American Concrete Institute®
Advancing concrete knowledge

Technical Session in Honor of Tony Fiorato, Part 2

ACI Spring 2010 Xtreme Concrete Convention
March 21 - 25, Chicago, IL

ACI Web Sessions

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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, 37, and 79). 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 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 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.

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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.

Topics recently added to the program:

- RAP Bulletin 10: Leveling and Reprofiling of Vertical and Overhead Surfaces
- RAP Bulletin 11: Slabjacking
- RILEM Report on Self-Compacting Concrete (Parts 1 and 2)

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

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ACI Web Sessions

This ACI Web Session includes 3 speakers presenting at the ACI Xtreme Concrete convention held in Chicago, IL, March 21st through 25th, 2010.

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

Please enjoy the presentations.

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ACI Spring 2010 Xtreme Concrete Convention
March 21 - 25, Chicago, IL

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Paul Tennis is Manager of Cement and Concrete Technology for PCA in the Product Standards and Technology Department. With almost 20 years of experience in cement and concrete materials and specifications, he is responsible for developing research programs related to concrete durability and standards. Dr. Tennis holds a B.S. in Ceramic Engineering from Clemson University, and an M.S. in Materials Science and Engineering and Ph.D. in Civil Engineering, both from Northwestern University. He is an active member of both ASTM and ACI.

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Controlling and Mitigating ASR Through Effective Specifications

Paul D. Tennis, Ph.D.
Portland Cement Association

2010 ACI Spring Convention
Technical Session in Honor of Tony Fiorato, Part 2
March 22, 2010
Chicago, Illinois

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Alkali-Aggregate Reaction (AAR)

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Alkali-Aggregate Reaction (AAR)
- Alkali-Carbonate Reaction (ACR)
- Alkali-Silica Reaction (ASR)

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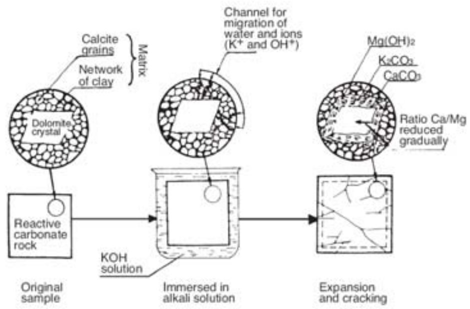
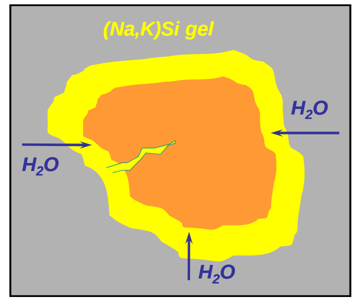
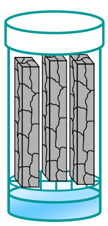
ACR

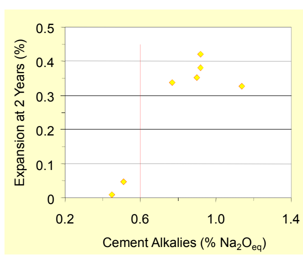


Alkali-Silica Reaction (ASR)



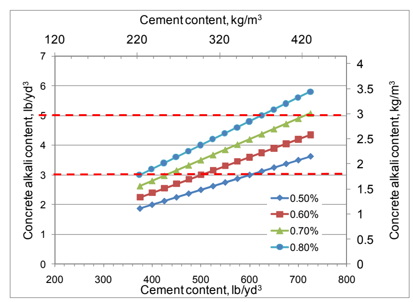
Results of Stanton's Mortar Bar Tests *(Stanton, 1940 & 1952)*





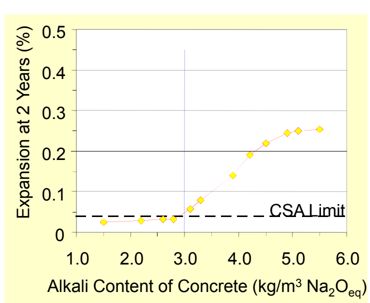
WRONG!

