50th Brazilian Concrete Congress
Salvador, Bahia
September 6, 2008

A GLIMPSE INTO SUSTAINABLE TERNARY-BLENDED CEMENTS OF THE FUTURE

P.Kumar Mehta
Professor Emeritus
Civil & Environmental Engineering
University of California, Berkeley

TOPICS

I. THE MOST URGENT SUSTAINABILITY ISSUE - GLOBAL WARMING

II. REPORT CARD ON CEMENT INDUSTRY'S CO_2 EMISSIONS, AND TOOLS FOR CUTTING CO_2

III. SUSTAINABLE TERNARY-BLENDED CEMENTS: COMPOSITION AND PROPERTIES

I. WHAT IS GLOBAL WARMING?

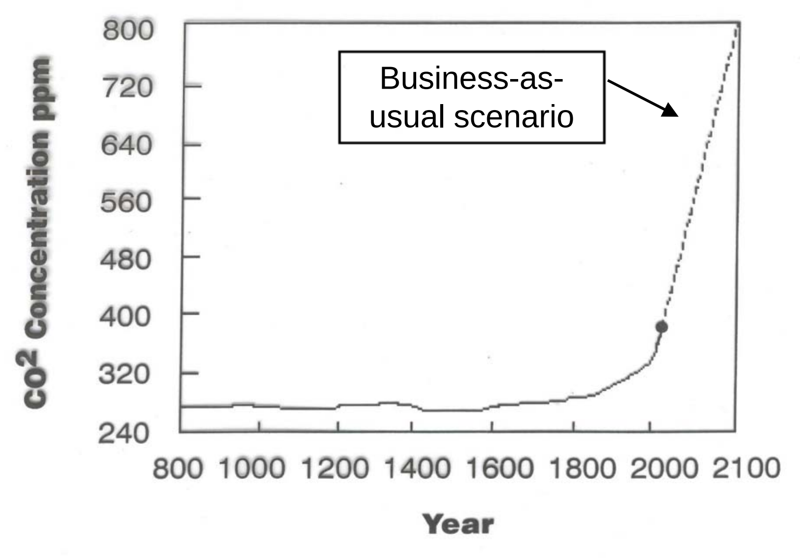
- The term ***global warming*** refers to a steady increase in the earth's surface temperature since 1950s. ***The devastating effects of climate change are being experienced worldwide.***

- Scientists have found a ***linear relationship between the earth's surface temperature and atmospheric concentration of CO_2*** which makes up to 85% of the gases responsible for the green-house effect.

CUTTING THE CO_2 EMISSIONS - THE MOST URGENT GLOBAL PROBLEM

Before the industrial revolution, the Earth's atmospheric CO_2 concentration remained at 280 ppm. During 1950 - 2000, it rose to 390 ppm. Today, it is 400 ppm, and rising at the rate of 2-3 ppm every year.

About 450 ppm is the critical threshold that must not be crossed to prevent irreversible climate change.



Historic and Future Atmospheric CO_2 Concentration (IPCC)

The window of opportunity is thus limited to 20 years.

II. CO_2 EMISSIONS - A REPORT CARD FROM THE CEMENT AND CONCRETE INDUSTRY

- In 1960, the world consumption of concrete was 3 billion T/y (1T/capita). Today, it is 20 billion T/y (3T/capita).
- Over 90% of carbon emissions from the concrete industry are attributable to portland clinker production in cement kilns. Approximately 1 tonne CO_2 is generated for making 1 tonne of clinker.

