The Effects of Coal-Derived Graphene Nanomaterials in Cementitious Materials

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NATIONAL ENERGY TECHNOLOGY LABORATORY

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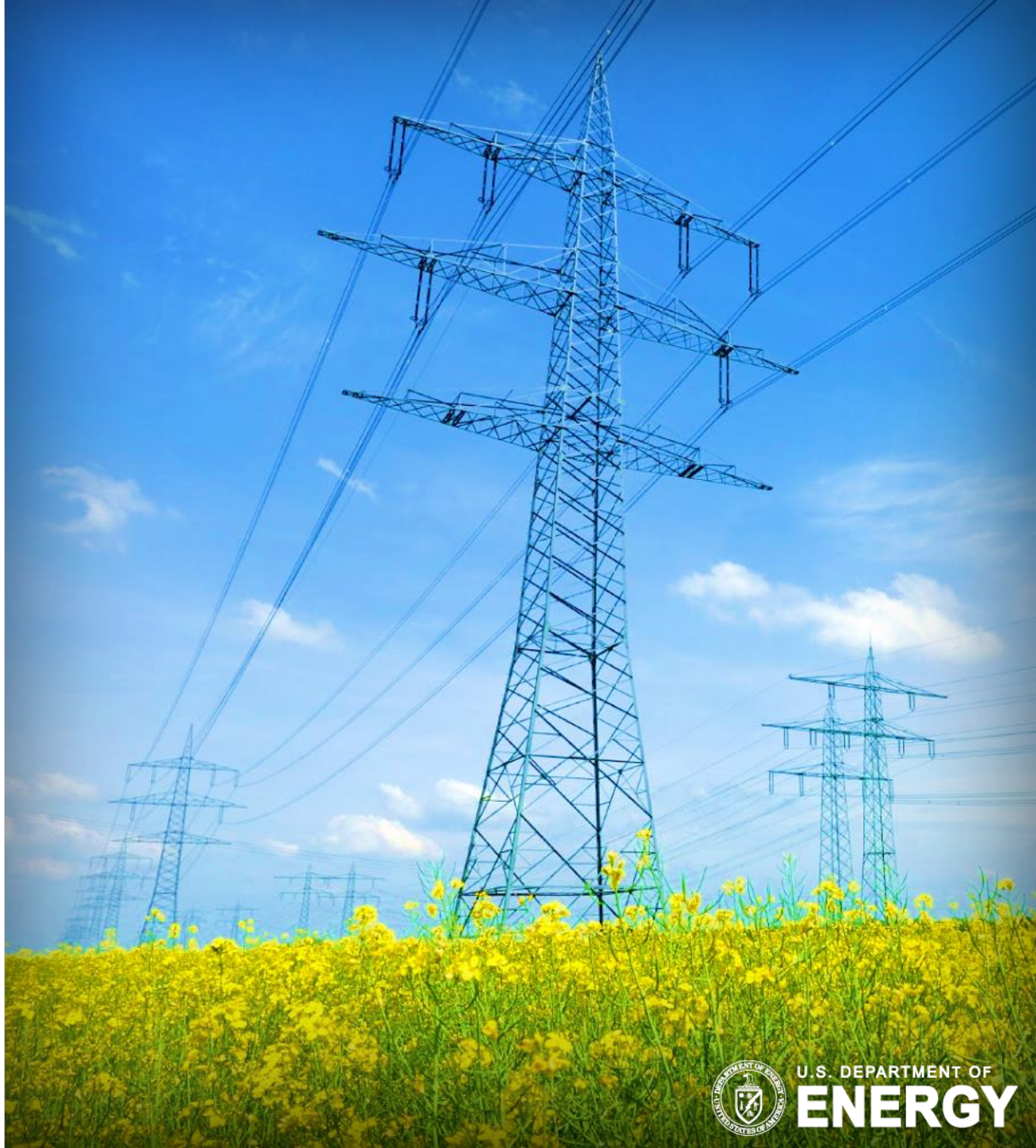
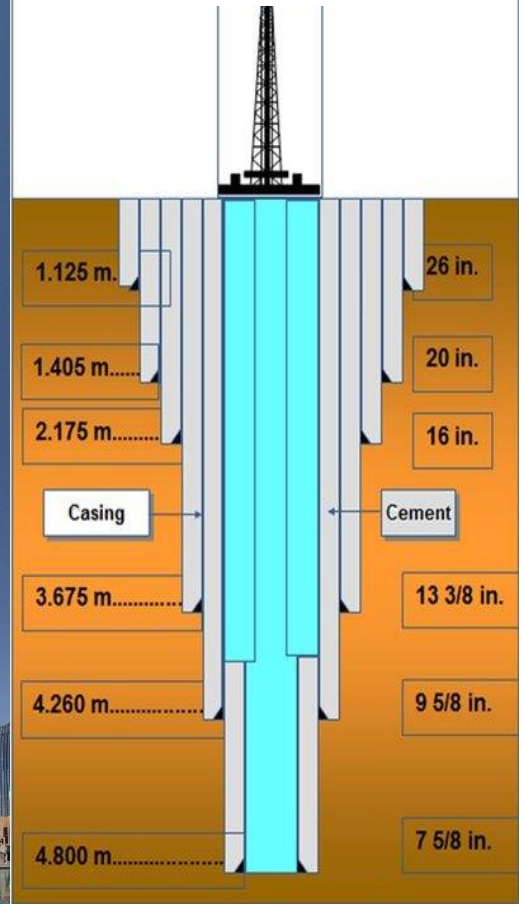


