“Safety Concrete” – A Material Designed to Fail

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Motivation to Engineer a Novel Cement-Based Material

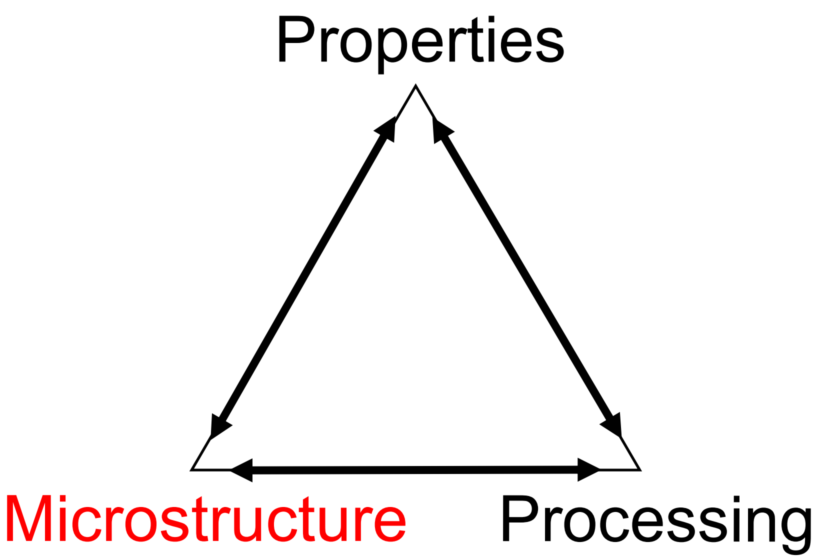
In the event of a terrorist bombing, concrete *security* barriers can fracture into large, heavy *projectiles*, resulting in considerable loss of life and destruction of property.

Example,1983 bombing of U.S. Embassy in Beirut

A Solution through Materials Science

Apply a **materials science approach** to engineer a cement-based material with unique properties

“Materials Science Approach”



Analogous to safety glass,
safety concrete’s microstructure forces the material to fracture into small pieces upon explosive loading

Achieve Properties through Microstructure

Design a material to have a **network of microcracks** throughout its volume and a **state of internal tensile stress**

- *Under static compressive loading*, it will behave as a normal (although) low-strength concrete
- *Under catastrophic loading*, microcracks will propagate and connect, causing the material to fracture into small particles

Generating the Desired Microstructure

Binder based on blast furnace slag

Slag has a strong tendency to form shrinkage cracks when dried at an early age

Controlled drying at critical state of hydration

Terminate hydration to control internal stress state and evolution of shrinkage microcracks