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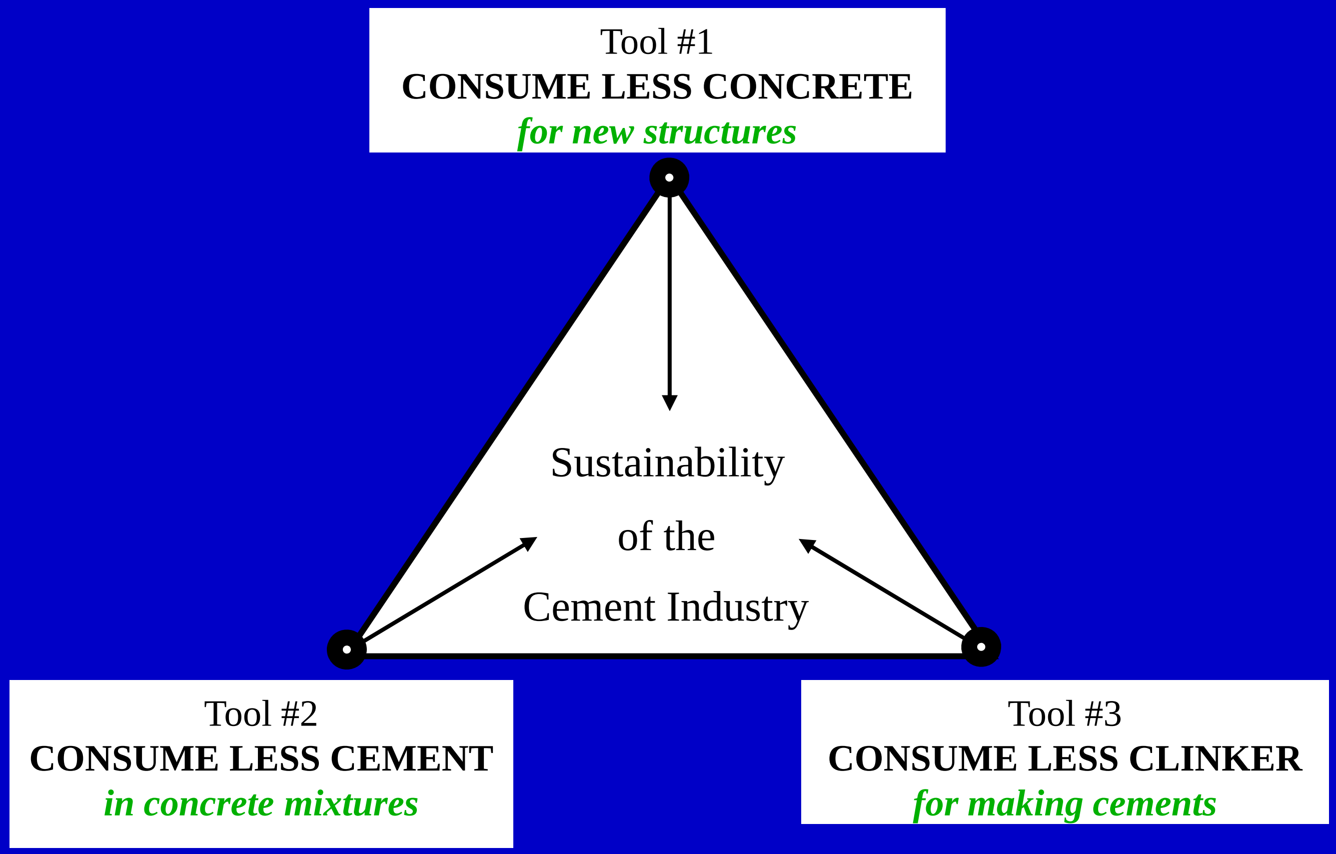
- In 1990, direct CO_2 emissions from cement kilns were about 940 million T/y, compared to 1740 million in 2005. *During the last 15 years, the carbon footprint of the cement industry has almost doubled.*
- Recently, world cement production is growing at the rate of 8 - 10% per year. With business as usual, in next 20 years it is projected to grow at a rate of 6% per year, which is unacceptable because, compared to 1990, this will triple the cement industry's carbon footprint by 2030.

TOOLS FOR CUTTING THE CEMENT INDUSTRY'S CARBON EMISSIONS TO THE 1990 LEVEL IN NEXT 20 YEARS



Tool #1 + Tool #2 ⟶ 30% cement saving

Tool #1 + Tool #2 + Tool #3 ⟶ 40 - 50% clinker saving

TOOLS FOR CONSUMING LESS CONCRETE

Note that 45% of the worlds concrete is consumed by new buildings, 15% by infrastructure projects, and 40% for repair and renovation of the built environment.