Cement Composites

- **Cement Composites**
  - Aggregates: sand, coarse aggregates
  - Supplementary cementitious materials (SCMs): fly ash, slag, silica fume
  - Chemical admixtures
  - Reinforcement: steel, fiber
  - Nanomaterials

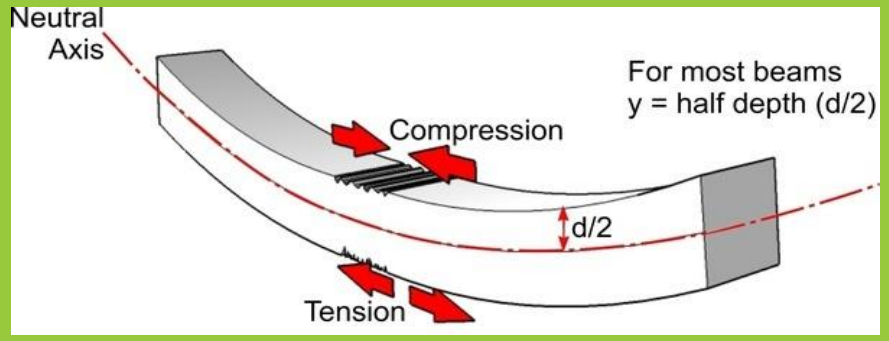
Burj Khalifa in Dubai

Cement Oil Well

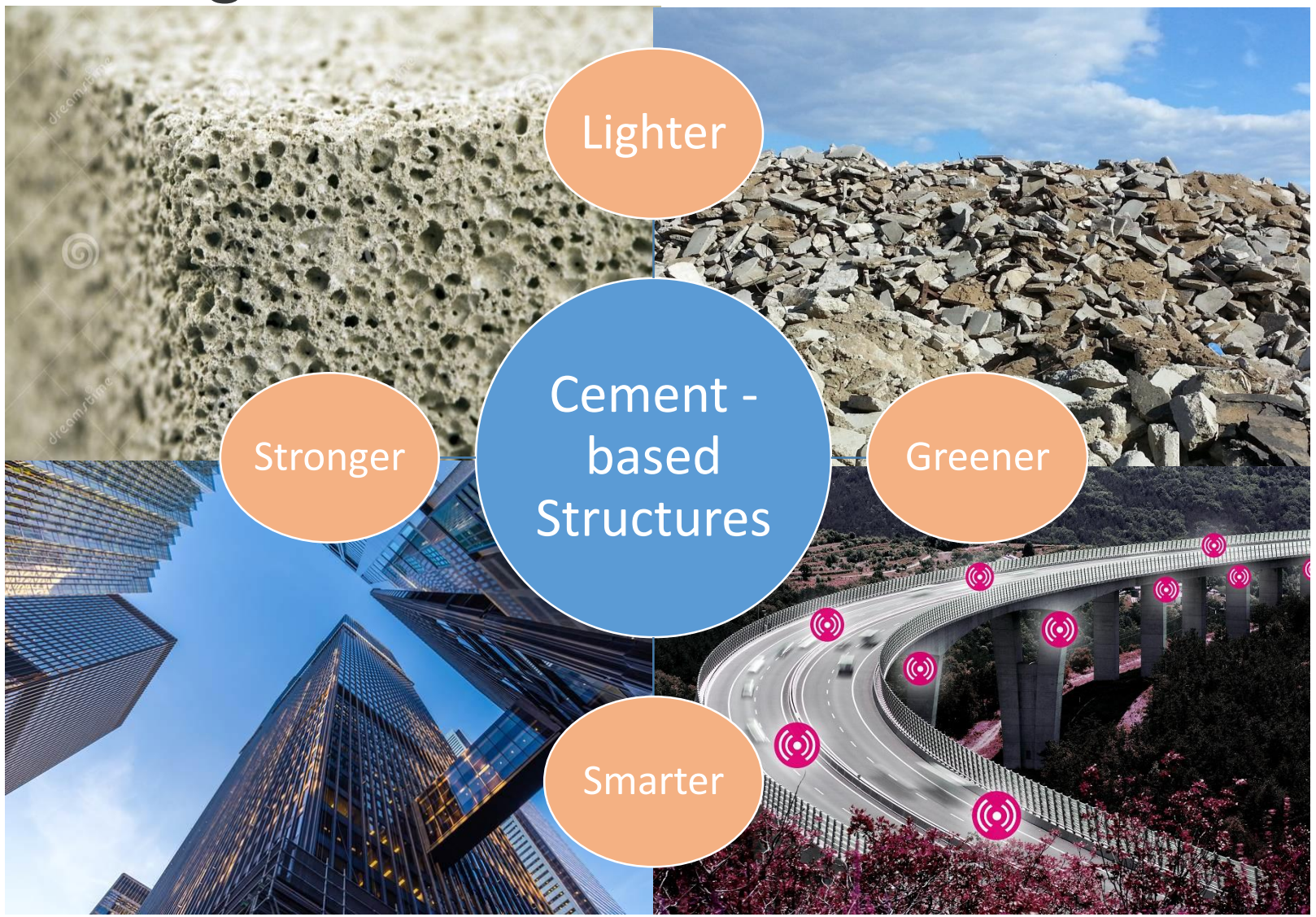


Typical Issues with Cement Composites

- Low tensile/flexural strength
- Creep/Shrinkage
- Corrosion



New Challenges on Cement-based Structures



Coal Products in Cement Composites

- Fly ash and slag (15-25 wt%)
- Pitch-based short carbon fibers (0.5-2 vol%)
- **Coal-based carbon nanomaterials (0.05-0.2 wt%)**