Cement vs. Concrete alkali content

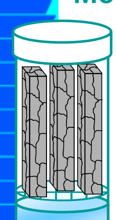


Effect of Concrete Alkali Content

Expansion unlikely if alkali content of concrete < 3.0 kg/m³

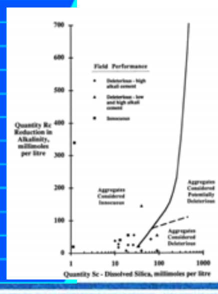


ASTM C227, Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar-Bar Method), 1950



- Mortar bars (25x25x285 mm)
- Stored over water
- 37.8°C
- Na_2O_{eq} > 0.8%
- 0.10% expansion at 6 months (alt. 0.05% at 3 months)

ASTM C289, Potential Alkali-Silica Reactivity of Aggregates (Chemical Method), 1952



- Aggregate reacted with 1 N alkaline solution for 24 hours at 80°C
- Reduction in alkalinity of solution and dissolved silica plotted
- Fast but unreliable
- 3 zones

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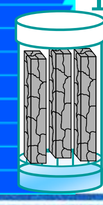
ASTM C441, Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction, 1959



- Similar to C227
- Uses Pyrex glass as model aggregate
- Comparison to low-alkali cement control

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Strategic Highway Research Program (SHRP) 1987-1993

- Despite use of C289 and C227 tests for several decades, new methods were shown to be necessary and were developed in part through this program

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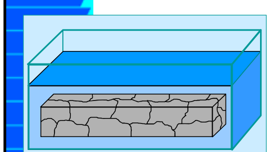
ASTM C1260, Potential Alkali Reactivity of Aggregates (Mortar-Bar Method), 1989



- Cured 2 days then immersed in 1 N NaOH solution at 80°C
- Expansion at 16 days
  - >0.10%--further testing
  - >0.20%--deleterious
- C1567

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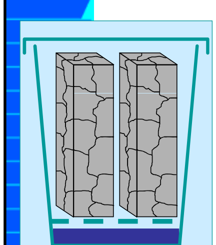
ASTM C1293, Determination of Length Change of Concrete Due to Alkali-Silica Reaction, 1995



- 420 kg/m^3 cementitious material
- NaOH added to 1.25% Na_2O_{eq}
- Concrete prisms 75 x 75 x 285 mm
- Stored over water at 38°C and 100% RH for 1 or 2 years
- <0.04% expansion 1 yr/2 yr

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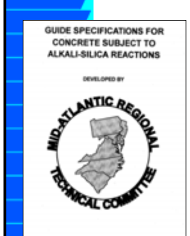
MARTC Guide Specification, 1993



- Atlantic area ASR not observed until 1965
- Noted that a low percentage of particles could be reactive
- Recommended C1260 (P214) testing for aggregate
- 3 options for mitigation
- Testing (C441) to demonstrate mitigation using blended cements or pozzolans or slag

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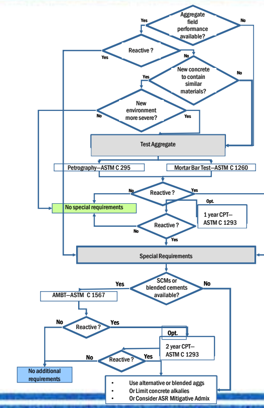
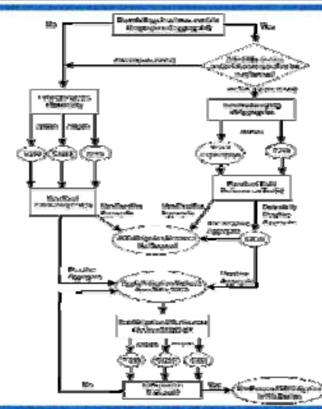
PCA, NRMCA, ACPA Guide Specification, 1994

- Field history
- 3 options for demonstrating mitigation
  - Option A-SCMs
  - Option B-blended cement
  - Option C-limit concrete alkalies
- Flowchart
- Mentioned lithium admixtures



Lead States Team on ASR AASHTO Guide Specification, 1998

- **Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction**
- Similar to PCA Guide Spec
  - 3 options
  - Similar tests
  - Different criteria
- Lithium