- **Reduce project footprint by *innovative architecture*.**
- **Reduce thickness of foundations, columns, walls and beams by *smart structural designs*.**
- **Use highly durable *concrete mix designs* for foundations and other massive elements of new structures and for repair of old structures.**

CONSUMING LESS CEMENT IN CONCRETE MIXTURES

- For foundations and piers, 56 or 91-day ***strength*** requirement can result in significant cement savings.
- To increase the ***consistency*** of fresh concrete, instead of using more cement and mixing water, use plasticizing chemical admixtures.
- Reduce the ***volume of cement paste***, by using optimum size and grading of aggregate.

CONSUMING LESS CLINKER IN CEMENTS

An emerging technology shows that 50 to 70% portland cement can be replaced with one or several complementary cementing materials, such as coal fly ash, granulated BFS, natural pozzolans*, silica fume and rice husk ash, *with dramatic improvements in properties of concrete*. This can be done either by blending in a cement plant or during concrete batching.

*ACI Material Journal, Mar-Apr. 2008

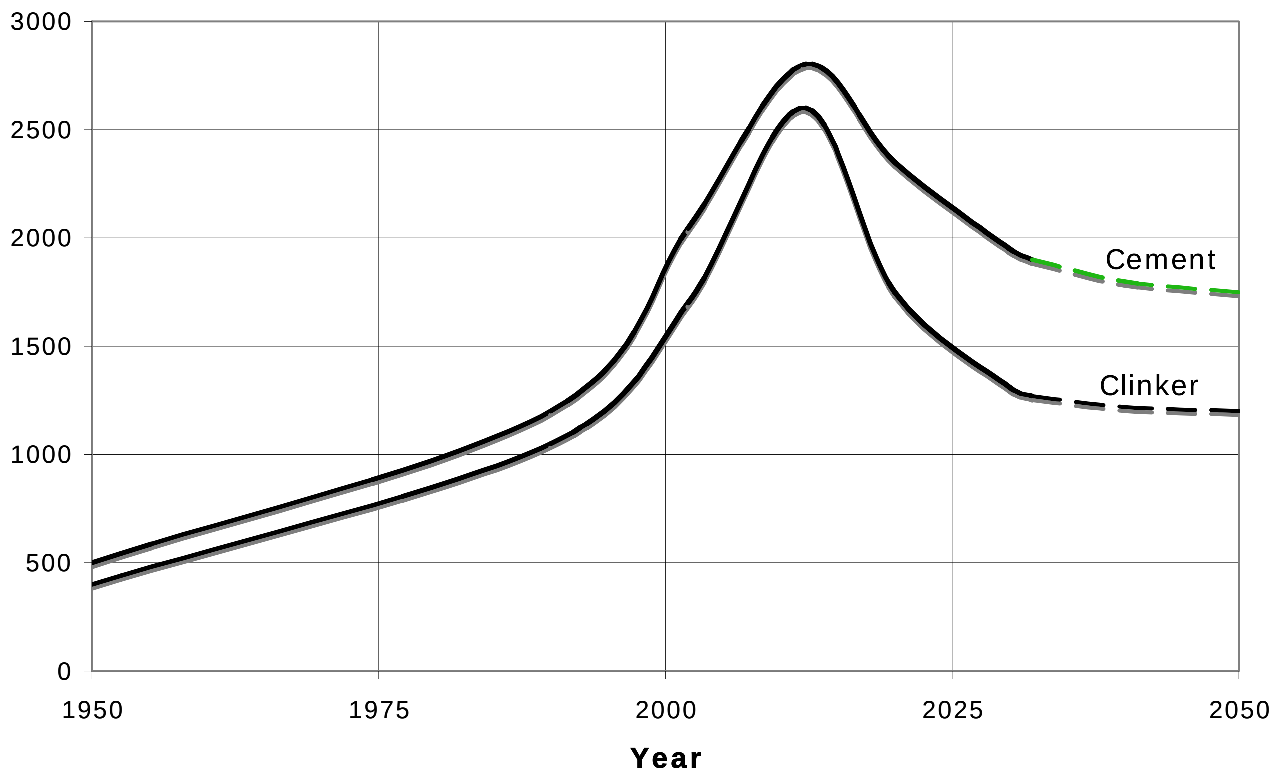


Fig. 1 Historic and Projected Cement and Clinker Consumption Rates

A Roadmap for Reducing Global Cement Consumption, and CO_2 Emissions from Clinker Production

