Third International Workshop on FRP Bars for Concrete Structures (IW-FRPCS3)

Workshop Theme: "Advances in concrete reinforcement"

Date: August 3-4th, 2021

DAY 2 Wednesday, August 4th

Session 5: FRP Rebar Research Needs and Advancements (10:00-11:30am)

(Gaps in Research & Latest Advances)

RoundTable discussion preceded with 5-minute presentations by panelists.

Moderator: Brahim Benmokrane (US)

Panelists (5 mins)

- New ACI Center of Excellence and future collaboration opportunities: David Lange (ACI NEx)
- Endurance Limits – Creep Rupture & Fatigue: Antonio Nanni (UM) & Brahim Benmokrane (US) No Slides
- Shear Reinforcement Strain limits: Abdeldjelil "DJ" Berlarbi (UH) Slides pending
- Flexural Resistance Factors: Carol Shield (UMN)
- Ductility/Deformability Index: Ozzie Bayrak (UT-Austin)
- Thermoplastic-rebar: Tomaso D'Antino (Polimi)
- Nano-Rebar: Mahmoud Reda Taha (UNM)
- NDT Inspection: Reza Zoughi (IASU)

NEx
An ACI Center of Excellence for Nonmetallic Building Materials

My first talk about NEx

David A. Lange, PE, Ph.D
NEx Executive Director
Emeritus Professor, University of Illinois

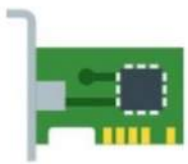
Third International Workshop on FRP Bars for Concrete Structures (IW-FRPCS3)
Workshop Theme: "Advances in concrete reinforcement"
August 3-4th, 2021

2018-19
My year as ACI President

- April 18, 2018 -- Hearing held by Congressional Committee on Science, Space and Technology -- Subcommittee on Research and Technology.
- **Topic: How can we overcome barriers to use of composite materials in infrastructure.**
- **Lack of codes & standards:** "Adoption of advanced composite materials has been slow due in part to the presence of two dominant design paradigms in commercial construction – reinforced concrete and steel, but there will be numerous benefits from the integration of these newer materials."
- **… and engineering education that follows.**

ACI strategic planning -- innovation and vision

From ACI’s 2030 Report



TECHNOLOGICAL ADVANCES

Robots, 3D printing, BIM, GPS, RFID and other technology are having an immediate impact on businesses.

Technological Advances — The field of concrete materials and structures is continually infused with new ideas and practices. New materials, products, methods, designs, and equipment impact the way infrastructure is constructed. Robots and 3D printing will have an impact on construction methods. Components of concrete materials (e.g., new binders, fibers, admixtures), structural systems (e.g., connections, reinforcement), construction practices (e.g., BIM, GPS, RFID tagging) and new technologies (sensors, probes, data mining) affect costs and efficiencies. These factors have immediate impact on business and represent a challenge for organizations that seek to provide technical leadership.

From ACI's 2030 Report

EXPAND THE REACH OF THE ACI

Expand into materials and areas the ACI currently doesn't represent as well. Expand interorganizational relationships. Improve the ACI's reach across industries. Extend the ACI's reach into educational programs.

Recommendation 9: Expand reach of ACI

We believe that an ACI with broader reach is a healthier ACI. We recommend that ACI adopt policies and actions to expand its reach to new constituencies. We see evidence that effective alliances can be established that lead to revenue streams through CAM, and ACI has been an incubator of organizations that work within the concrete industry (e.g., ICRI, TMS, PTI, KCI, JCI). Some ways to do this include:

- Expand ACI into materials that we do not currently represent as well, such as alternative cements, polymers, and composites for civil infrastructure. These materials may not be as established as

NEx

An ACI Center of Excellence for Nonmetallic Building Materials

Partnership drives action

21 km long reinforced concrete flood mitigation channel reinforced with GFRP at the site of the Jazan Economic City

"Aramco has been developing and deploying nonmetallic solutions within our own operations for more than 20 years, as they offer superior life-cycle cost, efficiency, and environmental advantages over their metal alternatives. The potential for using nonmetallic advanced polymetric materials, however, goes way beyond the oil and gas sector and includes the building and construction industries, where there is significant potential. That is why this new Center of Excellence for Nonmetallic Building Materials offers enormous and exciting opportunities."

Ahmad A. Al-Sa'adi,
Senior Vice President of Technical Services, Aramco,
Founding Member of NEx

What is an “ACI Center of Excellence”?

NEx
An ACI Center of Excellence for Nonmetallic Building Materials

Vision

NEx envisions a future where everyone has the knowledge needed to use nonmetallic building materials effectively to meet the demands of a changing world.

NEx MISSION

To collaborate globally on the use of nonmetallic building materials to drive research, education, awareness, and adoption.

NEx STRUCTURE

American Concrete Institute

As a stand-alone subsidiary of the American Concrete Institute with its own Board of Direction, Steering Committee, and committees, NEx leverages the resources and relationships of ACI to further its mission.

NEx PARTNERS

Companies and organizations across the value chain are needed to support and collaborate on executing the core functions and meeting NEx's objectives. These prospective partners include:

- Manufacturers and suppliers of nonmetallic products
- Standards bodies
- Technical societies/institutes
- Oil and gas companies
- Research centers
- Construction companies and developers
- Training centers
- Specifying agencies

CORE FUNCTIONS

Committees will be developed to align with NEx's priorities, with direction and funding from the NEx Steering Committee. Committees will advance the following core functions:

Standards and Specifications

It is recognized that critical design and construction tools for the deployme of nonmetallic building materials are only partially available. There is a nee for unambiguous standards in the form of building codes, construction specifications, material specifications, and more.

Technical Committee Acceleration

American Concrete Institute committees are recognized as a resource for unbiased *consensus* information on topics related to reinforced concrete. Where ACI already has committees that address certain aspects of nonmetallic reinforcement, NEx can support these committees with the latest technical information and research. In some instances, coordination with other industry organizations may be appropriate.

Professional Development

Technology transfer is at the core of successful deployment—designers, contractors, and owners are not necessarily familiar with new technologies NEx will develop and deliver programs including short courses, webinars, and software tools, while also leveraging ACI facilities in Michigan, Californ Illinois, Dubai, and beyond.

Certification of Personnel

Workforce certification is a must to transform the construction industry and ensure safety. The creation of specific certification programs for field personnel may include topics such as: reinforcement storage, handling, installation, and field inspection and Q/A.

Plant Audit/Certification

The setup of plants to manufacture nonmetallic building materials may not be capital-intensive; thus, new manufacturers can appear with unsubstantiated product performance claims. Additionally, changes in key constituents in product manufacturing are hard to detect. Plant production Q/C and plant certification appear to be a critical opportunity to ensure quality and consistency.

Research and Development

Even though research and development has been conducted over the last 30+ years, more needs to be done for the effective and efficient deployment of nonmetallic reinforcement technology in terms of better understanding physical performance (for example, slabs-on-ground); development of new tools (for example, mechanical couplers, reinforcement detection, and repair of damaged reinforcement); methods for establishing financial viability (for example, procurement protocols and LCC/LCA studies), and more. Through the support of partners, NEx will fund these industry-critical initiatives.

Advocacy and Technical Support

NEx will develop educational campaigns on NEx initiatives and the benefit of nonmetallic building materials for appropriate communication to the international community.

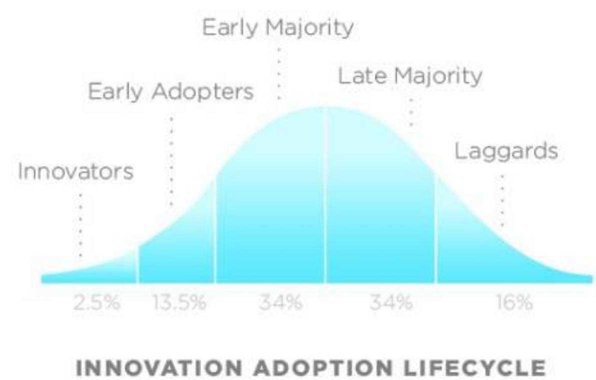
International Outreach

NEx will strategically leverage ACI's relationships and network of global leaders, international partners, and international chapters to meet the global needs of the Center of Excellence.

FUTURE

The uses for nonmetallic building materials far exceed the bounds of the concrete industry—additional areas include asphalt, cladding, structural components, flooring, and soil. These other areas will make it necessary for NEx to develop relationships with leading technical societies specializing in these areas.

Comments from previous speakers today about barriers:
“harmonization of codes”
“steel writes the rules”
“civil engrs are conservative … slow”
”industry has been at this a long time…it takes a village to innovate”



NEX
An ACI Center of Excellence for Nonmetallic Building Materials

We are just getting started.
Join us!

THIRD INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURS

"Advances in concrete reinforcement"

August 3-4, 2021 - Virtual

Flexural (and Shear) Resistance Factors

Carol Shield, University of Minnesota, USA

Ayman Okeil, Louisiana State University, USA

UNIVERSITÉ DE SHERBROOKE UNIVERSITY OF MIAMI Center for Integration of Composites into Infrastructure FDOT

History of calibration

- First calibration done in 2004
- At that point there were only two major FRP bar manufacturers
  - Statistics for $f_{fu\_tested}/f_{fu\_guarenteed}$

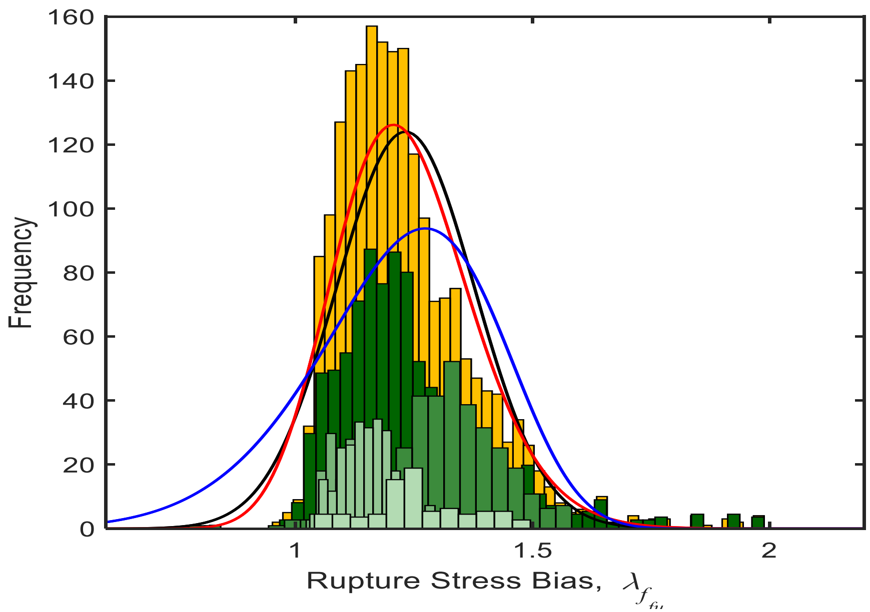
    Average between 1.1 and 1.2, COV between 4 and 12% (depends on bar size)
  - Statistics for $E_{f\_tested}/E_{f\_nominal}$

    Average 1.04, COV of 8%
- Flexural test-to-predicted ratios from 62 tests in the literature
- Results ϕ=0.55 for rebar rupture failures

  ϕ = 0.65 for concrete crushing failures
- Shear resistance factor was not calibrated at that time

Challenges of Calibrations Today

- Many more FRP bar manufacturers
  - Different statistics (Ave and COV) for the different manufacturers
  - How to chose bias an COV for calibration?



Analysis results of tensile strength, f_{fu}, test data

Manufacturer	No. of Tests*	Bias	COV
A	1,012	1.235	12.94%
B	38	1.191	5.35%
C	382	1.323	8.72%
D	34	1.122	4.17%
E	205	1.146	6.66%
F	292	1.155	5.13%
G	90	1.260	8.57%

Challenges of Calibrations Today

- Very limited published data on **shear** failures (especially with stirrups)
  - Keeping only published data with measured material properties
    - 57 tests with no stirrups
    - 11 tests with stirrups
  - Very large COV on this set of test data

	No stirrups	With Stirrups
N points	57	11
Min	0.68	0.78
Max	3.85	2.61
Ave	1.8	1.6
COV	31%	41%

Lessons Going Forward

- Need more quality tests (especially for shear)
  - Measured material properties
  - Report key parameters (like d and cover)
  - Make sure other code requirements are met (like stirrup spacing no larger than d/2)
- Probably need to standardize more than one GFRP bar type
  - Need to develop new standards in addition to ASTM D7957
  - Would help to make bar properties more uniform between producers

Redundancy

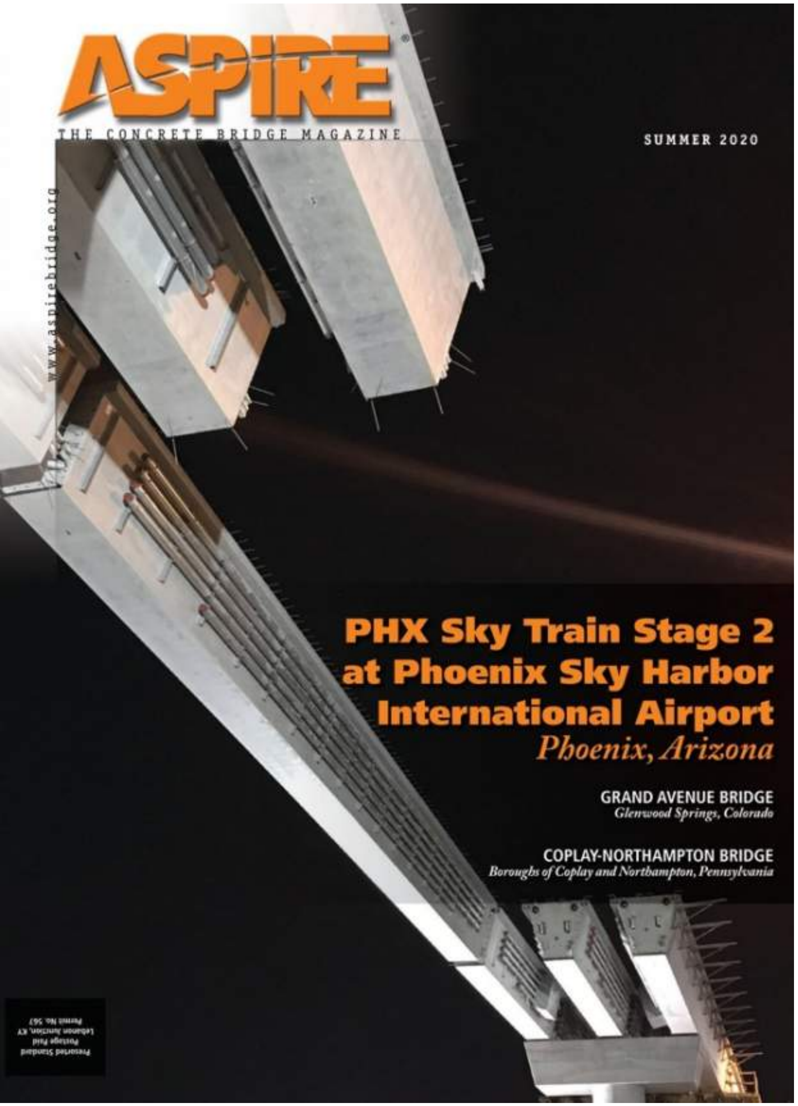
OGUZHAN BAYRAK, Ph.D., P.E.

