Strength is Not Enough

(Performance Evaluation of Novel Concrete Binders)

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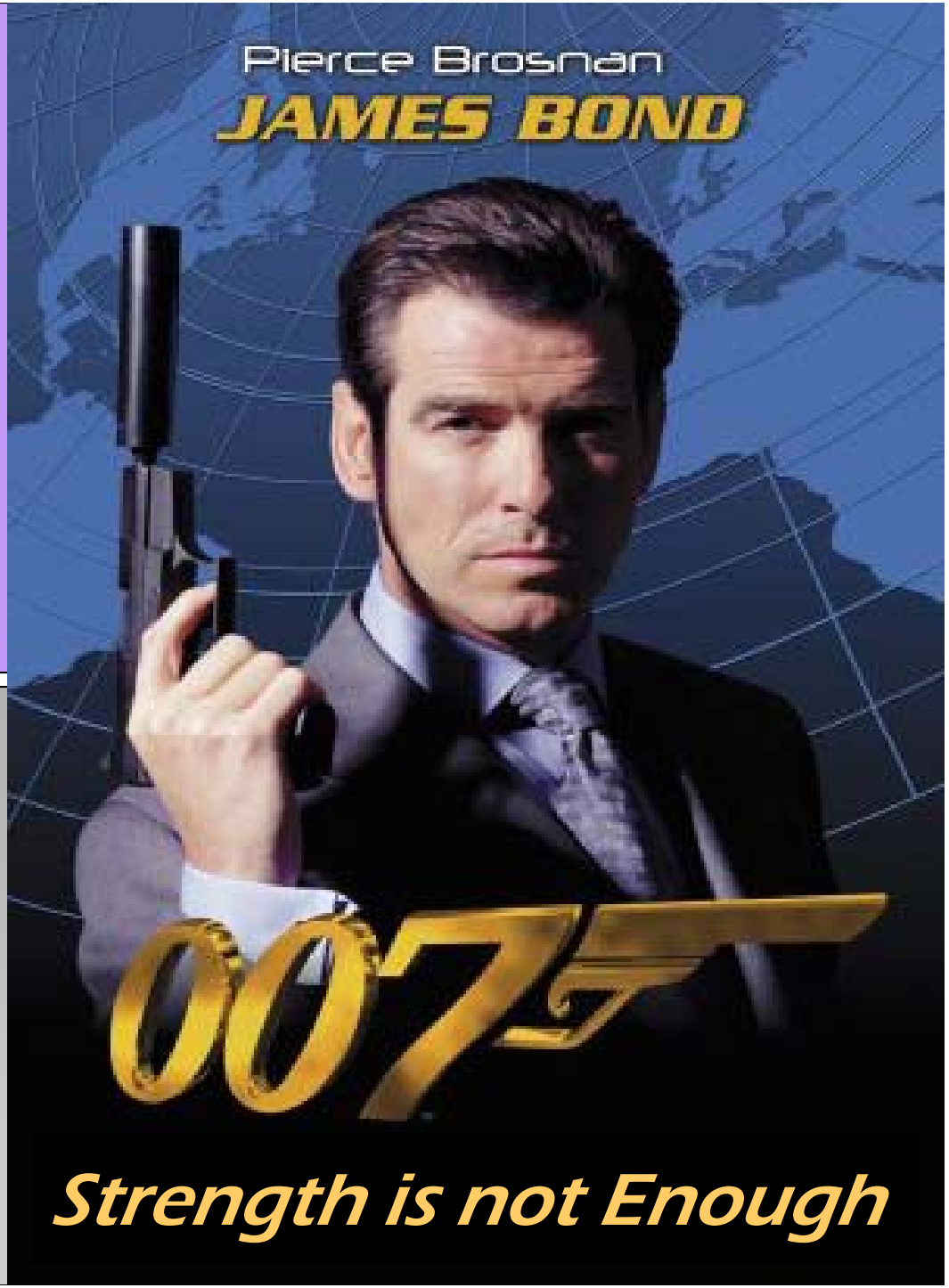


Evaluation of New Materials

- Due to interest in reducing the embodied CO_2 & energy of concrete, there has been significant research and some commercialization of new non-portland cement binders for concrete.
- However, in most cases, current specifications & standards are not appropriate/sufficient for evaluating performance of these new materials.
- And even with new specifications, to be used in buildings, they still then need to be approved for use in Building Codes.