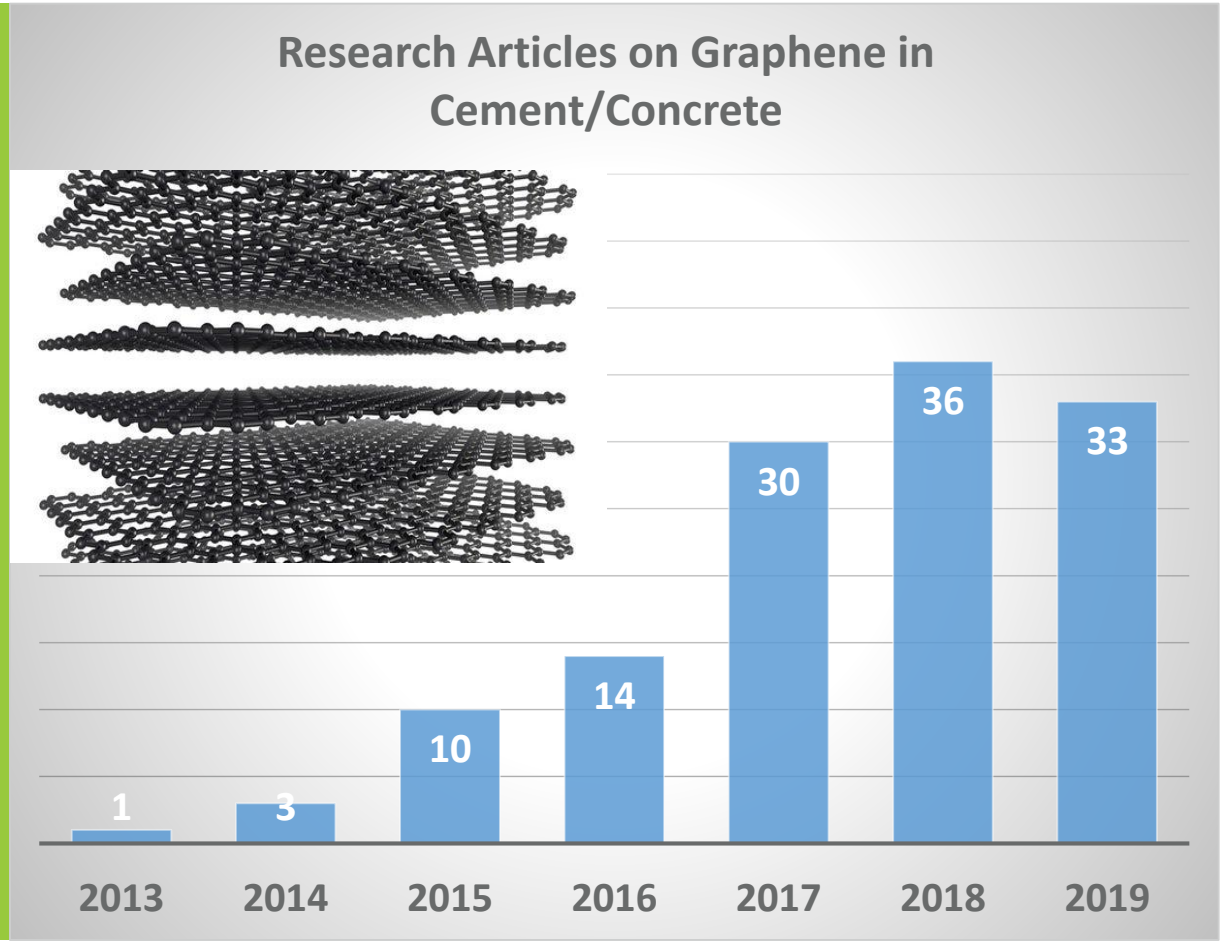
Short carbon fibers

Carbon Nanotubes

Carbon Nanomaterials in Cement/Concrete

Graphene/Graphene oxide

- Increase mechanical properties
- Reduce corrosion
- Potential increase on thermal conductivity
- Better bonding with cement matrix than carbon fiber/nanotube