Year	2010	2030
Cement Consumption (million tonnes)	2800	1960
Clinker Factor*	0.83	0.60
Clinker Requirement (million tonnes)	2300	1180
CO_2 Emission Factor**	0.9	0.8
Total CO_2 Emission (million tonnes)	2070	940

** Tonnes of clinker per tonne of cement*

***Tonnes of CO_2 per tonne of clinker*

III. WHAT ARE TERNARY-BLENDED CEMENTS

__***Ternary cements*** **are multi-component cements that are made by blending portland cement (clinker + gypsum) with** ***two complementary cementing materials*****, such as coal fly ash, natural pozzolans, granulated blast-furnace slag, silica fume and reactive rice-husk ash.**

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SUSTAINABLE TERNARY-BLENDED CEMENTS DEFINITION AND CHARACTERISTICS

- *Sustainable ternary-blended (STB) cements* may be defined as those that have both a very low clinker factor, *achieved by substituting at least 40% (by mass) of two complementary cementing materials* for portland clinker, and are *highly resistant to tensile cracking* when exposed to a variety of physical and chemical causes (e.g., severe weathering, alkali-aggregate reaction, sulfate attack and corrosion of reinforcement).

RADICAL ENHANCEMENT OF DURABILITY
- A HOLISTIC TECHNOLOGY

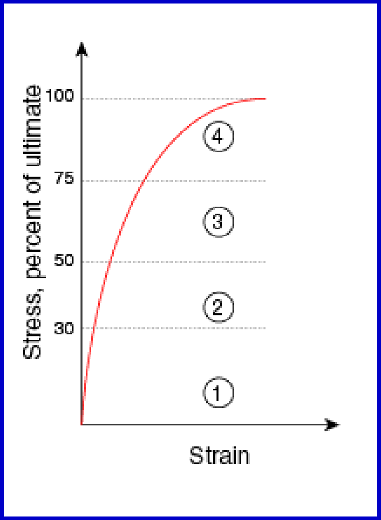
- ***Radical enhancement of durability of materials is essential as a long-term strategy for sustainability*.**
- **Using a fundamental approach, it is possible to understand and control the primary causes of deterioration of concrete in field structures (Mehta, ACI SP-234, 2006).**

WATER - THE FIRST COMMON DENOMINATOR

The presence of water in concrete is the common denominator in most of the causes of deterioration, such as the corrosion of reinforcing steel, frost action, sulfate and alkali-silica attack.

Question: Why do essentially impermeable, exposed concrete structures lose their water-tightness?

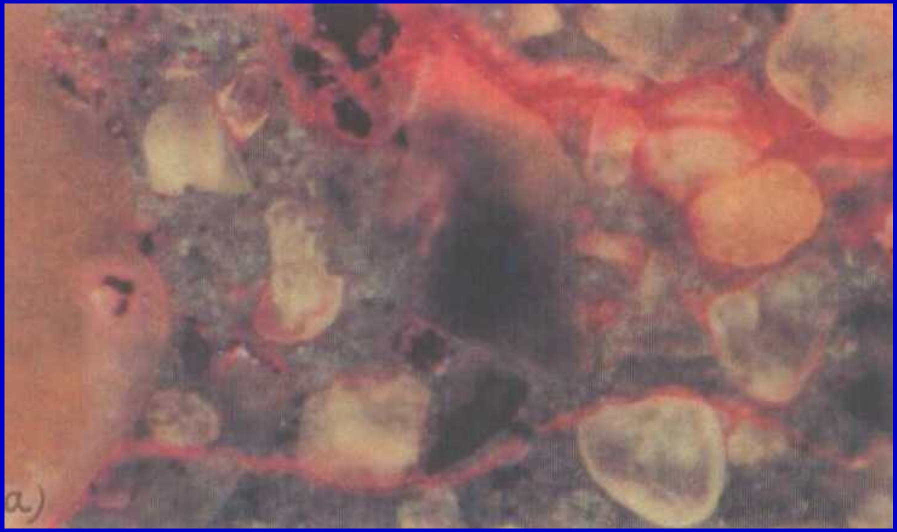
MICROCRACKS - THE SECOND COMMON DENOMINATOR



In addition to voids and some structural cracks, concrete contains invisible microcracks.