Important Considerations

1. Uniform distribution of microcracks

2. No large (visible) cracks

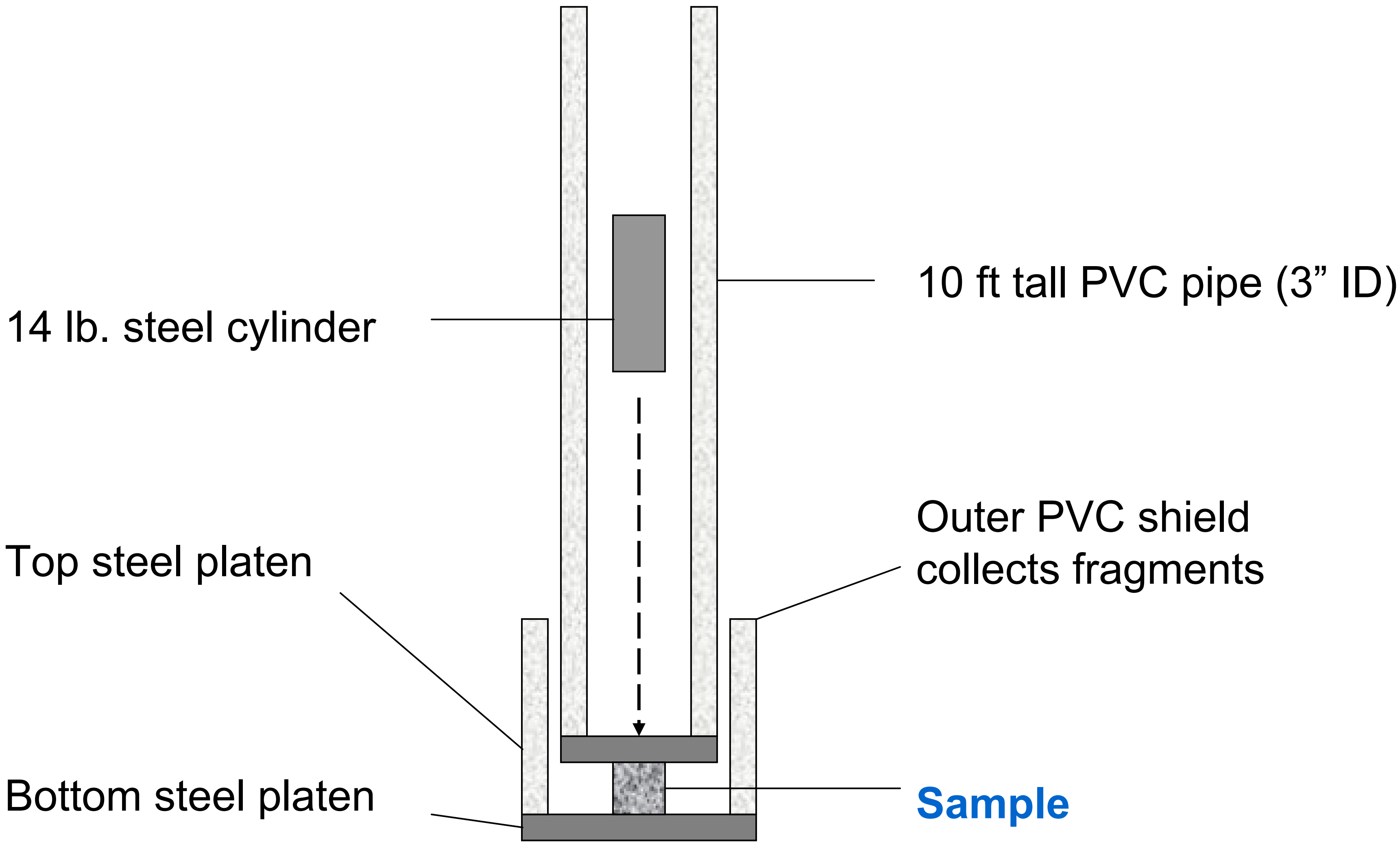
3. Stability of microcracks over time

4. No large aggregate, only sand

Design Variables

Composition Variables	***Processing Variables***
▪ Binder composition • Slag, OPC, CKD ▪ Activator • sodium silicate, NaOH, $CaCl_2$ ▪ Sand/binder ratio ▪ Water/binder ratio	▪ Cure (hydration) time ▪ Cure temperature ▪ Drying treatment

Laboratory Impact Test



Material Properties: Criteria

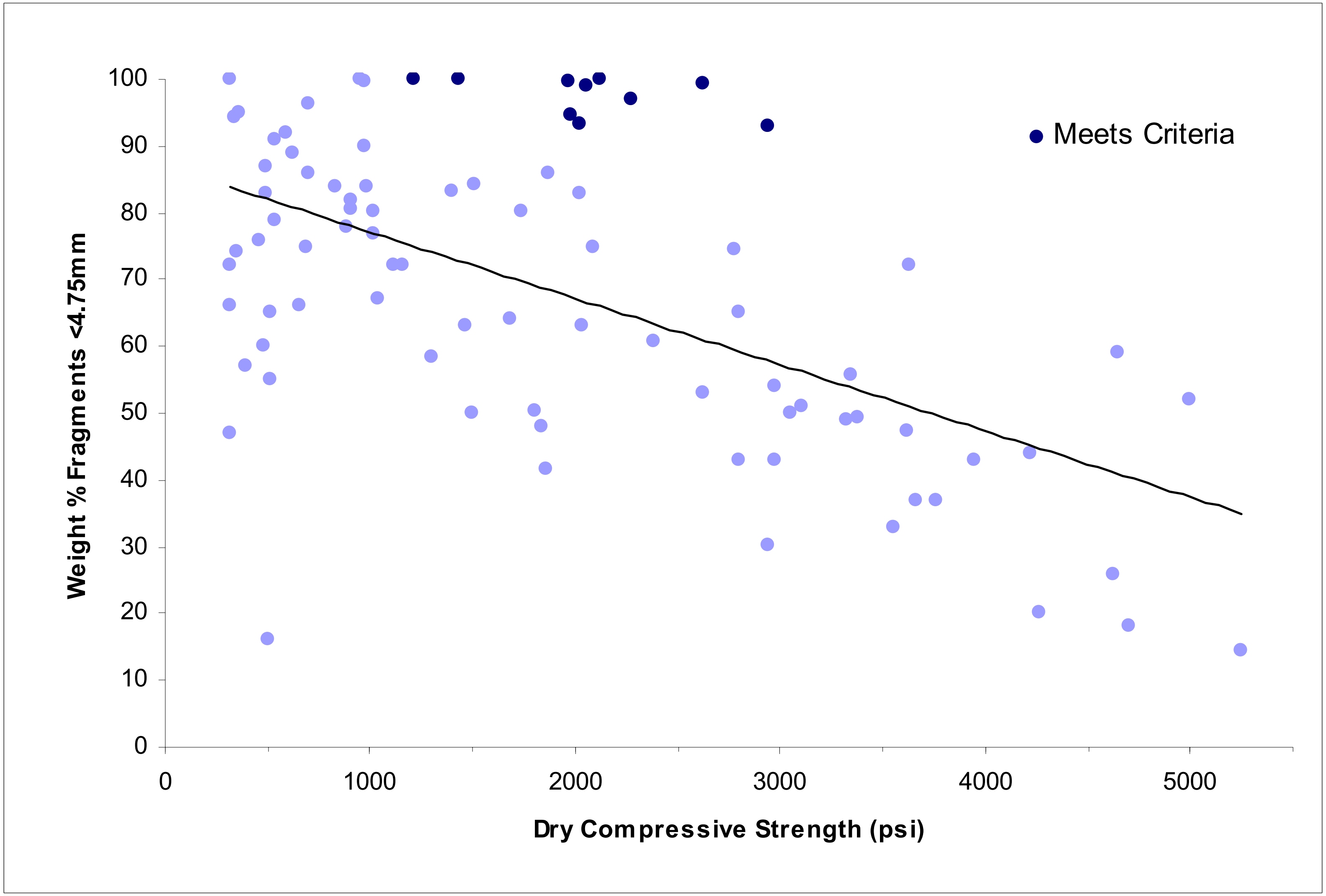
Property (measured on dry 2”x2” cylinder)	***Criteria***	***Best Designs***
Compressive Strength	> 1000 psi	> 2000 psi
Impact Behavior (weight % of particles < 4.75mm)	> 90%	> 95%

