IOWA STATE UNIVERSITY
Institute for Transportation

BRIDGE ENGINEERING CENTER

# Investigation of Macro-Defect Free Concrete for ABC including Robotic Construction

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# Background

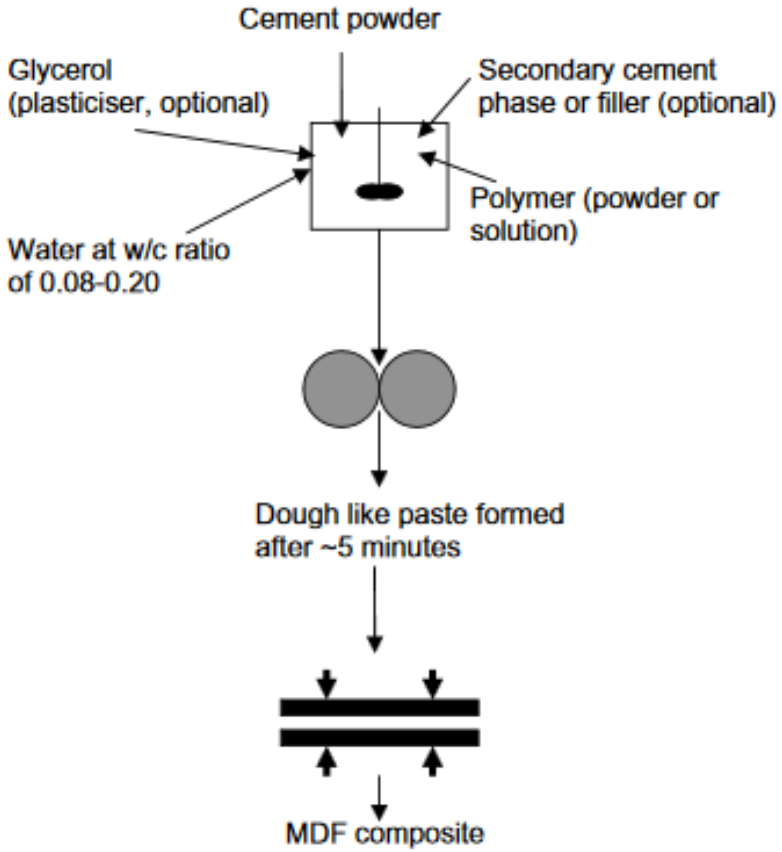
- Several formulations of macro-defect free concrete have been developed by a construction equipment company
- Material is more closely related to rubber than other cement-based materials
- Lack of knowledge of “what it is” vs. “what it isn’t”

# Macro-Defect Free Concrete

- Developed in the early 1980's
- Properties similar to those of ceramics, plastics, and metals
- High shear mixing of polymers and hydraulic cements at low w/c ratios (typically 0.08-0.20)

# Macro-Defect Free Concrete

- Typical manufacturing process:




**Stage**

1. Premixing in planetary orbital mixer (optional)
2. High shear mixing in twin roll mill
3. Compaction at up to 6Mpa (time and temperature can vary)
4. Curing – time and temperature vary

Donatello et al. 2009

# Macro-Defect Free Concrete

- Property comparisons:

| Material | Density ($g/cm^3$) | Flexural strength (MPa) | Youngs modulus (GPa) | Fracture energy ($J/m^2$) |
|---|---|---|---|---|
| OPC | 2.3 | 5–10 | 20–25 | 20 |
| MDF cement | 2.3–2.5 | >150 | 40–45 | 300–1000 |
| Aluminium | 2.7 | 150–400 | 70 | 1,00,000 |
| Glass | 2.5 | 70 | 70 | 10 |
| Wood | 1.0 | 100 | 10 | 10,000 |

* Ordinary Portland Cement (OPC)
* Macro-Defect Free Cement (MDF)

# Macro-Defect Free Concrete

- Traditional limitations of MDF:
  - Low moisture resistance
  - Shrinkage
  - Difficulties processing on a commercial scale
- However, modifications have overcome moisture and shrinking issues- economical large scale manufacturing issues remain