CSA A23.3-27A Practice to Identify Degree of Alkali-Reactivity of Aggregates and to Identify Measures to Avoid Deleterious Expansion In Concrete, 2004

- Input from massive CANMET-Industry cooperative research program

FHWA ASR Benchmark Workshop, June 2006

- 74 participants, 2 ½ days
- Reviewed current state of the practice and FHWA, FAA, DOD experience
  1) ASR test methods and identification techniques;
  2) ASR prevention in new construction and current specifications;
  3) ASR mitigation in existing concrete

FHWA/AASHTO Practice, 2010?

- Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

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FHWA/AASHTO Practice

- 4 Tables to determine risk/mitigation
  - Aggregate reactivity (R0 - R3)
  - Exposure (Levels 1 - 6)
  - Classification of Structure (S1 - S4)
  - Level of prevention (V – ZZ)
- Mitigation approaches
  - PCC alkali content
  - SCM content
  - Combination
  - Lithium dosage

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Materials Specs

- C150 (M85): low alkali content (0.60%)
- C595 (M240) and C1157: C227 (C441) max.
  - 0.020% exp at 14 days and
  - 0.060% exp at 8 weeks
- C618: C441 with expansion same or lower than low-alkali portland cement control
- C989: C441 with either
  - 75% of control (unknown proportions) or
  - 0.020% exp at 14 days (job proportions)
- C1240: C441 max. 80% of control

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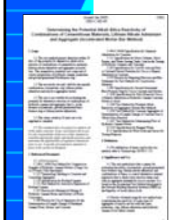
Lithium Testing



- FHWA 2003
- USACE 2009
- FHWA/AASHTO 2009/2010
- Accelerated mortar bar methods
  - 1 N NaOH, 80°C, *28 days*
  - Lithium in the mortar mix water
  - Lithium in solution
- Similar interpretation of results

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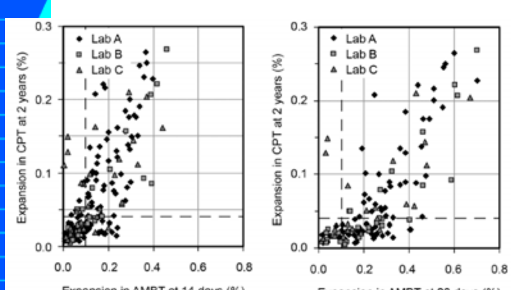
14-d vs. 28-d



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Summary

- ASR has been studied for more than 70 years
- Changes in recommendations for ASR have been evolving along with our knowledge
- More complex testing specification requirements have evolved: progress?

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T.D. Lin is President of Lintek International, Inc. in Wilmette, IL. He received his Ph.D. in Engineering Mechanics from Oklahoma State University. Dr. Lin served as a research engineer and principle engineer at CTLGroup for over 20 years, and then as a university professor for several years. He developed lunar and Martian cement/concrete technologies, and a dry-mix/steam-injection (DMSI) method for high-strength concrete cast, for which he was awarded a U.S. patent in 1993. He is currently researching using ionized hydrogen/oxygen for concrete construction on the Moon, and developing a full-scale furnace equipped with an electrically heated nitrogen gas mechanism to provide enclosed heating for a structural element or frame assembly fire test.

Lunar Concrete

Beyond Codes and Standards

T. D. Lin, President,
Lintek International, Inc., Wilmette, IL

Highlights

1. *Introduction*
2. *Concrete Materials*
3. *Hydration of Cement with Water or Steam*
4. *Lunar Environment*
5. *In-Situ Lunar Materials*
6. *Concrete Made with Apollo 16 Lunar Soil*
7. *Lunar Cementitious Materials Formulation*
8. *Envisioned Hi-Tech for Casting Concrete on The Moon*
9. *Discussion*
10. *Questions and Answers*

