American Concrete Institute®
Advancing concrete knowledge

Green Binders Technology
Part 3 of 3

ACI Fall 2010 Convention
October 24 - 28, Pittsburgh, PA

ACI WEB SESSIONS

ACI Web Sessions

The audio for this web session will begin momentarily and will play in its entirety along with the slides.

However, if you wish to skip to the next speaker, use the scroll bar at left to locate the speaker's first slide (indicated by the icon in the bottom right corner of slides 9 and 45). Click on the thumbnail for the slide to begin the audio for that portion of the presentation.

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ACI WEB SESSIONS

ACI Web Sessions

ACI is bringing you this Web Session in keeping with its motto of "Advancing Concrete Knowledge." The ideas expressed, however, are those of the speakers and do not necessarily reflect the views of ACI or its committees.

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ACI Web Sessions

ACI Web Sessions are recorded at ACI conventions and other concrete industry events. At regular intervals, a new set of presentations can be viewed on ACI's website free of charge.

After one week, the presentations will be temporarily archived on the ACI website or made part of ACI's Online CEU Program, depending on their content.

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ACI Online CEU Program

ACI offers an easy-to-use Online CEU Program for anyone who needs to earn Continuing Education credits.

Once registered, you can download and study reference material. After passing a 10-question exam on the material, you will receive a certificate of completion that you can present to local licensing agencies.

Visit **www.concrete.org/education/edu_online_CEU.htm** for more information.

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ACI Conventions

ACI conventions provide a forum for networking, learning the latest in concrete technology and practices, renewing old friendships, and making new ones. At each of ACI's two annual conventions, technical and educational committees meet to develop the standards, reports, and other documents necessary to keep abreast of the ever-changing world of concrete technology.

With over 1,300 delegates attending each convention, there is ample opportunity to meet and talk individually with some of the most prominent persons in the field of concrete technology. For more information about ACI conventions, visit www.aciconvention.org.

ACI WEB SESSIONS

ACI Web Sessions

This ACI Web Session includes two speakers presenting at the ACI fall convention held in Pittsburgh, PA, October 24 – 28, 2010.

Additional presentations will be made available in future ACI Web Sessions.

Please enjoy the presentations.

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Advancing concrete knowledge

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Part 3 of 3

ACI Fall 2010 Convention
October 24 - 28, Pittsburgh, PA

Prasad Rangaraju is Associate Professor of Civil Engineering at Clemson University. His areas of interest include cement, concrete, aggregates, and supplementary materials; microscopy and petrography of cement-based composites and aggregates; durability of cementitious sytems; and concrete pavement design, construction, and rehabilitation. He is a member of ACI, American Society of Civil Engineers, American Society of Testing Materials, and the Transportation Research Board. Dr. Rangaraju holds a B.S. in Civil Engineering from Jawaharlal Nehru Technical University in India, an M.S. in Civil Engineering from Iowa State University, and a Ph.D. in Civil Engineering from Purdue University. He is registered as a Professional Engineer in Minnesota and is the author or co-author of numerous research publications.

Biogenic Silica from Rice Husk
A Sustainable SCM for Use in Portland Cement Concrete

Prasad Rangaraju
Harish K.V.

Clemson University
Clemson, SC

ACI Fall 2010 Convention
Pittsburgh, PA
October 27, 2010

Acknowledgements

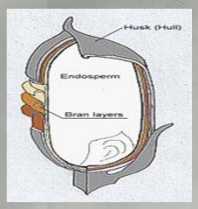
- ***Dr. Raj Vempati, ChK Group, Inc.***
- ***NSF -SBIR Program***
- ***Anheuser-Busch Companies***

Overview

- Introduction to Rice Husk and its Ash (RHA)
- Characterization of RHA Properties
- Influence of RHA on Properties of Mortar
- Influence of RHA on Properties of Concrete
- Conclusions

Rice Husk

- Rice husk is the outside shell of a rice grain



- Rice husk accounts for about 20% by mass of rice grain

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Rice Production

Annual Production of Rice Grain (2007):

- Worldwide = 659 million tons
- United States = 10 million tons

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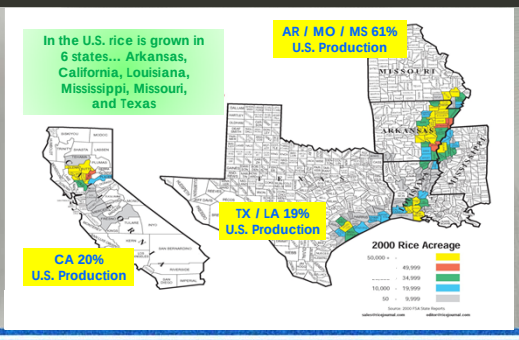
U.S. Rice Production by State/County