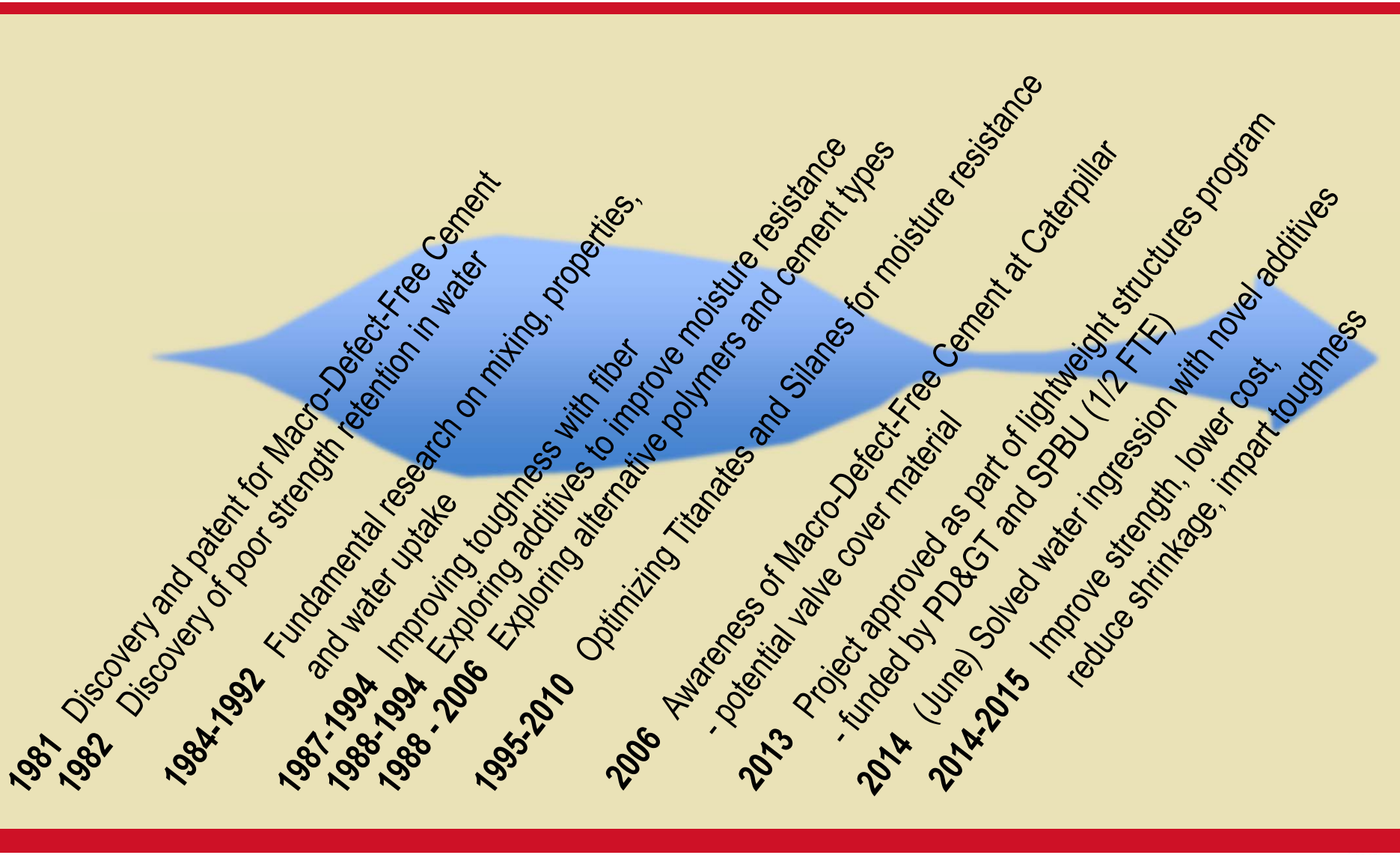
# Macro-Defect Free Concrete

- Applications:
  - Roofing
  - Fire-resistant doors
  - Pipes
  - Shutters
  - Plastic molds
  - Thermal insulators
  - Boat decking
- Applications replace metals or plastics due to corrosion resistance properties

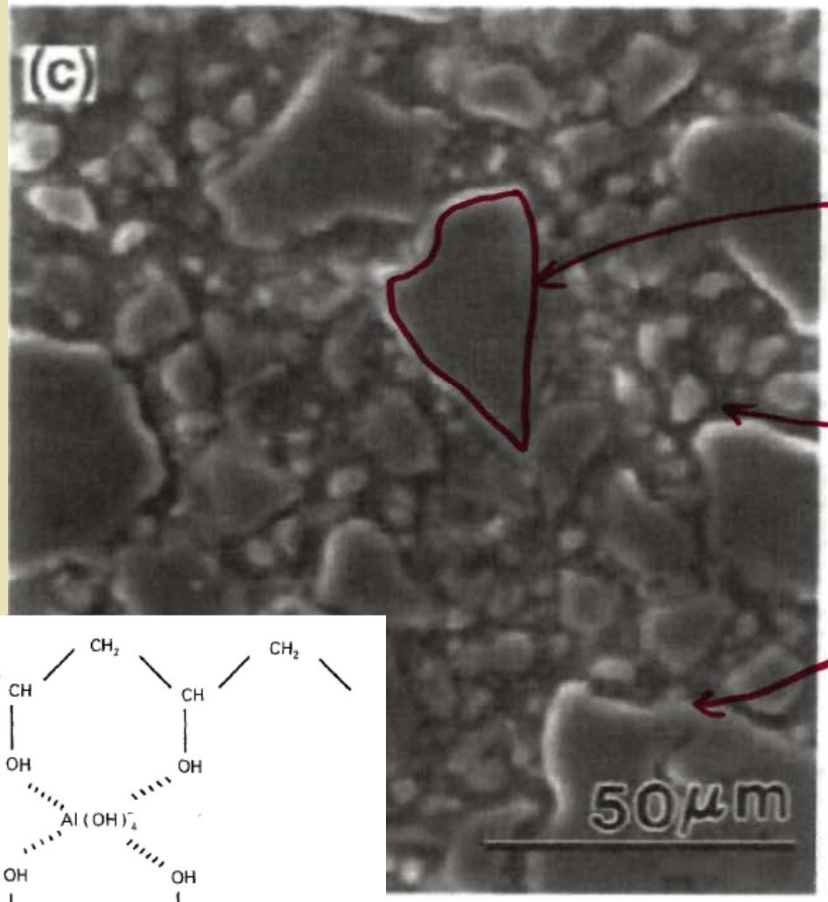
# Development: Cemposit

- Large construction equipment manufacturing company (Caterpillar) developed new formulations of MDF: called it Cemposit