1. Introduction

- *President George Bush announced "Building Bases on The Moon and Sending Humans to Mars" in December 2006.*
- *NASA established a goal; "In-Situ Resource Utilization" in 1980's and supported experiments on (1) concrete made with lunar soil ('86) and (2) cementitious materials made with lunar simulants ('89) at Construction Technology Laboratories (CTL), Portland Cement Association (PCA).*
- *NASA announced the discovery of ice in the Cabeus crater, October 8, 2009. Water is an essential ingredient of concrete.*
- *International News appeared on Jan. 1st, 2010; "Moon Hole Might Be Suitable for Colony and Its Lava Tube Measures 213 ft Wide and 260 ft. Deep."*
- *Hi-tech will be needed in converting the abundant in-situ lunar materials into concrete using unlimited solar energy to achieve NASA's goal.*

2. Concrete Materials

The basic materials of concrete include coarse/fine aggregates, cement, water, and admixtures.

Their chemical compositions are:

Aggregates – SiO_2, $CaCO_3$, Al_2O_3, Fe_2O_3, MgO…

Water -- H_2O

Portland Cement – C_3S(wt.50%), C_2S(25%), C_3A(12%), C_4AF(8%)

Where C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3, M = Mgo

** *Admixtures – air entraining, chemical, mineral, …*

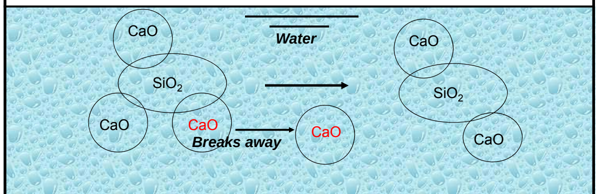
3. Hydration of Cement with

(a) Water

(b) Steam

3 (a). *Hydration of Cement with Water -* Wet-Mix

*** Hydration of C_3S (a portion of the 50 wt%)***



$CaO + H_2O \longrightarrow Ca^{++} + 2(OH)^-$

$\longrightarrow Ca(OH)_2$ ***Crystal 20%***

The generated heat (63.7 kJ/mol of CaO) turns into activation energy that induces hydrations of other compounds.

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3 (a). *Hydration of Cement with Water,* Continue

*** Hydrations of other compounds:***

$(C_3S, C_2S, C_3A, C_4AF) + H_2O \rightarrow$ ***Gel, 80%***

For example:

$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3CH$

Vol. = 252.8 cm^3 → Vol. = 238.7 cm^3

****The volume reduction (~5%) signifies a positive influence of pressure upon the chemical reaction***

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3 (a). *Hydration of Cement with Water,* Continue

Based on the theoretical assumption that heat and pressure enhance the hydration reaction, a research proposal entitled, "Dry-Mix/Steam-Injection for Casting Concrete" was submitted to National Science Council of Taiwan in 1991 and was subsequently awarded in the same year.

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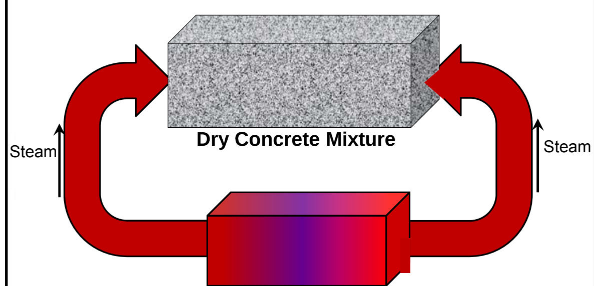
3 (b). Dry-Mix/Steam-Injection Method

The proposed DMSI experiment was carried out at National Chiao Tung University in 1992



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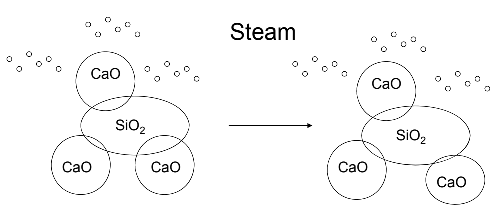
3 (b). Dry-Mix/Steam-Injection Method, Continue