Examples of Novel Materials

- Alkali-activated cements
  - Including activated, fly ashes, slags, meta-clays & other natural pozzolans
- Supersulfated cements
- Transformative carbonate cements
- Magnesium silicate cements
- Belite cements
- Calcium sulfo-aluminate cements

Performance Specifications

- **ASTM C1157** was developed as a performance option to C595 that allowed use of compositions and combinations of mainly traditional cementing materials without any prescriptive limits.
- **ASTM C1600** was recently developed along similar lines for high-early strength binder systems.
- But, do these specifications provide adequate user protection when non-traditional binders are used?

ASTM C1157

TABLE 1 Standard Physical Requirements

		GU	HE	MS	HS	MH	LH
Fineness	C204	*A*	*A*	*A*	*A*	*A*	*A*
Autoclave length change,	C151	0.80	0.80	0.80	0.80	0.80	0.80
Time of setting, vicat	C191						
Initial, not less than, minutes		45	45	45	45	45	45
Initial, not more than, minutes		420	420	420	420	420	420
Air content of mortar volume, %	C185	*C*	*C*	*C*	*C*	*C*	*C*
Compressive strength minimum, MPa [psi]	C109/C109M						
1 day		...	12.0 [1740]	...	...	...	...
3 days		13.0 [1890]	24.0 [3480]	11.0 [1600]	11.0 [1600]	5.0 [725]	...
7 days		20.0 [2900]	...	18.0 [2610]	18.0 [2610]	11.0 [1600]	11.0 [1600]
28 days		28.0 [4060]	...	...	25.0 [3620]	...	21.0 [3050]
Heat of hydration	C186						
7 days, max, kJ/kg [kcal/kg]		...	...	...	...	290 [70]	250 [60]
28 days, max, kJ/kg [kcal/kg]		...	...	...	...	...	290 [70]
Mortar bar expansion	C1038						
14 days, % max		0.020	0.020	0.020	0.020	0.020	0.020
Sulfate expansion (sulfate resistance)	C1012						
6 months, max, %		...	...	0.10	0.05	...	...
1 year, max, %		...	...	...	0.10	...	...

Plus optional tests for ASR (by C227), early stiffening, 28d f'c, & shrinkage

But no tests for injurious materials or requirements for testing in concrete

Types of Materials used in C1157

NOTE 8—The following list contains suggested generic names for some possible ingredients of hydraulic cements. The list is representative and is not inclusive.

Class of Ingredient	Examples of Generic Terms
Cement	Portland cement, portland cement clinker.
Calcium Ingredient	Calcium carbonate, limestone, lime, hydrated lime, cement kiln dust (CKD).
Pozzolan	Class F fly ash, Class C fly ash, uncalcined natural pozzolan, calcined natural pozzolan, silica fume.
Slag	Granulated iron blast-furnace slag.
Additions	Calcium sulfate, water reducer, accelerator, retarder, water-reducing retarder, air-entraining addition, processing addition.

While most of the materials on this list are used today---the list is open-ended

ASTM C1600/C1600M–11 Specification for Rapid Hardening Hydraulic Cement

- 4 classes of rapid cements based on early mortar strength performance at 1.5, 3, 6h & 1, 7, 28d.
- Other req'ts include set time (>10min.), autoclave exp'n, & mortar shrinkage.
- Optional test limits include ASTM C1038 (for excess SO_3), C186 (for HOH), C1012 (for SR) and C441(for ASR).