# Development: Cemposit



# Development: Cemposit

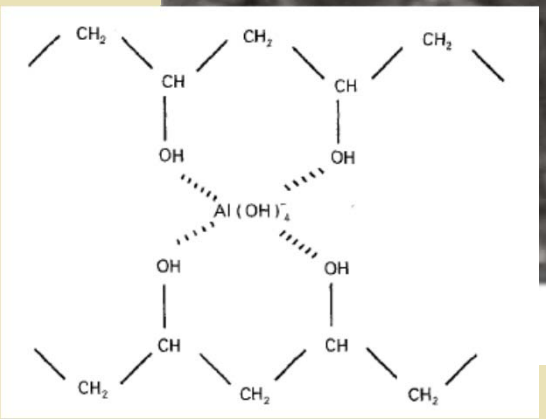



CEMENT GRAIN
(MOSTLY UNREACTED)

MATRIX: POLYVINYL ALCOHOL
WATER
$Ca^{2+}(OH^-)_2$, $Al^{3+}(OH^-)_4^-$
ADDITIVES

BOUNDARY LAYER OF
CEMENT GEL, SMALL CEMENT
HYDRATE CRYSTALLITES

NO LARGE AGGREGATE
NO LARGE POROSITY



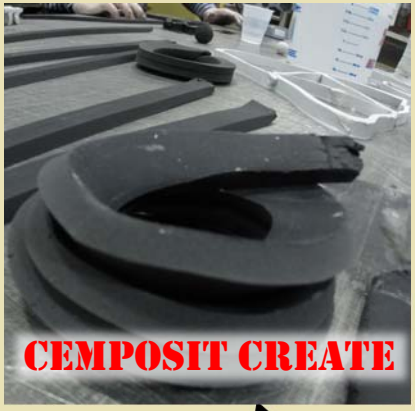
# Development: Cemposit

Make a gel or “gum” with the polymer and water

