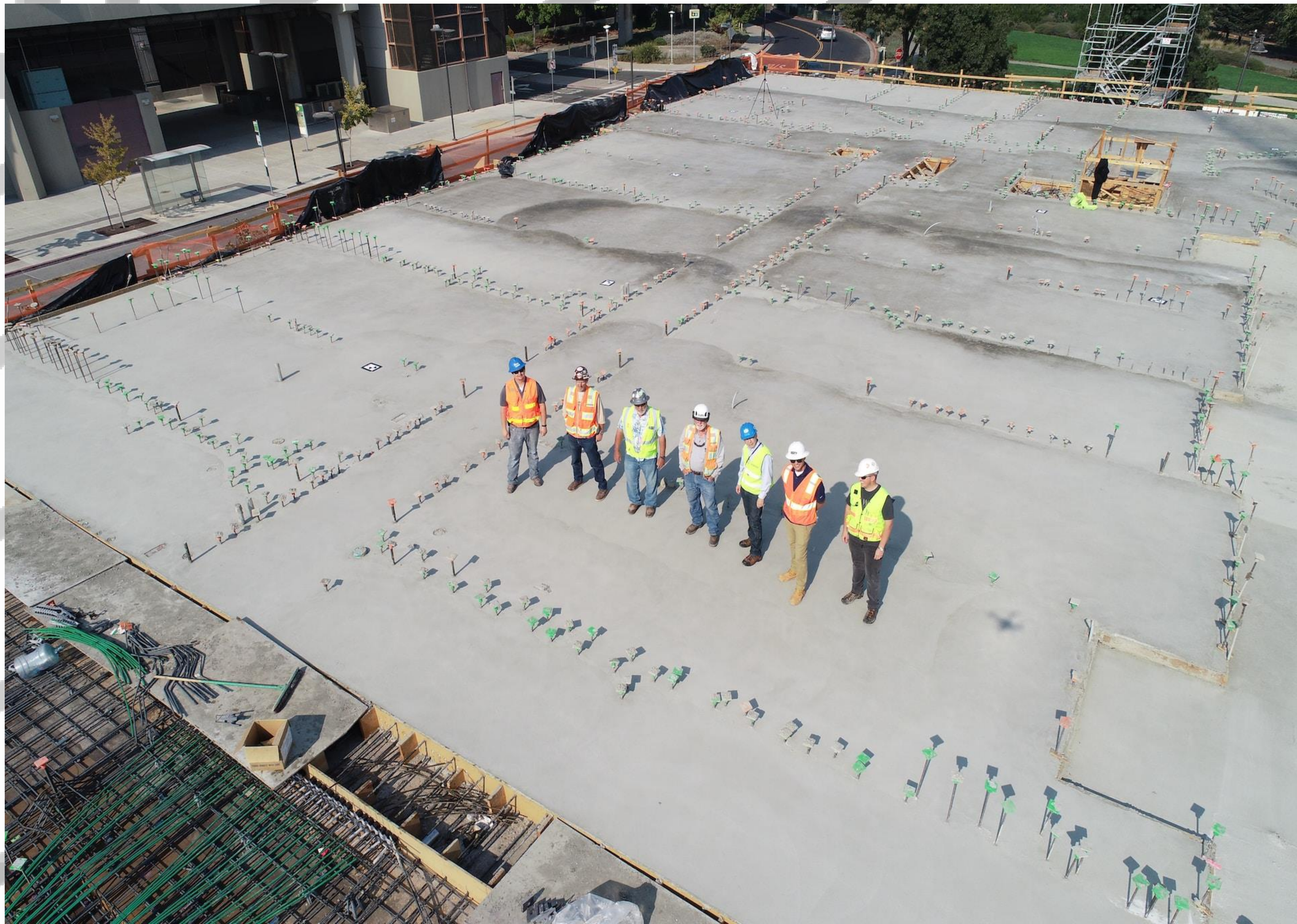
Revolutionizing Concrete: The Growing Might of Carbon Allotropes in Sustainable Construction

Progress Report on Graphene, CNTs, and CNFs in Concrete

Shaun Lane
Founder/President
NanoCrete Inc.
Email: shaun@nano-crete.com

Overview

- Background
- Purpose
- Motivation
- Objectives
- Summary



Background

NanoCrete Inc.

- Shaun Lane

- Late-Bloomer Concrete Enthusiast

- Innovating Sustainable SCM's

Purpose

Learning Objectives

1. Discuss recent techniques, material requirements, specification activity, and procedures related to structural and material aspects of carbon nanotubes, fibers, and graphene;

2. Describe emerging ideas that are possible with carbon nanotubes, fibers, and graphene; and

3. Summarize case studies related to deployment of carbon nanotubes, fibers, and graphene in concrete for structures and infrastructure.