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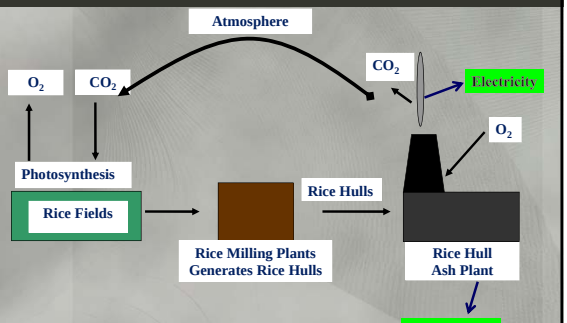
CO_2/C Neutral Cycle



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Rotary Furnace Operating Conditions

- **Aerobic Conditions (produces low-carbon RHA)**
  - No Graphitic Carbon
- **Furnace Vol.-to-Material Vol. is Critical**
- **Furnace Configuration is Important**
  - Prevent Hot Spots
  - Prevents Crystalline SiO_2 Formation
- **Continuous Process**

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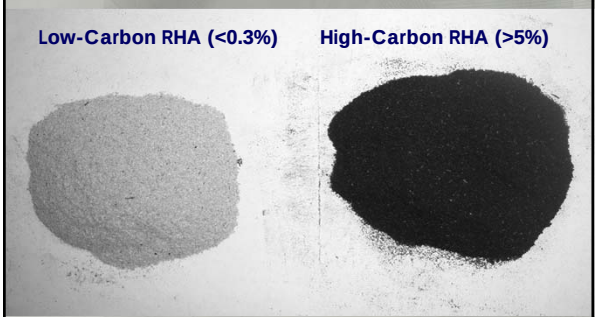
Rice Husk Ash



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Fundamental Investigation into Properties and Performance of Low-Carbon Rice Husk Ash

- **Chemical Properties**
  - Chemical Composition
  - X-ray diffraction (XRD) pattern
- **Physical Properties**
  - Particle size distribution (PSD)
  - Influence of grinding on PSD
  - Microstructure
  - Specific Gravity
  - Bulk Density

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Chemical Composition of RHA

Oxides	Zhang et al [1996]	Nehdi et al [2003]	Vempati [2008]
	%	%	%
CaO	0.55	0.6	-
SiO_2	87.2	89.1	94.8
Al_2O_3	0.15	0.1	0.52
Fe_2O_3	0.16	0.04	0.13
MgO	0.35	0.5	-
Na_2O eq	3.54	0.86	2.92
Carbon	5.91	5.1	0.24
P_2O_5	0.5	0.9	1.09

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Physical Properties of Low-Carbon RHA

- Specific gravity of RHA is 2.2
- Color of RHA is off-white, due to its low carbon content.
- High internal porosity and high specific surface area
  - 32,000 m^2 per kg – BET method

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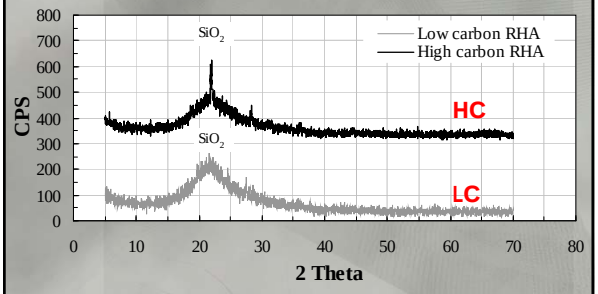
X-Ray Diffraction Pattern of RHA



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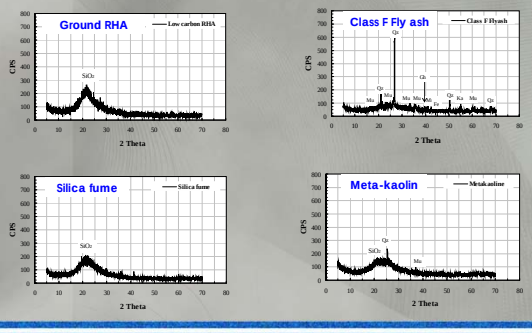
X-Ray Diffraction Analysis



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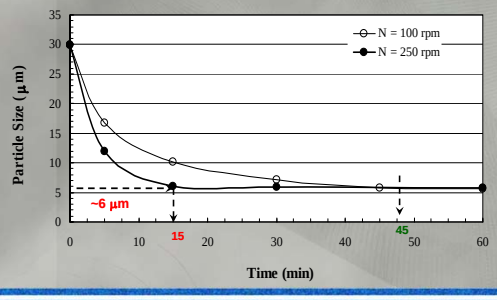
Effect of Grinding RHA on Particle Size