Incorporate fillers on a rubber mixer

Cut or shape preforms

Shape product for air cure

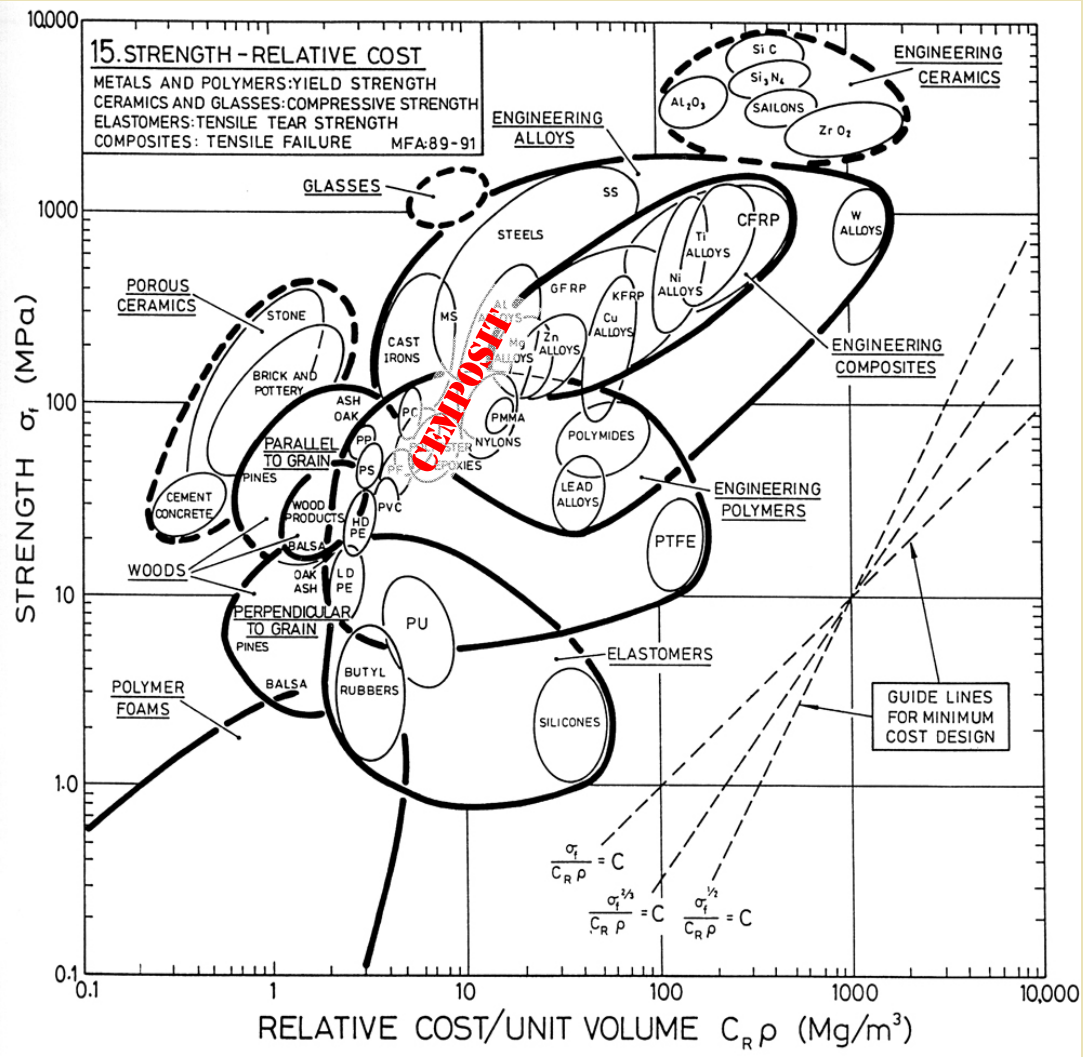



Mold to shape in heated hydraulic press

# Development: Cemposit

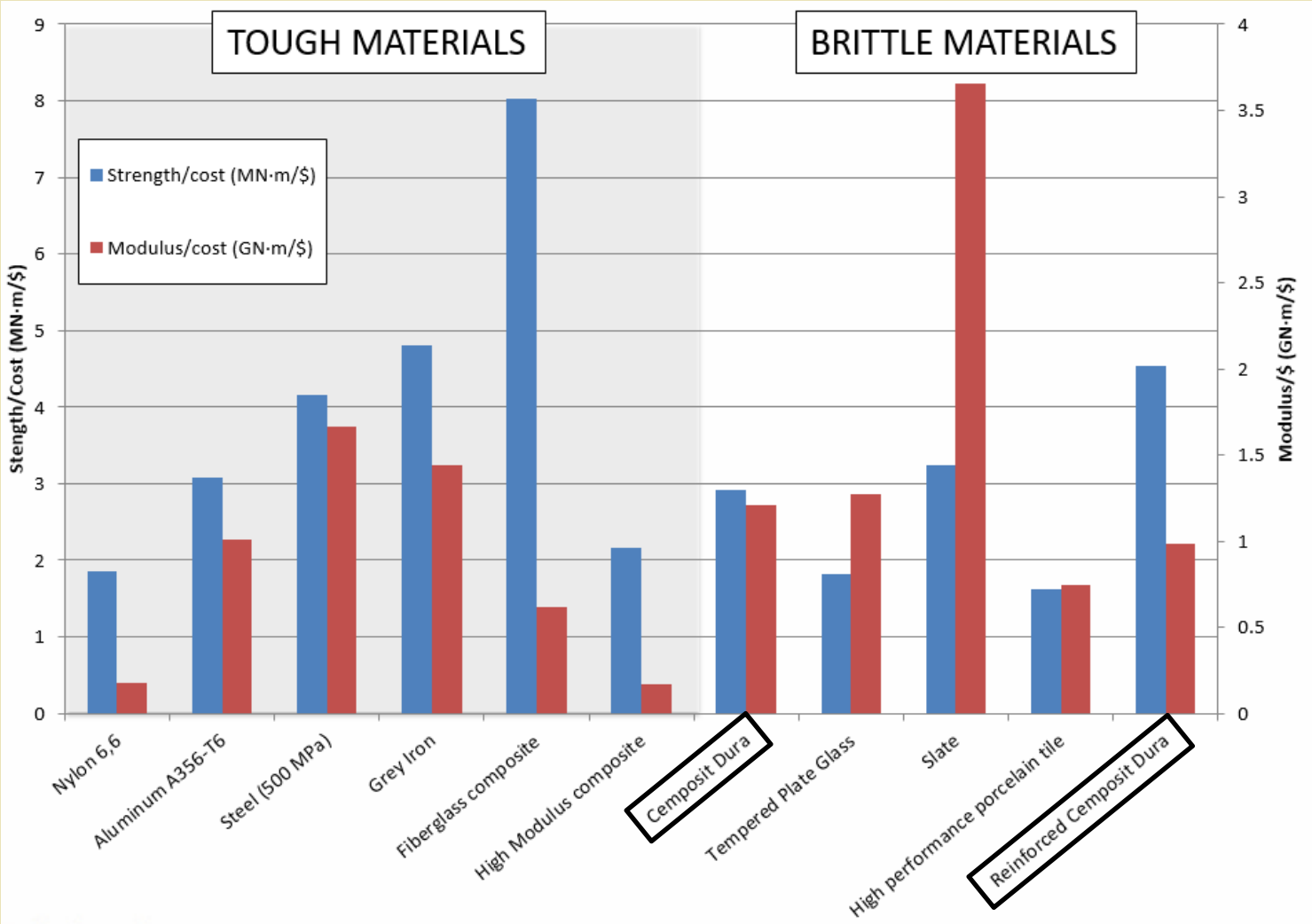
Mixing Process

# Development: Cemposit




| | Flexural Strength | Flexural Modulus |
|---|---|---|
| Heat & Pressure Molded **CEMPOSIT DURA** | 120 MPa | 50 GPa |
| Ambient cured **CEMPOSIT CREATE** | 50 MPa | 20 GPa |