Depending on the service conditions, *the microcracks in concrete become unstable and begin to grow.*

When the growing *microcracks, interlink* voids and structural cracks, the water-tightness of concrete is lost.



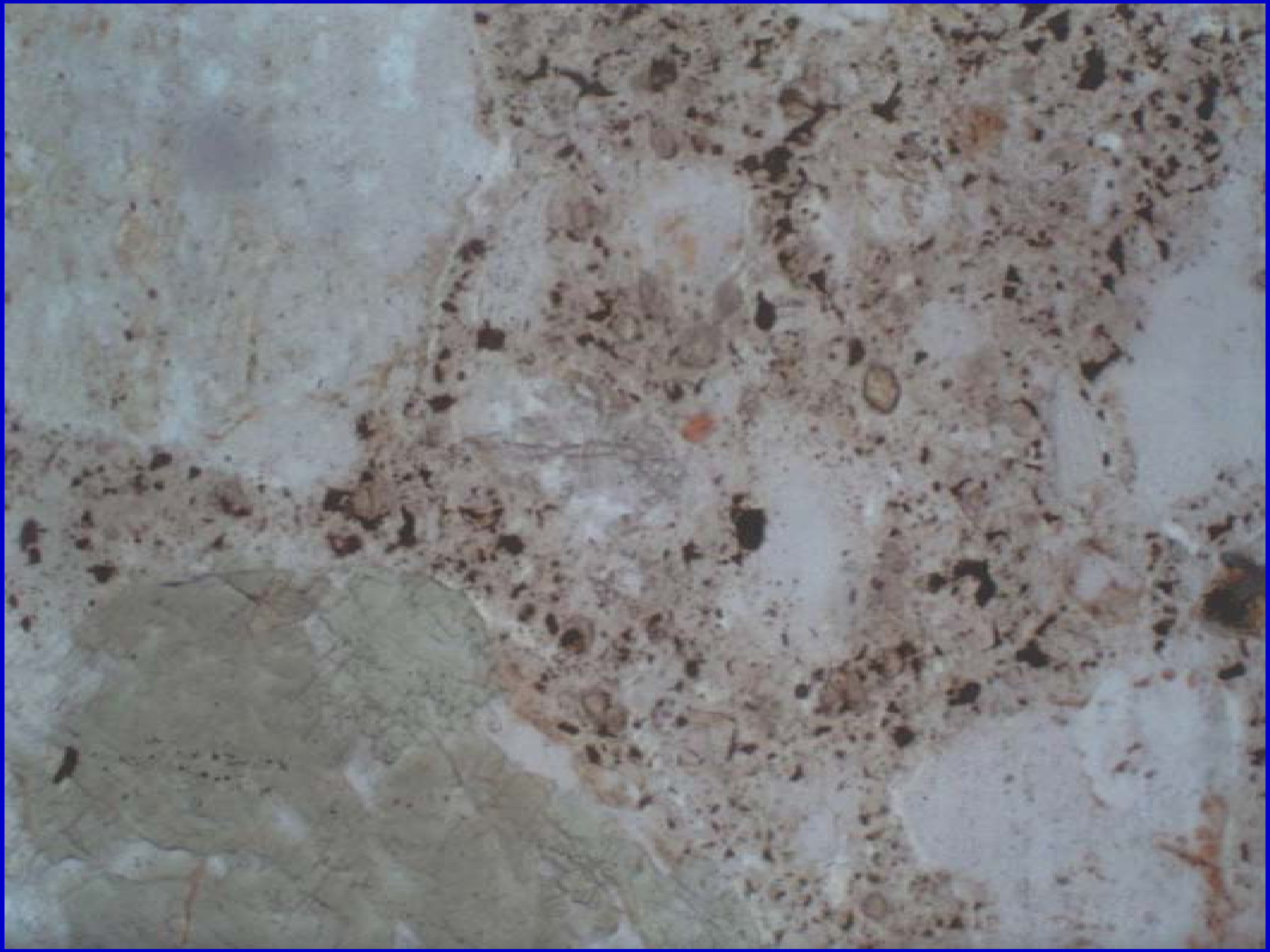
Question: Where do microcracks come from?