Motivation

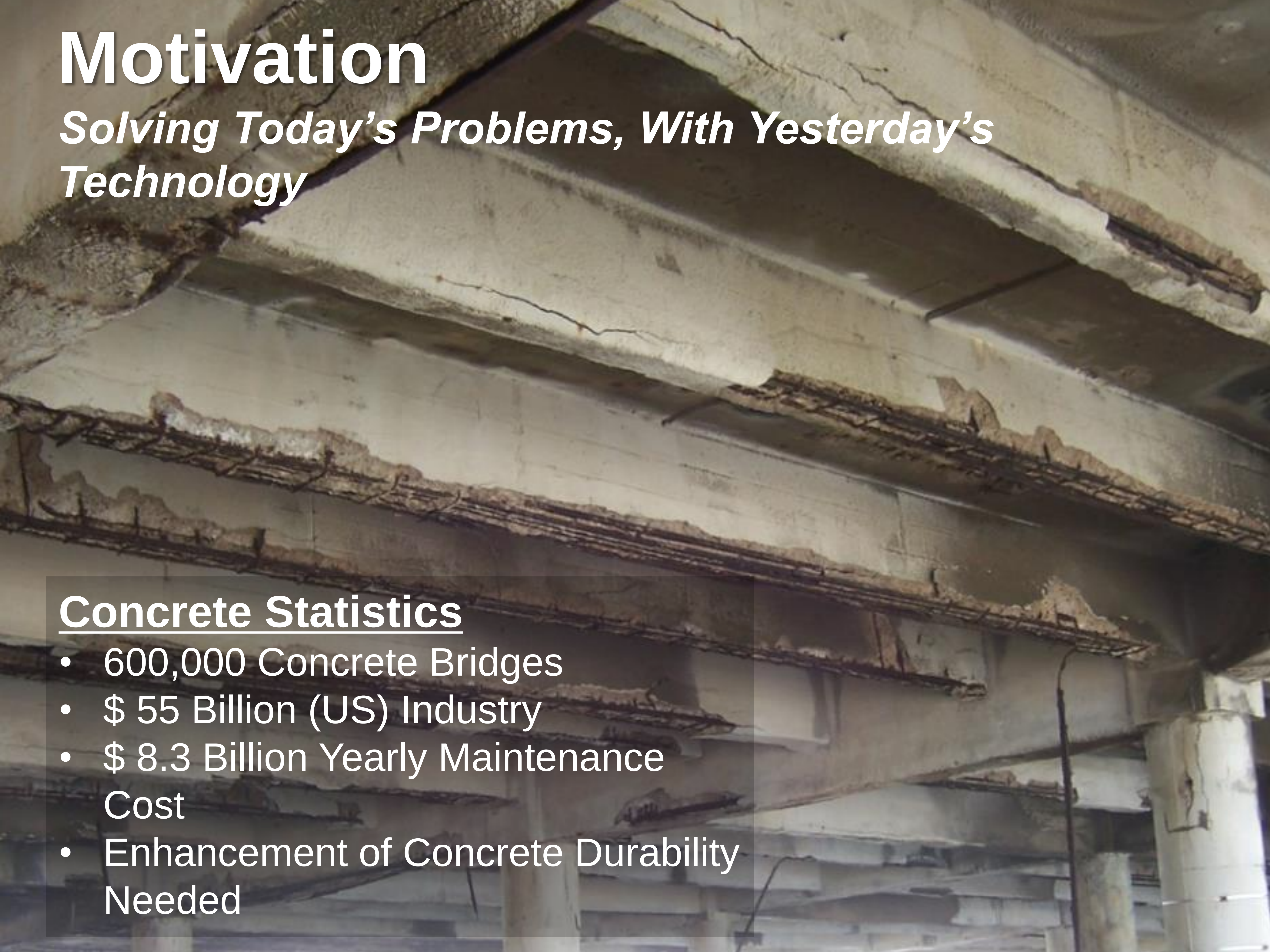
Why Should the Ready-Mixed Industry Care?

- **We have a limitation on ‘old’ options**
- **A WIDE variety of ‘new’ options**
    - CNTs, Graphene, …
    - Colloidal Silica
    - ASCMs
    - Pond Ash

Colorado Sourced Class F Fly Ash

Motivation

Solving Today's Problems, With Yesterday's Technology



Concrete Statistics

- 600,000 Concrete Bridges
- $ 55 Billion (US) Industry
- $ 8.3 Billion Yearly Maintenance Cost
- Enhancement of Concrete Durability Needed

Motivation

Corrosion of Reinforcing Steel

1. Deicing Salts and Brines
2. Fatigue from Traffic Loads
3. Inevitable Concrete Breakdown / Reduction in Service-Life
   - Abrasive Wear from Tides
   - Chemical Impact of Deicing Salts

Motivation

Better Environmentally Friendly Concrete

1. **Reduced Carbon Footprint**
2. **Reduced Waste & Increased Resource Efficiency**
3. **Innovative Sustainable Solutions**

Purpose

Learning Objectives

1. **Discuss recent techniques, material requirements, specification activity, and procedures related to structural and material aspects of carbon nanotubes, fibers, and graphene;**

2. Describe emerging ideas that are possible with carbon nanotubes, fibers, and graphene; and

3. Summarize case studies related to deployment of carbon nanotubes, fibers, and graphene in concrete for structures and infrastructure.

How It All Began

Learning Objective 1

1. **Graphene**:

   - **Discovery**: Graphene was first isolated in 2004 by Andre Geim and Konstantin Novoselov at the University of Manchester

2. **Carbon Nanotubes (CNTs)**:

   - **Discovery**: Sumio Iijima is credited with the discovery of multi-walled carbon nanotubes in 1991.

3. **Carbon Nanofibers (CNFs)**:

   - **Discovery**: Early in the 1970s, Japanese researcher Morinobu Endo reported the discovery of carbon nanofibers, including that some were shaped as hollow tubes.

Definitions

Learning Objective 1

- **Allotropes of Carbon**
  - Different microstructures of an element, in the case of this lecture, different arrangements of carbon microstructures.
- **What are the top 3?**
  1. Graphene
  2. Carbon Nanotubes (CNT)
  3. Carbon Nanofibers (CNF)
- **Breaking them down**
  1. What makes each one different?
  2. What are the benefits to concrete?
  3. What are the negative side effects?

Definitions

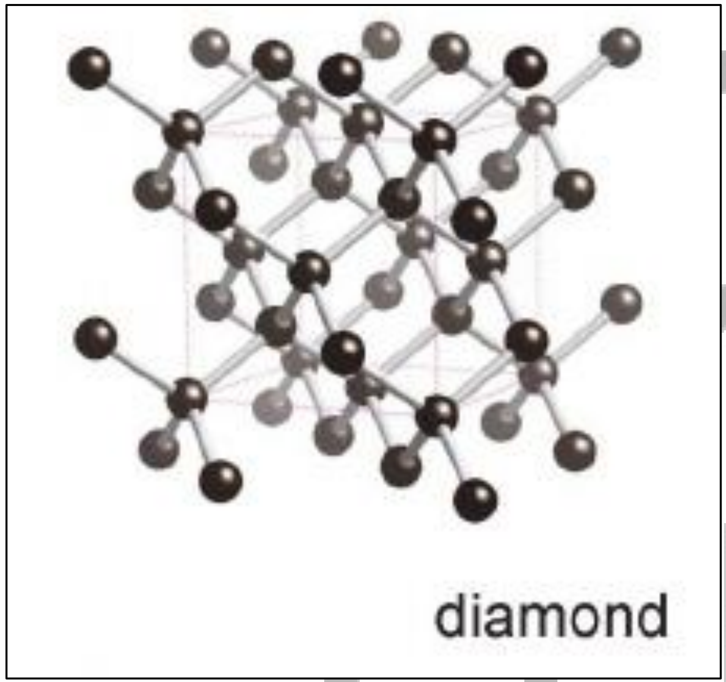
Learning Objective 1

- **Microstructure**
  - Compositional/structural inhomogeneities that may consist of spatially distributed phases of different compositions/structures, grains of different orientations, structural defects (Khanna 2014).
- **Bonds**
  - Carbon–carbon bond is a covalent bond between two carbon atoms.
- **Why do these matter?**
- **Will I be tested after the talk today?**

Definitions

Learning Objective 1

- **Microstructure**
  - Different arrangements of carbon (Oganov 2013).