Redundancy: You can Google that…

“…The state of being not or no longer needed or useful…”

“…Redundant does not mean repetitive. People sometimes get confused because the 're' in redundant suggests repetition. In fact, the word has a totally unrelated meaning. Redundant means unnecessary or superfluous…”

Redundancy : Aspire Summer 2020



PERSPECTIVE

Perspectives on Structural Behavior and Redundancy: Structural, Load Path, and Internal Redundancies

by Dr. Oguzhan Bayrak, University of Texas at Austin

Concrete bridges have long been a preferred solution for bridge owners due to their adaptability, versatility, durability, and reliability. An important attribute of concrete bridges relates to their redundancy, which can be defined as the ability of a concrete bridge at either its system level or the component level to develop alternate load paths at the strength limit state or under extreme loads. This article focuses on redundancy, with the intent of providing a succinct discussion about the effects of redundancy on structural behavior.

Structural Redundancy

At its most basic level, redundancy can be described by the level of indeterminacy present in a structure. The level of structural indeterminacy controls the behavior of a structure as it is gradually loaded to failure. To facilitate a discussion of collapse mechanisms as a function of redundancy, consider a reinforced concrete beam with ample shear capacity for which flexure is the controlling failure mode.

If a simply supported reinforced concrete beam supporting a concentrated load at its midspan is loaded to failure (**Fig. 1a**), the beam develops a plastic hinge at the section of maximum moment. At this point a plastic mechanism forms and the beam collapses. The beam fails in this manner because the beam is statically determinate.

If the same beam is continuous at support B (**Fig. 1b**), the beam is statically indeterminate—that is, there are more support reactions than the number of equilibrium equations that can be written to determine the support reactions. In this case, under a gradually increasing load *P*, the first plastic hinge will form either at midspan or at support B. The location where the first hinge occurs is a function of the magnitude of the applied moments at those sections, as well as the respective flexural capacities of the reinforced concrete beam at the maximum positive and negative bending moment sections. Regardless of its location, the beam does not collapse at the formation of the first plastic hinge. A second plastic hinge is needed to complete the collapse mechanism shown in Fig. 1b. The incremental load needed to form the second plastic hinge gives an opportunity for engineers, inspectors, and the general public to observe the structure in distress and take necessary actions.

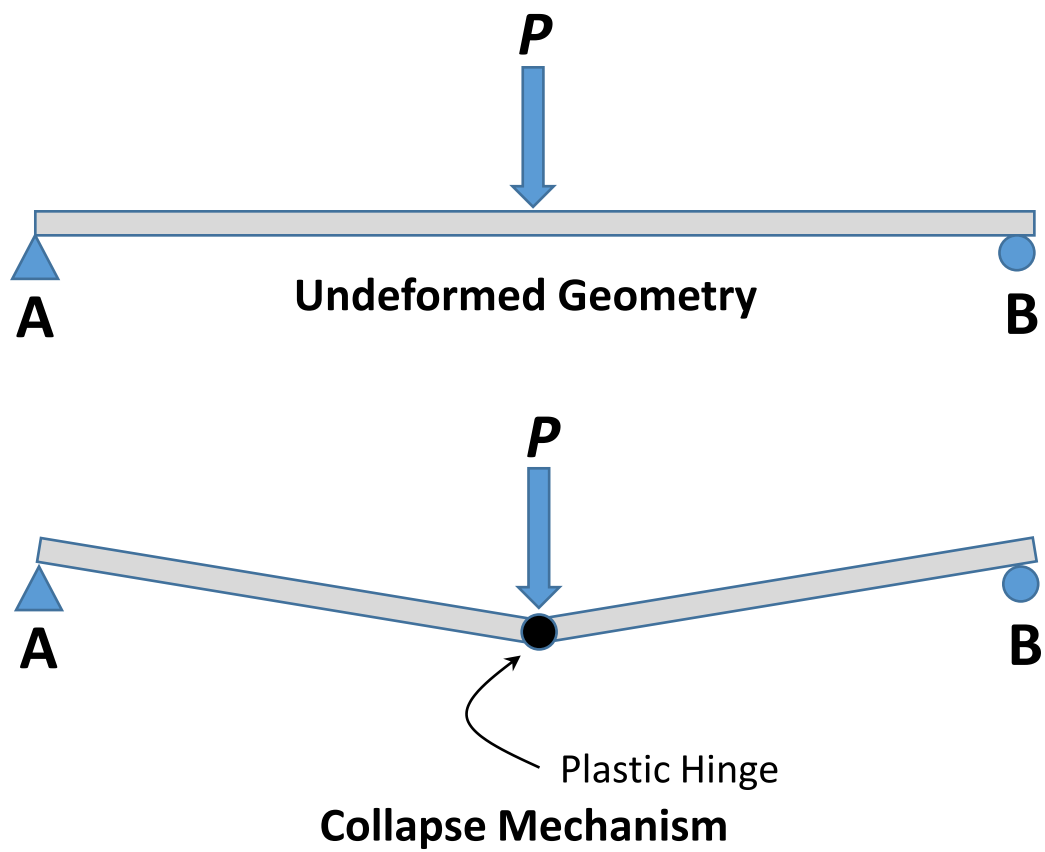
Load Path Redundancy

To discuss load path redundancy, let us focus on a bridge with five girder lines (**Fig. 2**). In this case, assume that the bridge span under consideration is simply supported. That is to say, the reinforced concrete deck is supported on five simply supported pretensioned concrete girders that are supported on bearing pads and are free to rotate at the supports. In this case, the superstructure has load path redundancy, which is explained in the following discussion.

If one of the fascia girders shown in Fig. 2 were to be hit by a truck at location 1 and all prestressing strands were severed, we can assume that the fascia girder has failed because it has no positive moment resistance. If the reinforced concrete deck has top and bottom mat reinforcement in longitudinal and transverse directions at location 2 of Fig. 2, the load that can no longer be supported by the

Structural Redundancy

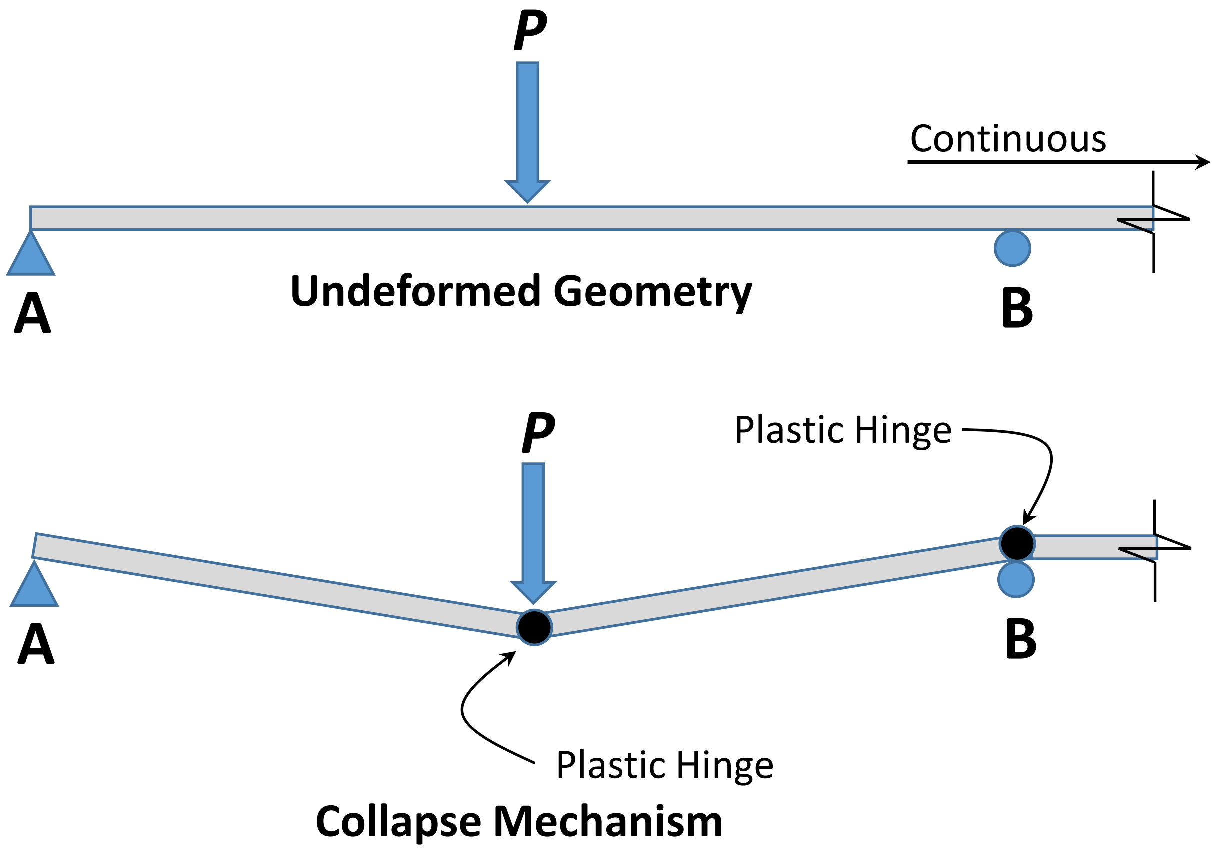
- The level of indeterminacy present in a structure



