EMC Cement BV

Independent Technical Report

A Summary of Technical Evaluations & Analytical Studies
of CemPozz® Derived from Californian Natural Pozzolans

A SUMMARY OF TECHNICAL EVALUATIONS & ANALYTICAL STUDIES OF CEMPOZZ® DERIVED FROM CALIFORNIAN NATURAL POZZOLANS

Dr. Boris Stein

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CMT
CONSTRUCTION MATERIALS TECHNOLOGY
RESEARCH ASSOCIATES, LLC

About CMT

Construction Materials Technology Research Associates, LLC is an engineering consulting, research and development, and technology transfer firm specializing in inorganic cementing materials, concrete science and innovative concrete construction methods. Boris Stein is a co-founder of CMT Research Associates, LLC.

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ABSTRACT

This Summary presents condensed data and conclusions from a one-year long technical evaluation and analytical study of CemPozz® as conducted by Construction Materials Technology Research Associates, LLC (**CMT**).

CemPozz® is a supplementary cementitious material (also referred to as "**SCM**") for the production of concrete. CemPozz® is produced from volcanic rock mined in California using the proprietary low-energy and near-zero carbon dioxide emissions process referred to as EMC Technology.

The evaluation and study demonstrated that:

- The Californian sources of volcanic rock, tested by CMT, met the compositional requirements for natural pozzolans specified by ASTM C618.[1]
- The proprietary EMC processing method allows for the production of SCMs meeting the physical requirements of ASTM C618, without first having to expose the pozzolans to the energy intensive and costly calcination process. It is this calcination process that has generally limited the use of natural pozzolans over the past thirty years to special projects only.
- Previous research by CMT indicated that none of the SCMs commercially used for the production of concrete in California originated in the State. This escalates the importance of introducing a local pozzolan-based product to the market.
- EMC Technology is the most technically- and cost-efficient process known to the authors that allows for the production of SCMs from volcanic rock, which is widely available in California.
- CemPozz® allows for the high-volume replacement (about 50%) of Portland Cement (also referred to as **PC**) in concrete.
- Processed natural pozzolans improve the durability and extend the service life of concrete, all enhancing the sustainability of construction and reducing the cost of maintenance. The addition of pozzolan-based SCMs provide for:
    - Efficient mitigation of the deleterious expansion of concrete containing reactive siliceous aggregates - a serious and increasing durability challenge in California;

[1] **ASTM C618** "Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete."

- Reduced permeability and reduced ingress of water, water vapor & corrosive ions;
- Improved sulfate resistance of concrete;
- Reduced ingress of chlorides, the prime cause of the initiation of corrosion in reinforcing steel and the termination of the service-life of reinforced structures and pavements;
- Reduced heat generation and thermal loading on concrete.[2]

1. THE SUSTAINABILITY AND PERFORMANCE BENEFITS OF CEMPOZZ®

One major benefit of replacing PC in concrete with SCMs is the reduction of the carbon footprint, over 90% of which comes from the PC. Replacing PC with SCMs is by far the most efficient method of reducing this carbon footprint.

In addition to reducing the carbon footprint, a number of performance benefits enhancing the sustainability of construction can be achieved, among them:

- The enhanced long-term strength of the concrete;
- The increased durability and service life of structures and pavements;
- The reduced maintenance cost of pavements and structures over their service life;
- The potential to use aggregates that otherwise could have not been utilized — including recycled materials;
- The reduced rate of depletion of natural resources for producing one ton of PC/Natural Pozzolan SCM blend, as compared to neat PC;
- A reduced embodied-energy content.

Generally, SCMs used for concrete construction in California are not originated in the State. Research of the supply and demand of SCMs demonstrates that: (i) the future supply of fly ash is uncertain; (ii) the supply of ground-granulated blast furnace slag is limited to sources in Pacific Asia and this is also uncertain; and (iii) the long-term alternative to the referenced industrial by-products are processed natural pozzolans that are widely available in California.[3]

Natural pozzolans have many similarities with fly ash Class F, the most commonly used SCM in California and the United States. In contrast to fly ash, which is a by-product of coal combustion at power plants, EMC's natural pozzolan-based SCM is a manufactured product having controlled and consistent chemical and mineral compositions. EMC Technology is a low-energy process consisting of mechanical grinding and activation. The end-product has a high degree of amorphization, optimized particle-size distribution and improved surface morphology, all enhancing its concrete-making properties.