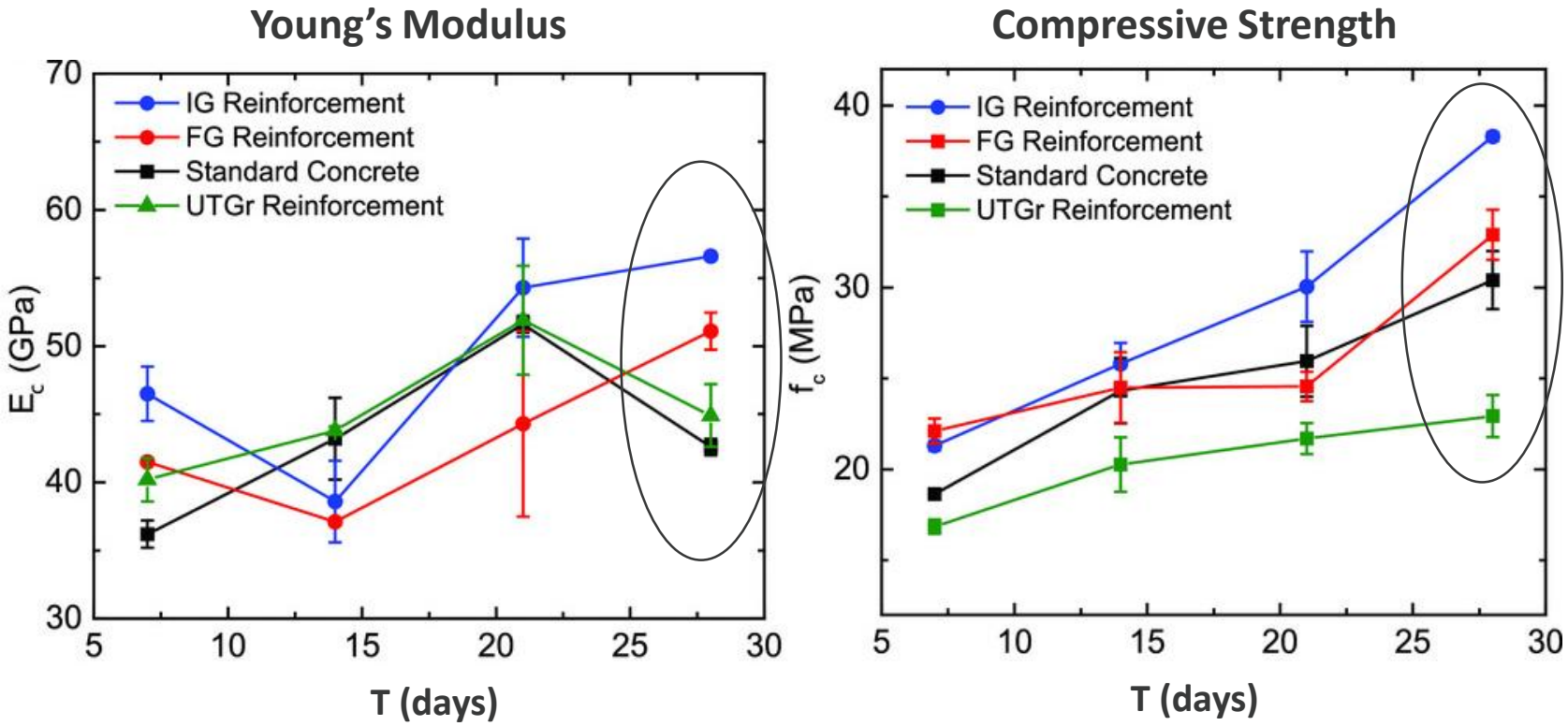
From Coal to Carbon Nanomaterials

	Feedstocks	Large-scale Production Techniques
Graphene/ Graphene Oxide	Methane, SiC, graphite, **coal**	CVD, mechanical/chemical exfoliation, etc.

Coal as the precursor is more affordable and abundant.

Carbon Nanomaterials in Cement/Concrete

Graphene/Graphene oxide



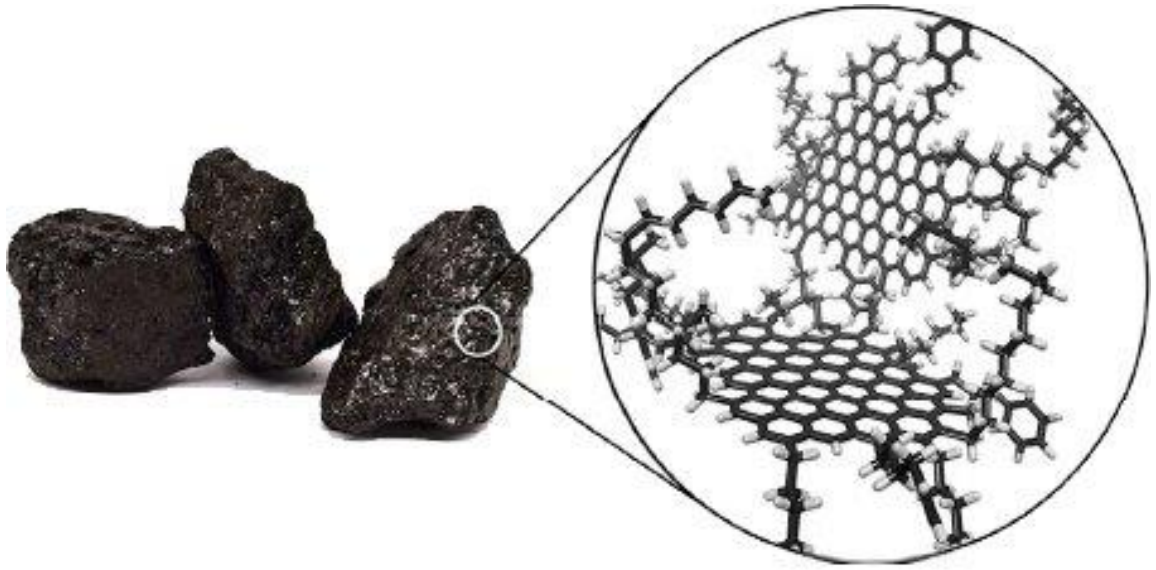
- IG: Industrial-grade Graphene Nanoflakes
- FG: Few-layered Graphene Nanoflakes
- UTGr: Graphite