(a) Simply Supported Span

Structural Redundancy

- The level of indeterminacy present in a structure

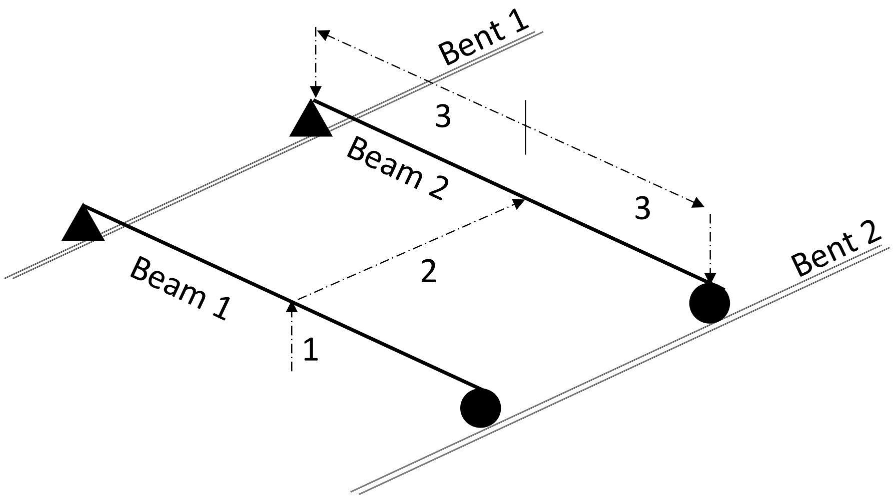


(b) Continuous at one end

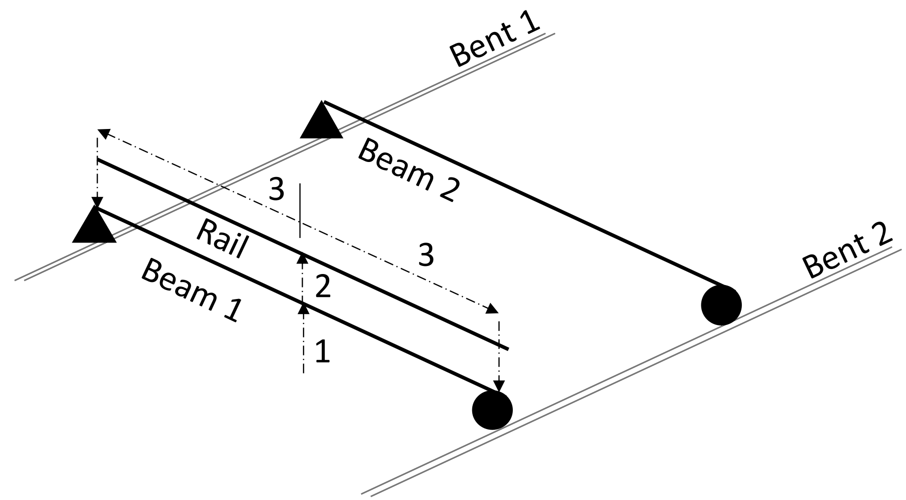
Load Path Redundancy

Picture Credit: Mark Bloschock

Load Path Redundancy



Alternate Load Path 1

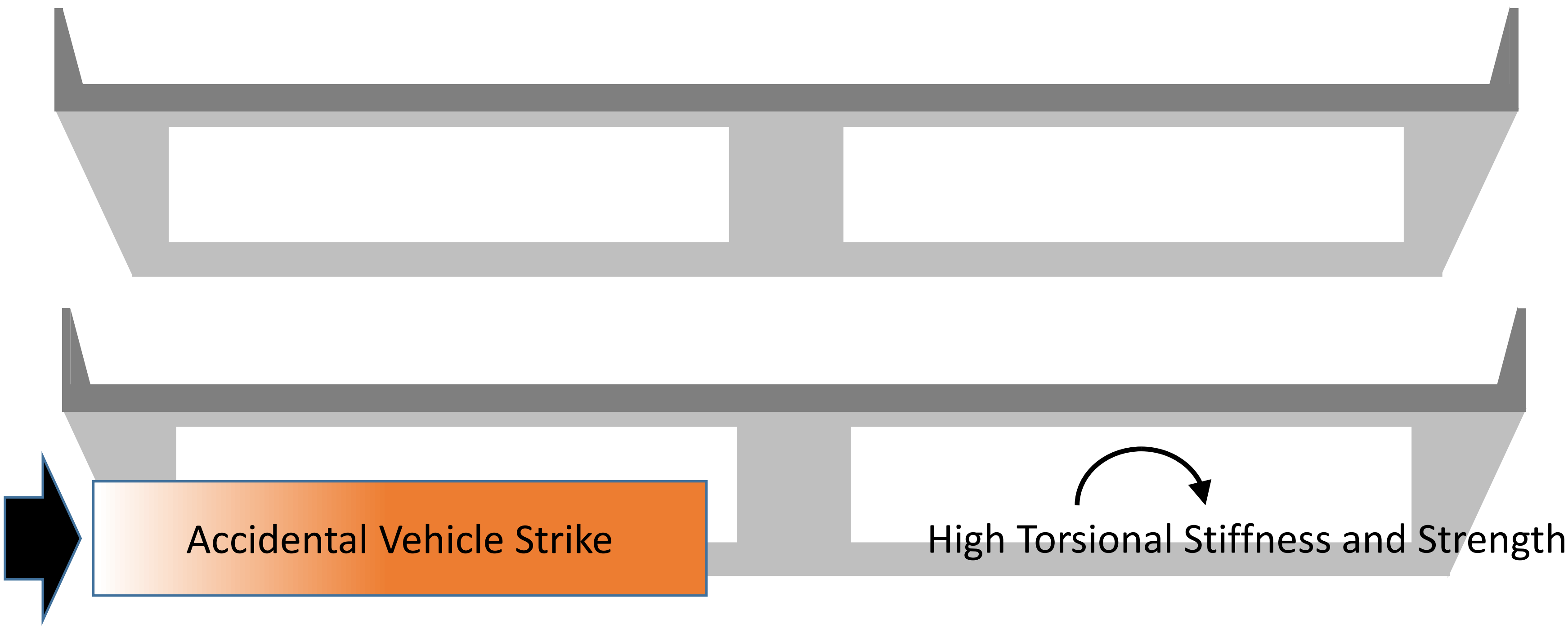


Alternate Load Path 2

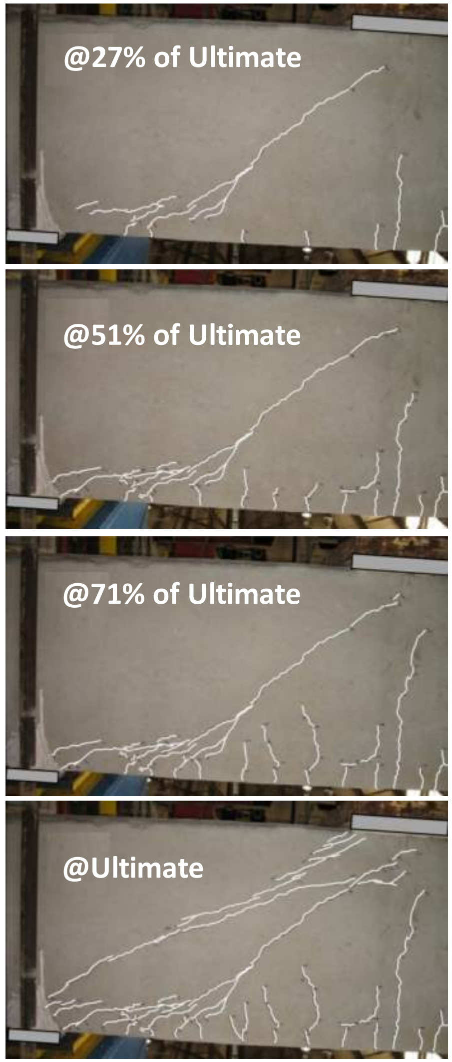
Load Path Redundancy

Picture Credit: Mark Bloschock

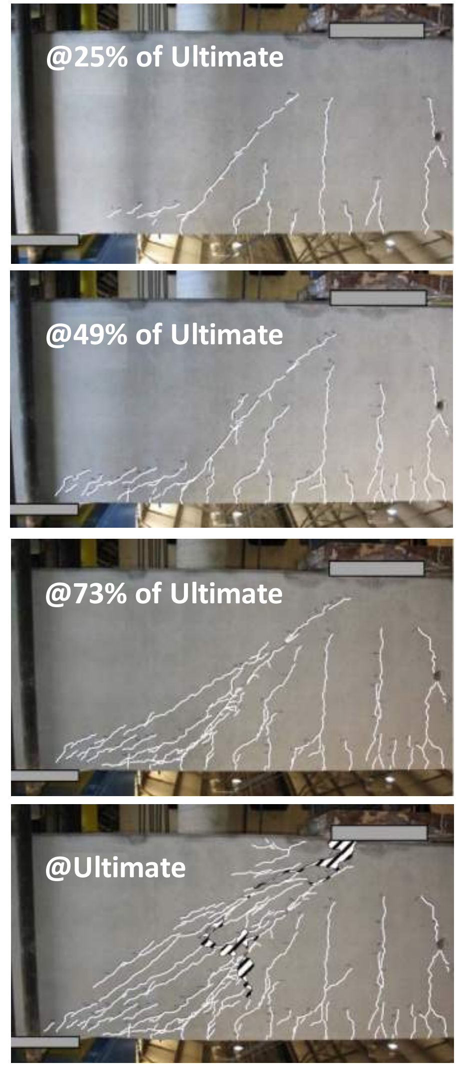
Load Path Redundancy



Internal Redundancy



Specimen without
Crack Control Reinforcement

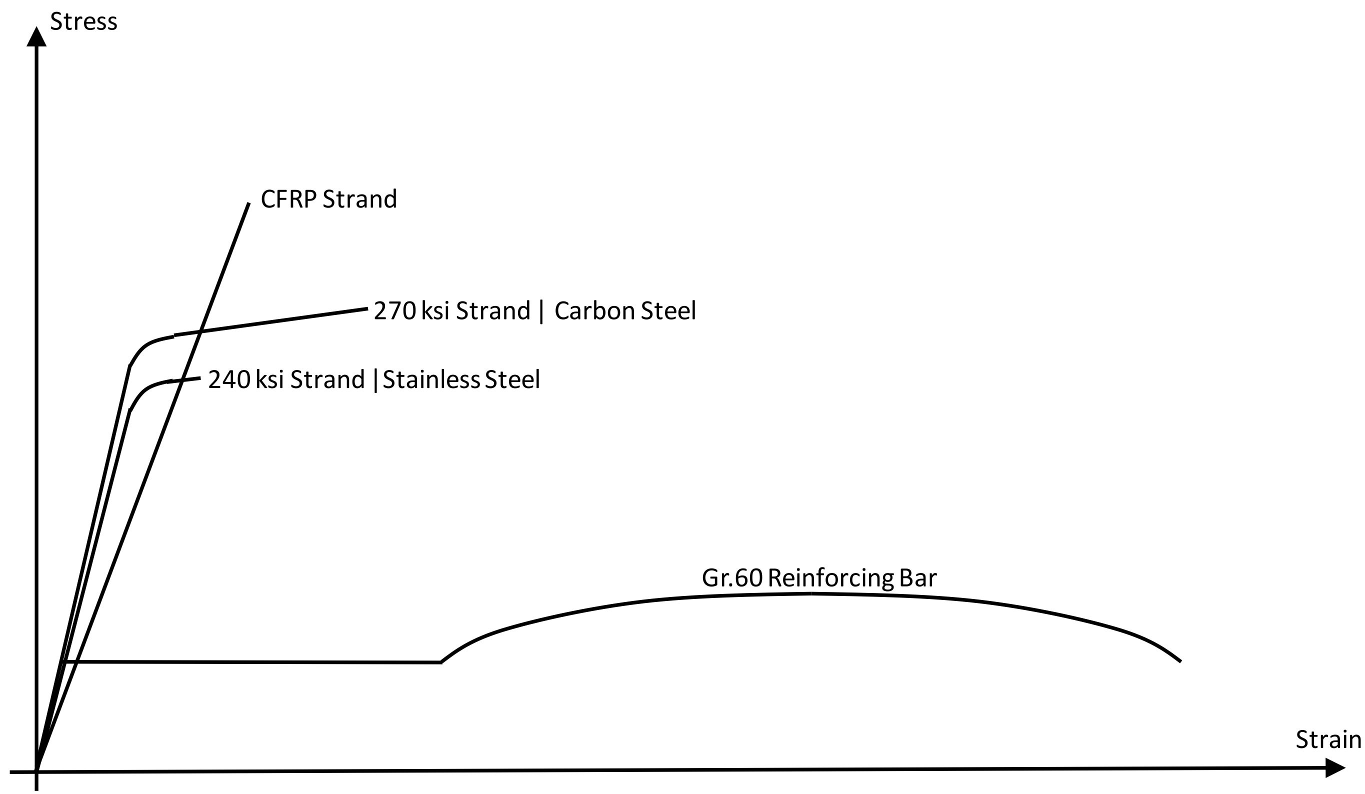


Specimen with
Crack Control Reinforcement

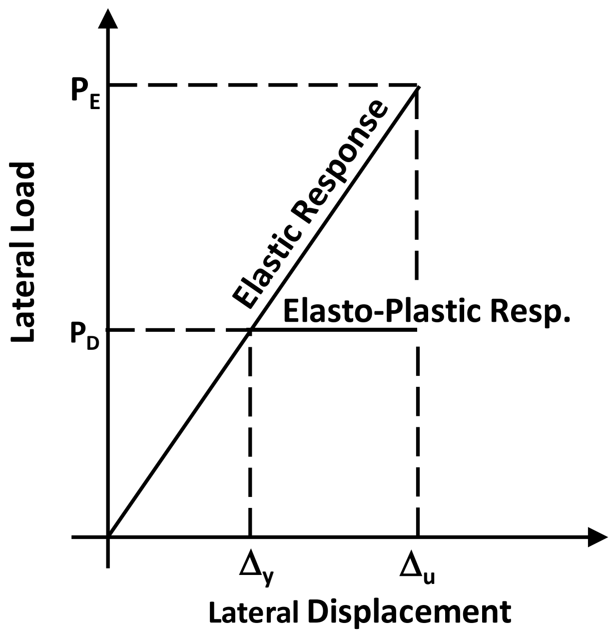
LRFD | New Materials and Technologies

- Brittle (non-ductile), and less-ductile materials
- Appropriate load and resistance factor selection
- Implications on system reliability