No CaO break-off means the following reaction

$CaO + H_2O \longrightarrow Ca^{++} + 2(OH)^-$

does not occur in the DMSI process

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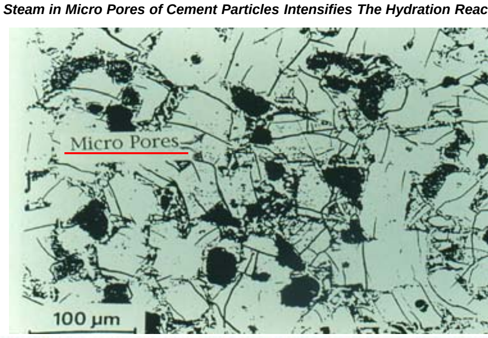
3 (b). Dry-Mix/Steam-Injection Method, Continue

Steam in Micro Pores of Cement Particles Intensifies The Hydration Reaction



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3 (b). **Dry-Mix/Steam-Injection Method, Continue**

Test Procedure & Results:

Condition	*DMSI*	*Wet-MIX*
Temp.	*180 c*	*Ambient.*
Pressure	*180 psi*	*Ambient.*
Curing	*1 day*	*28 days*
Measured f_c'	*700 kgf/cm^2 (10,000 psi)*	*315 kgf/cm^2 (4,500 psi)*
f_c' ratio	***2*** :	***1***

***Note:** The substantial increase of f_c' by DMSI could be attributed to the hydration reaction within the micro pores of cement*

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4. Lunar Environment

- ***Gravitation:*** *1/6 g*
- ***Vacuum:*** *not considering solar plasma*
- ***Solar Wind:*** *Radiation, H^+, He^{++}, Neon, argon, electrons, and protons. High speed plasma (T >10,000 C, V > 800km/sec)*
- ***Surface Temp:*** *From 110 F to – 270F depending on locations*
- ***Landscape:*** *Highland, Mare, Craters, Lava Tubes, Holes, Hills, Rocks, Soils, & Regolith*

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4. Lunar Environment, Continue

Lunar Surface

Mare

Highland

Craters

Apollo Landing Sites

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4. Lunar Environment, Continue

Earth and Moon in Solar System

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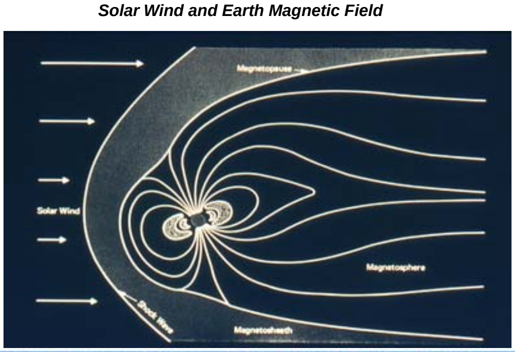
4. Lunar Environment, Continue

Solar Wind and Earth Magnetic Field



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5. Lunar Materials

Chemical compositions of lunar materials are basically similar to those of terrestrial materials, but differ in proportions.

Oxide	*Terrestrial Materials (Lunar Simulant)* Wt%	*Lunar Materials (Lunar Soil)* Wt%
SiO_2	48.8	47.3
Al_2O_3	15.7	17.8
CaO	10.4	11.4
FeO	8.88	10.5
MgO	8.48	9.6
TiO_2	1.49	1.6
MnO	0.19	0.1

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5. Lunar Materials, Continue

Regolith: Result of Continuous Bombardment of Micro Meteoroids

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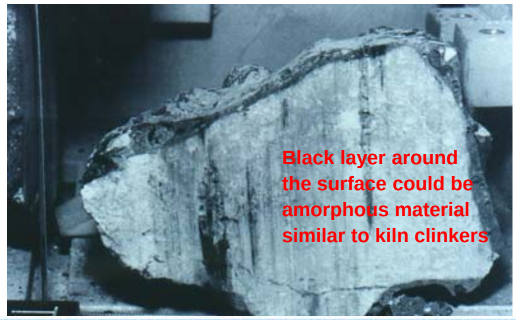
5. Lunar Materials, Continue

NASA Lunar Anorthosite Rock



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5. Lunar Materials, Continue

Principal Minerals of Lunar Anorthosite NASA Sample 15415

CaO	19.7 %
SiO_2	44.1 %
Al_2O_3	35.5 %

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5. Lunar Materials, Continue