Experimental Design

Used statistically designed experiments to investigate the relative importance and effects of different variables

From this information, studied specific designs to gain further understanding of variable interactions and to optimize the design to meet the criteria

Properties of Investigated Designs



Laboratory Test Results

Control

14-day old OPC mortar

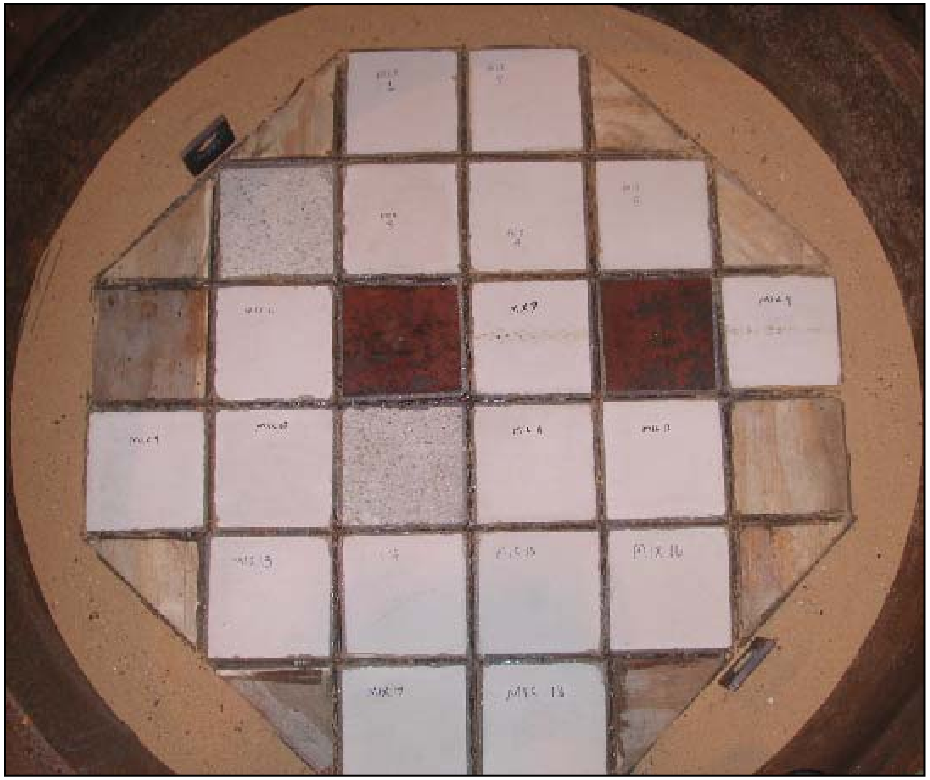
A Safety Concrete

compressive strength 2000 psi

Shock Tube Test (ERDC)

Shock Tube Sample Chamber

Panel Frame



Fragment Collection Cup

Shock Tube Test Results

Control

14-day old OPC mortar

A Safety Concrete

compressive strength 1400 psi

General Safety Concrete Design

- 100% slag binder
  Maximize effect of high-shrinkage binder
- Alkali-activated with sodium silicate
  Accelerates slag hydration and increases drying shrinkage
- High sand/binder ratio
  Introduces stress-concentrating defects
- Low-slump water/binder ratio
  Ideal for rapid molding and demolding, increases strength
- Controlled hydration time at RT or 60°C
  Balance hydration against evolution of internal stresses and microcracks
- Drying treatment at 110°C for 24 hours
  Terminate hydration reaction and induce drying shrinkage

Summary & Future Work

Impact and Shock Tube tests have provided proof of concept of Safety Concrete.

Need to probe microstructure (porosity, drying shrinkage) of Safety Concrete to elucidate structure-property relationships and verify failure mechanism

Need to make blocks from Safety Concrete for an explosive field test (ERDC)