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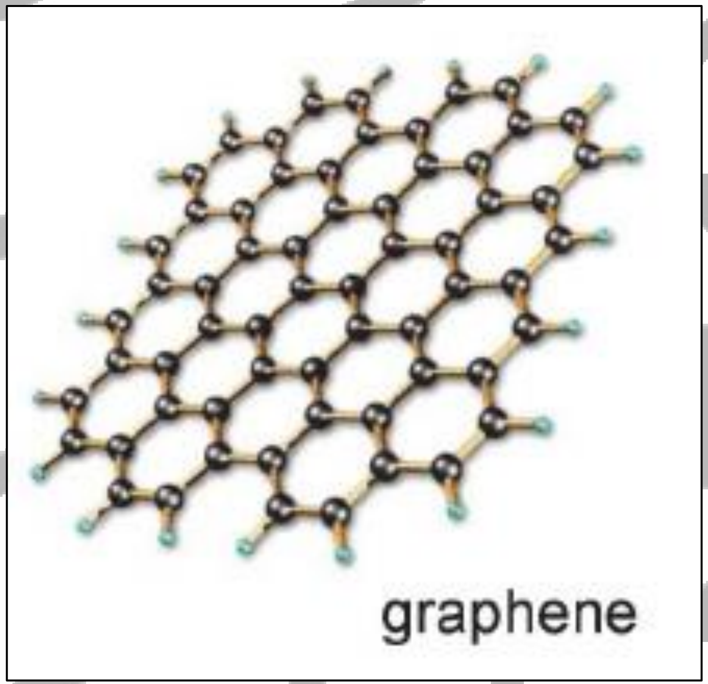

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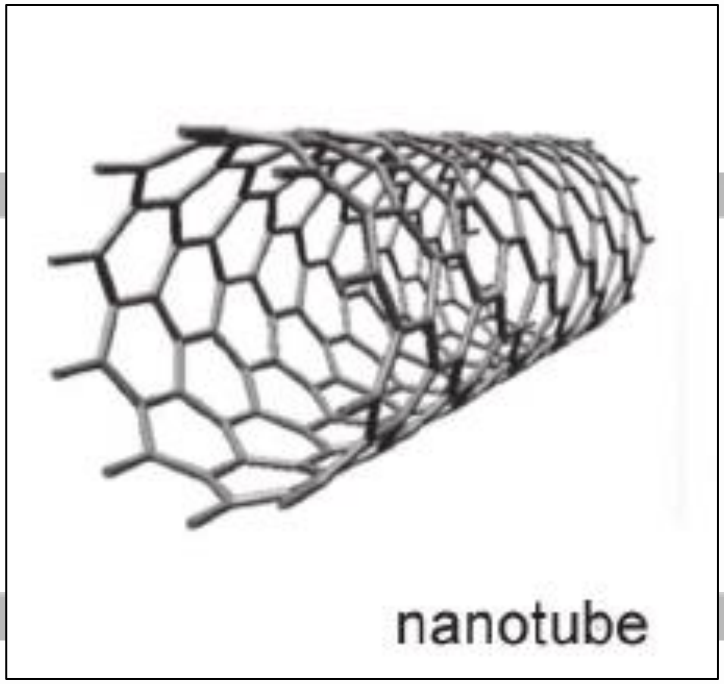


sp^2 hybridized

Definitions

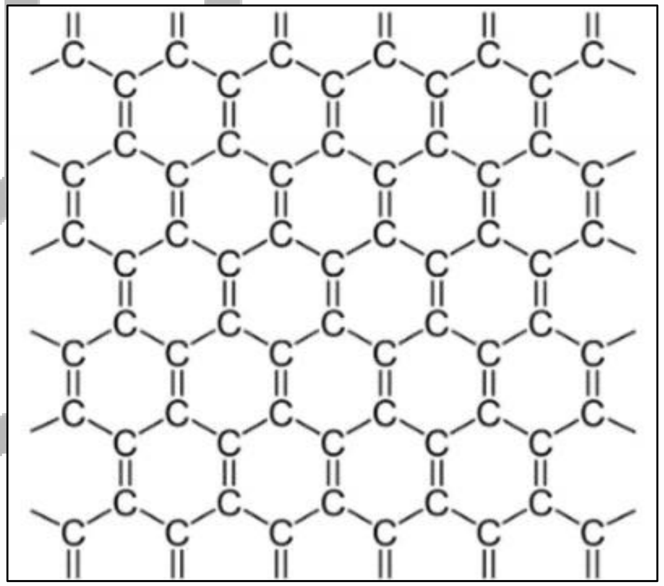
Learning Objective 1

- **Why do these microstructures matter?**
  - Properties are a result of the bond type
  - How well it works with others
    - Suspension
    - As Part of the Composite
- **Will I be tested after my discussion?**
  - **No…**

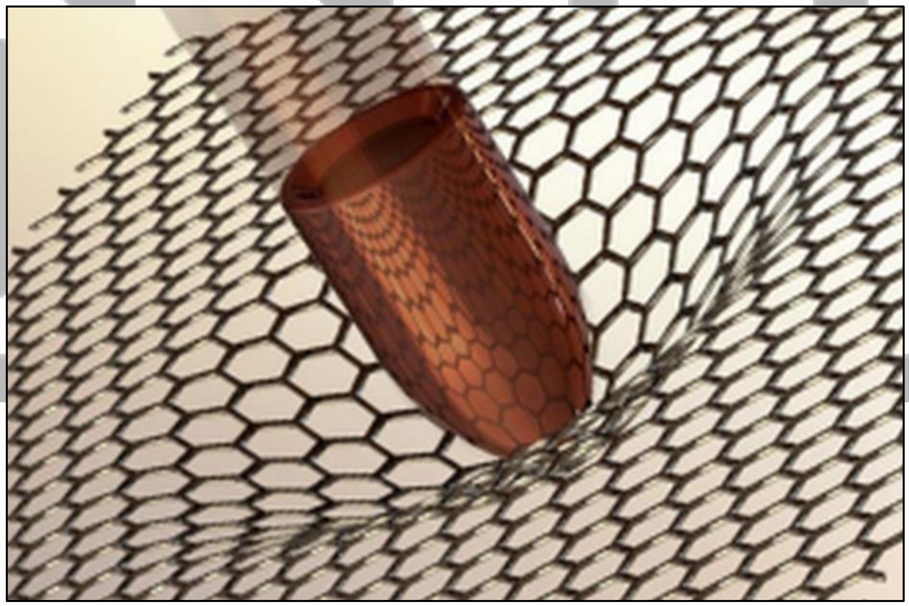
Graphene

Learning Objective 1

1. **What makes each one different?**
   - Monolayer of Carbon atoms
   - 2D sheets
   - No defects in the structure
2. **What are the benefits to concrete?**
   - High thermal conductivity.
   - High electrical conductivity.
   - High elasticity and flexibility.
   - High hardness.
   - High chemical resistance.
   - Antibacterial
   - And more…
3. **What are the negative side effects?**
   - Stability in Suspension, rarely delivered in dry form to concrete.
   - Tightening of Slump.
   - Bonding to Hydrated Cementitious Matrix



Graphene 'Honey-Comb' Monolayer (Metalgrass 2021).