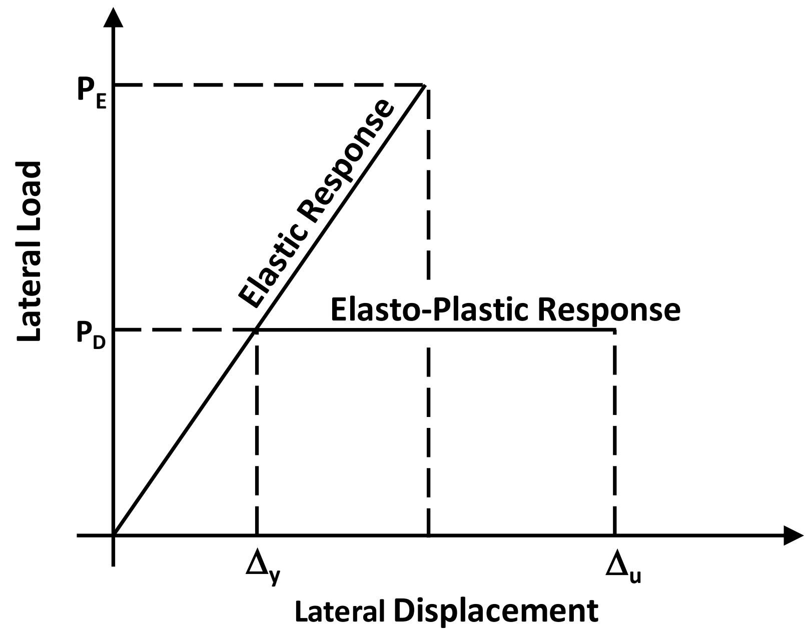
LRFD | New Materials and Technologies



LRFD | New Materials and Technologies



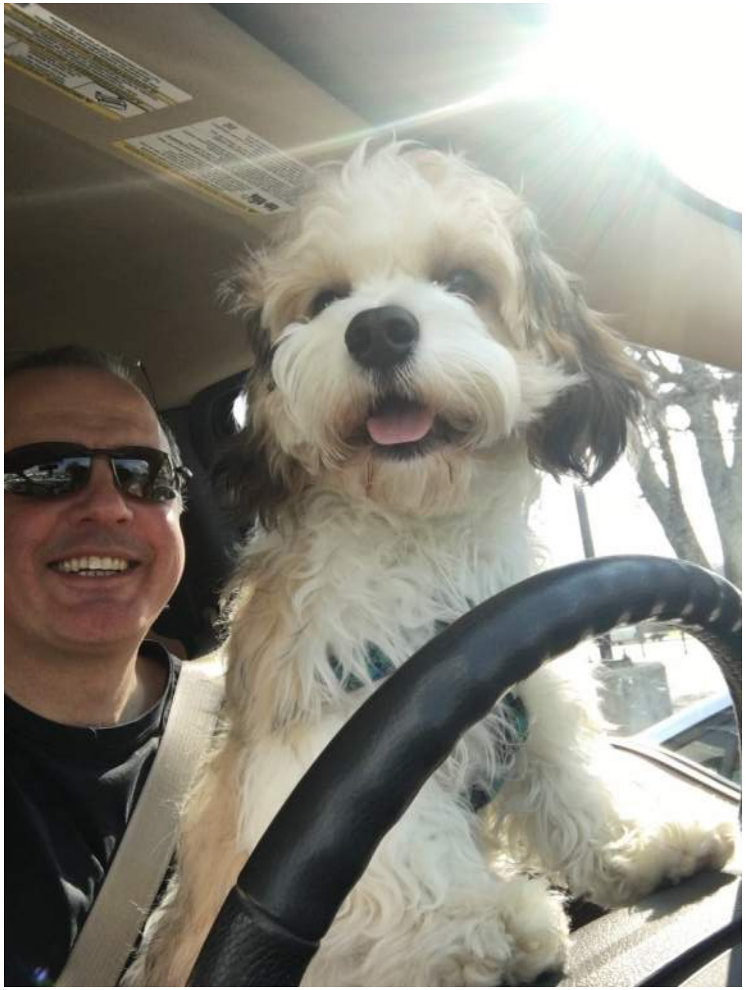
a. Principle of Maximum Displacement



b. Principle of Maximum Potential Energy

Important Considerations

- Concrete bridges have been performing well
- As we introduce new materials and technologies, we must be careful about building in:
  - Alternate load paths
  - Trying to force ductile failure, where possible
  - Use low ϕ-factors, for brittle/undesirable failure modes
- It is hard (but not impossible) to improve already efficient, well-performing and durable systems (i.e. concrete bridges). We must think through all intended (e.g. increase durability by using flexible fillers) and unintended (e.g. inability to re-develop a strand if it experiences a wire break)



Oguzhan Bayrak, Ph.D., P.E.
Phil M. Ferguson Professor
Distinguished Teaching Professor
The University of Texas at Austin

(512) 232-6409 –voice FSEL
(512) 232-7826 –voice campus
(512) 471-1944 –fax
(512) 965-2875 –mobile

THIRD INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURS

"Advances in concrete reinforcement"

August 3-4, 2021 - Virtual

Thermoplastic-rebar

Tommaso D'Antino, Politecnico di Milano, Milan, Italy

POLITECNICO MILANO 1863 | UNIVERSITÉ DE SHERBROOKE | UNIVERSITY OF MIAMI | Center for Integration of Composites into Infrastructure | FDOT | sireg

Thermoplastic-rebar

The Thermoplastic-rebar allows the **diffusion and large-scale use of GFRP rebar** in the construction sector.

GFRP thermoplastic-rebars can be universally applicable **exactly like steel rebars** in today market:

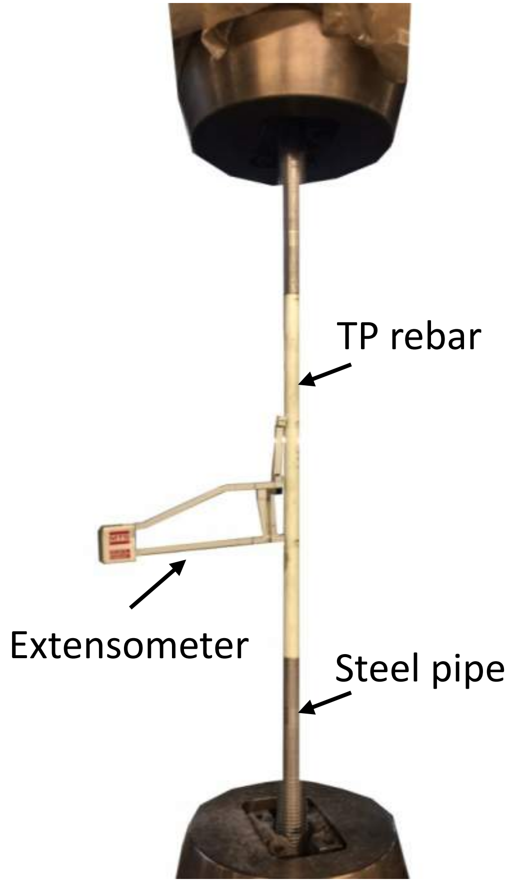
1. Produced by GFRP manufacturer in standard straight rebars or coils (**from make-to-order to make-to-stock model**) ⟶ shorter lead time from order to delivery on site

2. Shipped to bending and distribution centers (i.e actual steel rebar distribution and bending centers) ⟶ Optimized transportation costs and times

3. Bended with certified and automated bending machine:

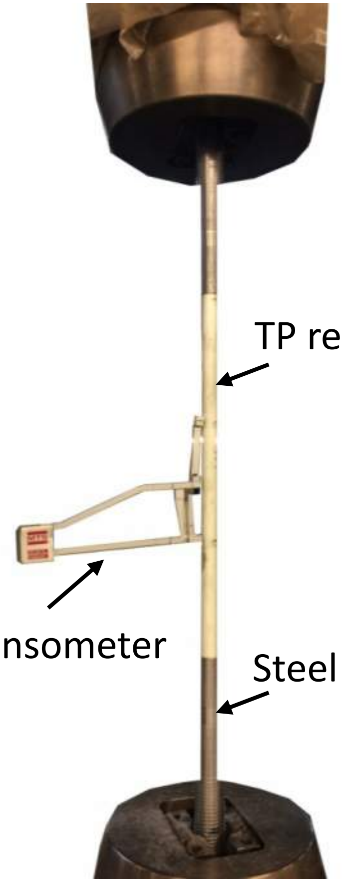
   - Same mechanical properties and durability of straight thermoset rebars
   - Better quality of the bent
   - Reduced bent radius of bent rebars

Tensile testing (3 specimens)



Failure load (avg) = 135 kN (30.30 kip)
Tensile strength (avg) = 1192 MPa (173 ksi)
Elastic modulus (avg) = 61013 MPa (8849 ksi)

Tensile testing after alkali exposure (3 specimens)

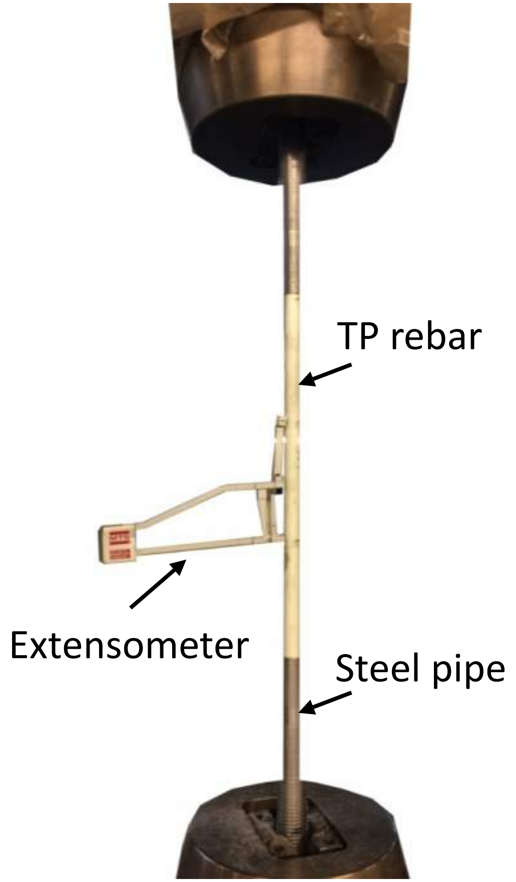


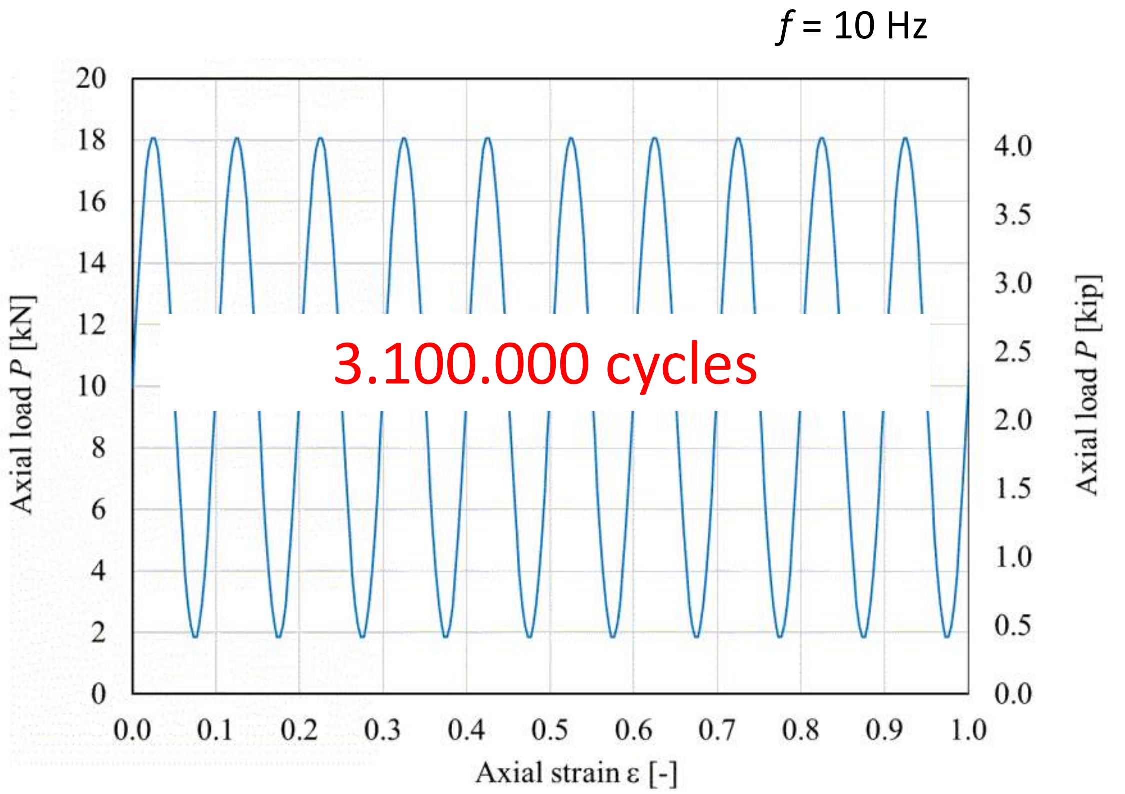
ph=13.5
60°C

	Retained
Failure load (avg) = 115 kN (25.85 kip) →	85%
Tensile strength (avg) = 1017 MPa (148 ksi) →	85%
Elastic modulus (avg) = 50100 MPa (7266 ksi) →	82%

POLITECNICO MILANO 1863 FDOT sireg

Fatigue (tensile) testing





P_{min} = 1.84 kN (0.41 kip)
P_{max} = 18.41 kN (4.14 kip)

→ 2A = 16.57 kN (3.72 kip)
R = 0.1

Thank you for your attention

tommaso.dantino@polimi.it

Nano FRP Bars

Mahmoud Reda Taha, PhD, PE, F. ASCE, FACI
Distinguished Professor & Chair
Department of Civil, Construction & Environmental Engineering
University of New Mexico

Introduction

- GFRP is an excellent structural material with a few limitations

- Limitations of GFRP includes
  - ***limited shear strength***
  - ***Limited creep rupture*** and ***fatigue strengths***
  - ***Durability limitations due to UV exposure***

- Almost all the above limitations are attributed ***to the relatively weak bond between the matrix and the glass fibers***.