D Dimov, et al., **Ultrahigh Performance Nanoengineered Graphene-Concrete Composites for Multifunctional Applications**, *Advanced Functional Materials*, V. 28, I 23, 2018

Coal-derived Carbon Nanomaterials Synthesis at NETL

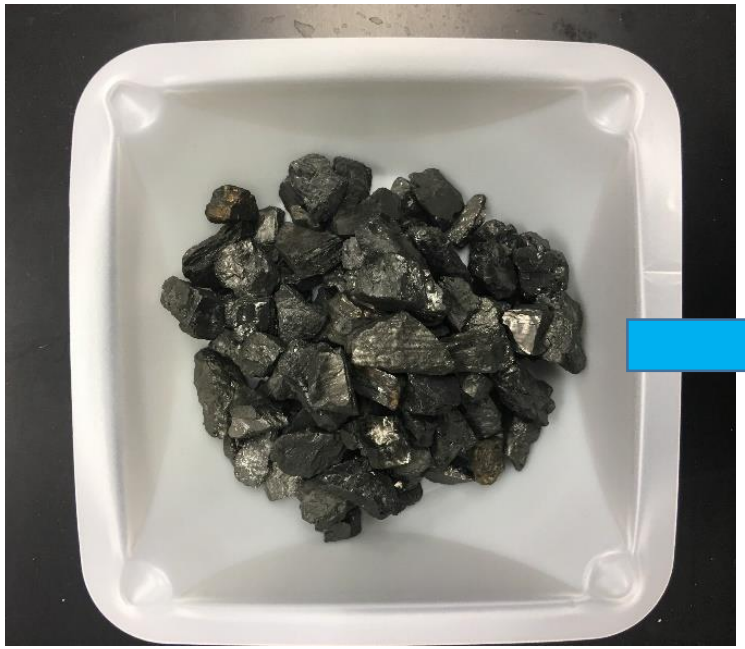
- Bituminous
- Anthracite
- Coal char (thermally treated coal)