# Development: Cemposit



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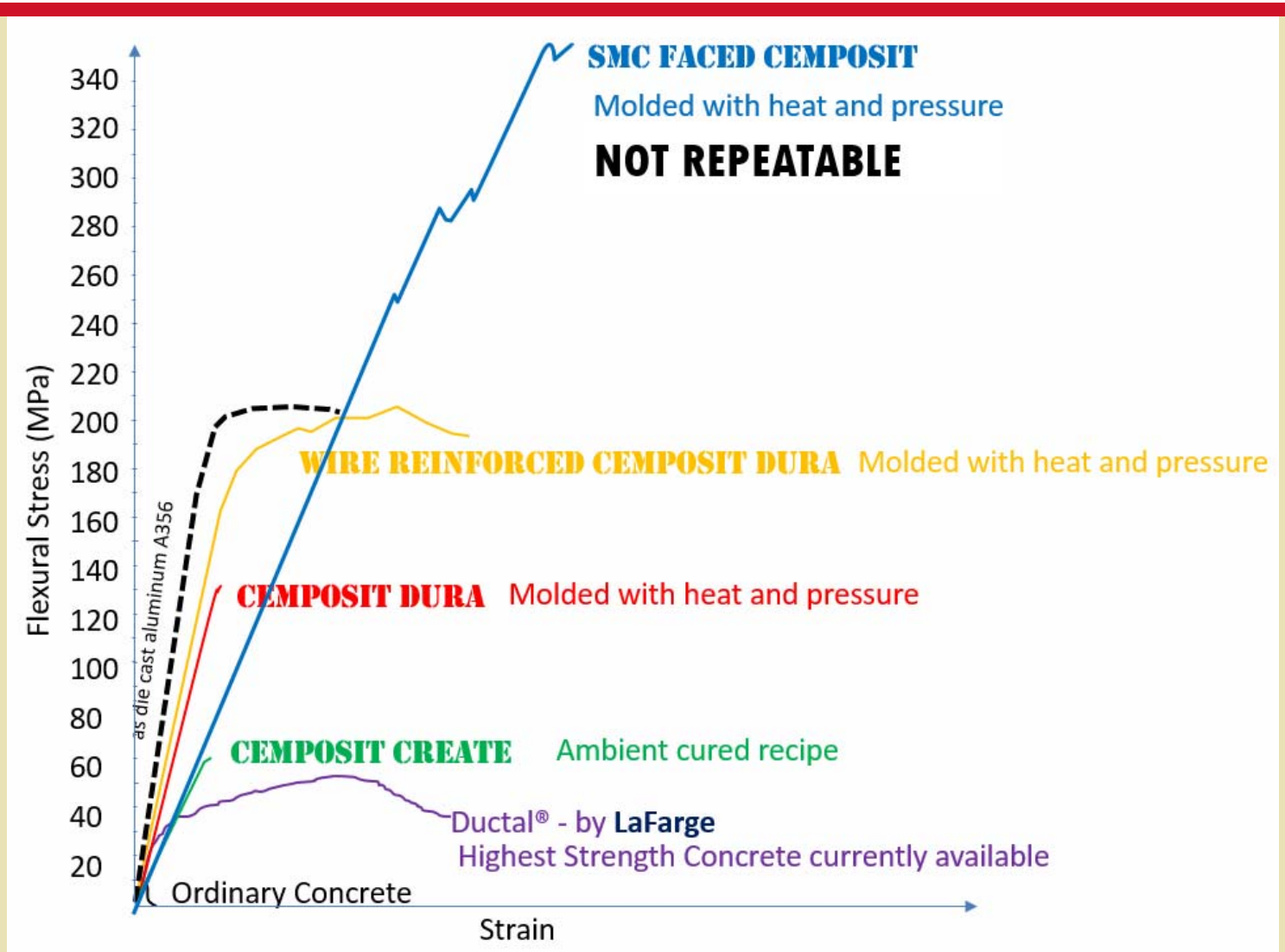

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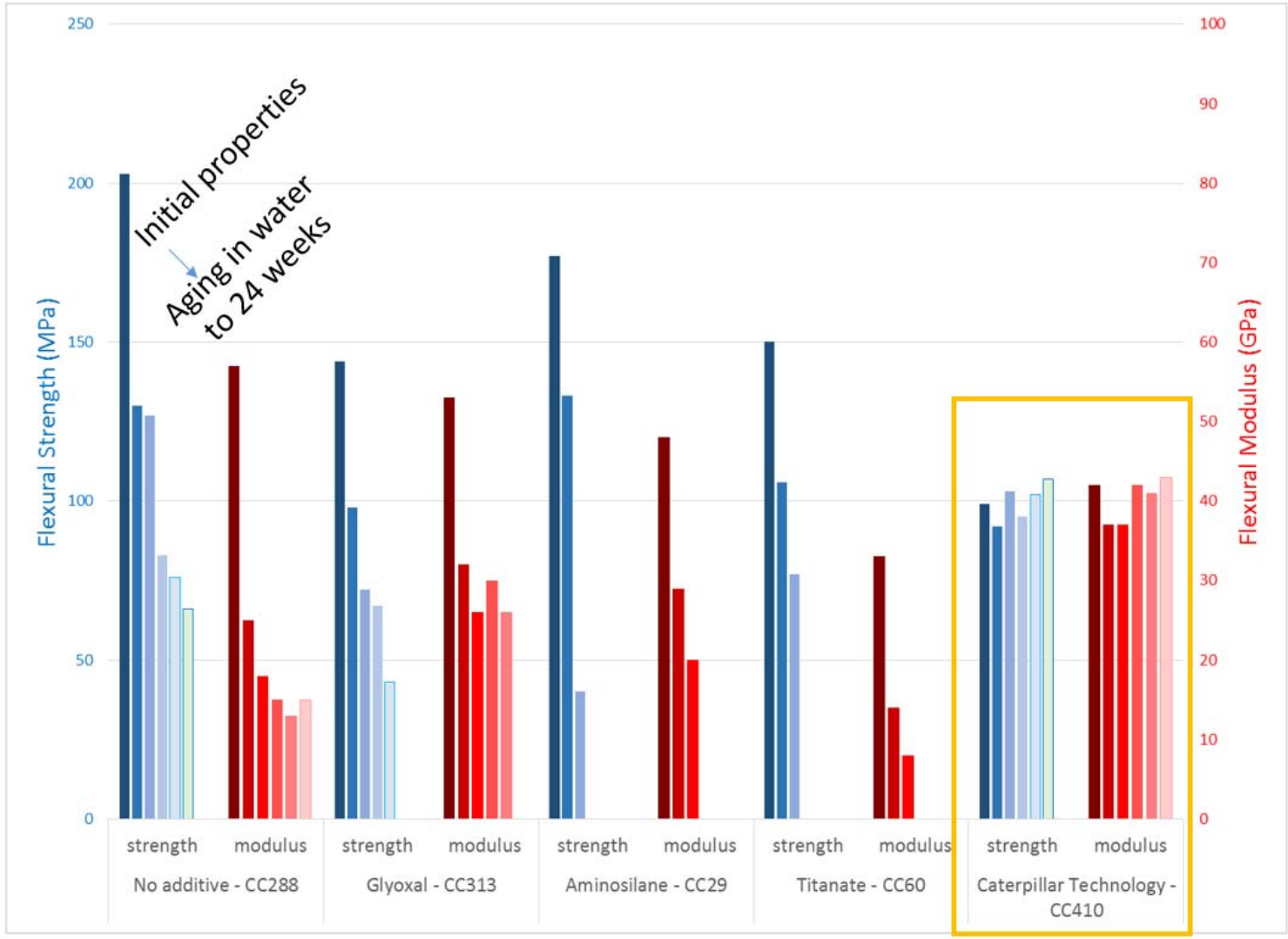