Goal and Hypothesis

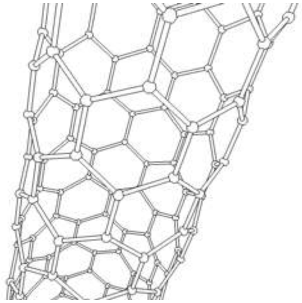
Our Goal is to *improve mechanical properties of* ***pultruded GFRP reinforcing bars*** *using carbon nanotubes*

Our Hypothesis incorporating ***well dispersed carbon nanotubes in the polymer matrix*** prior to GFRP fabrication can overcome many of the current structural limitations of GFRP

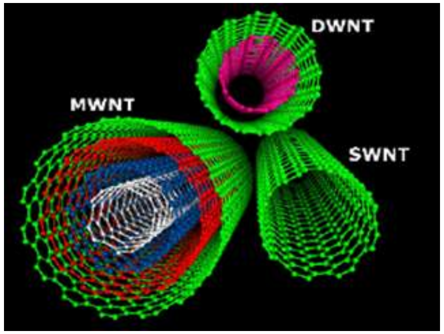
Pultruded Nano-modified GFRP bars

Multi-Walled Carbon Nanotubes (MWCNTs)

COOH functionalized MWCNTs provided by Cheap-Tubes with ***20-30 nm outer diameter, 5-10 nm inner diameter, and length of 10-30 μm***



Material	Young's Modulus (GPa)	Tensile Strength (GPa)	Density ($g.cm^{-3}$)
CNTs	**~1000**	**~100-200**	**~0.7-1.7**
Steel	210	1.3	7.8
Carbon fibers	230	3.5	1.75



S. Ganguli, H. Aglan, P. Dennig & G. Irvin. Effect of loading and surface modification of MWCNTs on the fracture behavior of epoxy nanocomposites. Journal of Reinforced Plastics and Composites, 2006; 25(2), 175-188.
Kohlenstoffnanoroehre Animation. Digital image. Wikimedia, 29 Dec. 2004. Web. 10 May 2015.