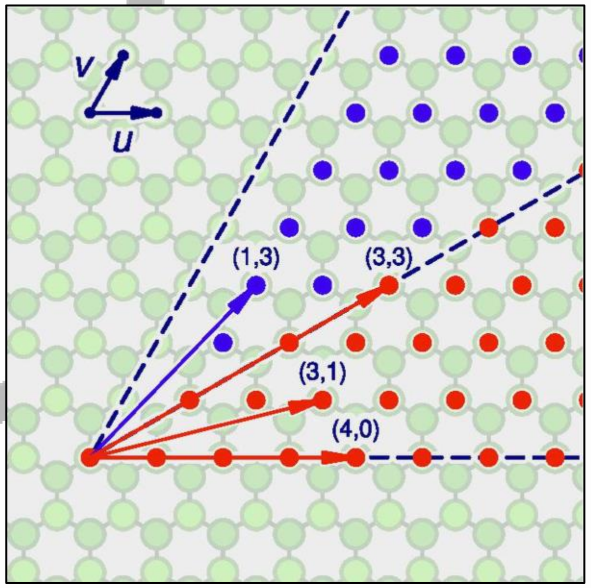


Artist Rendering of Graphene Catching A Bullet (Nanografi 2021).

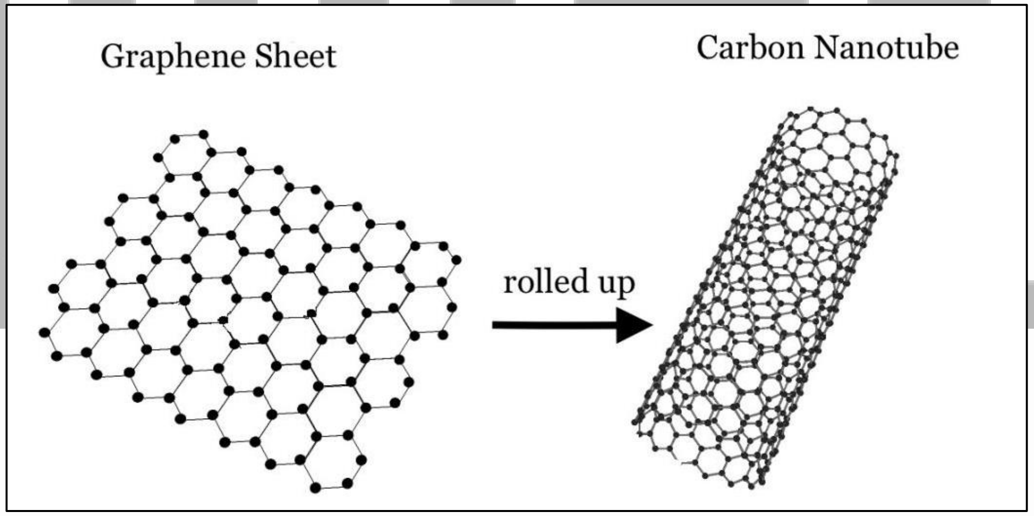
Carbon Nanotube

Learning Objective 1

1. **What makes each one different?**
   - **Rolled Up Graphene Sheet**
   - **Single- or Multi-Walled**
   - **No defects in the structure**
2. **What are the benefits to concrete?**
   - **High thermal conductivity.**
   - **High electrical conductivity.**
   - **High elasticity and flexibility.**
   - **High hardness.**
   - **High chemical resistance.**
   - **Antibacterial**
   - **And more…**
3. **What are the negative side effects?**
   - **Stability in Suspension, rarely delivered in dry form to concrete.**
   - **Tightening of Slump.**
   - **Bonding to Hydrated Cementitious Matrix**



CNTs from a Graphene Sheet. (Stolfi 2019).

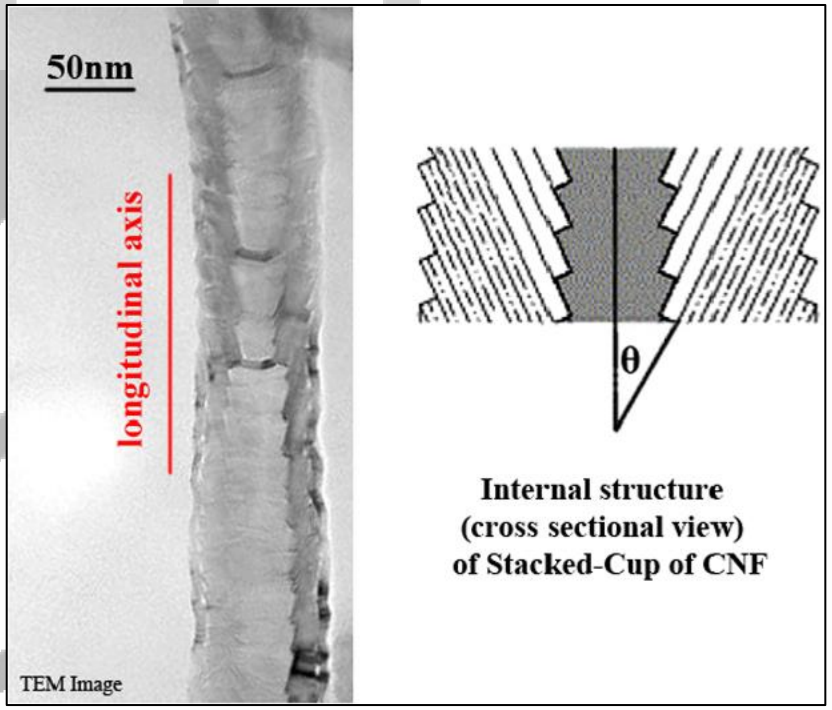


Artist Rendering of Graphene and CNT (Zuo 2018).