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[2] The positive effects of natural pozzolan on the impermeability, sulfate resistance of concrete and the reduction of heat generation are well-documented in multiple references. Therefore testing was not performed during the first year of studies.

[3] Analytical research was performed by CMT and also by Keybridge Research and CTL Group for the Coalition for Sustainable Cement Manufacturing & Environment. The Coalition for Sustainable Cement Manufacturing & Environment comprises all the Portland Cement manufacturers operating in California today.

2. SPECIFICATIONS

The use of processed natural pozzolans is specified and/or addressed in the following documents governing concrete construction in the United States and/or California.

ACI 318 specifies the use of natural pozzolans.[4] **ACI 318** specifically recommends the addition of pozzolans to concretes subject to very severe sulfate exposure.[5] The usage of both fly ash and natural pozzolans is not limited except for those concretes exposed to freezing and thawing that are in continuous contact with moisture, and that are exposed to de-icing chemicals. For concretes subject to such exposures, the content of pozzolans is limited to 25% of the total weight of cementitious material. However, in California concretes can subject to freezing and thawing only at elevations greater than 4,000 feet.

Caltrans Standard Specifications ("CSS") mandate the use of SCMs, with processed natural pozzolans being among them.[6] Equations for concrete proportioning in CSS, maximize the optimal usage of SCMs in concrete for transportation structures and pavements.[7]

The Standard Specifications for Public Work Construction ("Greenbook"), provides the requirements for the use of natural pozzolans.[8] The Greenbook states that upon the approval of the Engineer, such materials can be used to replace Portland Cement beyond 20% of the total cementitious content in the concrete ("Threshold"). Below the Threshold, no such approval is required.

In short, the codes and standards used in California promote the beneficial use of processed natural pozzolans for concrete structures and pavements. CemPozz® tested by CMT comply with those codes and standards used in California. The proportion added to concrete so as to replace Portland Cement would be governed by constructability, performance and durability considerations. These factors include:

- Workability and setting characteristics of fresh concrete;
- Gain of strength;
- Volume changes;
- Permeability and durability.

The technical evaluations demonstrate that CemPozz® made from natural pozzolans can be used in concrete at ~ 50% of the total cementitious content.

4 **ACI 318** "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary", Chapter 3, Materials.

5 Ibid., Chapter 4, Durability Requirements.

6 Section 90, Portland Cement Concrete.

7 Section 90-1.02B.

8 Section 201-1.2.5, Supplementary Cementitious Materials (for concrete).

3. SCOPE OF STUDIES

Studies performed in 2011-2012 included:

- The analysis of the supply and demand of SCMs in California;
- The analysis of the efficiency of pozzolan-based SCM for enhancing the sustainability and reducing the carbon dioxide footprint of concrete;
- The selection and evaluation of deposits of volcanic rock;
- The processing of experimental batches of volcanic rock into SCM;
- Optimizing the properties of CemPozz® through a series of physical tests under control of chemical composition;
- The qualification of CemPozz® products for compliance with the requirements of ASTM C618;
- The evaluation of the efficiency of CemPozz® products for the mitigation of deleterious expansion of mortar caused by reactive siliceous aggregates;
- The development, together with the laboratory and field evaluations, of concrete mixes with CemPozz®;
- The development of preliminary recommendations for the use of CemPozz® in concrete.

4. THE PROCESSING, COMPOSITION AND PROPERTIES OF CEMPOZZ®

Natural pozzolan was processed at the EMC pilot plant in California. The composition of the base product complies with the requirements of ASTM C618. The Index of pozzolanic activity at 7 days was 80% and at 28 days was 88%, which exceeded the relevant standard's requirements (75% at both ages).

Particle-size distribution of CemPozz® and its morphology were studied by Luleå University of Technology, Sweden. Those studies evidenced the improvement in the surface smoothness of particles of natural pozzolans processed by the proprietary EMC method. This explains the positive impact of the EMC processing method in reducing the water requirement of CemPozz®.