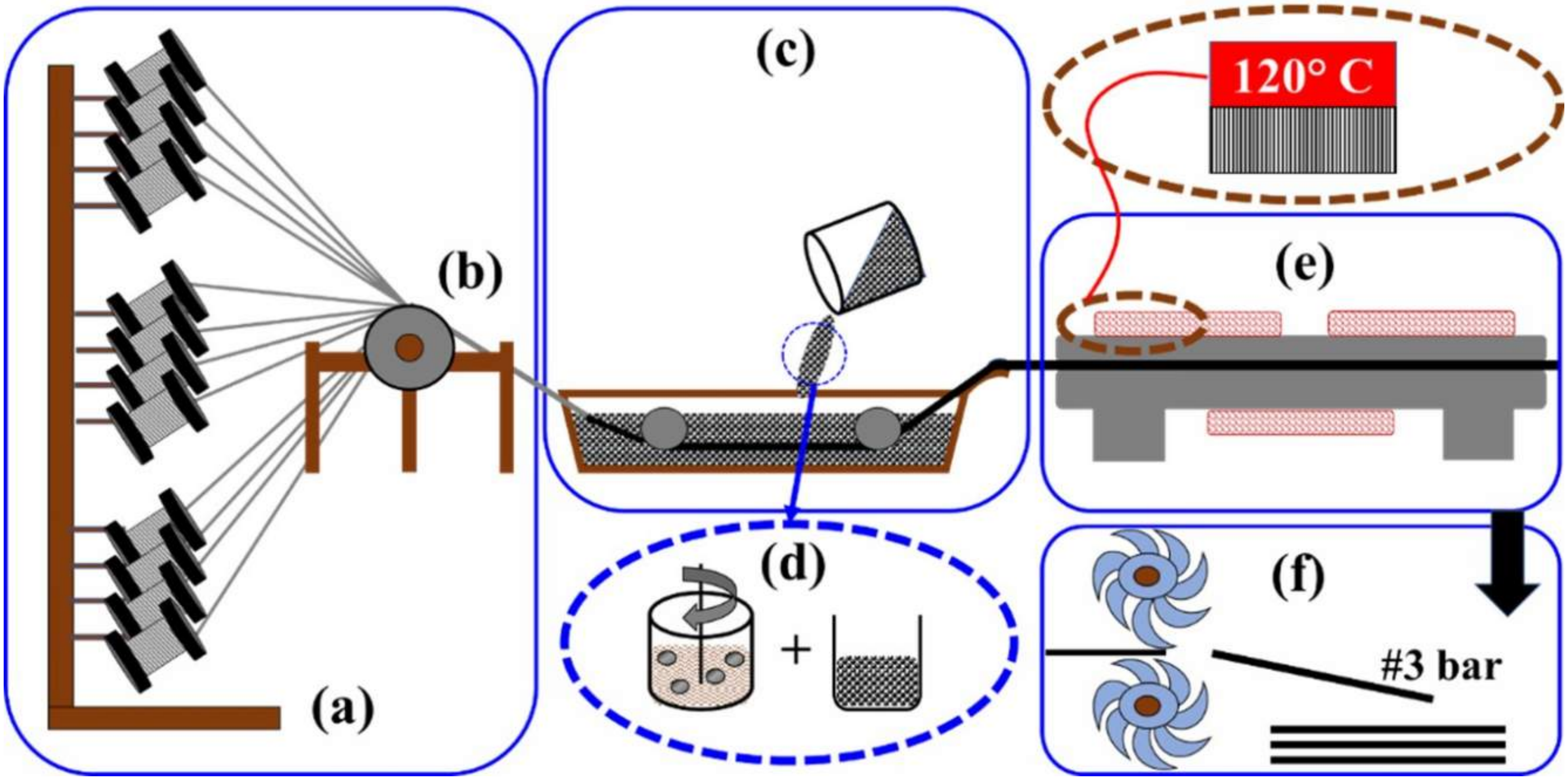
Pultruded Nano-modified GFRP bars

Vinylester resin
Methyl Ethyl Ketone Peroxide

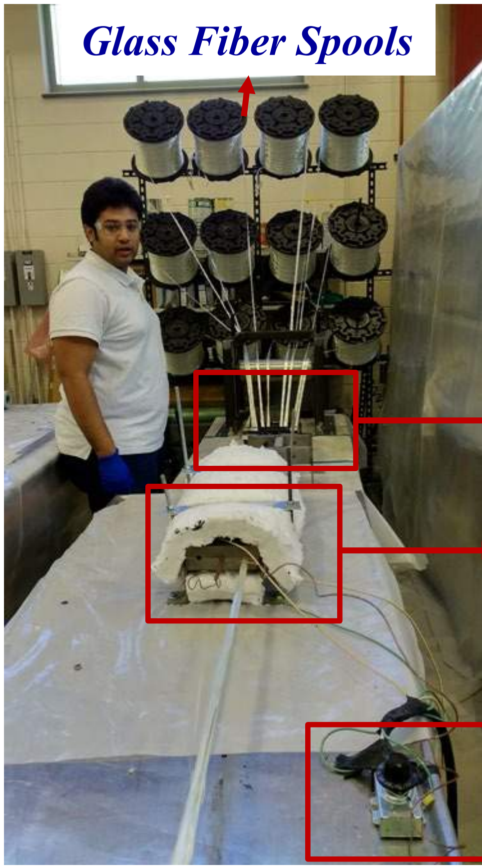
1 hours ultrasonication at 60°C

2 hours Magnetic Stirring at 80°C

Pultruded Nano-modified GFRP bars

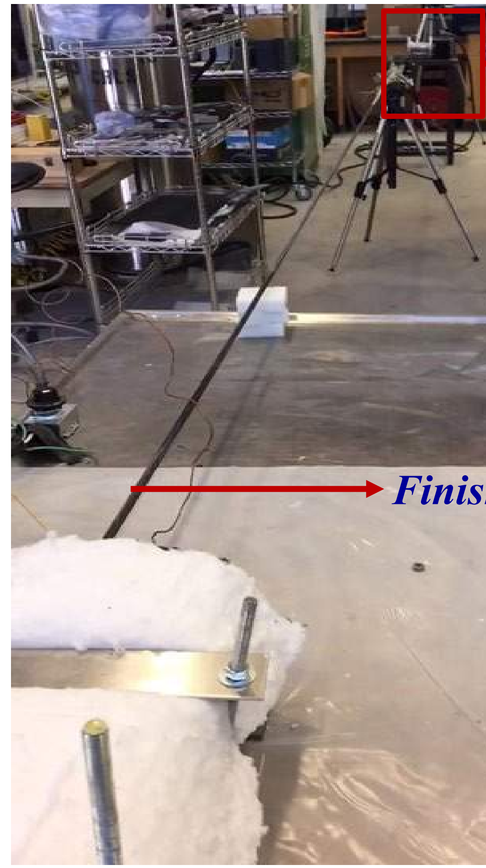


Pultruded Nano-modified GFRP bars



Heat adjustable die

Temperature control

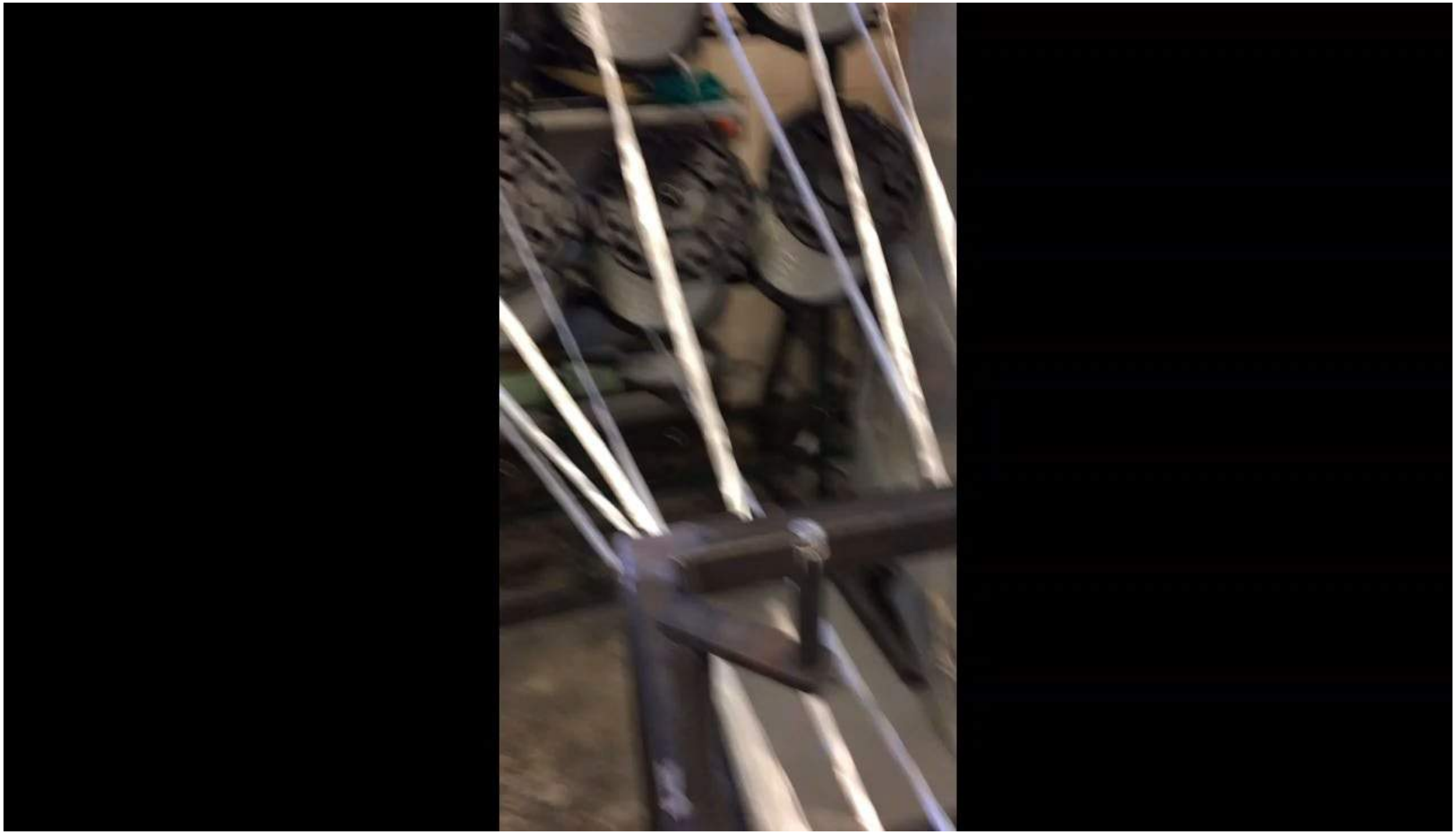


Pull motor with speed control

Finished #3 GFRP rebar

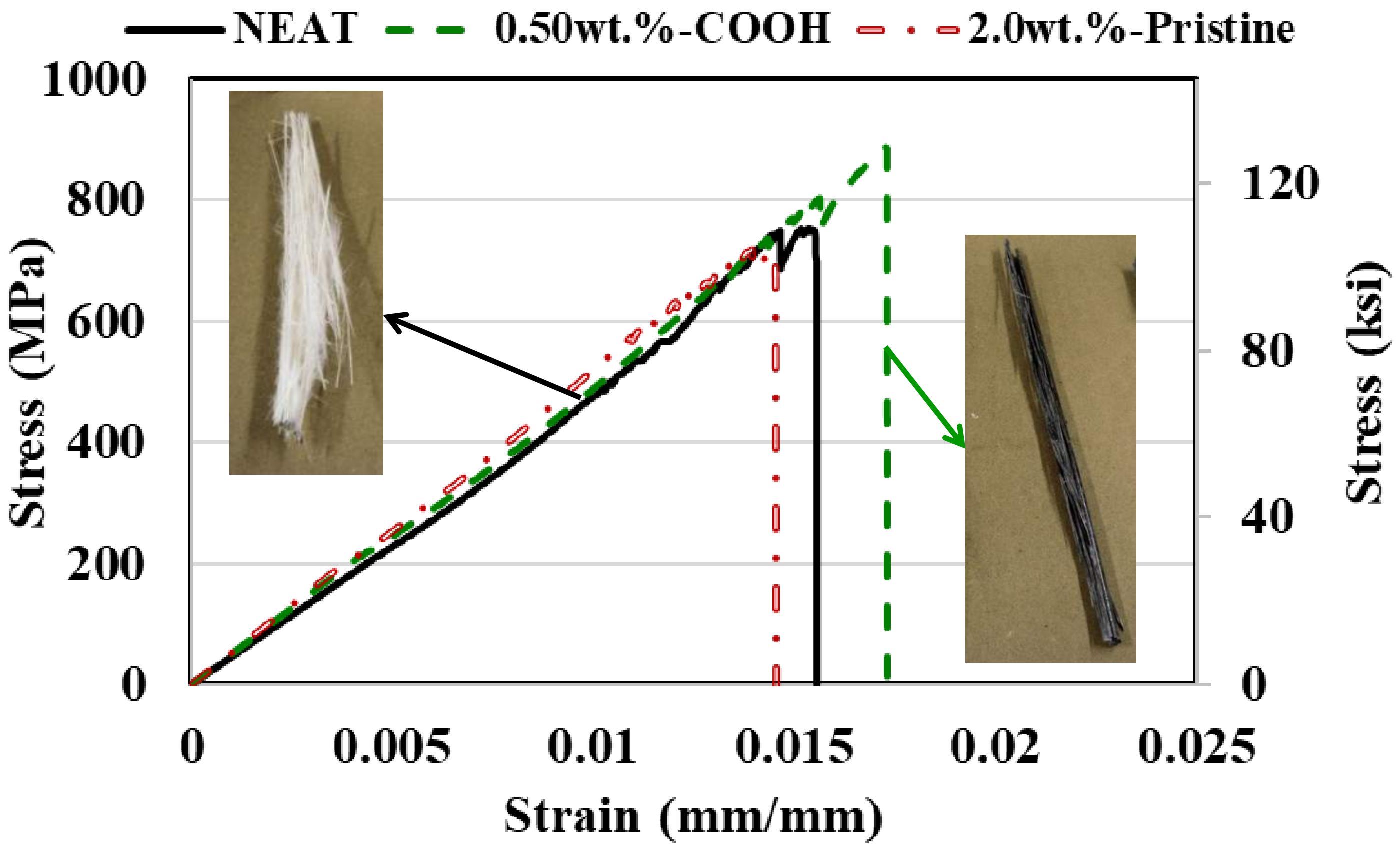
Temperature in the die – 150°C,
Pulling speed – 4mm/sec