Average Particle Size of RHA = 30 microns (Laser Diffraction)



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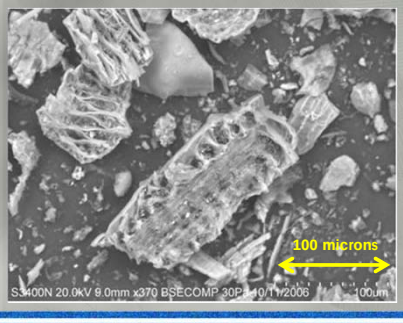
Microstructure of As-obtained RHA



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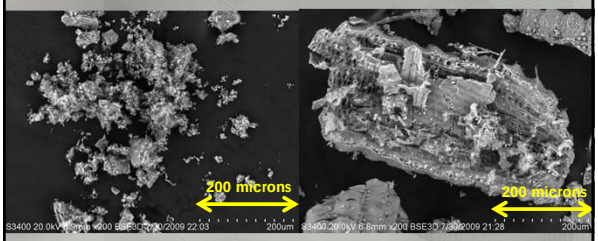
Microstructure of RHA

Ground RHA @ 200x **Unground RHA @ 200x**



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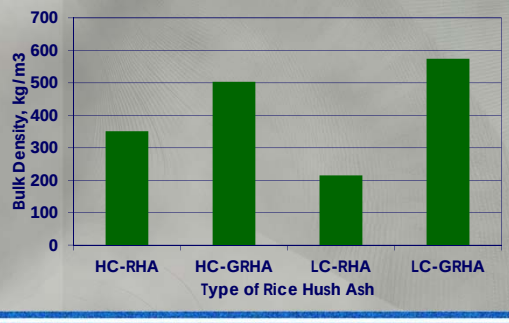
Bulk Density of RHA



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Fundamental Investigation into Performance of Low-Carbon Rice Husk Ash

Engineering Properties

- Pozzolanic Reactivity
  - Strength Activity Index
  - Thermo-Gravimetric Analysis
- Normal Consistency and Setting Time
- Superplasticizer Demand
- Compressive Strength of Concrete
- Rapid Chloride Ion Permeability
- Alkali-Silica Reactivity
- Sulfate Resistance

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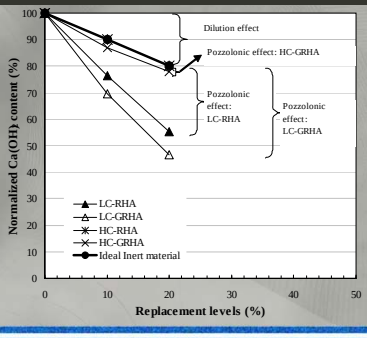
Pozzolanic Reactivity (TGA)



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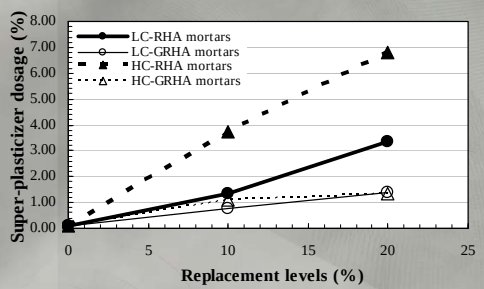
Superplasticizer Demand to Achieve 110% Flow



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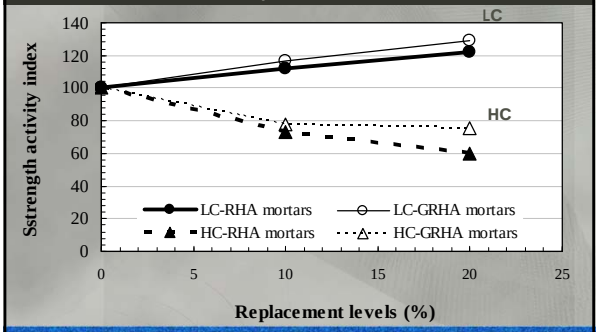
Strength Activity Index of RHA Mortars at Different Replacement Levels



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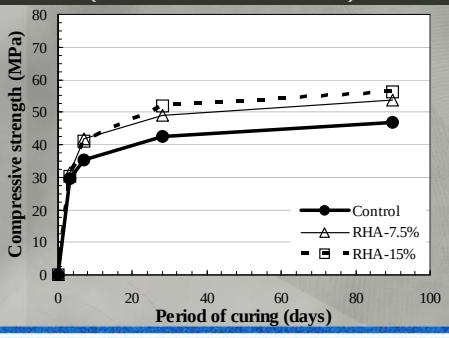
Compressive Strength of Concrete (As-Obtained RHA)