No tests for injurious materials or requirements for testing concrete

ASTM C1600 cont'd

- Has no requirements that such cements be tested or be durable in concrete, yet there is a request to include C1600 cements in the ACI 318 Building Code.
- Several alkali-activated fly ash products are being produced to meet C1600.
- They maybe ok but the tests in C1600 are insufficient to evaluate concrete performance & durability.

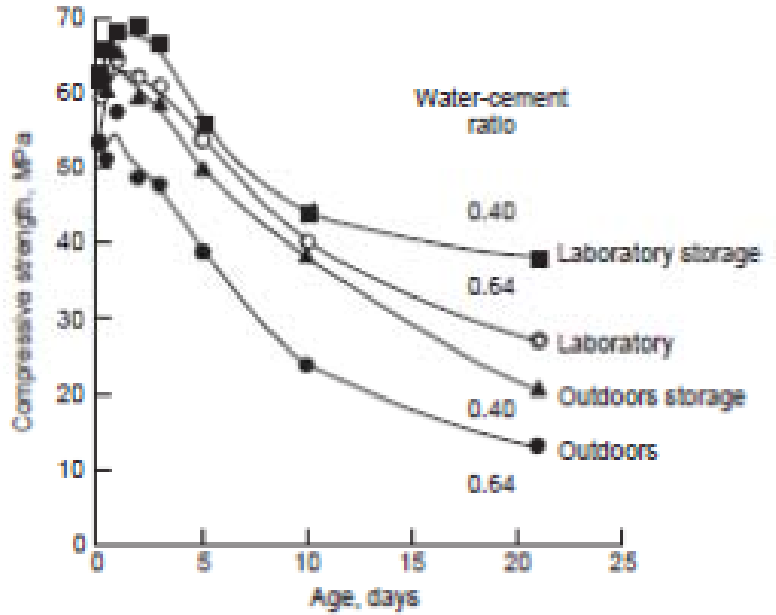
High-Aluminous Cement would meet ASTM C1600

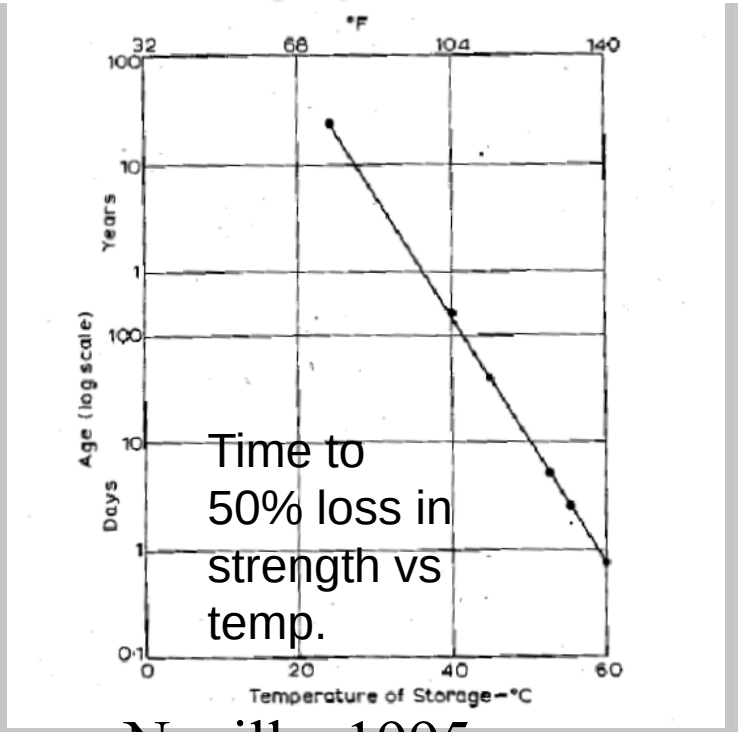
HAC was not a new product when problems occurred in the UK in the 1960's ---but its application in high-strength precast beams was new.

The conversion reaction that led to large strength loss was not known to design engineers and its use resulted in several structural failures.