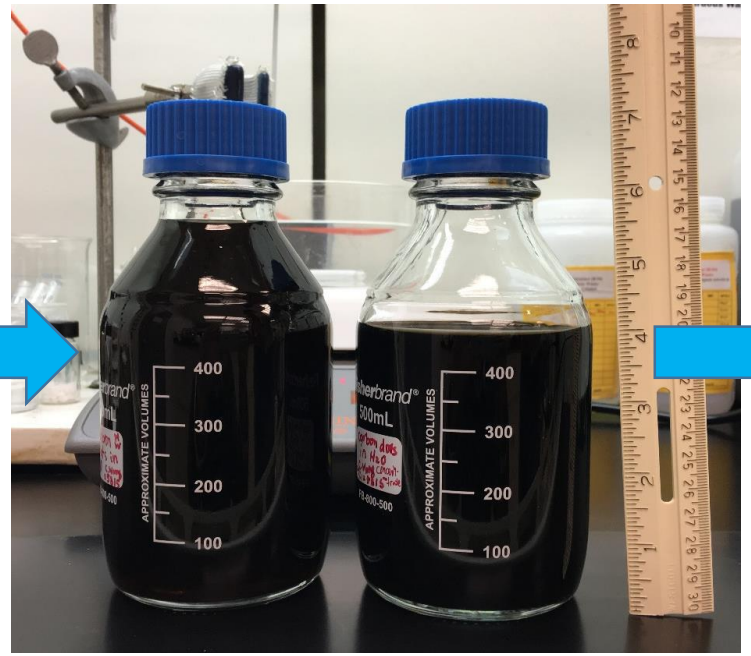
Increasing structural order

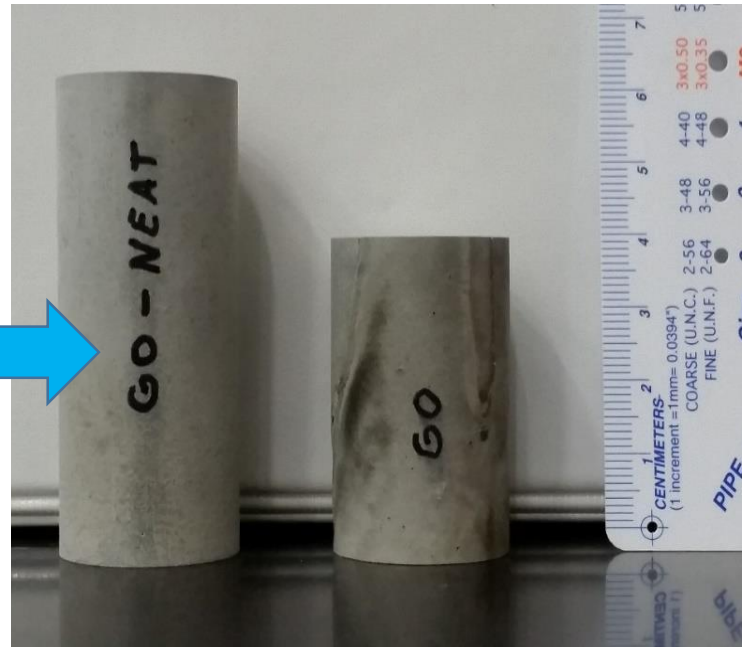


Graphitic Structure

Addition of Coal-derived Carbon Nanomaterials in Cement Composites







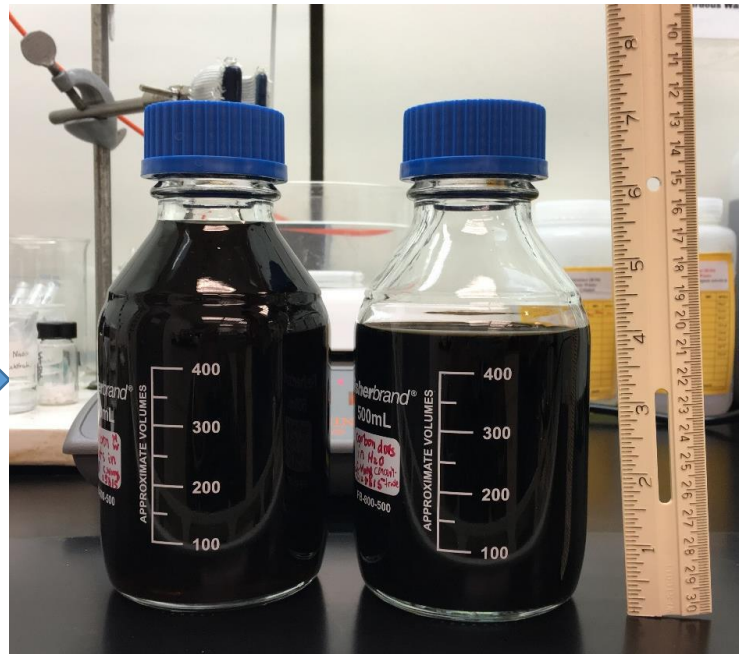
Synthesis of Carbon Nanomaterials from Coal