NASA Lunar Basalt Rock

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5. Lunar Materials, Continue

Principal Minerals of Lunar Basalt – NASA Sample

Pyroxene	$(Ca,Mg,Fe)SiO_3$
Olive	$(Mg,Fe)_2SiO_4$
Plagioclase	$(Ca,Na)Al(Al,Si)_3O_8$
Ilmenite	$FeTiO_3$
Tridymite	SiO_2

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6. NASA Lunar Concrete Cube Tests, 1986

- ***Objective:***
  To investigate the physical property of concrete made with 40 grams of lunar soil collected during the Apollo 16 mission.
- ***Tests were conducted at CTL, PCA.***

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6. NASA Lunar Concrete Cube Tests, Continue

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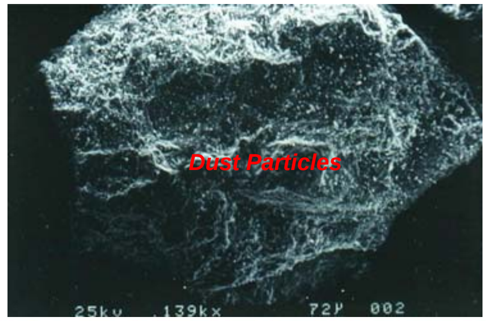
6. NASA Lunar Concrete Cube Tests, Continue

Countless Micro Dust Particles Fused on The Surface of Soil Particle



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6. NASA Lunar Concrete Cube Tests, Continue

Petrographic Analysis

Particle Color	Constituents
White	99% Plagioclase
Gray & Black	60 – 75% Plagioclase
Glossy Clear	Plagioclase Feldspar Crystals

Chemical Oxide	Compositions Wt%
SiO_2	47.3
Al_2O_3	17.8
CaO	11.4
MgO	9.6
FeO	10.5
TiO_2	1.6
MnO	0.1

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6. NASA Lunar Concrete Cube Tests, Continue

40 g sample was used to cast one 1" cube, one ½" cube and 3 small slabs

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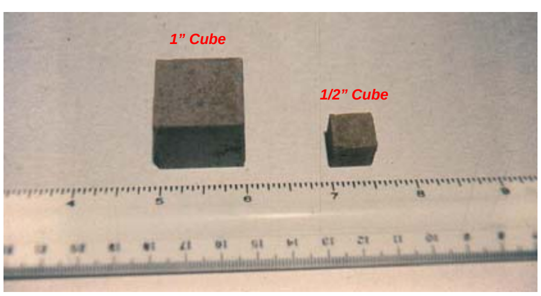
6. NASA Lunar Concrete Cube Tests, Continue

Strength measurement of small cubes requires special equipment & evaluations
120 companions made with simulant were tested before the lunar specimens



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6. NASA Lunar Concrete Cube Tests, Continue

Measured Strengths

1" Cube (Tested in 1986)

(a). f_c' (lunar) = 10,977 psi (75.7 MPa)

(b). f_c' (simulant) = 7,960 psi (54.9 MPa)

(a) > (b) : The surface characteristics of soil particles is the primary factor

½" Cube (Tested in 2001): To study durability of lunar concrete

f_c' (lunar) =~10,000 psi (70.0 MPa)

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7. Lunar Cementitious Material Formulation

NASA – SBIR Project, 1990 @ CTL

Objective:

To develop adequate technology for producing cementitious materials using in-situ lunar materials such as anorthite and basalt rocks.