$3CAH_{10} + H \rightarrow C_3AH_6 + 2AH_3 + 18H$

HAC is fine as long as the concrete is designed for its converted strength





Neville, 1995

CSA A3004-E1

Standard Practice for the Evaluation of Alternative Supplementary Cementing Materials (SCMs) for use in Concrete

- It was originally developed in 2003 an an Appendix to provide guidance for staged testing of new *alternative supplementary cementing materials* since it was recognised that current requirements for Portland & blended cements as well as for traditional SCMs used with Portland cement, are inadequate to provide a comprehensive evaluation of new materials.
- Transformed into a Standard Practice in 2008

ASTM C1709 – 11

Standard Guide for Evaluation of Alternative Supplementary Cementitious Materials (ASCM) for Use in Concrete

Its format is very similar to the 2003 version of the CSA document

What are ASCMs ?

ASCMs are **inorganic constituents that show pozzolanic or hydraulic properties, or both, and contribute to the strength or other characteristics of concrete.** Such materials do not meet the definitions of supplementary cementing materials in CSA A3001. They may be natural, manufactured, or reprocessed materials. Such materials can include

(a) non-ferrous slags from pyro-metallurgical processes;

(b) steel slag;

(c) incinerator or co-combustion ashes;

(d) by-products from ferro-silicon alloy processes;

(e) finely ground glass cullet;

(f) silica fume with SiO_2 content less than 75%; and

(g) other industrial by-products containing amorphous silica.

Scope of A3004-E1

- *This standard practice is intended to provide a technical approach to the evaluation of supplementary cementing materials that fall outside the scope of the CSA A3001 Standard.*
- But the approach used in CSA A3004-E1 or ASTM C1709 could be adapted to evaluate novel alternative binder systems.

A3004-E1 (2008) Types of ASCM

(a) ***Type A ASCM*** *—* ***Highly reactive SCM*** *that contributes to early-age properties (e.g., strength and permeability) of concrete. The Type A ASCM should* ***increase the strength and reduce the permeability of concrete at the age of 28 days*** *conforming to the requirements listed in Tables 1 and 2.*

(b) ***Type B ASCM*** *—* ***Slowly reacting SCM*** *that contributes to the long-term properties of concrete. The Type B ASCM should* ***increase long-term strength and reduce the permeability of concrete at the age of 91 days****, conforming to the requirements listed in Tables 1 and 2*

A3004-E1 Stages of Evaluation

- The Alternative SCM should be evaluated in a comprehensive laboratory test program followed by field trials. A phased program suitable for many types of Alternative SCMs is as follows:

Stage I Characterization of the Materials

Stage II Determination of Optimum Fineness

Stage III Concrete Performance Tests

Stage IV Field Trials and Long-Term Durability Performance

Stage I in CSA A3004-E1

- A **complete chemical and mineralogical analysis** of the material should be conducted. The chemical analysis should include the identification and quantification of **trace elements in addition to major compounds**. The main crystalline components should be determined on a semi-quantitative basis using x-ray diffraction techniques.
- When interpreting the data, consideration should be given to the **potential for the compounds present to be injurious to the hydration of cement or properties of concrete**. If such compounds are present, then suitable leaching tests should be conducted to determine the "availability" of these compounds.

ASTM C1709-11

5.2.4 *Stage III:* The ASCM should be tested for comparison with the chemical, physical, and uniformity requirements of Specification C618 (including the supplemental optional physical requirements), C989, or C1240. In addition, determine and report the following:

(1) **Chlorides** (Test Method C1218/C1218M)

(2) **Free calcium oxide** (Test Methods C114, Section 28)

(3) **Soluble alkalis** (Test Method C114)

(4) **Leachable heavy metals** (Test Method D3987)

(5) **Air void stability**—For ASCM similar to fly ash, the stability of the air bubbles formed during mixing a paste suspension may be an indication of the air void stability in concrete made with the same materials (Foam Index Test).