5. THE EFFECTIVENESS OF CEMPOZZ® FOR MITIGATING THE DELETERIOUS EXPANSION CAUSED BY ALKALI-SILICA REACTIONS

In order to evaluate effectiveness of CemPozz® for reducing the expansion due to alkali-silica reaction, a Northern Californian coarse aggregate source was used. It was selected because this aggregate was known to produce higher than acceptable level of expansion. The control mortar-mix used a straight low-alkali PC, Type II/V. The test combination of materials contained 50% of CemPozz® by total weight of the cementitious material. Tests were performed according to ASTM C1260 and ASTM C1567.[9]

[9] **ASTM C1260** "Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Mortar-Bar Method)" and **ASTM C1567** "Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)."

The replacement of 50% of PC with CemPozz® reduced expansion in 14 days from ~0.40% (control specimens) to ~0.04% (test specimens).

The reduction in the deleterious expansion is illustrated additionally by the Figure below:

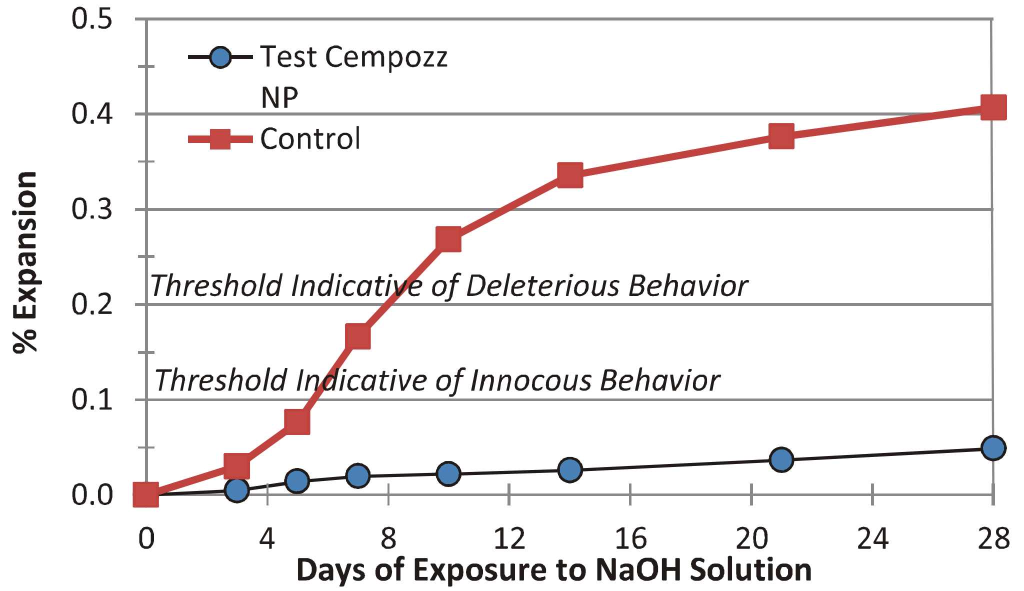

Figure: The Reduction in the Deleterious Expansion in Concrete Containing CemPozz®

6. THE INFLUENCE OF CEMPOZZ® ON THE PROPERTIES OF FRESH & HARDENED CONCRETE

One objective of these studies was the evaluation of concrete mixtures with 30%-50% replacement of PC with CemPozz®. Concrete was proportioned using the absolute volume method; the replacement of PC with CemPozz® was performed on 1:1 weight basis.

Laboratory trial-batches were conducted to conform to the provisions of ASTM C192.[10] Compressive strength was tested using 4 x 8" cylinders according to ASTM C39.[11]

Concrete mixtures were proportioned with the following materials:

- Portland Cement: low-alkali Type II/V manufactured in California;
- CemPozz® made with Southern Californian natural pozzolans;
- Aggregates: Siliceous, both natural and crushed, originated in Southern California;
- Chemical Admixtures: Polycarboxylate high-range water reducers.

The results demonstrated that EMC Technology has a sufficient positive impact on the water requirement to obtain satisfactory workability and strength of concrete, at about 50% replacement of PC.

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[10] **ASTM C192** "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory."

[11] **ASTM C39** "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens."