Mechanical Approach

Ball Milling
Shear Mixing
Ultra-sonication

Chemical Approach

Oxidation
Exfoliation
Reduction

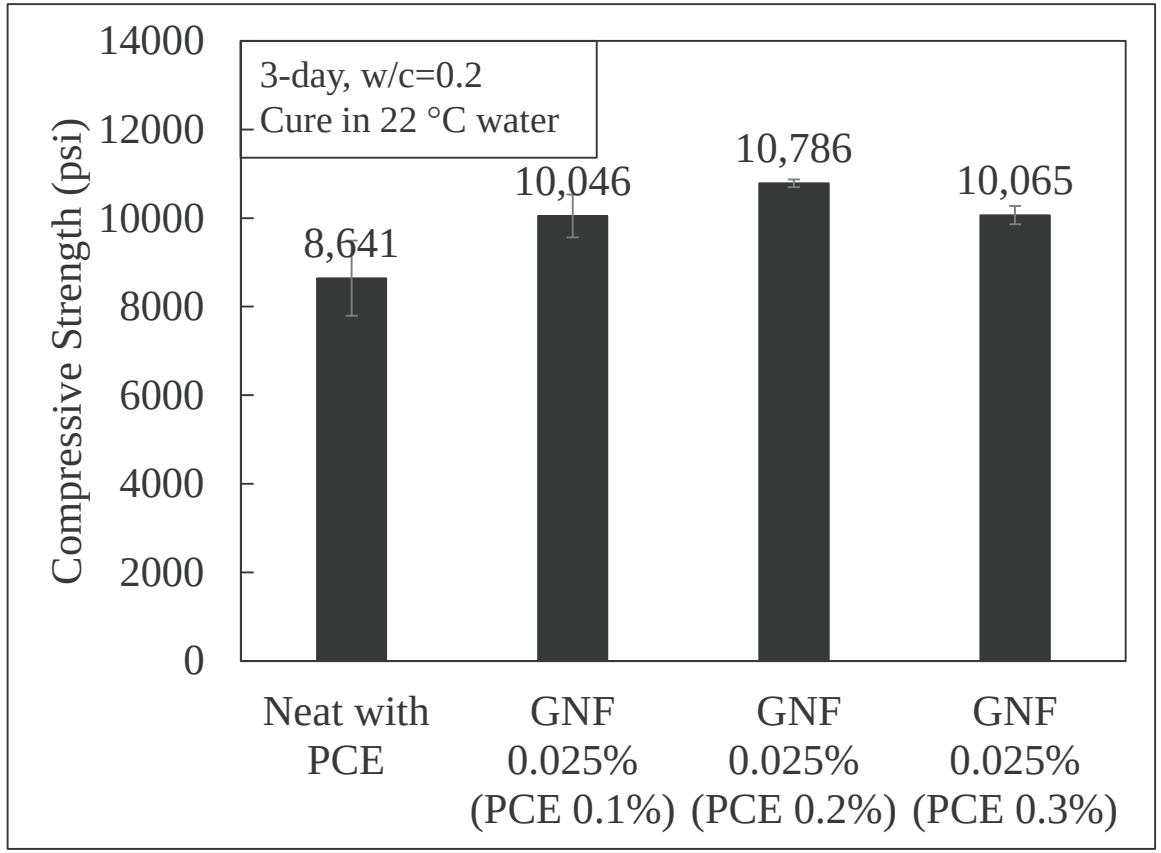


Graphene Materials from Coal

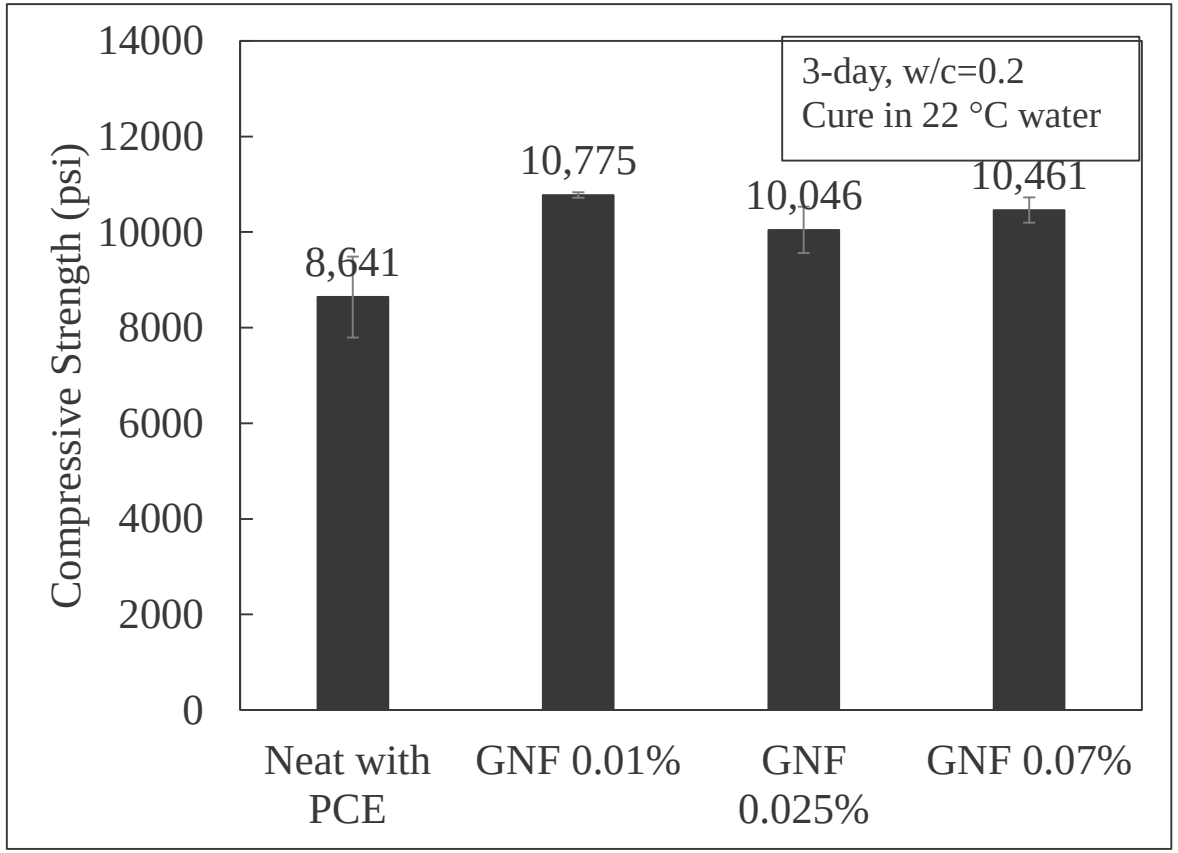
- Carbon Quantum Dots (CD)
- Graphene Nanoflakes (GNF)
- Oxidized Graphene Nanoflakes(OGNF)

- **Size: GNF=OGNF>CD**
- **Functional Groups: CD>OGNF>GNF**
- **Affordability: GNF>OGNF>CD**
- **Dispersibility: GNF>OGNF>CD**