# Cemposit Summary

- Higher strength than concrete
- Improvements to shrinkage susceptibility
- Improvements needed for toughness
- Better properties if heat cured- half strength right away, full strength in 8 hours
- With ambient curing, not hard or rigid until 3-4 hours

Given these characteristics, how can it be used to advance ABC?

# Laboratory Testing

- Material tests were performed at the Iowa State Structures Laboratory:
  - Split tensile
  - Compression
  - Freeze thaw

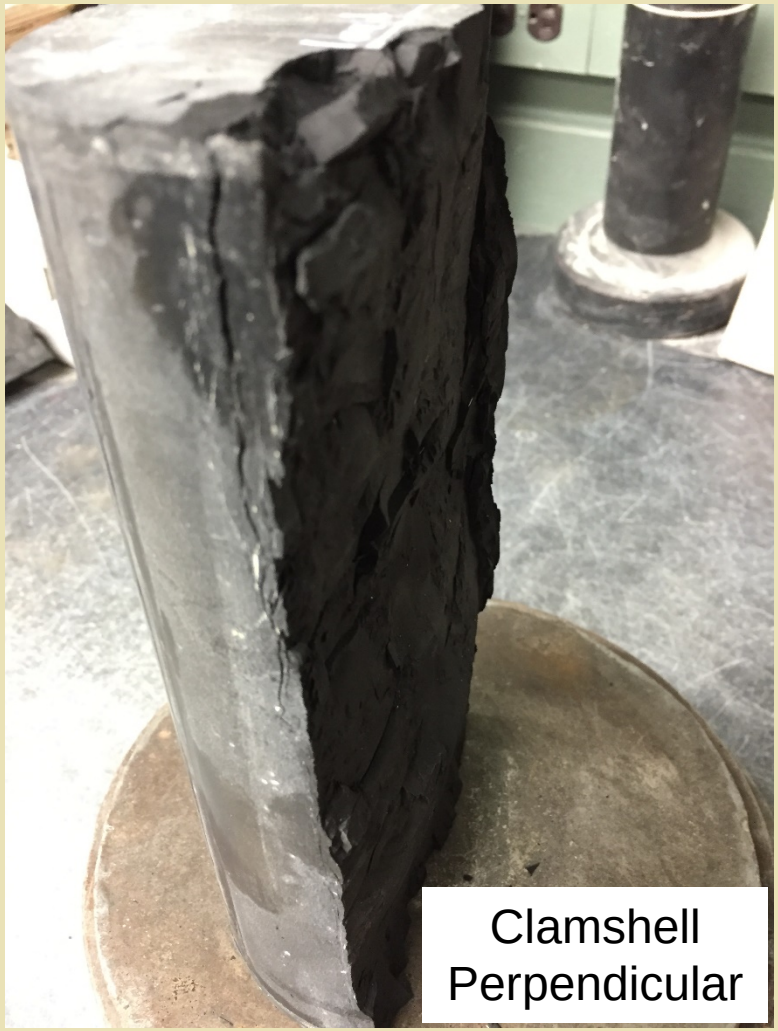
# Laboratory Testing

- Split Tensile: 9- 4”x8” cylinders were tested, in varying orientations

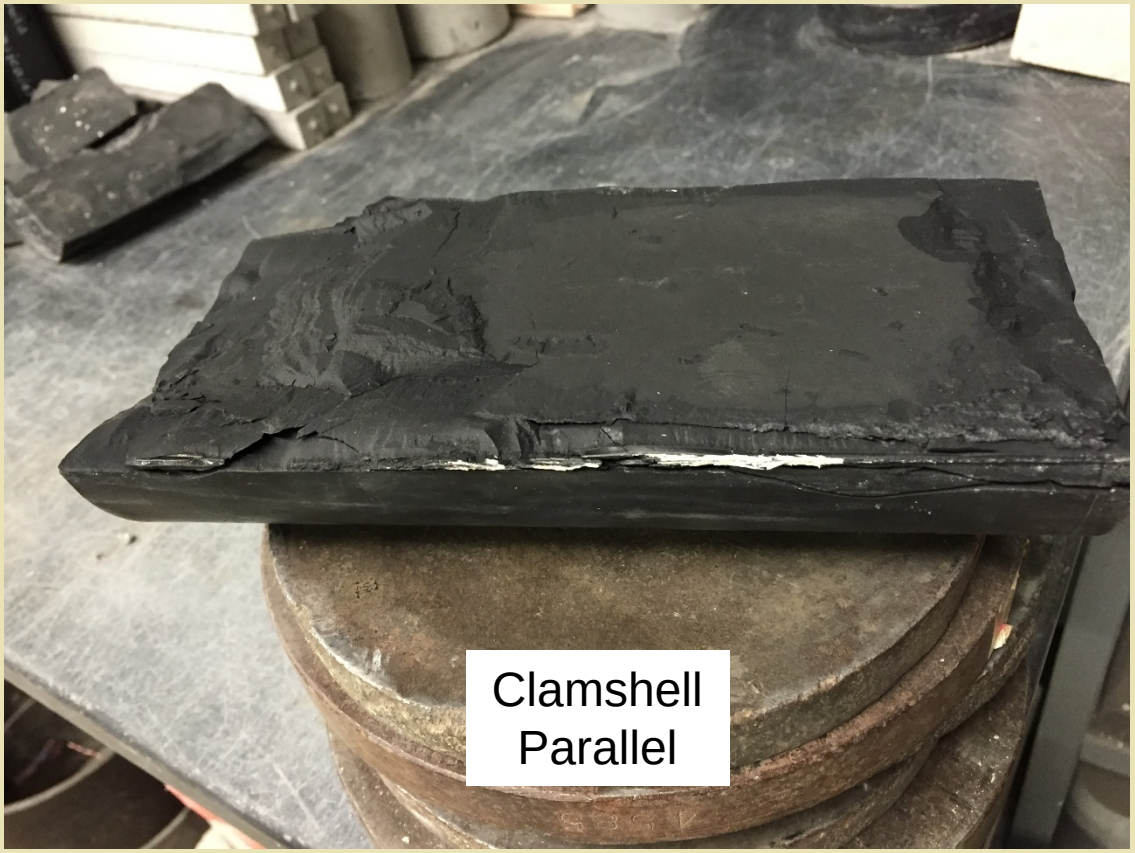
| Type | Clamshell | | | | | | Spring form | | |
|---|---|---|---|---|---|---|---|---|---|