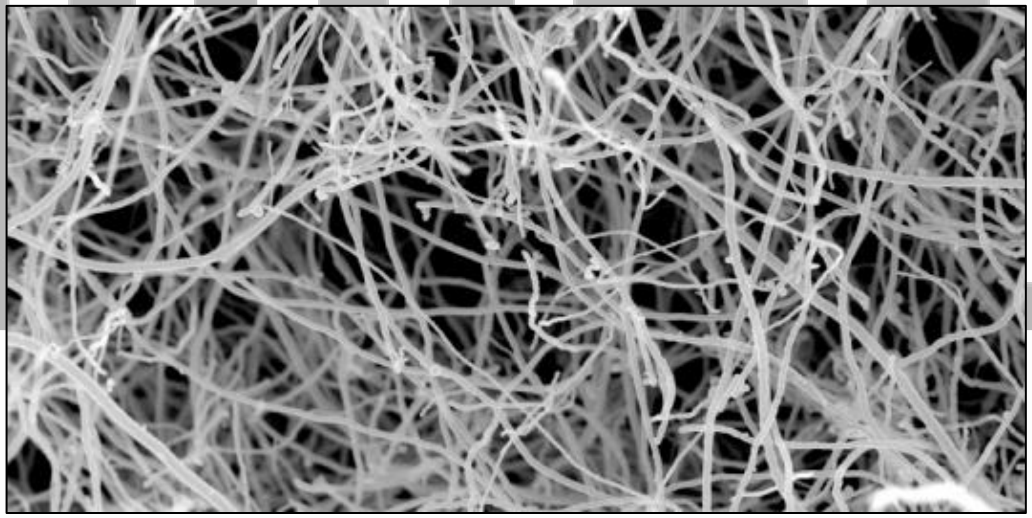
Carbon Nanofiber

Learning Objective 1

1. **What makes each one different?**
   - **Rolled Up Graphene Sheet**
   - **Single-Walled**
   - **Defects in the structure**
2. **What are the benefits to concrete?**
   - **High thermal conductivity.**
   - **High electrical conductivity.**
   - **High elasticity and flexibility.**
   - **High hardness.**
   - **High chemical resistance.**
   - **Antibacterial**
   - **And more…**
3. **What are the negative side effects?**
   - ~~**Stability in Suspension, rarely delivered in dry form to concrete.**~~
   - **Tightening of Slump.**
   - **Bonding to Hydrated Cementitious Matrix**



Stacked-Cup C-Nanofiber. (Tucci 2013).



Carbon nanofibers (Guadagno 2013).

Material Properties, 1

Learning Objective 1

What are the benefits to concrete?

- **High thermal conductivity.**
- **High electrical conductivity.**
- **High elasticity and flexibility.**
- **High hardness.**
- **High chemical resistance.**
- **Antibacterial**
- **And more…**

Material Properties, 2

Learning Objective 1

- **Fresh Properties**
  1. Reduction in Bleed Water
  2. Stabilization of Air Content
  3. Enhancement of Slump
  4. Creamier Finish
- **Hardened Properties**
  - Increased f'c and fr
  - Reduced Permeability
  - Increased Resiliency to Corrosion
  - Increased Abrasion Resistance
  - Reduction in Cracking

Material Properties, 2

Learning Objective 1

- **The different types of Cement Composites with Carbon Allotropes**

PERVIOUS CONCRETE (Xu 2015).

SHOTCRETE (Karagoz 2020).

CONCRETE

Specification Activity

Learning Objective 1

aci American Concrete Institute
Always advancing

rilem

The Graphene Council

What to Ask?

Learning Objective 1

1. Is this technology for technology's sake?
2. What is the concrete issue we are trying to solve?
3. What is the cost – in terms of time, money and resources?
4. What is our plan to get the technology into operations?
5. How do we get the entire concrete team bought in?

Purpose

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Research Institutions

Learning Objective 2

- **Increasing Concrete Blast Resistance with CNFs, *Northwest Polytech University***
- **Evaluation of Carbon Nanotube Incorporation in Cementitious Composite Materials – *Evangelista 2018***
- **Review on graphene-reinforced 3DCP composites for structural applications, *Composites Part A: Applied Science and Manufacturing*- Volume 167, *April 2023***

Research Institutions cont.

Learning Objective 2

- **Recent Advancements in Carbon Nanofiber-Infused Cementitious Composites – *Kanellopoulos, Silesian University of Technology 2021***
- **Graphene oxide as nano-material in developing sustainable concrete – A brief review – *Akarsh , 2022***
- **Ultrahigh Performance Nanoengineered Graphene–Concrete Composites for Multifunctional Applications – *Dimov, 2018***

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Case Study, 1 – Pervious Concrete

Case Study Conducted by Univ Alaska (Xu 2018)

Figure 4.1 Pervious concrete cylinders with capping: (left to right) cement, cement + GO, fly ash, fly ash + GO

Case Study, 1 – Pervious Concrete

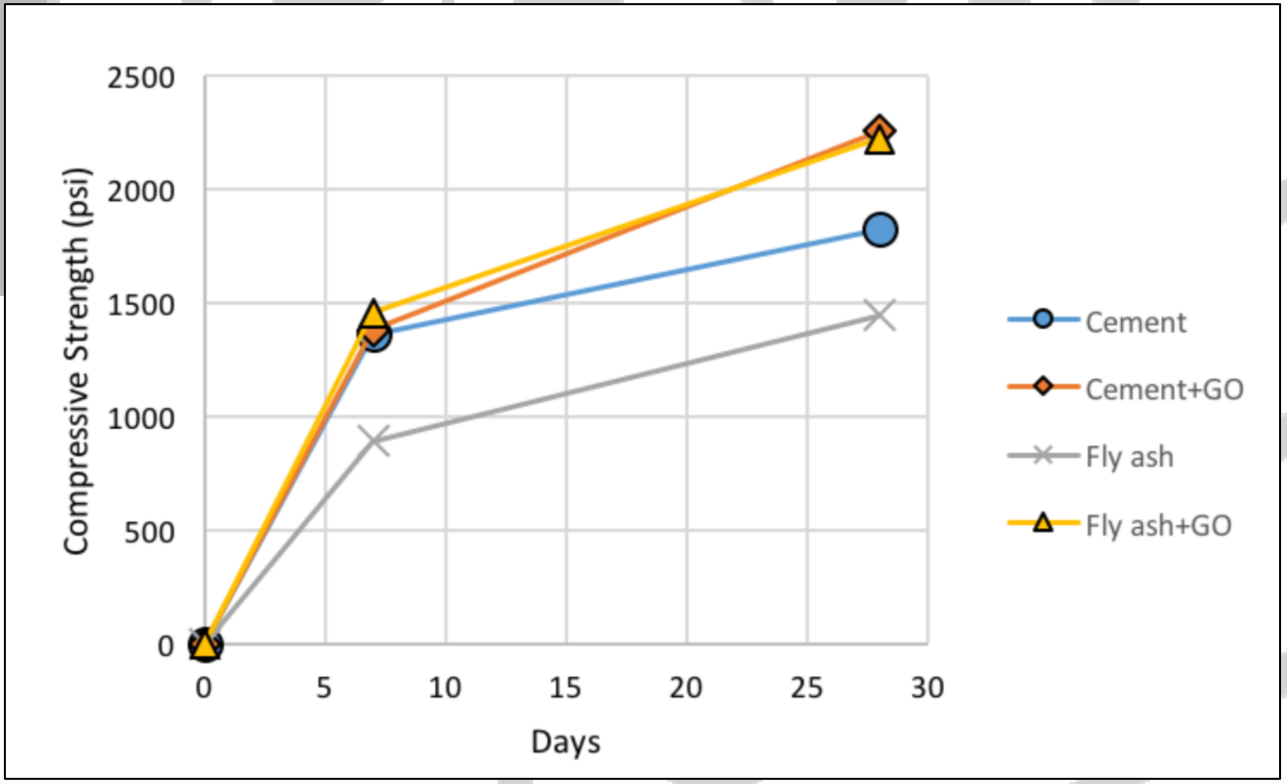
Case Study Conducted by Univ Alaska (Xu 2018)