Due to time limitation only test results are shown,

1.) Specimens made with sintered mixture of lunar anorthite and lime simulants:
Measured fc' @ 28 days = 5500 psi

2.) Specimens made with sintered lunar basalt glass simulant and cured in 100-C steam for 24 hours:
Measured fc' = 7,100 psi

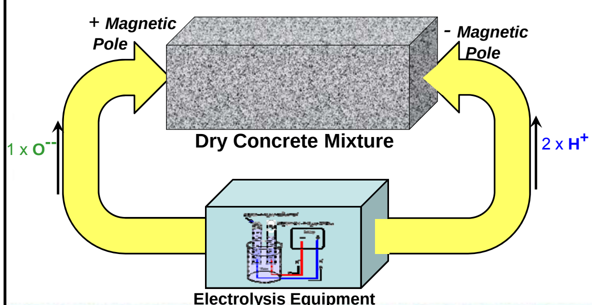
8. Envisioned Cast Methods

Using Dry-Mix/H⁺O⁻⁻ (or Plasma) Injection

- ***Proposal 1 - Dry-Mix/H⁺O⁻⁻ - Injection***
- ***Proposal 2 - Dry-Mix/Plasma - Injection***

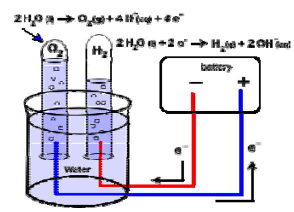
8. Envisioned Cast Methods, Continue

Proposal 1 - Lunar Concrete Cast Using Water Electrolysis



8. Envisioned Cast Methods, *Continue*

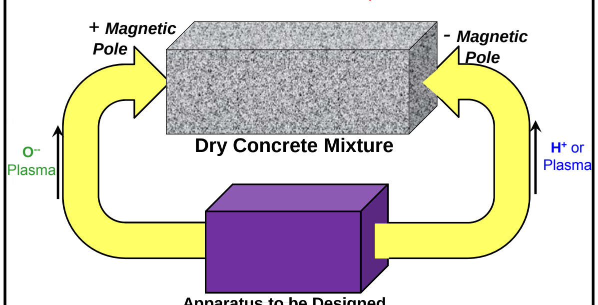
Proposal 1 - Lunar Concrete Cast Using Water Electrolysis



Electrolysis Apparatus

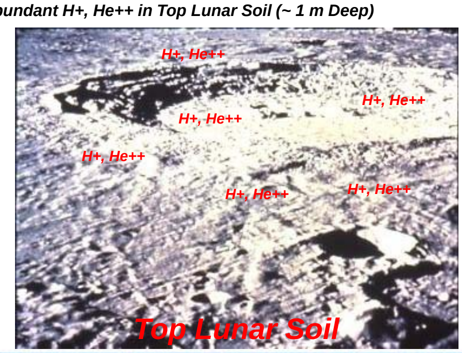
8. Envisioned Lunar Cast Method

Proposal 2 – Cast Lunar Concrete Using Solar Plasma or H+, He++ in Lunar Soils



8. Envisioned Lunar Cast Methods

Abundant H+, He++ in Top Lunar Soil (~ 1 m Deep)



8. Envisioned Lunar Cast Methods, Continue

NASA's Announcement

After shooting 2 rockets onto the lunar south pole region on October 8 2009, NASA confirmed ice in the Cabeus crater. The crater dimensions: diameter ~ 60 km and depth ~ 5.7 km.

The permanent darkness in the Cabeus crater area results to an extremely low temperature; approximately -240 C.

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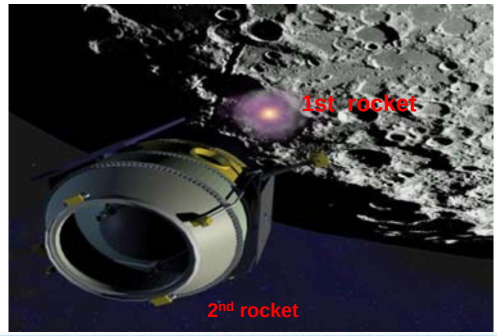
8. Envisioned Lunar Cast Methods, Continue

The 2nd rocket hit the Cabeus crater 40 seconds after the 1st one did



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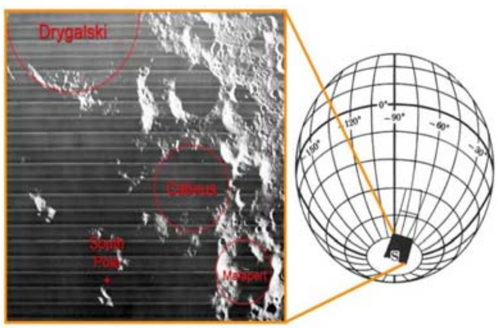
8. Envisioned Lunar Cast Methods, Continue

Location of Cabeus Crater



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8. Envisioned Lunar Cast Methods, Continue

To get the ice out of the crater will be a profound challenge to scientists and engineers. Can laser technologies be used?