| Layer Orientation | Parallel | | | Perpendicular | | | | | |
| Splitting Tensile Strength (psi) | 1074 | 1352 | 620 | 647 | 1613 | 1939 | 2387 | 2374 | 1068 |
| Average (psi) | 1015 | | | 1400 | | | 1943 | | |

Typical concrete values: 300-700psi

# Laboratory Testing

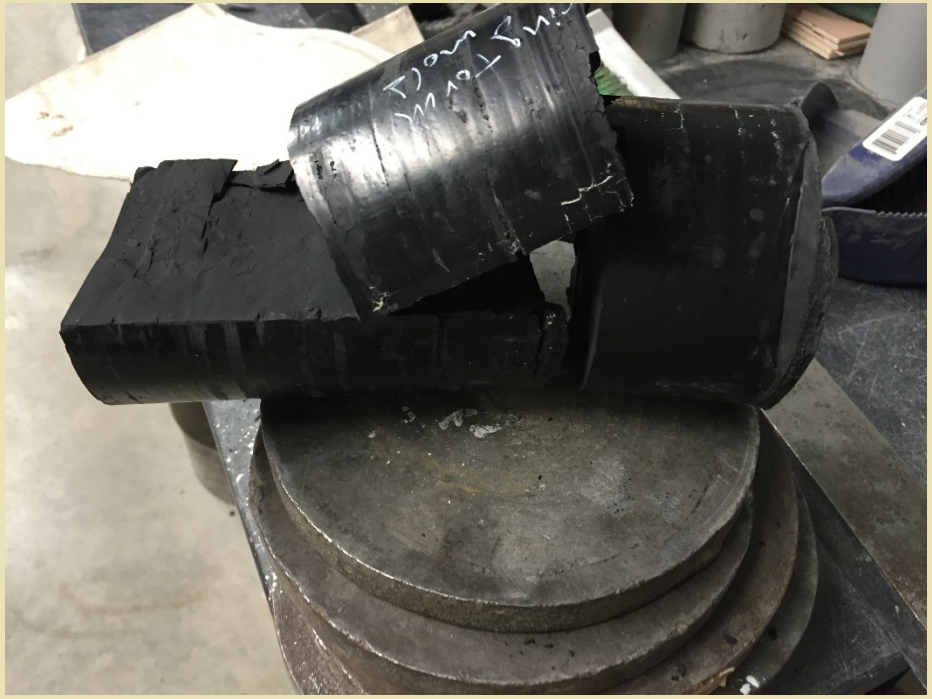


Clamshell
Perpendicular



Clamshell
Parallel

# Laboratory Testing



Spring form

# Laboratory Testing

- Compression: 6- 4”x8” cylinders were tested

| Specimen | Compressive Strength (ksi) | Average Compressive Strength (ksi) | |
|---|---|---|---|
| Clamshell 1 | 24.7 | 21.8 | 21.8 |
| Clamshell 2 | 19.1 | | |
| Clamshell 3 | 21.7 | | |
| Spring form 1 | 22.5 | 21.7 | |
| Spring form 2 | 22.1 | | |
| Spring form 3 | 20.5 | | |