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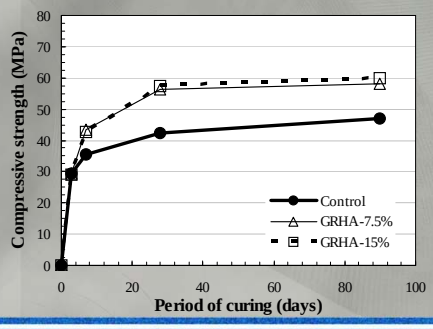
Compressive Strength of Concrete (Ground RHA)



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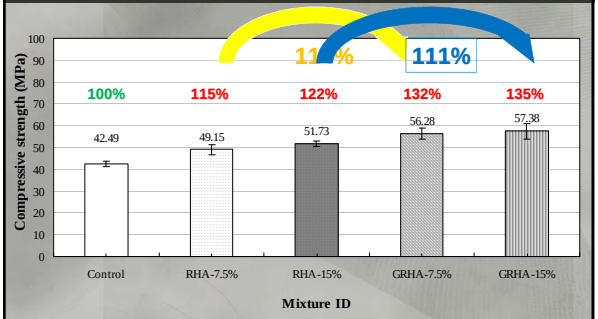
Comparison of 28-day Comp. Strength



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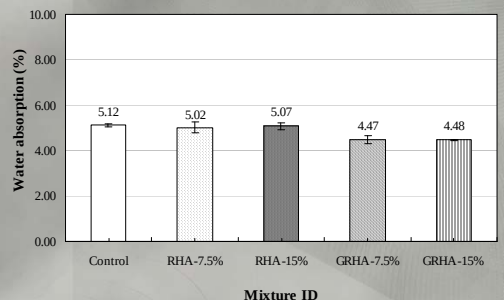
Water Absorption (ASTM C 642)



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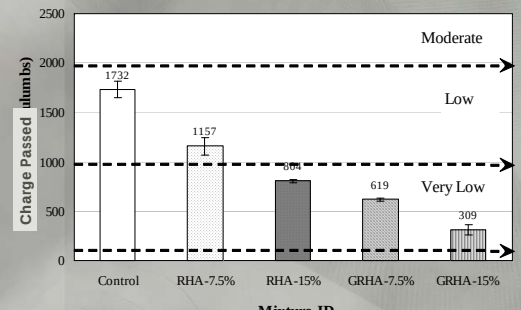
Rapid Chloride Ion Permeability



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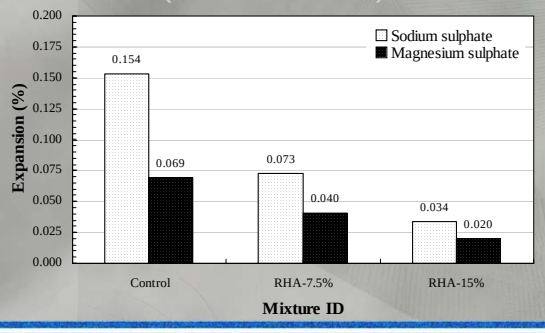
Resistance to Sulfate Exposure (ASTM C 1012)



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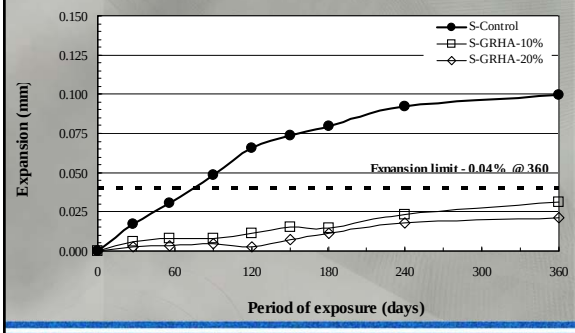
Mitigation of Alkali-Silica Reaction ASTM C 1293 Test



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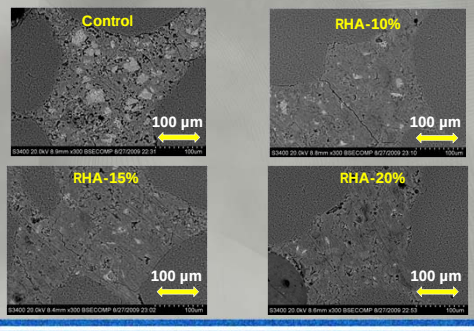
Microstructure of RHA Mortars



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Conclusions

- Low-carbon RHA is highly pozzolanic in nature, regardless of the particle size.
- Grinding significantly increased the bulk density of as-obtained RHA, thus improving ability to handle this material.
- As-obtained RHA showed considerable water-demand (and hence superplasticizer) to achieve a given level of flow.
- Grinding RHA to a finer particle size significantly decreased the water-demand for a given level of flow.