Pultruded Nano-modified GFRP bars

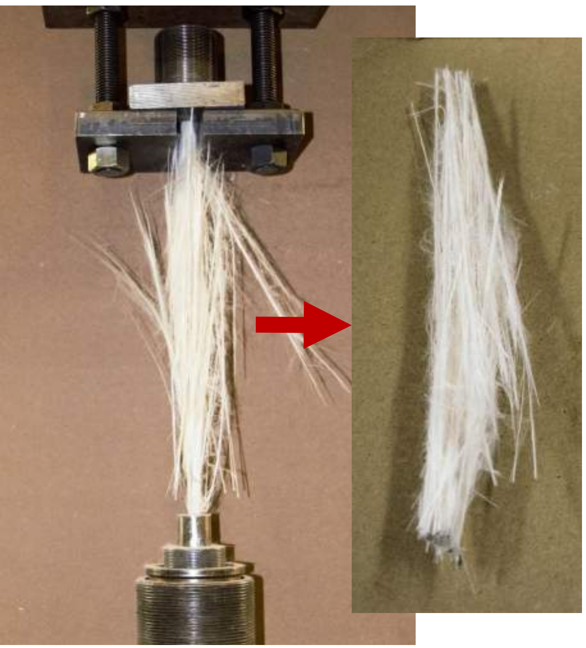


Pultruded Nano-modified GFRP bars

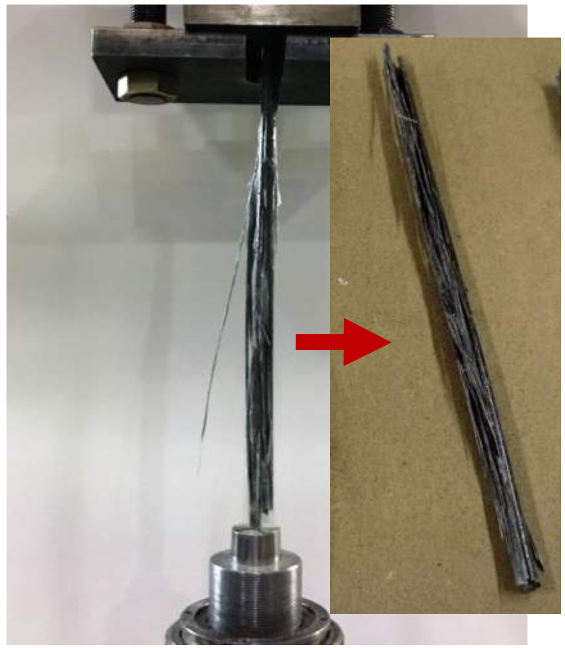
Tension Test



Pultruded Nano-modified GFRP bars



NEAT GFRP
Significant broom

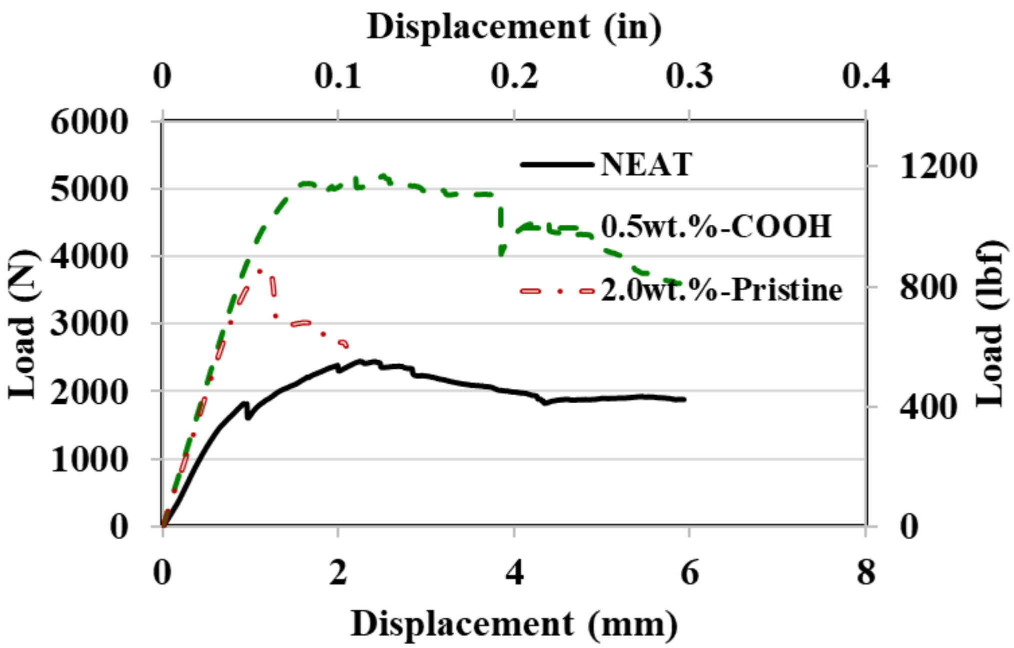


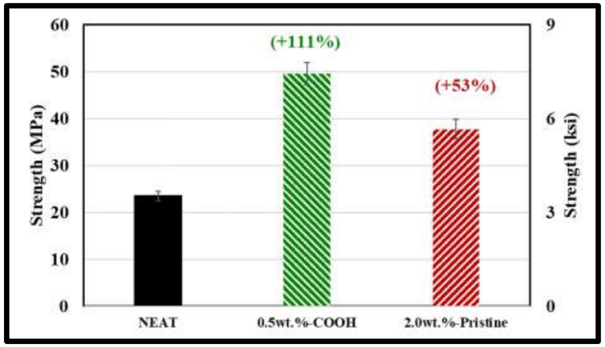
0.5wt.% -COOH GFRP
No broom

2.0wt.% Pristine GFRP
Significant broom

Pultruded Nano-modified GFRP bars

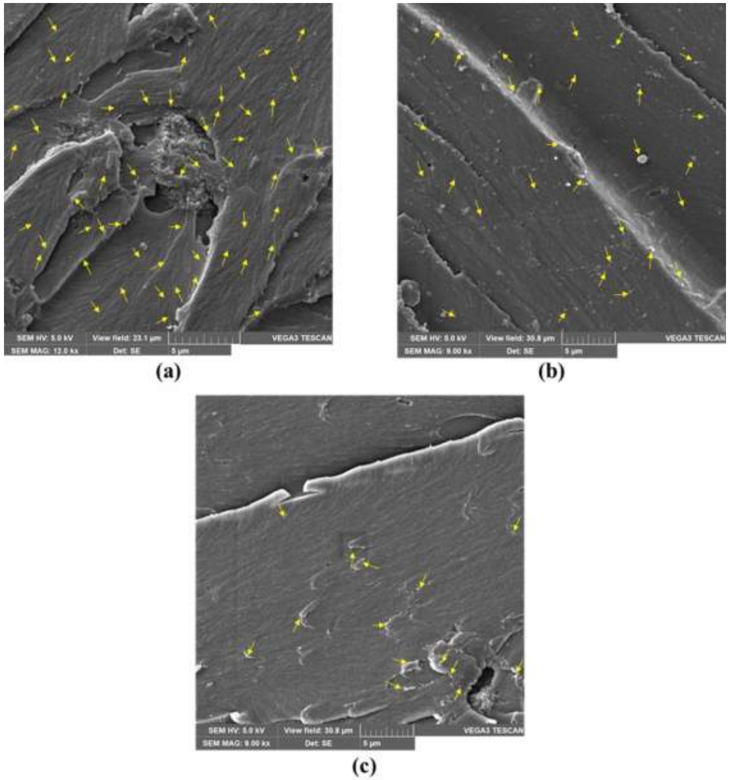
Short Beam Test

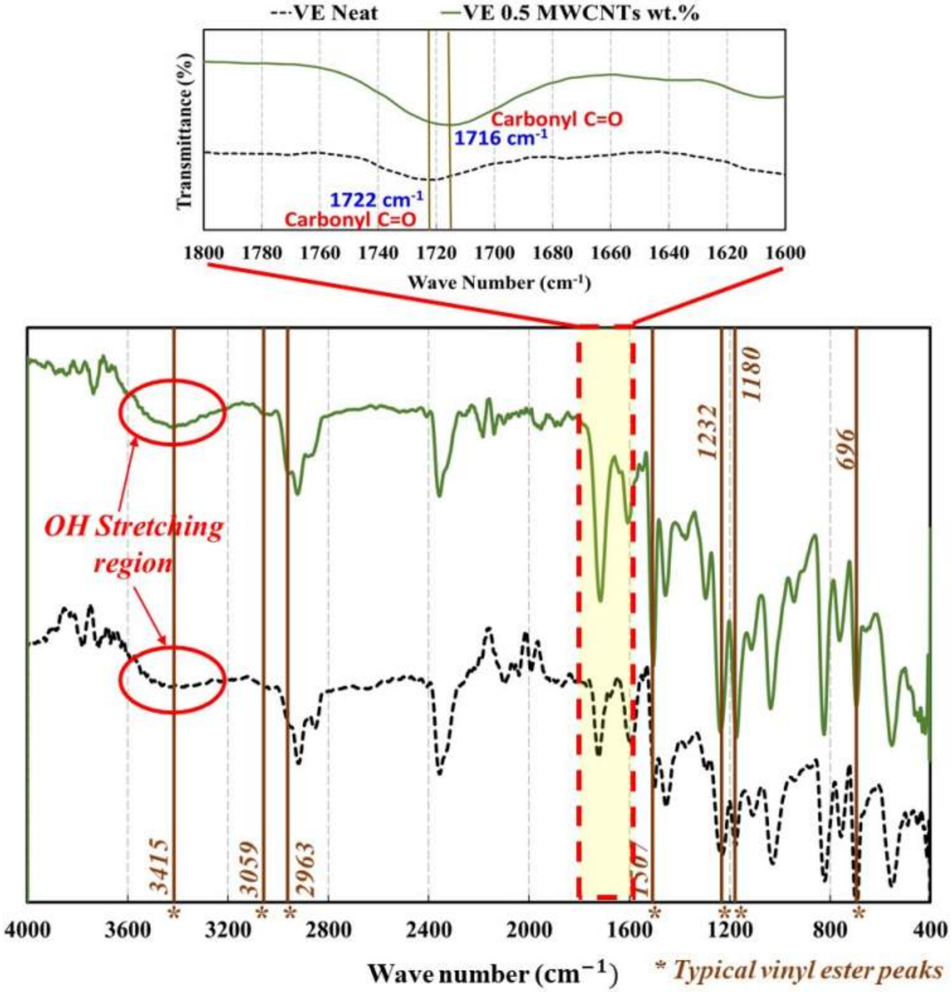


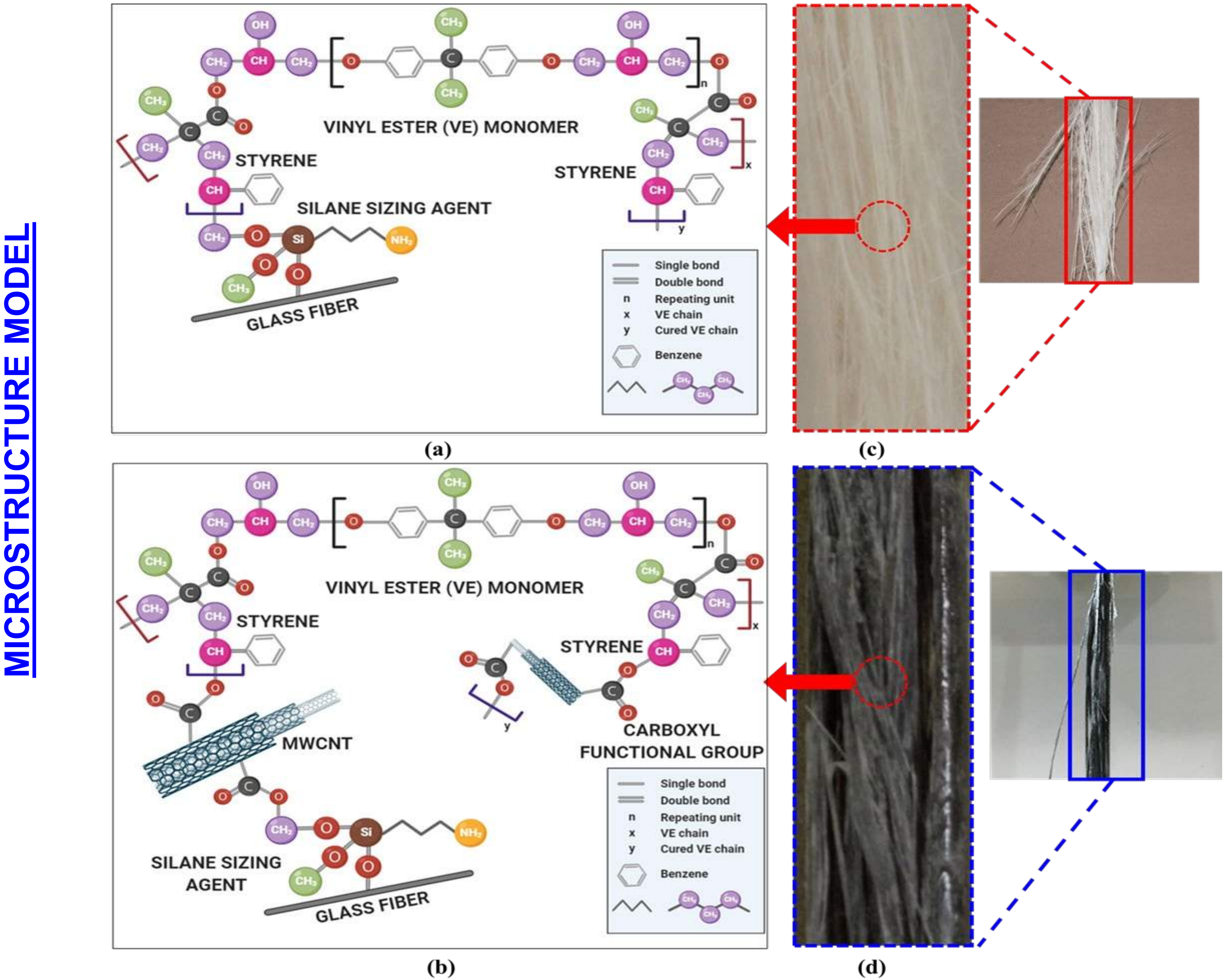


Pultruded Nano-modified GFRP bars

SEM & FTIR







MICROSTRUCTURE MODEL
VINYL ESTER (VE) MONOMER
STYRENE
SILANE SIZING AGENT
GLASS FIBER
STYRENE
Single bond
Double bond
n Repeating unit
x VE chain
y Cured VE chain
Benzene
(a)
(c)
VINYL ESTER (VE) MONOMER
STYRENE
STYRENE
MWCNT
CARBOXYL
FUNCTIONAL GROUP
SILANE SIZING
AGENT
GLASS FIBER
Single bond
Double bond
n Repeating unit
x VE chain
y Cured VE chain
Benzene
(b)
(d)

Conclusions

- ***Incorporating functionalized MWCNTs*** improved the tensile strength of GFRP reinforcement bar by up to ***20%*** and improved GFRP shear strength by ***111%*** with an evident change of GFRP failure mode.

- The new GFRP can be used for full or part of bar (e.g., for anchorage, bent areas) to improve shear strength and prevent premature failure.

- ***It is possible to produce Nano GFRP bars*** with improved shear strength ***using 0.5% MWCNTs***. Lower content is also possible and to be investigated. The new bars might have a ***15% increase in cost***

- We have performed additional research and showed that MWCNTs can also
  - ***Improve fatigue strength***
  - ***Enhance UV resistance***
  - ***Improve creep rupture strength***

Patent

Nano FRP bar work performed in collaboration with

Dr. Rahulreddy Chennareddy – Dibble Engineering, Phoenix, Arizona

***Dr. Amr Riad*, Department of Civil Engineering, Al-Azhar University, Cairo, Egypt**

US 20200354271A1

(19) **United States**
(12) **Patent Application Publication**
Taha et al.

(10) **Pub. No.: US 2020/0354271 A1**
(43) **Pub. Date: Nov. 12, 2020**

(54) **PULTRUDED GFRP REINFORCING BARS, DOWELS AND PROFILES WITH CARBON NANOTUBES**

(71) Applicant: **STC.UNM**, Albuquerque, NM (US)

(72) Inventors: **Mahmoud Reda Taha**, Albuquerque, NM (US); **Rahulreddy Chennareddy**, Albuquerque, NM (US); **Amr H. Riad**, Cairo (EG)

(73) Assignee: **STC.UNM**, Albuquerque, NM (US)

(21) Appl. No.: **16/760,392**

(22) PCT Filed: **Nov. 2, 2018**

(86) PCT No.: **PCT/US2018/059015**
§ 371 (c)(1),
(2) Date: **Apr. 29, 2020**

Related U.S. Application Data

(60) Provisional application No. 62/580,627, filed on Nov. 2, 2017.

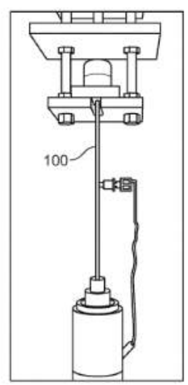
Publication Classification

(51) **Int. Cl.**
C04B 18/02 (2006.01)
C08J 5/04 (2006.01)
C08K 3/04 (2006.01)
C08K 9/04 (2006.01)
C08K 13/06 (2006.01)
E04C 5/07 (2006.01)

(52) **U.S. Cl.**
CPC ***C04B 18/022*** (2013.01); ***C08J 5/043*** (2013.01); ***C08K 3/041*** (2017.05); ***C08K 9/04*** (2013.01); *E01D 19/125* (2013.01); ***E04C 5/073*** (2013.01); *C08J 2333/04* (2013.01); *C08J 2367/00* (2013.01); *C08K 2201/011* (2013.01); ***C08K 13/06*** (2013.01)

(57) **ABSTRACT**

A glass fiber reinforced polymer reinforcing structure comprised of glass fibers mixed with one or more polymers. Incorporated in the polymer are a hybrid mix of pristine multi-walled carbon nanotubes at 0.0-4.0 wt. % of the polymer and multi-walled carbon nanotubes functionalized with carboxylic group at 0.0-2.0 wt. % of the polymer. The above mixture is pultruded to produce GFRP reinforcing bars, dowels or structural profiles.



Publications

materials MDPI

Article

Pultruded GFRP Reinforcing Bars Using Nanomodified Vinyl Ester

Shreya Vemuganti [1], Rahulreddy Chennareddy [1], Amr Riad [2] and Mahmoud M. Reda Taha [1,*]

1 Department of Civil, Construction and Environmental Engineering, University of New Mexico, Albuquerque, NM 87131-0001, USA; svemuganti@unm.edu (S.V.); rahulreddy4@unm.edu (R.C.)
2 Department of Civil Engineering, Faculty of Engineering, Al-Azhar University, Cairo 11371, Egypt; amrriad20@yahoo.com
* Correspondence: mrtaha@unm.edu; Tel.: +50-(52)-771258; Fax: +50-(52)-771988

Received: 5 November 2020; Accepted: 9 December 2020; Published: 14 December 2020

check for updates

Abstract: Glass fiber-reinforced polymer (GFRP) reinforcing bars have relatively low shear strength, which limits their possible use in civil infrastructure applications with high shear demand, such as concrete reinforcing dowels. We suggest that the horizontal shear strength of GFRP bars can be significantly improved by nanomodification of the vinyl ester resin prior to pultrusion. The optimal content of functionalized multiwalled carbon nanotubes (MWCNTs) well dispersed into the vinyl ester resin was determined using viscosity measurements and scanning electron micrographs. Longitudinal tension and short beam shear tests were conducted to determine the horizontal shear strength of the nanomodified GFRP reinforcing bars. While the tensile strength of the GFRP reinforcing bars was improved by 20%, the horizontal shear strength of the bars was improved by 111% compared with the shear strength of neat GFRP bars pultruded using the same settings. Of special interest is the absence of the typical broom failure observed in GFRP when MWCNTs were used. Differential scanning calorimetry measurements and fiber volume fraction confirmed the quality of the new pultruded GFRP bars. Fourier-transform infrared (FTIR) measurements demonstrated the formation of carboxyl stretching in nanomodified GFRP bars, indicating the formation of a new chemical bond. The new pultrusion process using nanomodified vinyl ester enables expanding the use of GFRP reinforcing bars in civil infrastructure applications.

Keywords: pultrusion; GFRP; carbon nanotubes; vinyl ester; shear strength

Construction and Building Materials 220 (2019) 679–689

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ELSEVIER

UV-resistant GFRP composite using carbon nanotubes

Rahulreddy Chennareddy, Hesham Tuwair [1], Usama F. Kandil [2], Mohamed ElGawady [3]
M.M. Reda Taha *

Department of Civil, Construction and Environmental Engineering, MSC01 1070, 1 University of New Mexico, Albuquerque, NM 87131-0001, United States

H I G H L I G H T S

- MWCNTs well-dispersed in resin prior to fabrication produce a UV-resistant GFRP.
- 0.5–1.0 wt% carboxylic functionalized MWCNTs protect GFRP against UV degradation.
- UV-resistant GFRP eliminates the need to apply UV protection paint.

A R T I C L E I N F O

Article history:
Received 22 November 2018
Received in revised form 24 March 2019
Accepted 27 May 2019

Keywords:
Ultra-violet radiation
Glass fibers
Carbon nanotubes
GFRP durability

A B S T R A C T

Degradation due to exposure to ultraviolet (UV) radiation is an important durability challenge with glass fiber reinforced polymer (GFRP) composite. Design and construction guidelines of GFRP suggest using UV protection paint to prevent GFRP degradation. In this study we examine the possible use of multi-walled carbon nanotubes (MWCNTs) dispersed in epoxy matrix to produce UV-resistant GFRP composite. We suggest that MWCNTs can result in a significant improvement to UV degradation resistance in the GFRP. Direct tension tests of GFRP coupons incorporating 0.25 wt%, 0.50 wt%, and 1.0 wt% of MWCNTs show inherent stability and good resistance to UV degradation. Microstructural analysis shows the ability of MWCNTs to resist polymer backbone disassociation caused by UV radiation thus preventing UV degradation in GFRP. Scanning electron microscopy (SEM) images show MWCNTs can resist microcracking caused by UV radiation and thus improve UV degradation resistance of GFRP.

Fibers **2015**, *3*, 13-29; doi:10.3390/fib3010013

OPEN ACCESS

fibers

ISSN 2079-6439

www.mdpi.com/journal/fibers

Article

Improving Fatigue Performance of GFRP Composite Using Carbon Nanotubes

Moneeb Genedy [1], Sherif Daghash [2,†], Eslam Soliman [3,†] and Mahmoud M. Reda Taha [1,*]

1 Department of Civil Engineering, University of New Mexico, Albuquerque, NM 87106, USA; E-Mail: moneeb@unm.edu
2 Department of Civil Engineering, University of Virginia, Charlottesville, VA 22901, USA; E-Mail: smd7an@virginia.edu
3 Department of Civil Engineering, Assuit University, Assuit 71515, Egypt; E-Mail: eslam.soliman@eng.au.edu.eg

† These authors contributed equally to this work.

* Author to whom correspondence should be addressed: E-Mail: mrtaha@unm.edu; Tel.: +1-505-277-1258; Fax: +1-505-277-1988.

Academic Editor: Jonathan Phillips

Received: 14 November 2014 / Accepted: 6 January 2015 / Published: 15 January 2015

Original Article

JOURNAL OF REINFORCED PLASTICS & COMPOSITES

Journal of Reinforced Plastics and Composites
0(0) 1–14
© The Author(s) 2017
Reprints and permissions: sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/0731684417697827
journals.sagepub.com/home/jrp
SAGE

Improving shear strength of bolted joints in pultruded glass fiber reinforced polymer composites using carbon nanotubes

Moneeb Genedy [1], Rahulreddy Chennareddy [1], Eslam M Soliman [2], Usama F Kandil [3] and Mahmoud M Reda Taha [1]

Abstract

The structural design of the bolted fiber reinforced polymer elements is typically governed by the capacity of the joint rather than the fiber reinforced polymer member, while the joint capacity is typically governed by the shear strength of the fiber reinforced polymer. Here, the possibility of improving the shear strength of bolted joints is investigated in the unidirectional glass fiber reinforced polymer plates by incorporating the multiwalled carbon nanotubes during glass fiber reinforced polymer fabrication. Glass fiber reinforced polymer double-shear bolted lap joints were fabricated using up to 1.0 wt% multiwalled carbon nanotubes—epoxy nanocomposites. Finite element modeling using multicontinuum theory and element deletion techniques was performed to explain the joint behavior. The experimental investigations show that incorporating multiwalled carbon nanotubes improved the shear strength, ductility, and energy absorption significantly. Microstructural analysis proves that a chemical reaction between multiwalled carbon nanotubes and epoxy improves the shear strength of the matrix.