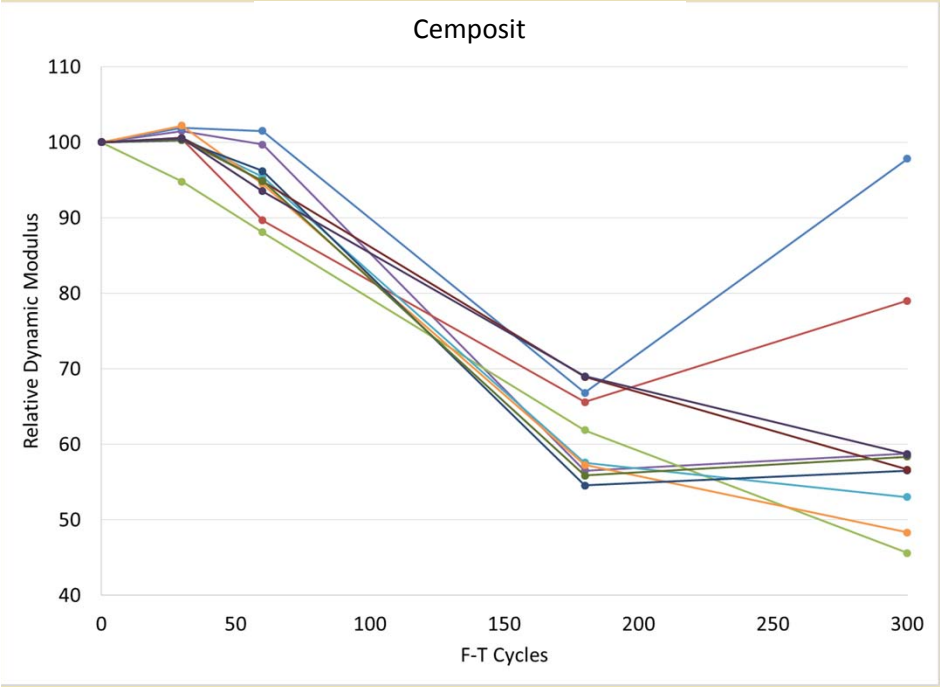
# Laboratory Testing

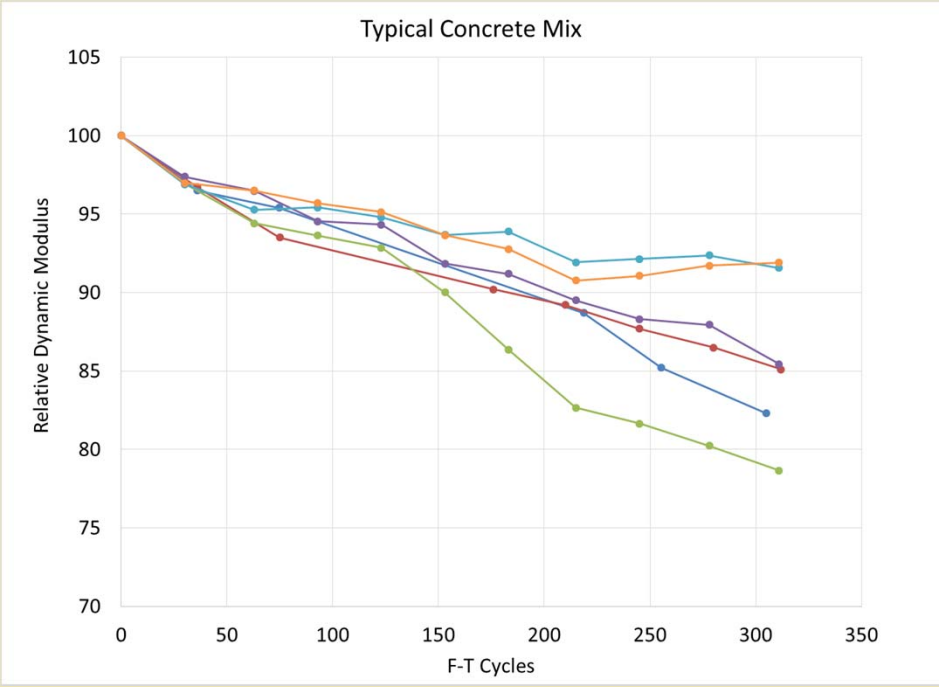
Spring form

Clamshell

# Laboratory Testing

- Freeze Thaw- 10- 3”x3”x11” specimens were subjected to 300 F-T cycles



# Laboratory Testing

- Average relative dynamic modulus of elasticity values were calculated

| Cycles | 0 | 30 | 60 | 180 | 300 |
|---|---|---|---|---|---|
| Average Relative Dynamic Modulus of Elasticity | 100 | 100.3 | 94.8 | 61.4 | 61.3 |

- Durability Factor at 300 cycles: 61

Typical concrete DF values: 80-90

# Cemposit Limitations

- Positives: High compressive and tensile strength (even at early ages)
- Negatives: low toughness, low durability

# Cemposit Applications: ABC

- Joints? – material performs best when molded and heated, thus in-situ placement isn't realistic
- Pre-formed members? – to improve toughness, fibers can be added. But the amount of fibers needed results in a mix that isn't workable

# Questions?