1. **What type of concrete?**
   a) Pervious Concrete for Stormwater
   b) Air Entrained
2. **What type of Carbon-Allotrope?**
   a) Graphene Oxide in Liquid Suspension
3. **Why was the technology used?**
   a) "…graphene oxide (GO) shows potential as an admixture for concrete because it is a two-dimensional carbon sheet with an aspect ratio of 30,000 or higher (Tung et al. 2009), has a Young's modulus of 1 TPa and an intrinsic strength of 130 Gpa, and is highly hydrophilic (Lee et al. 2008)"
4. **How much of the technology was used?**
   a) 0.1% Addition by Weight of Binder
5. **How well did it work?**

Case Study, 1 – Pervious Concrete

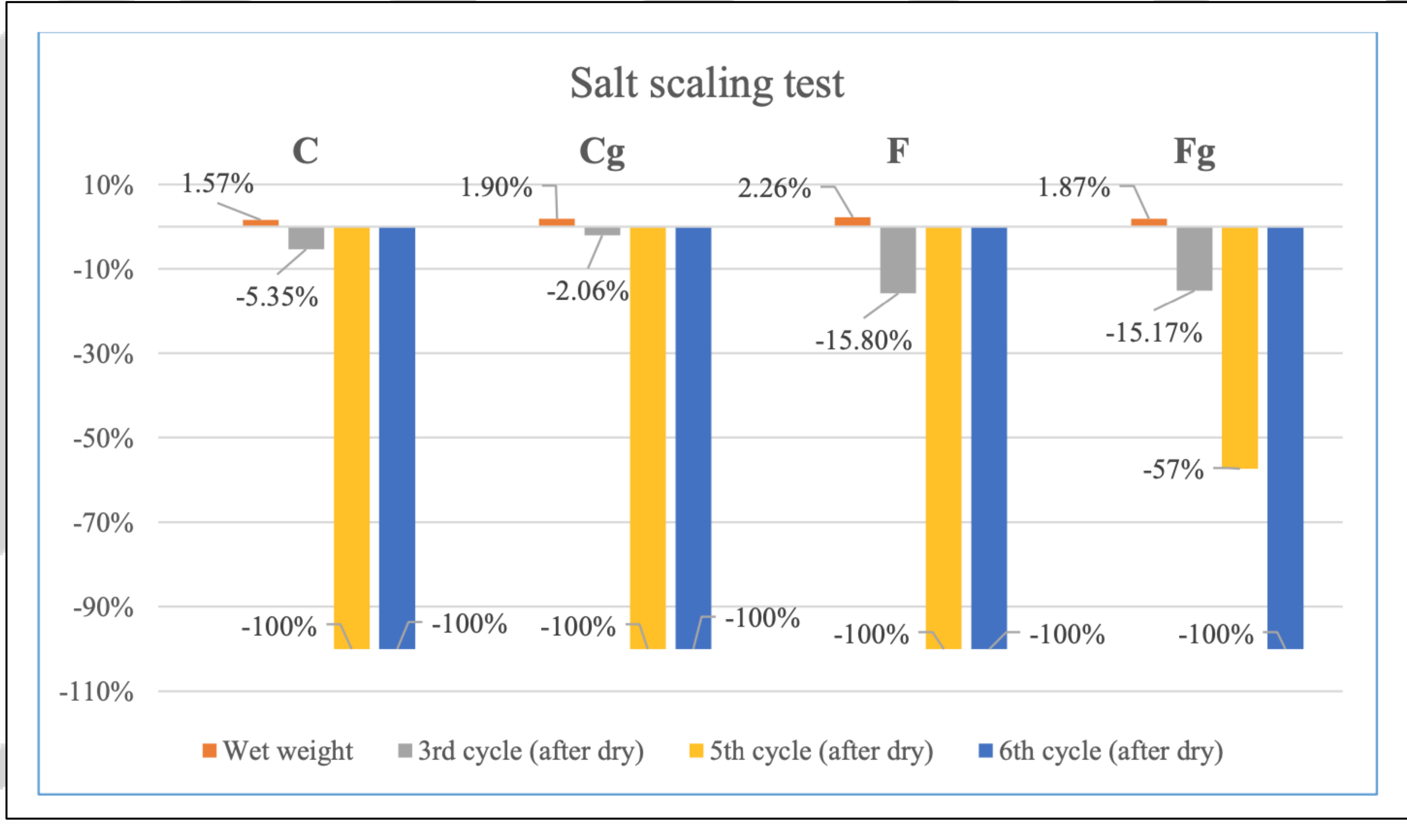
Case Study Conducted by Univ Alaska (Xu 2018)

5. How well did it work?



F'c

Salt Scaling



Case Study, 2 – CDOT Class E 12 hr

Case Study Conducted by UCD (Patel 2018)