Keywords

Glass fiber reinforced polymer, carbon nanotubes, bolted joints, ductility, toughness

Acknowledgment

taha.unm.edu

TS-NANO SEALANTS

Los Alamos NATIONAL LABORATORY EST.1943

U.S. DEPARTMENT OF ENERGY

AFOSR AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

NSF

NMDOT

Tran-SET Transportation Consortium of South-Central States

AIR FORCE RESEARCH LABORATORY

Sandia National Laboratories

Thank you

Questions: Email mrtaha@unm.edu

taha.unm.edu

THIRD INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURS

"Advances in concrete reinforcement"

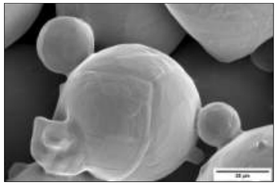
August 3-4, 2021 - Virtual

Microwave Evaluation of GFRP (Dielectric) Rebars

Reza Zoughi
Professor of Electrical and Computer (ECpE) Engineering
Iowa State University (ISU)
Ames, IA 50011, USA
rzoughi@iastate.edu

THIRD INTERNATIONAL WORKSHOP ON FRP BARS FOR CONCRETE STRUCTURS

"Advances in concrete reinforcement"



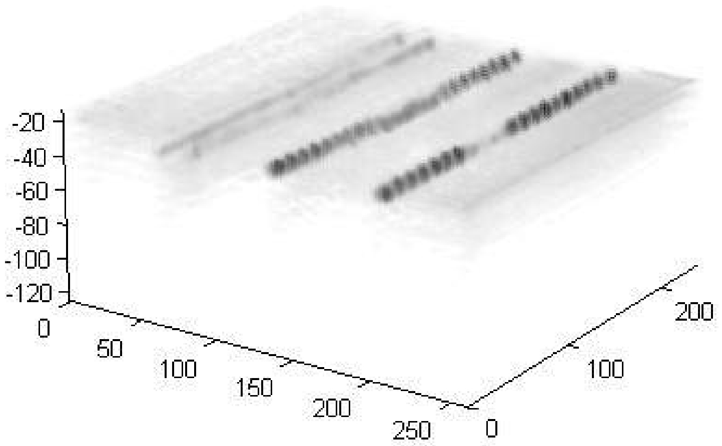
Director: Center for Nondestructive Evaluation (CNDE)

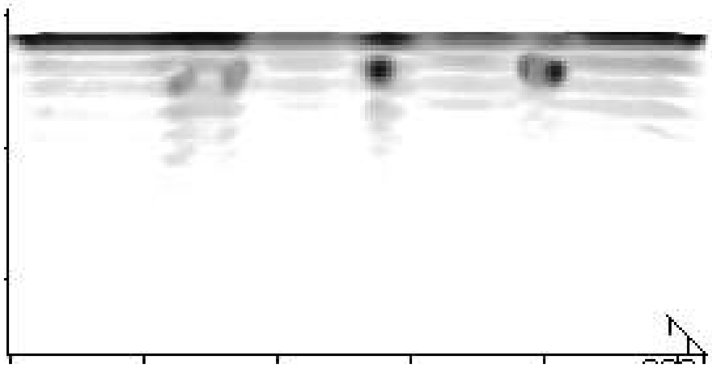
CNDE

Attributes of Microwave NDE

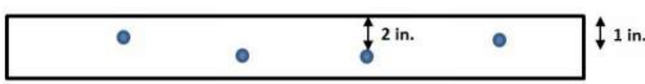
- Research focused on microwave NDE for the past 30+ years, in particular in the area f high-resolution, real-time and portable SAR imaging systems for NDE.
- High-frequency signals - penetrate concrete structures and interact with their internal structures.
- SAR imaging provides for real-time, high-resolution and 3D images of concrete structures.
- Dielectric property contrast is the foundation of detection and property evaluation – concrete vs. steel, FRP and basalt rebars.

Ku-Band (12.4-18 GHz) Results

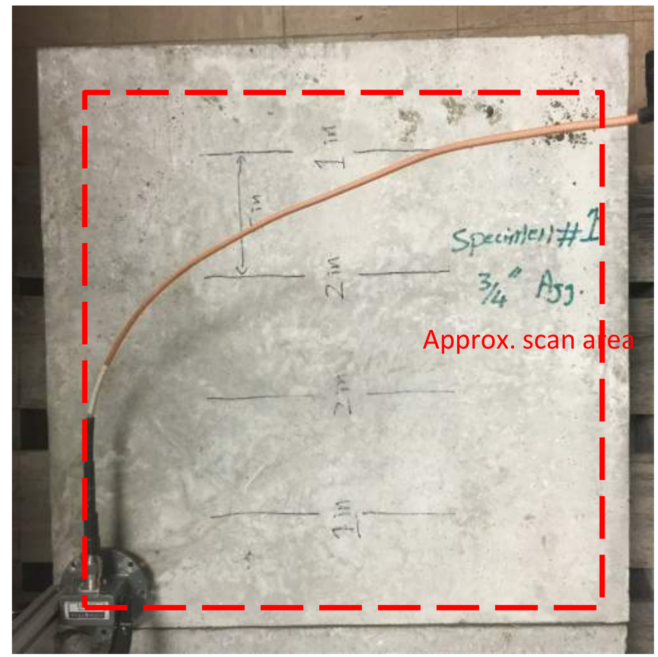




Glass Rebars Panel – ¾" Aggregates

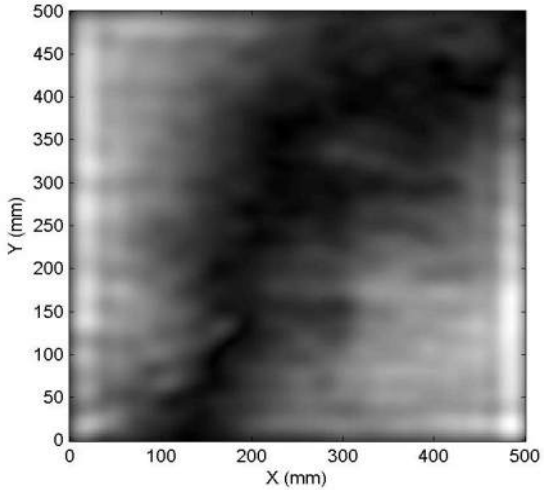


Cross section for concrete panel

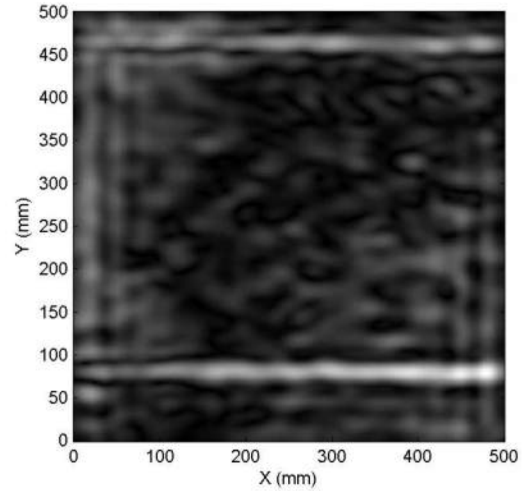


SAR Images at G-Band (3.95-5.85 GHz)

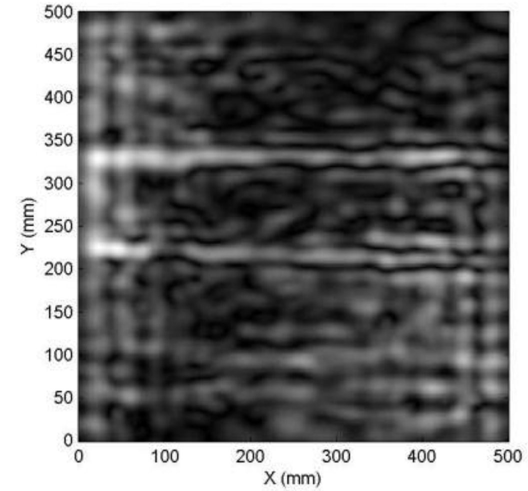
Surface

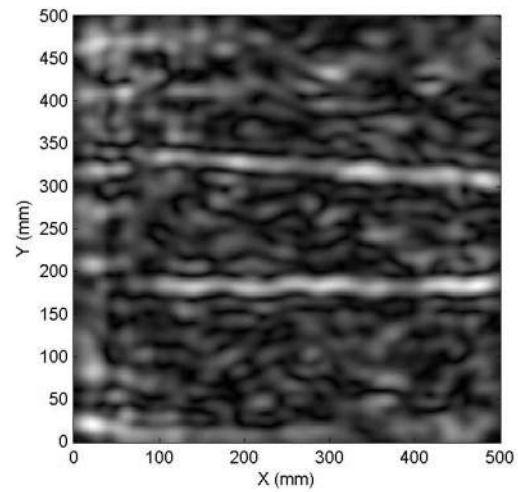


1" Deep



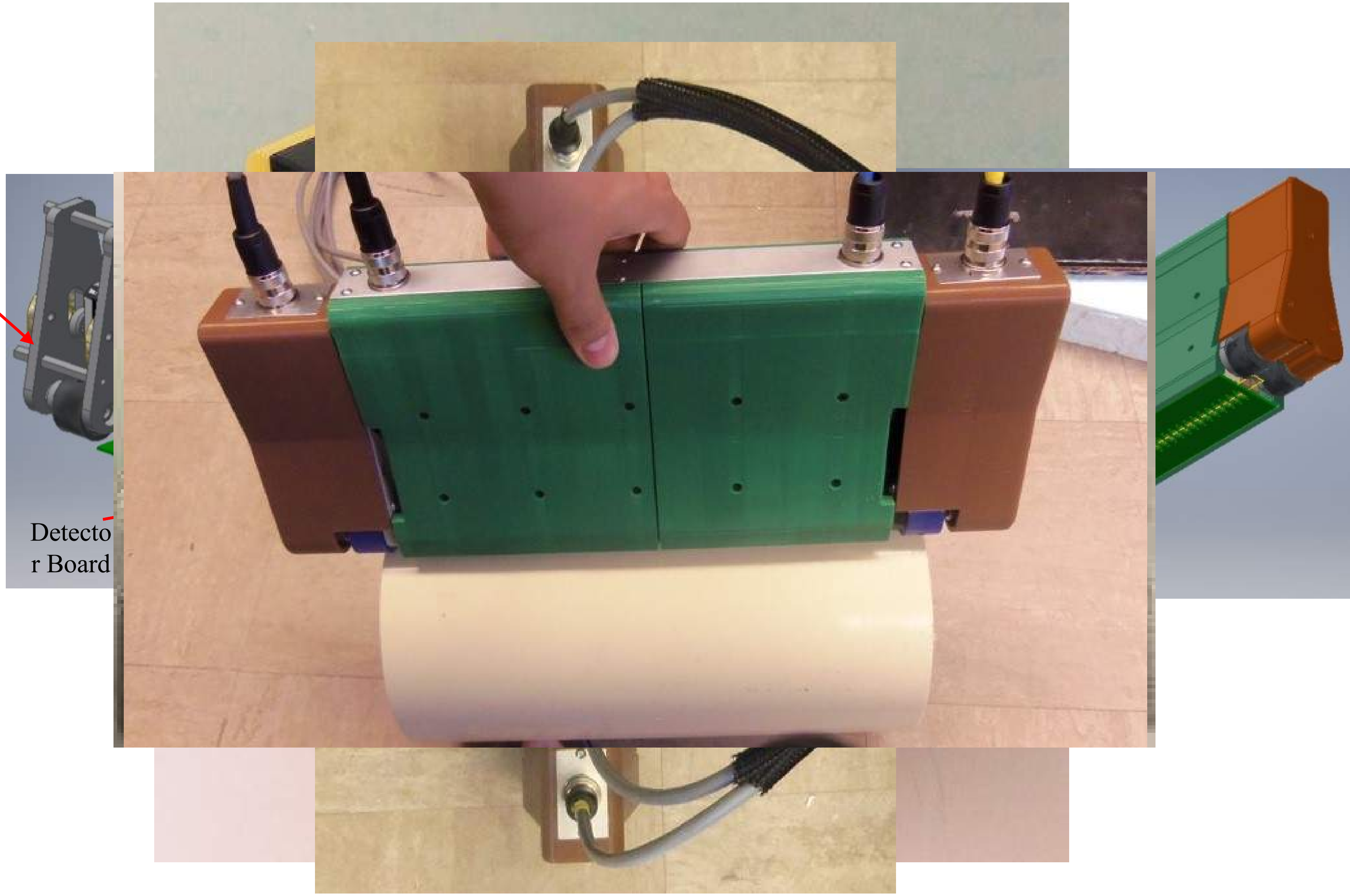
2" Deep





2" Deep with
3/8 " Aggregates

Wheel with Decoder



Future

- TRL has already been improved over the past two decades.
- Need advocate/sponsor/partner and resources to bring to in-field testing level.
- Work with interested agencies to optimize and improve capabilities as per the needs and requirements.
- Has the potential to be an impactful technology to address issues related to non-metallic reinforcements – detection, damage assessment, unexpected movement, etc.