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Conclusions

- Grinding of RHA improved strength activity index of RHA mortars.
- In concrete mixtures, both as-obtained RHA and ground RHA resulted in significant increase in compressive strength, both at 7.5% and 15% mass replacement of cement.

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Conclusions

- Concrete mixtures containing ground RHA reduced water-absorption in concrete.
- Ground RHA significantly improved the resistance of concrete against chloride ion permeability, sulfate attack and alkali-silica reaction.
- The use of RHA also appears to promote internal curing in concrete.

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Environmental Impact of RHA

- **Low-Carbon RHA is a:**
  - Sustainable,
  - Renewable, and
  - Green SCM
- **The use of low-carbon RHA can make a positive contribution in reducing the carbon foot-print of concrete.**

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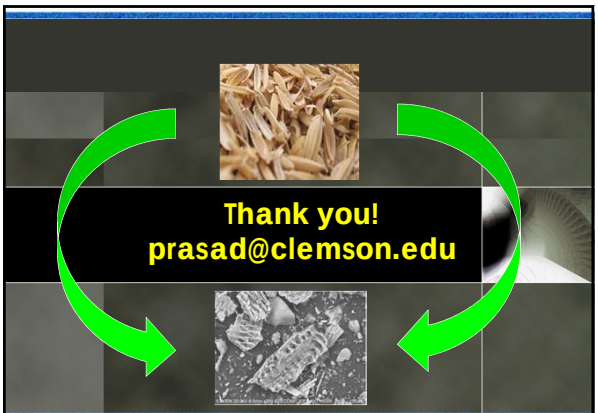

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P.A. Muhammed Basheer is Professor (Chair) of Structural Materials at Queen's University Belfast in Northern Ireland. His teaching interests include structural engineering: analysis, design, inspection, monitoring, and maintenance of the built environment. His research interests include structural materials: science and technology of concrete, durability and transport mechanisms of structural materials, non-destructive testing, structural monitoring, corrosion of steel in concrete, nanotechnology of concrete, and sustainable development. He is an active member of ACI and numerous other committees and research councils. Dr. Basheer holds both a B.S. and M.S. in Engineering and a Ph.D. in Civil Engineering.

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Queen's University Belfast

Fresh Properties and Physical and Durability Properties of Low Energy, Lightweight Concretes for Structural Applications

Professor P.A. Muhammed Basheer

Centre for Built Environment Research
School of Planning, Architecture and Civil Engineering
Queen's University Belfast, Northern Ireland, UK

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Queen's University Belfast

Fresh Properties and Physical and Durability Properties of Low Energy, Lightweight Concretes for Structural Applications

P.A.M. Basheer[1], K. J. Owens[1], J. Kwasny[1], D. Moore[2], Y. Bai[1], M. Sonebi[1], S. Taylor[1], A. Gupta[3], D. Cleland[1]

[1] Queen's University Belfast, Northern Ireland, UK
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[3] Macrete Pre-cast Concrete Engineers, Northern Ireland, UK

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Outline of the Talk

- Background to Research
- Objectives of the Work Reported
- Experimental Details
- Results
- Conclusions

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Project:

Development of Low Energy, Lightweight Normal and Self Compacting Concretes for Novel Structural Applications

Funded by: Technology Strategy Board

Project Partners: City University London, University of Liverpool, Creagh Concrete, Macrete, ARUP, Network Rail

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Flexible Arch Bridge

"Flat pack" system brought on truck

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Novel Flexible Arch Bridge

Arch Unit During Lifting

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Novel Flexible Arch Bridge

Arch Units in Place

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Precast Service Core Panels

- ❑ Normally, cast *in situ*
- ❑ Heavily reinforced

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Issues to be Addressed

- Reduce the utilisation of Portland cement
- Reduce the weight of precast units → reduced cost of transportation and improved lifting, handling and haulage.
- Make concrete flowable → utilise self compacting concrete
- Sufficient early age strength to allow faster formwork removal → Use of special cementitious materials

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Supplementary Cementitious Materials

- Pulverised fuel ash (PFA)
- Ground granulated blast furnace slag (GGBS)
  - Widely used
  - Many improved properties
  - Slow strength gain – unwelcome by concrete pre-casters due to delay in formwork stripping

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Objectives of the Project

- To develop lightweight, low energy concretes for use in structural applications.
- To maximise the utilisation of non-Portland cementitious materials
- To reduce energy usage and CO2 emissions.

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Outline of the Talk

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Objectives

- To investigate the effects of lightweight concretes made with cementitious materials containing alkali activated pulverised fuel ash (fly ash) and ground granulated blastfurnace slag on fresh and hardened properties.
- To establish their durability characteristics.
- To compare their carbon footprint with that of conventional concretes of similar compressive strength.