HETEROGENEITIES IN THE CEMENT PASTE - THE THIRD COMMON DENOMINATOR

***Large capillary voids and massive calcium hydroxide crystals*, formed during cement hydration create a plane of weakness *in the interfacial transition zone* between the cement paste and the particles of aggregate (or embedded steel in concrete).**

Question: How to get rid of the heterogenous microstructure of the hydrated cement paste in concrete?

A ***homogeneous microstructure***, resistant to microcracking, can be obtained by using less mixing water, and a large amount of pozzolanic materials with portland cement (e.g., 50% siliceous fly ash or 60-70% GBFS or calcareous fly ash).



Photomicrograph of a thin section of HVFA concrete

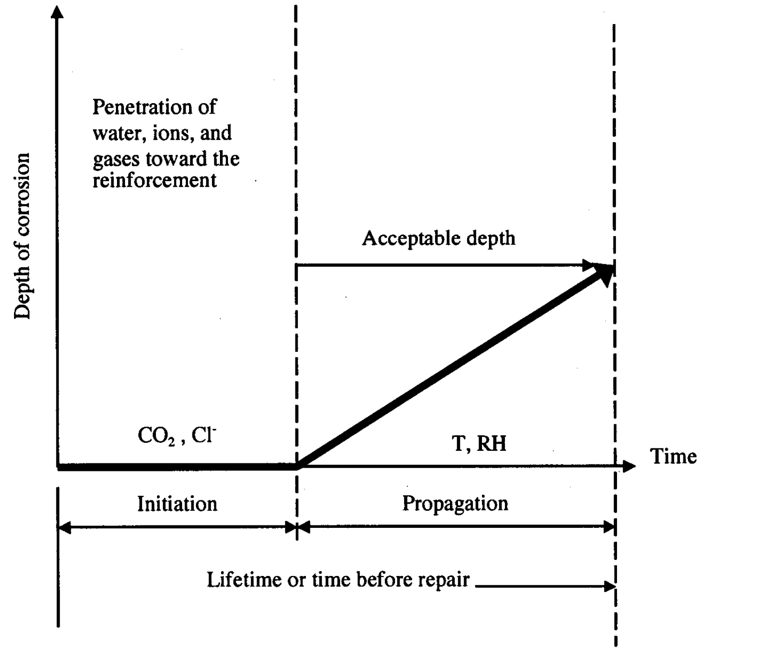


Fig. 2 – Schematic diagram of the two stages of steel corrosion process in reinforced concrete (Tuutti, 1982).

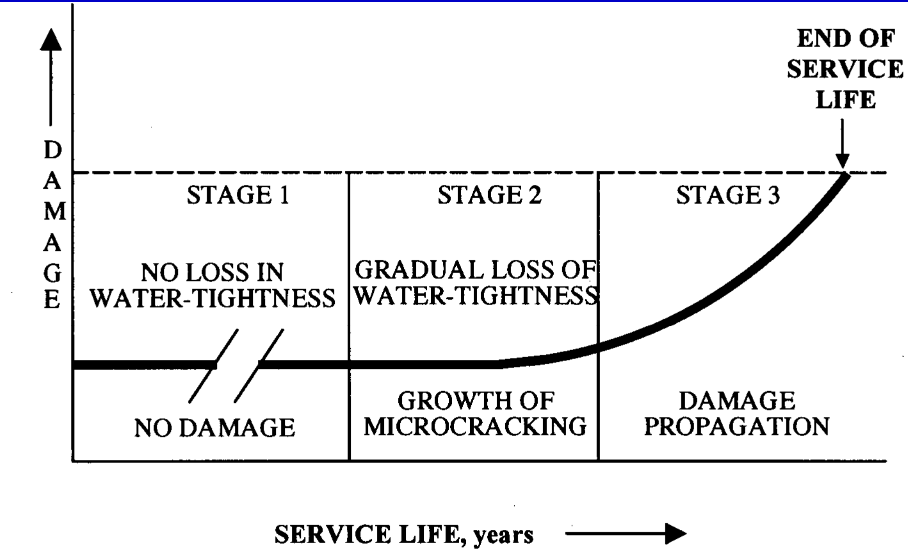


Fig. 3 – A holistic approach illustrating the three-stages of concrete damage process.