CSA Uniformity Req’ts

- The potential for product pre-qualification uniformity during full-scale production shall be established as part of the initial evaluation process of this Standard Practice.
- If the ASCM is manufactured from a continuous stream, **samples of the raw material shall be taken at monthly intervals for 12 consecutive months.** If the ASCM is being produced from a stockpiled material, 12 samples shall be taken from various locations to be representative of the stockpile.
- The 12 samples shall be processed separately to produce samples of the ASCM, which shall then be tested to measure pozzolanicity or hydraulicity, specific gravity, and fineness.
- **The coefficient of variation of these properties should not exceed 10%.**
- **Note:** *The uniformity of the product should be established prior to potential full-scale production*

Uniformity: Remember Pyrament?

- Lonestar introduced this geopolymer cement ~1988.
- It was ahead of its time and was used successfully for rapid patch repairs even in cold weather.
- It could not be used with reactive agg. due to ASR
- The company had financial issues and Pyrament was gone by 1996.
- But the product also had uniformity issues in that in some cases, it did not perform the same in sequential truckloads of concrete.

A3001 - Alternative SCMs

- Stage III: Concrete performance tests
  - Comprehensive test program to be undertaken to determine performance in both fresh and hardened concrete.
  - Comprehensive series of mixtures from 0.4, 0.5, & 0.7 w/cm to be used for the various tests.

CSA A3004-E1 Physical Reqts for Concrete Tests (in 0.4, 0.5 & 0.7 w/cm concretes)

Table 1
Specifications and requirements for concrete testing*

	Concrete Class I W/CM = 0.40 ± 0.02 Air content 5 to 8%		Concrete Class II W/CM = 0.50 ± 0.02 Air content 5 to 8%		Concrete Class III W/CM = 0.70 ± 0.02 Air content 4 to 7%	
	ASCM Type					
Requirements	A	B	A	B	A	B
Strength, at given age						
3 days	≥ 85% of control	No requirement	≥ 85% of control	No requirement	≥ 85% of control	No requirement
28 days	≥ 90% of control	≥ 75% of control	≥ 90% of control	≥ 75% of control	≥ 90% of control	≥ 75% of control
90 days	≥ 95% of control	≥ 85% of control	≥ 95% of control	≥ 85% of control	≥ 95% of control	≥ 85% of control
1 year	≥ 90 day strength					
3 years	≥ 1 year strength					
Durability						
Freeze-thaw	Durability Factor ≥ 80%					
Scaling resistance‡	No limit, but must be reported				No requirement	
56-day RCPT§	< control	No requirement	No requirement		No requirement	
91-day RCPT§	< control	< control	No requirement		No requirement	
Other						
Setting time**	Not more than 1:00 hour earlier or 1:30 hours later than the control					
Drying shrinkage	≤ 120% of the control					

Strengths up to 90d or 3 years, C666 F/T, C672 Scaling, C1202, Set time, shrinkage

CSA Stage IV: Field Trials

A series of field trials shall be conducted prior to commercialization of the ASCM.

Note: *Field trials are advisable, particularly for ASCMs intended for use in general concrete construction, in order to provide*

(a) confirmation of the performance characteristics, including strength and durability parameters;

(b) data on the effect of the ASCM on concrete finishing characteristics;

(c) data on the different properties of fresh concrete, including slump, air content, and time of set; and

(d) evaluation of exposed concrete in a challenging environment, e.g., freeze-thaw cycles in the presence of de-icing chemicals at an installation suitable for such performance monitoring. ***Widespread use of ASCMs should be reserved until an evaluation period of acceptable performance and durability of at least three years has been completed.***

Corrosion Protection & Fire

- Some new binder systems have very high pH (>14) but others can be below the passivation threshold for steel. —new systems need to be evaluated.