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Outline of the Talk

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Research Methodology

Improving the Early Age Strength

- Mechanical activation
- Thermal activation
- Curing at elevated temperatures
- Chemical activation

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Research Methodology

Reducing the Energy Input and Weight of Precast Units

- Replace Portland cement with supplementary cementitious materials
- Utilise lightweight aggregates (coarse and fine)
- Combine with chemical activation of supplementary cementitious materials

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Experimental Variables

Mix designation	Mix details
PC.N	100% PC with NWA
GGBS.N	50% PC + 50% GGBS with NWA
PFA.N	50% PC + 50% PFA with NWA
PFA.NA	50% PC + 50% PFA with NWA (Activated)
PC.L	100% PC with LWA
GGBS.L	50% PC + 50% GGBS with LWA
PFA.L	50% PC + 50% PFA with LWA
GGBS.LA	50% PC + 50% GGBS (activated) + LWA
PFA.LA	50% PC + 50% PFA (activated) + LWA

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Materials

- Lightweight aggregates
  - Sintered PFA fine and coarse aggregates
  - 100% coarse aggregate replaced
  - 60% fine aggregate replaced
- Portland Cement (CEM II)
- Pulverised Fuel Ash or Fly Ash (Class F)
- Ground Granulated Blastfurnace Slag
- Activation of GGBS & PFA mixes
  - Sodium sulphate – 4% by weight of binder

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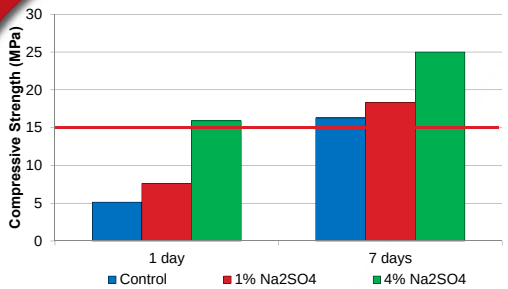
Why 4% Sodium Sulphate?



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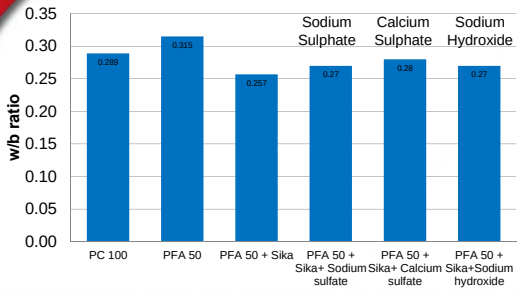
Why Sodium Sulphate as the activator?
Standard Consistence



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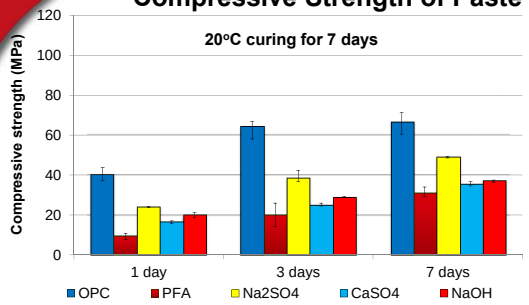
Why Sodium Sulphate as the activator?
Compressive Strength of Paste



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Mix Details

- Cementitious materials content – 450 kg/m^3
- Design Strength – 50 MPa
- Water/binder ratio – 0.42
- Workability – S3 Slump class (100-150mm)
- Superplasticiser – 0.5% by weight of binder

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Test Methods

- Slump
- Flow
- Compressive strength
- Hardened density
- Air permeability
- Sorptivity (water absorption)
- Salt scaling (RILEM method)
- Carbonation
- Chloride ingress
- Embodied carbon
- Embodied energy

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Test Methods

- Drying shrinkage
- Creep

Not reported here.

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Outline of the Talk

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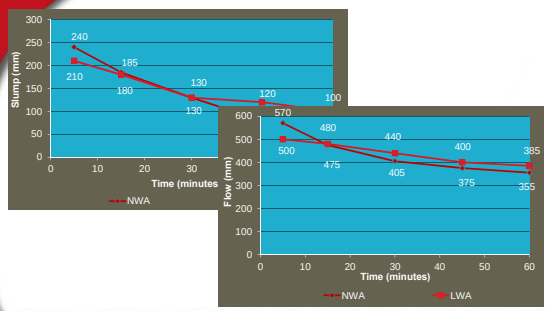
Workability (Slump and Flow)