A diagram of the 2 stages of reinf. concrete damage process (Tuutti, 1982)

A holistic approach illustrating the 3 stages of the concrete damage process (Mehta ACI-SP 234, 2006)

III. COMPOSITION AND PROPERTIES OF SUSTAINABLE TERNARY-BLENDED CEMENTS

1. **The properties of ternary-blended cements depend on chemistry, minerology, particle size distribution and surface area of the three components which make up the cementing material.**

   Differences in physical and chemical characteristics of individual components and their proportions can be *exploited for producing concrete mixtures with desired properties*.

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2. The early-age setting and hardening properties of concrete are controlled by portland cement (clinker + gypsum), which will continue to be one of the major components of ternary-blended cements.

   From standpoint of sustainability, it is desirable that the proportion of portland clinker is limited to a maximum of 50% by mass of the ternary-blended cement.

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3. **Complementary cementing materials for making sustainable ternary-blended (STB) cements may be divided into the following four types:**

   Type A - Normal pozzolans (e.g., siliceous fly ash and natural pozzolans)

   Type B - Cementitious and pozzolanic (e.g., GBFS and calcareous fly ash)

   Type C - Highly active pozzolans (e.g., silica fume, meta kaolin and rice-husk ash). These materials enhance workability, early strength, and durability.

   Type D - Workability enhancement materials (e.g., pulverized limestone)

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4. **For technical and economic reasons, the proportion of Type C and Type D materials in STB Cement can vary between 5 to 15 % by mass.**

   The presence of *microfine particles in the system* reduces the void space between large particles. Thus, bleeding and segregation is prevented and *workability of fresh concrete is enhanced*.

   Consequently, concrete placement, consolidation, finishing and curing operations are speeded-up, and construction time is saved.

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5. Typically, 35 to 45% by mass of STB Cement may be composed of pozzolanic Type A and Type B materials, either one or both combined.

Compared to portland cement, Type A and B materials *react slowly, thus producing a product that gives lower strength up to 28 days. Hydration of these cements continues for many years, so the ultimate strengths are high (50 -60 MPa).*

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6. A concrete structure that remains water-tight for an indefinite period under service conditions should remain durable on exposure to commonly known causes for loss of durability.

Therefore, STB cements with high volume of complementary cementing materials will have a long service life and a low life-cycle cost.

EUROPEAN CEMENT SPECIFICATION, EN 197/1, 2002
SUSTAINABLE BLENDED CEMENTS

Out of 26 blended cements covered by this specification, four have a low clinker factor, and two are STB cements.

Cement Type	Complementary Cementing Material	Clinker	CCM
III A - Slag-Portland Binary	Granulated Blast Furnace Slag (GBFS)	0.35-0.64	0.36-0.65
IV B - Pozz-Portland Binary	Siliceous or Calcareous Fly Ash, Natural or Thermally-activated Pozzolan, and up to 10% SF	0.45-0.64	0.36-0.55
V A - Ternary	18-30% GBFS 18-30% Pozzolans	0.40-0.64	0.36-0.60
V B - Ternary	31-40% GBFS 31-40% Pozzolans	0.20-0.38	0.62-0.80

ASTM C 1157 STANDARD SPECIFICATION, 1998 FOR PERFORMANCE-BASED HYDRAULIC CEMENTS

Six classes of both portland and blended-portland cements **are covered, with no restrictions on the type and amount of complementary cementing materials to be used for blending with portland cement.**