Analysis of the data from the laboratory trial-batches demonstrates that the effect of the high-volume replacement of CemPozz® on the strength gain of concrete, is somewhat similar to the effect of fly ash Class F, provided that the chemical admixtures used are properly selected and that the water to cementitious material ratio is optimized to enhance the rate of early-age strength gain.

Concrete with CemPozz® demonstrates a significant gain of compressive strength after 28 days. This creates an opportunity to extend the specification age of concrete to 56 or even 90 days as recommended by industry-governing documents for concretes with high volumes of replacement of PC with other SCMs.

The most common classes of concrete tested in the course of the studies (characterized by the specified compressive strength of 3,000 to 5,000 psi) can be produced using CemPozz® at replacement rates of about 50% with optimized water to cementitious material ratio.

The following example illustrates the strength gain of concrete containing CemPozz®:

- 50% of PC in the test-mix was replaced with CemPozz® at a 1:1 ratio. The total cementitious content was identical to a typical mix with the same aggregate (1-inch maximum size) designed for compressive strength of 3,000 psi at 28 days. The water-to-cementitious material ratio was limited to 0.51. The mix contained a high-range water reducer.

The table below demonstrates that at 28 days the concrete-mix meets the strength requirements for 3,000 psi and 3,500 psi concrete. Additionally, at 56 days the mix meets the strength requirements for 4,000 and 4,500 psi concrete.

Age, days	Compressive Strength, psi	Required qualifying-strength for concrete of:			
		3,000 psi strength(*)	3,500 psi strength(*)	4,000 psi strength(*)	4,500 psi strength(*)
7	2,190				
28	4,180	3,500	4,000		
56	5,190	3,630	4,130	4,630	5,130

Table: The Strength Characteristics of Concrete Containing CemPozz®

NOTE: (*) The required strength was calculated as the specified strength plus the safety margin. The safety margin was calculated as the assumed standard deviation increased by the coefficient of 1.34 (after the provisions of **ACI 318** "Building Code Requirements for Structural Concrete and Commentary"). The standard deviation was assumed to be 9% of the average strength at the given specific age.

7. HIGH-STRENGTH CONCRETE

EMC Technology also demonstrates the potential for producing the cement required for ultra-high strength concrete. The replacement of PC with this cementing material allowed for the reduction of the water requirement, together with a strength increase in 28 days of up to 30% - 40%. In 28 days, the maximum compressive strength of concrete exceeded 10,000 psi.

In 90 days it exceeded 13,000 psi. The content of the said EMC cement was equivalent to 7.5 sacks per one cubic yard only, which is used for 5,000 psi concrete.

BIOGRAPHY

Boris Stein, D.Sc., started his professional career as a concrete material scientist and consulting engineer in Moscow, Russia. In his research he concentrated on fundamental and applied aspects of the use of fly ash and other industrial by-products in concrete. In 1994 Boris Stein moved to the United States, where he joined Twining, Inc. in Long Beach, California as the Vice President of Applied Engineering and Research. Dr. Stein is a co-founder of CMT Research Associates, LLC.

While in the United States Dr. Stein has been actively involved in the development of the concrete construction industry in California. Boris Stein is known for his contributions to the implementation of innovative concrete technologies including rapid strength concrete, a technology that dramatically accelerates construction and is widely used for an emergency and planned rehabilitation of infrastructure. He has directed research, development and testing programs performed by Twining, Inc. related to the use of supplementary cementitious materials in concrete. Results of these studies have been used by state agencies and private industry. To assist the construction industry in transitioning to the production and application of concrete with a reduced carbon dioxide footprint, Twining, Inc. has collaborated with other companies to form the Engineering Center for Support of Sustainable Concrete Technologies. The Center was founded with the active participation of Dr. Stein.

Dr. Stein holds fifteen certificates on inventions registered in Russia. He is the author of technical papers, brochures, and textbooks for civil engineer candidates. Dr. Stein is a frequent lecturer and speaker on various aspects of concrete materials science, concrete technology, and construction practice. He teaches a review course on concrete for civil engineer candidates. He is a member of ACI Committee 232 Fly Ash and Natural Pozzolans in Concrete and others.

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Unless stated otherwise, references to “tons” means U.S. Short tons.

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