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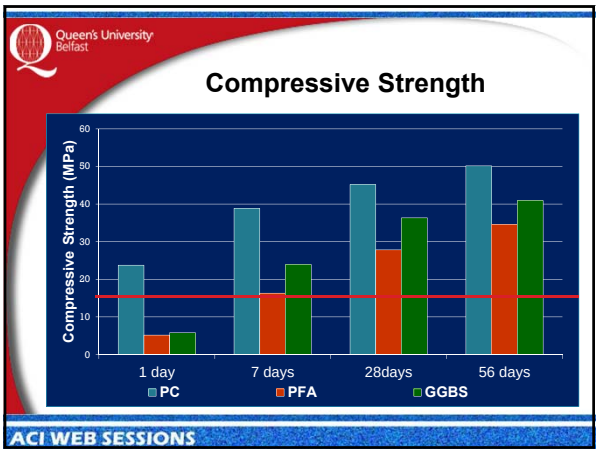
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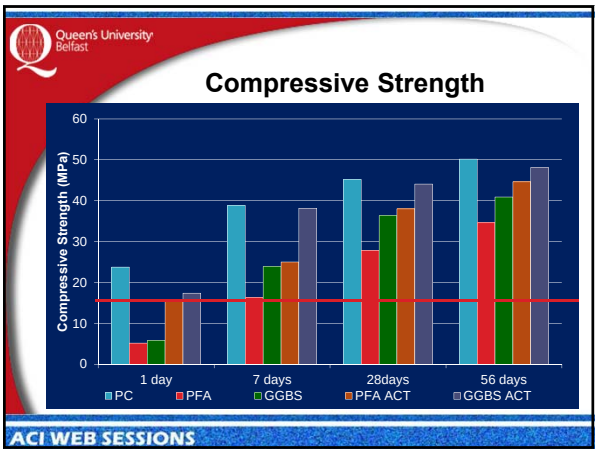
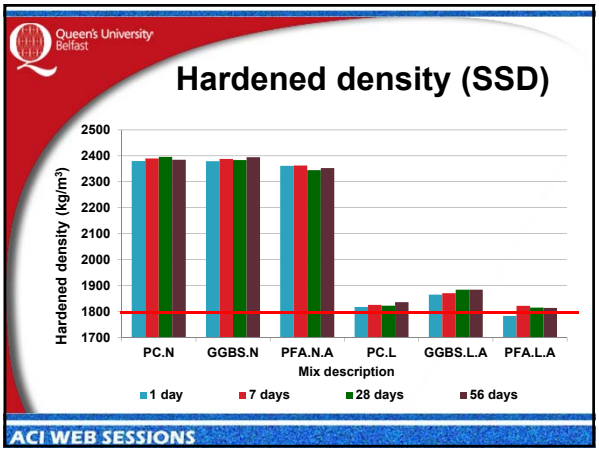
Compressive Strength
Compressive Strength (MPa)
0
10
20
30
40
50
60
1 day
7 days
28days
56 days
PC
PFA
GGBS
ACI WEB SESSIONS


