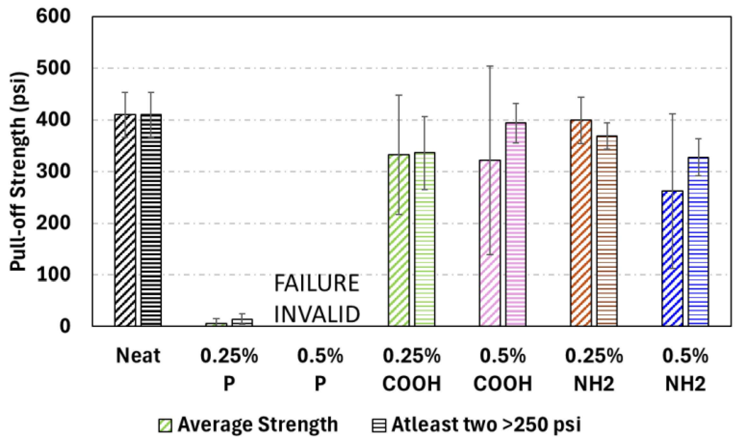
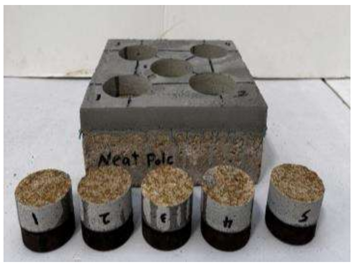
Results and Discussion



Results and Discussion



Failure in polymer concrete

Failure in interface of concrete substrate-polymer concrete

Failure in concrete substrate

Results and Discussion

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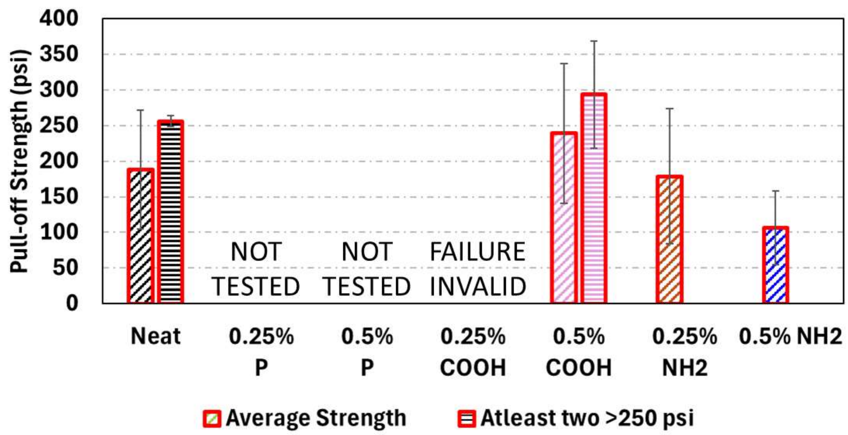
Results and Discussion



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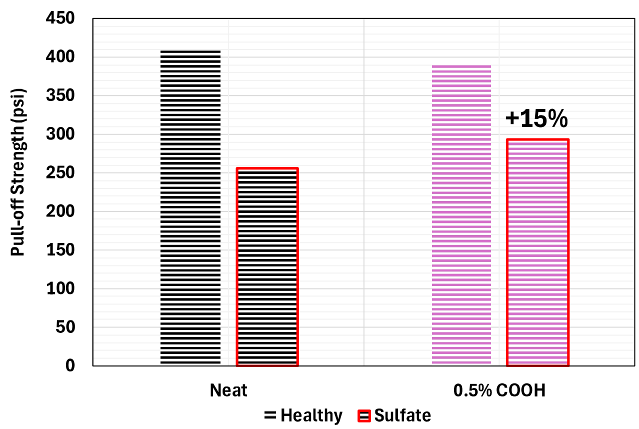
Results and Discussion



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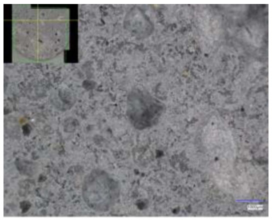
Results and Discussion (Microscopic Analysis)

Interface of pull off using the Keyence VHX-7000 ultramicroscope

Neat

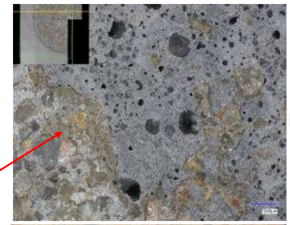
Healthy



Sulfate

0.5% COOH

Healthy



Sulfate

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CONCLUSIONS & FUTURE WORK

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Conclusion and Future Work

- This work investigates for the first time into pull off strength of nano-modified polymer concrete for concrete preservation
- Polymer concrete has a tensile strength of at least 3 times of concrete and is highly suitable for Accelerated Bridge Construction
- 0.5wt.% of COOH CNTs can have the same pull off strength as neat polymer concrete while offering other benefits such as ductility, improved fracture toughness and chemical effects
- Polymer concrete containing 0.5% COOH demonstrated 15% increase in pull off strength with sulphate exposed concrete substrate compared to neat polymer concrete.
- Pore character changes at interface on nanomodified polymer concrete were observed
- Investigating cost analysis, and also, the effects of other chemical and physical factors on the pull off strength can be considered for future work.

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Acknowledgements

ABC UTC ACCELERATED BRIDGE CONSTRUCTION UNIVERSITY TRANSPORTATION CENTER

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NSF National Science Foundation

ES ICC EVALUATION SERVICE

NEX An ACI Center of Excellence for Nonmetallic Building Materials

ODOT Oklahoma Department of Transportation

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