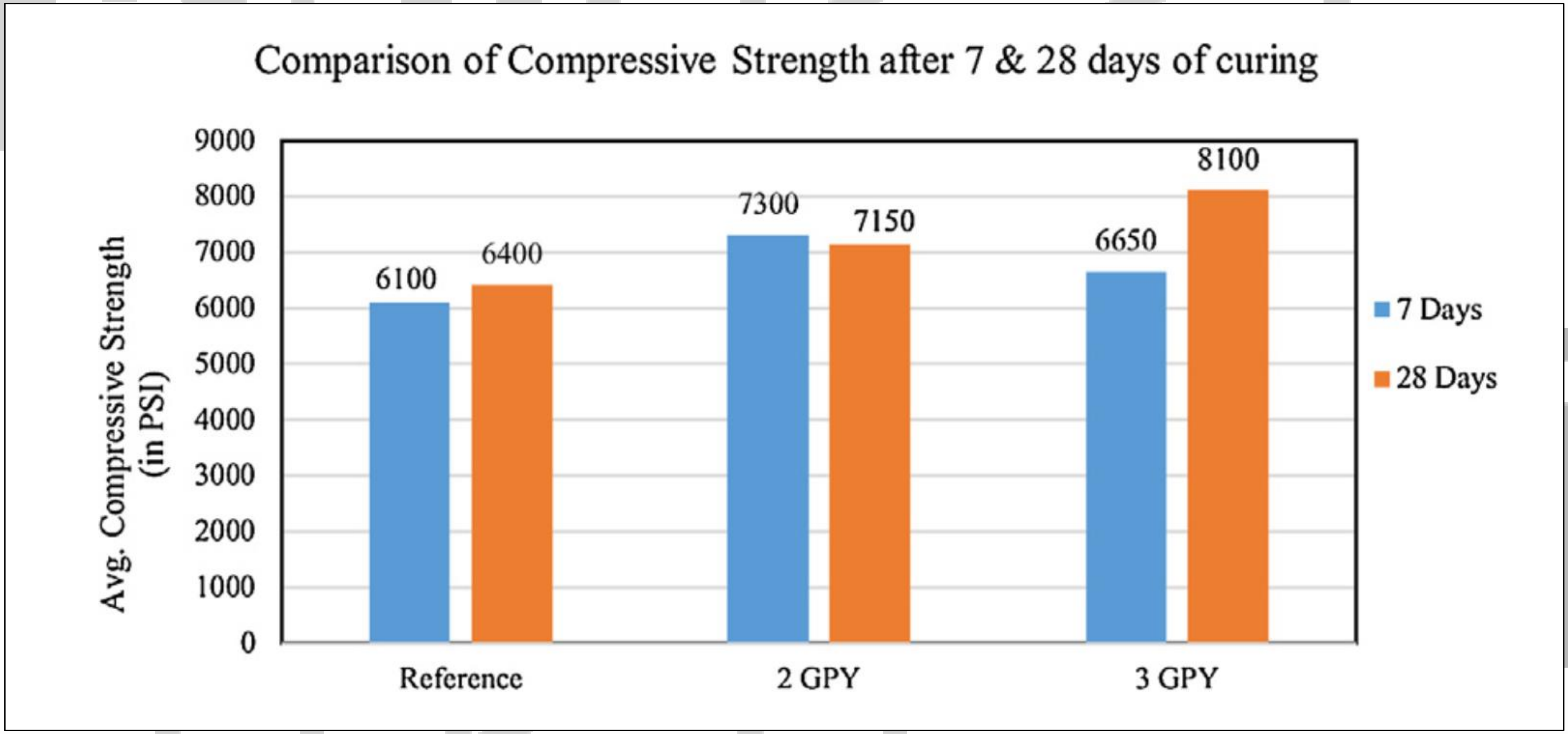
1. **What type of concrete?**
   a) Concrete Pavement designed to open traffic at 12 hr
   b) Air Entrained
   c) fr at 28-Days, 650 psi
   d) F'c at 28-Days, 4200 psi
2. **What type of Carbon-Allotrope?**
   a) Multi-Walled CNT in Liquid Suspension
3. **Why was the technology used?**
   a) "City and County of Denver was primarily interested in testing carbon nano-tube as an admixture to help to reduce road-way maintenance due to its lower permeability, reduced shrinkage and increased resistance to freeze-thaw."
4. **How much of the technology was used?**
   a) 2 Gallons Per Cubic Yard
   b) 3 Gallons Per Cubic Yard

DIVISION 600 MISCELLANEOUS CONSTRUCTION

Case Study, 2 – CDOT Class E 12 hr

Case Study Conducted by UCD (Patel 2018)

5. How well did it work?



Case Study, 2 – CDOT Class E 12 hr

Case Study Conducted by UCD (Patel 2018)

5. How well did it work?

Case Study, 3 – Conscious Concrete

Case Study Conducted by Univ Houston (Howser 2013)