Queen's University Belfast
Compressive Strength
Compressive Strength (MPa)
0
10
20
30
40
50
60
1 day
7 days
28days
56 days
PC
PFA
GGBS
PFA ACT
GGBS ACT
ACI WEB SESSIONS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Hardened density (SSD)
Hardened density (kg/m³)
1700
1800
1900
2000
2100
2200
2300
2400
2500
PC.N
GGBS.N
PFA.N.A
PC.L
GGBS.L.A
PFA.L.A
Mix description
1 day
7 days
28 days
56 days
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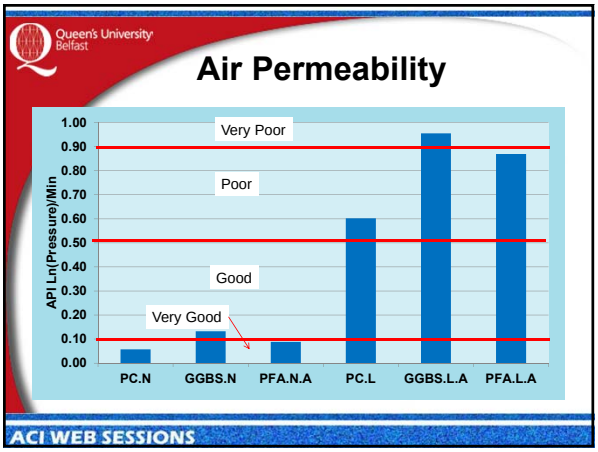
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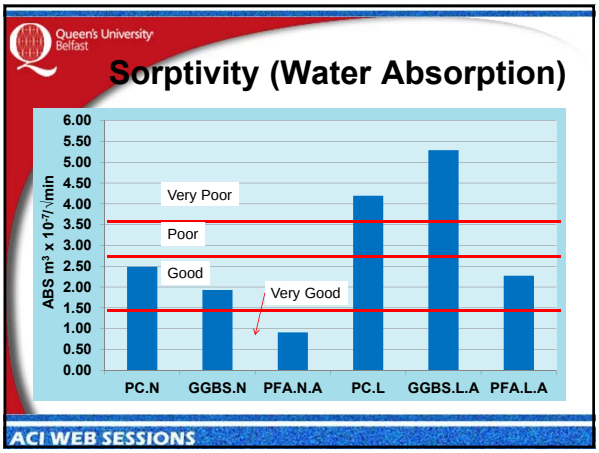
Air Permeability
API Ln(Pressure)/Min
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Very Poor
Poor
Good
Very Good
PC.N
GGBS.N
PFA.N.A
PC.L
GGBS.L.A
PFA.L.A
ACI WEB SESSIONS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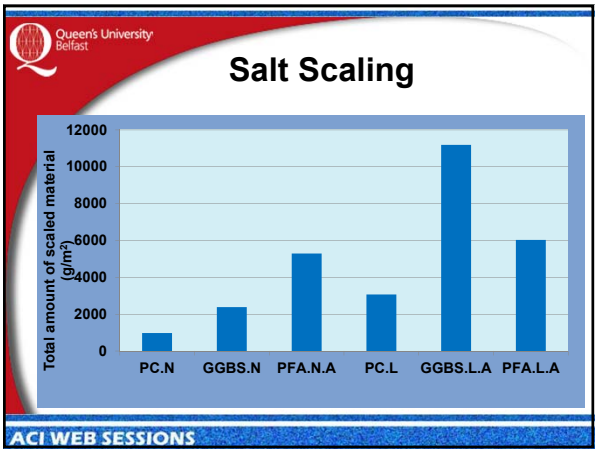
Sorptivity (Water Absorption)
ABS m³ x 10⁻⁷/√min
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
Very Poor
Poor
Good
Very Good
PC.N
GGBS.N
PFA.N.A
PC.L
GGBS.L.A
PFA.L.A
ACI WEB SESSIONS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Salt Scaling
Total amount of scaled material (g/m²)
0
2000
4000
6000
8000
10000
12000
PC.N
GGBS.N
PFA.N.A
PC.L
GGBS.L.A
PFA.L.A
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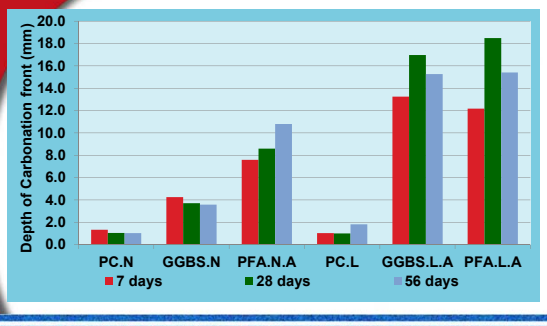
Depth of Carbonation



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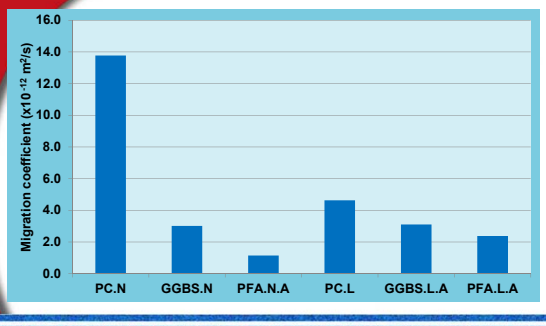
Chloride Penetration Resistance



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Carbon Footprint

Mix description	Carbon footprint ($kgCO_2$ /m^3)
PC.N	407.54
GGBS.N	224.14
PFA.N.A	234.13
PC.L	494.20
GGBS.L.A	335.23
PFA.L.A	320.94

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Embodied Energy

Mix description	Embodied energy (GJ/m^3)
PC.N	2.77
GGBS.N	1.77
PFA.N.A	1.66
PC.L	3.42
GGBS.L.A	2.58
PFA.L.A	2.30

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Conclusions

- Achieved lightweight concretes with hardened SSD density in the range of 1800-1900 kg/m^3.
- Replacement of PC with 50% PFA and 50% GGBS significantly reduced early age strength.
- Sodium sulphate as chemical activator improved strengths especially at early ages, making these binders attractive to precast manufacturers.
- PC and activated systems achieved strength of 16-24 MPa after 24 hours and 45-50 MPa after 56days of curing.

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Conclusions

- Chloride ingress → Lightweight, low energy concretes performed better than the normal weight concretes.
- Better carbon footprint and embodied energy than the PC normal weight concrete.
- Further research is needed for improving their salt scaling and carbonation resistances.

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Thank You.

Any Questions?

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