How to Add Carbon Nanomaterials in Cement



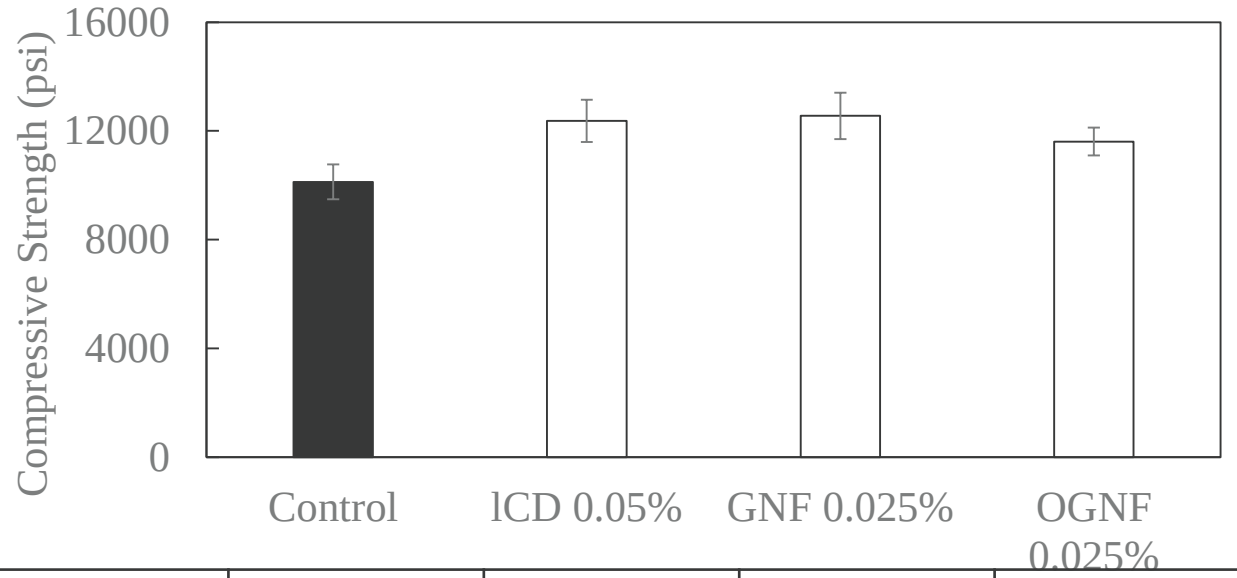
Effect of Surfactant to GNF Ratios



Effect of GNF Concentrations

Carbon Nanomaterials Enhanced Cement Composite

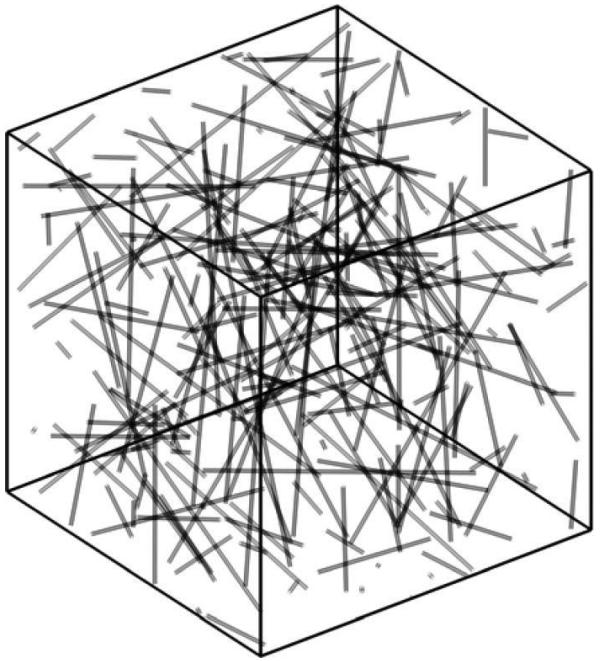
- Uniform distribution in cement matrix
- Mechanical properties
- Electrical properties
- Durability



	Control	Carbon Dots 0.05%	GNF 0.025%	OGNF 0.025%
28-day Compressive Strength, psi (Increase%)	10124	12372 (22%)	12556 (24%)	11610 (15%)

Challenges of Using Advanced Carbon Materials

Cost



Dispersion

Challenges--Cost

Convention Concrete: $100/yd^3

Ultra-high Performance Concrete(UHPC): ~$500/yd^3

Fiber-reinforced Concrete(FRC): ~800-1000/yd^3

Material/Topic	Ultra High Performance Concrete
White cement (lb/yd^3)	1311
Silica fume(lb/yd^3)	328
Fly ash(lb/yd^3)	318
HRWR(lb/yd^3)	48
Fine aggregate	1966
Cost($/yd^3)	494

0.3 lb of graphene in 1 cubic yard of concrete is expected.
Extra $500 dollars is added to UHPC.

Challenges-Dispersion

Dispersion and exfoliation in water

↓

Stability in cement

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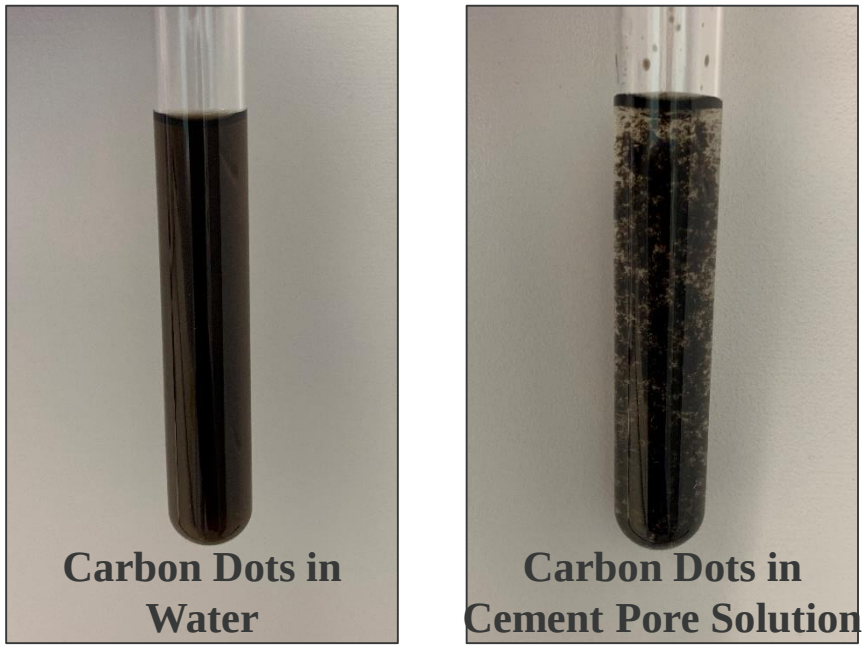
Compatibility with cement



Secondary-agglomeration in cement pore solution

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Questions?