PRODUCTION AND FIELD APPLICATIONS OF STB CEMENTS

- **Small quantities of Type V A and Type V B Ternary-Blended Cements meeting the EN 197/1 Standard Specification are being produced and marketed in Europe since 2002.**
- **In the U.S., there is essentially no commercial production of ternary-blended cements meeting the ASTM C 1157. Ready-mixed concrete containing 50-67% fly ash by mass of cement, has been successfully used for making all types of structural elements for several projects in the U.S.**

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BAPS HINDU TEMPLE, CHICAGO, 2003
Main raft (22 x 18 x 1m)

Foundation Mix
C = 105 kg/m^3
Class C, FA = 195 kg
w/cm = 0.33

10 MPa @ 3-d
27 MPa @ 7-d
48 MPa @ 56-d
60 MPa@ 1-y

RCPT
Conductivity @ 1-y
< 200 Coulombs

3,000 m^3 Concrete for unreinforced, monolith foundation, and cassions
Clinker Factor = 0.33
CO_2 reduction = 800 metric tons

Intricately carved, white-marble, column segments

CITRIS Bldg. at Univ. of California

Columns under construction (2007)

<u>Concrete Mix, kg/m^3</u>

C = 200 (50%)
Class F, FA = 200
Water = 140
w/cm = 0.35
Slump = 150 - 200 mm
Strength >27 MPa @ 28-d
>50 MPa @90-d

Concrete specifications required 27 MPa strength @ 28-d. 7000 m^3 of HVFA concrete was used for heavily reinforced foundations, shear walls and columns.

PRODUCTION AND FIELD APPLICATIONS OF STB CEMENTS

- Small amounts of *ternary-blended* cements are being manufactured by two cement companies in Eastern Canada.
- HOLCIM makes two kinds of high-durability ternary blends, called *Ter C Cements*. The general-use cement is composed of 70% portland cement, 24% fly ash and 6% silica fume. A low heat cement for massive infrastructure elements contains 60% portland cement, 35% fly ash and 5% silica fume.
- LAFARGE makes a ternary-blended cement of similar composition, using granulated blast furnace slag, instead of fly ash.

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PRODUCTION AND FIELD APPLICATIONS OF STB CEMENTS

Although the global cement industry has yet to embrace the technology of producing STB cements on a large scale, there are some interesting reports from projects, using ternary-blended cements produced by ready-mixed concrete plants.

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According to Fidjestol and Lewis (F.M. Lea's Chemistry of Cements), one of the world's longest single-span bridges, the Tsing Ma Bridge in Hong Kong, used concrete mixtures containing two different kinds of STB cements.

A low-heat cement, with 70% granulated blast-furnace slag and 6% silica fume, was used for slip-formed construction of two main towers. Another cement composed of fly ash and silica fume was used for construction of bridge-deck support towers and other structures.

1. CONCLUDING REMARKS

The cement and concrete industry is vital for meeting the housing and infrastructural needs of global society. Such basic industries cannot be permitted to follow the *cancer cell syndrome*.

***A cancer cell's only goal is to grow unrestricted and multiply itself, with no concern for self-destruction by destroying the organism of which it is a part* (Eckhart, Tolle - The New Earth).**

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2. CONCLUDING REMARKS

Ternary-blended portland cements offer a powerful technology for making sustainable cements and concrete products by enabling:

- ***an immediate and large reduction in carbon footprint of the cement industry***
- **use of two or more complementary cementing materials which makes it possible to exploit the differences in their particle size and other properties**
- ***the production of high-performance concrete mixtures, with excellent workability, high ultimate strength, and exceptional durability, at a low cost.***

3. CONCLUDING REMARKS

The tools for cutting the CO_2 emission attributable to cement industry are available, and they can be implemented without delay. Because the production and use of these cements will not require major modifications to the process equipment in cement plants and ready-mixed concrete plants.

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4. CONCLUDING REMARKS

A major obstacle in the production and use of STB cements in general construction is the mindset of fast-speed construction. Compared to conventional cements, STB cements are somewhat slower in setting and hardening. *However, in most projects no scheduling delays are reported.*

The construction industry will have to make a shift from the mindset of fast-speed construction to the mindset of sustainable construction.

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