Case Study, 3 – Conscious Concrete

Case Study Conducted by Univ Houston *(Howser 2013)*

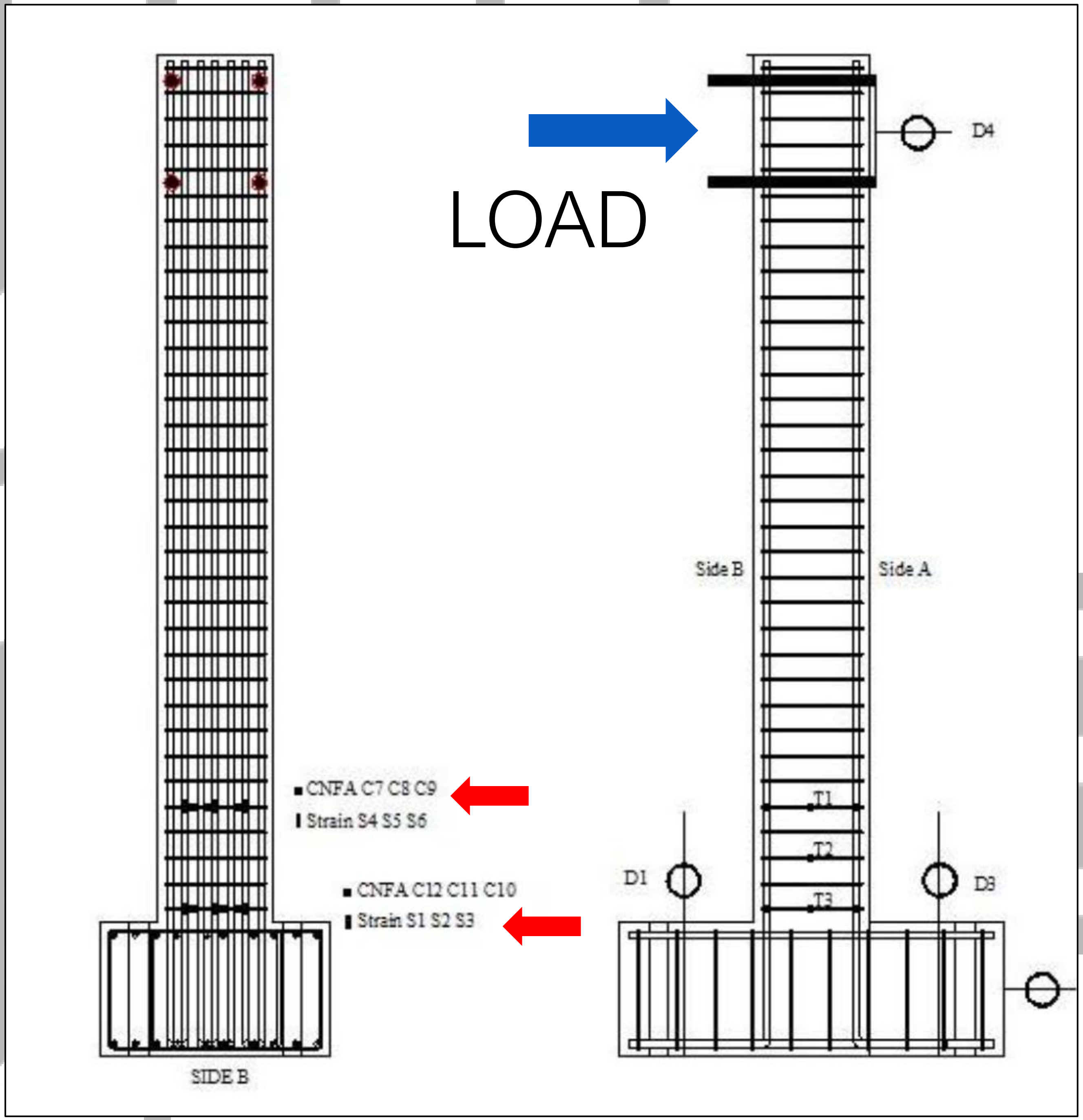
1. **What type of concrete?**
   a) Concrete Columns
   b) Conventional Concrete
2. **What type of Carbon-Allotrope?**
   a) Carbon Nanofiber Mortar Cubes
3. **Why was the technology used?**
   a) "…concrete ages and deteriorates, leading to substantial loss of structural integrity and potentially resulting in catastrophic disasters such as highway bridge collapses. A solution for preventing such occurrences is the use of structural health monitoring (SHM) technology"

   b) How much of the technology was used?
      i. Strategically placed throughout the column steel reinforcement cage
4. **How well did it work?**

Case Study, 3 – Conscious Concrete

Case Study Conducted by Univ Houston (Howser 2013)

Experimental Setup



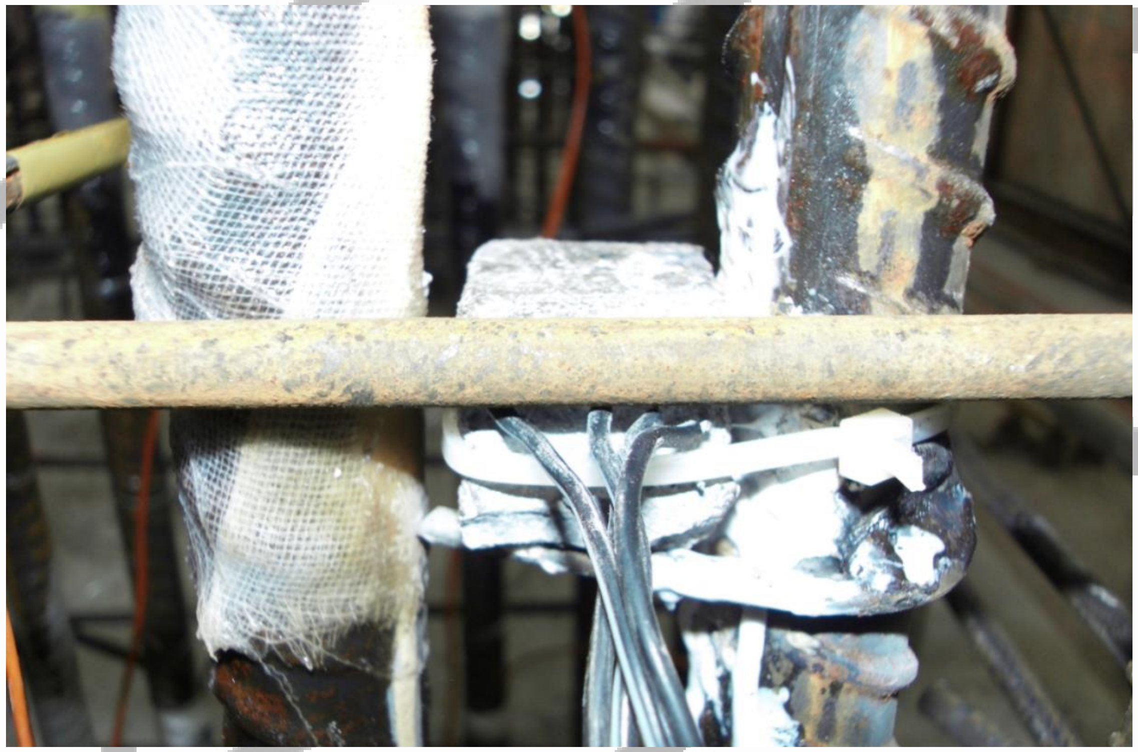
Schematic with Reinf and CNFA Sensors

Case Study, 3 – Conscious Concrete

Case Study Conducted by Univ Houston (Howser 2013)

5. How well did it work?

a) Monotonic Cyclic Load on Concrete Columns
b) CNFA sensors placed at based of column and foundation
c) 3 out of 12 CNFA sensor failed prematurely
d) CNFA was able to monitor complex strain behavior of concrete column as it failed in from fatigue



CNFA Sensor

Why Should the Industry Care?

Local Materials:

- Rounded Rock,
  - PGravel
  - Squeegee
- Powder Content
- Chemical Admixtures

Local Construction:

- Infrastructure
  - Transportation
  - Water Reclamation
- Subdivisions
- Industrial Applications

Labor Shortage

Summary

- **Opportunity to create long-term, strategic applications**
- **Increasing the overall sustainability of concrete as a 21st century building material**
- **Bringing value for all sectors of construction industry**

Questions