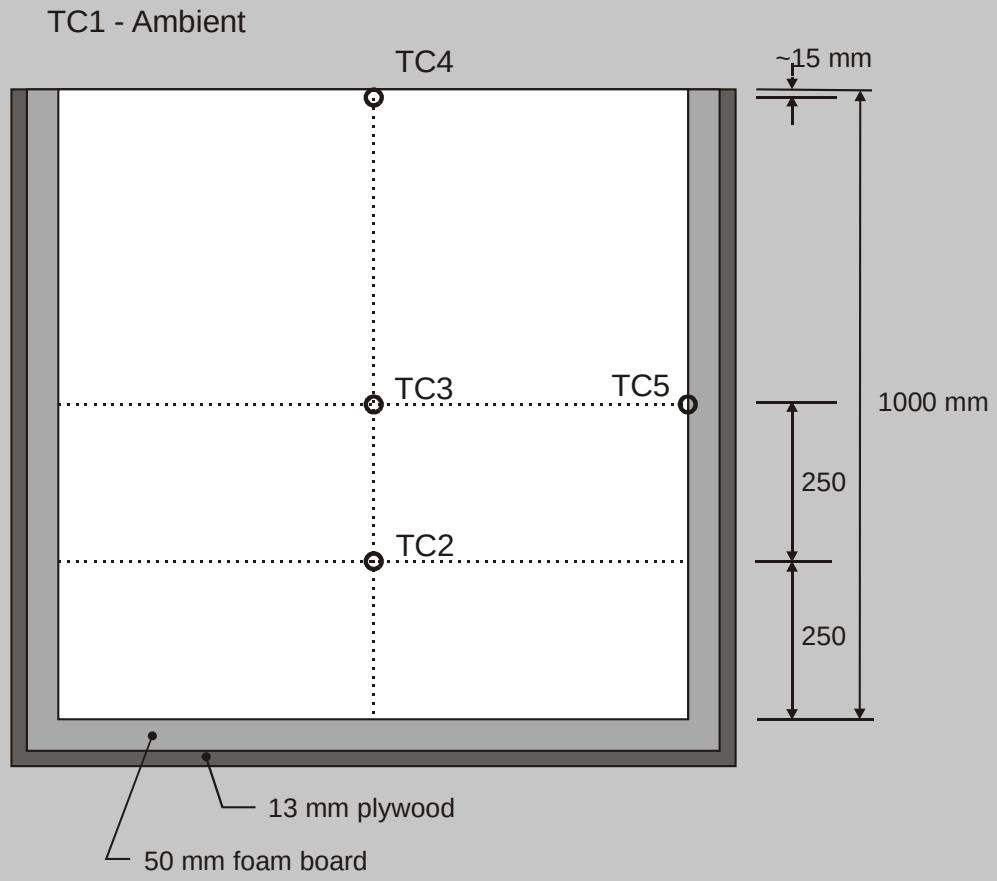
- Fire resistance: is the fire resistance of the new binder different from conventional concrete?—would new fire ratings need to be developed?

Going The Next Step in Evaluating Performance of New Materials

- Testing cylinders, and prisms cast from lab mixtures does not sufficiently mimic performance in structures.
- The next step (even with normal concretes) is to test in a large monolith block.
  - This allows evaluation of thermal gradients
  - Tests can then be performed on cores from the block

Performance Spec. Requirements: Monolith **Pre-Qualification** Tests for Mass Concrete Mixes