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9. Discussion

* *To build bases on the Moon in 2025 has been NASA's space exploration using in-situ lunar resources is NASA's goal.*

* *Concrete being inorganic-none metallic and capable of withstanding the harsh solar radiation will be an ideal construction material on the Moon .*

* *Studies show that in-situ lunar materials are rich in amorphous glass, a potential cementitious materials.*

* *Unlimited Solar energy can be used to cast precast concrete for assembling habitats, launching/landing pads, highways, storage boxes, and others.*

* *Use of in-situ lunar materials could save a tremendous construction cost and eliminate undesirable transportation difficulties.*

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10. Questions and Answers

Thank You !

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ACI Fellow **Michael Caldarone**, PE, is Principal Engineer with Concrete Engineering, LLC in Northbrook, IL. He has 25 years of broad expertise in concrete materials engineering, with extensive field experience in troubleshooting of fresh and hardened concrete, and the commercial development, production, and utilization of high-performance concrete. His book, "High Strength Concrete: A Practical Guide," provides a practical tool for specifiers, designers, producers, and builders. He was a co-recipient of the ACI 2001 Wason Medal for Materials Research, and holds a B.S. in Civil Engineering from the University of Illinois.

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Technical Session in Honor of Tony Fiorato
March 22, 2010

Case Histories in High-Strength Concrete

Michael A. Caldarone
CTLGroup
Skokie, IL

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Case History No. 1

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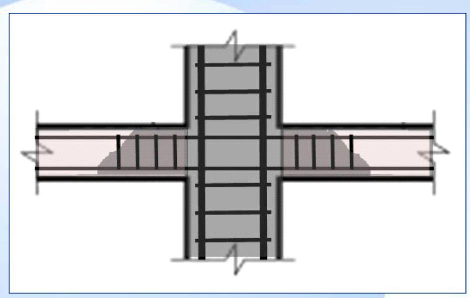

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Mix Design

- Specified Strength 14,000 psi (96 MPa)
- Original Mix
  - 56 day acceptance
  - 10% silica fume
- Revised Mix
  - 90 day acceptance
  - No silica fume

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Strength Performance

- Original
  - 16,500 psi (114 MPa) @ 56 days
- Revised
  - 14,500 psi (102 MPa) @ 90 days

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Case History No. 2

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Hot weather conditions
Insulated blanket curing
Cracking within 8 hours of placement

Mix Design

- 6000 psi (41 MPa) @ 28 days
- Chloride permeability ≤ 1000 Coulombs
- w/cm ≤ 0.36
- Very fine cementitious materials
- High-range water reducing admixture
- No retarder/hydration-controlling admixture

Mix Adjustments

- Water-reducing retarder
- w/cm raised from 0.36 to 0.38

Case History No. 3

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Related Documents

Alkali-Aggregate Reaction

- ACI 221.1R-98: Report on Alkali-Aggregate Reactivity (Reapproved 2008)
- ACI 201.2R-08: Guide to Durable Concrete
- Design and Control of Concrete Mixtures by Portland Cement Association
- SP-234: Ninth CANMET/ACI International Conference on Durability of Concrete

Lunar Concrete

- SP-125: Lunar Concrete

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Related Documents

High-Strength Concrete

- ACI 363R-10: Report on High-Strength Concrete
- ACI 211.4R-08: Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement & Other Cementitious Material
- SP-228: (Volume 1 & 2) Seventh International Symposium on the Utilization of High-Strength/High-Performance Concrete
- ACI 441R-96: High-Strength Concrete Columns
- ACI 234R-06: Guide for the Use of Silica Fume in Concrete
- ACI 212.4R-04: Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete
- ACI 363.2R-98: Guide to Quality Control and Testing of High-Strength Concrete

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