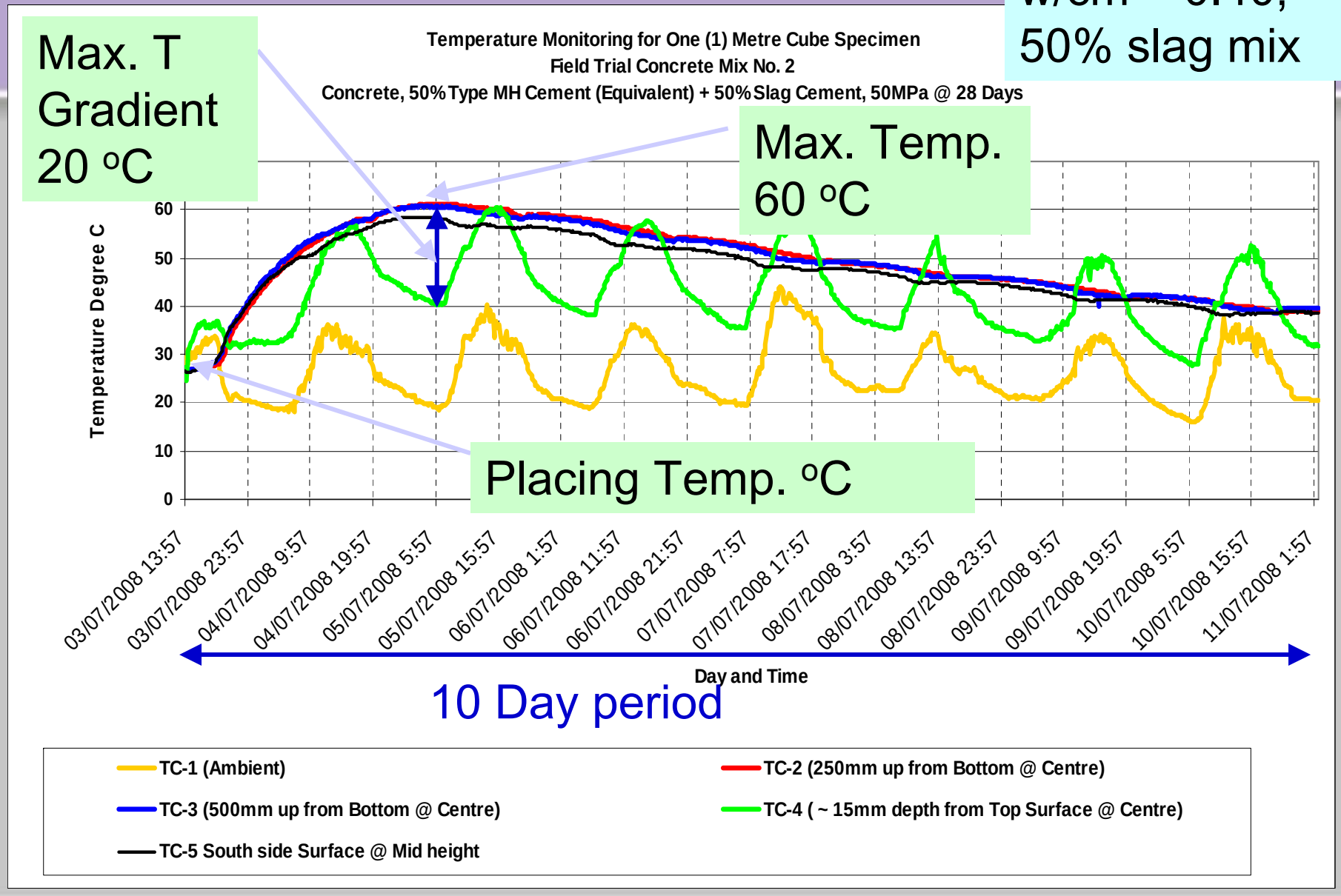
Concrete Suppliers must pre-qualify their Proposed Mixes using Monolith Tests and perform tests on cores from Block



Bickley & Hooton

Example 1m³ Trial Temperatures

w/cm = 0.40,
50% slag mix



Example Performance Tests on Monolith Block

- Peak temperature and max. thermal gradients
- Strengths at relevant ages for constructability and design strength
- Hardened air content and void spacing
- Chloride diffusion & rapid index tests for fluid penetration resistance
- Shrinkage

Example: Mag-phosphate cements

- Were proposed for use in tower line footings in remote, winter conditions (~1986).
- When cast in “mass” footings, for the formulation supplied, the temperatures rose too high, resulting in different reaction products with lower strength and durability.
- Problem was not picked up in lab concrete tests

Summary

While the advent of new binder systems for concrete is promising, sufficient information on robustness, long-term stability and durability in reinforced concrete is needed to avoid problems that could stop innovation.

Hopefully not coming soon :

Strength-fall