EMC Cement BV

Technical Paper Series

An Industrially Proven Solution For Sustainable Pavements With High Volume Pozzolan Concrete

AN INDUSTRIALLY-PROVEN SOLUTION FOR SUSTAINABLE PAVEMENTS OF HIGH VOLUME POZZOLAN CONCRETE — USING ENERGETICALLY MODIFIED CEMENT.

Dr. Vladimir Ronin, Tekn Dr.,
Adj. Professor, Cement and Concrete Chemistry and Technology,
Dept. of Civil, Mining and Environmental Engineering,
Luleå University of Technology, Sweden.

Peer-Review Prior to Submission (See: Acknowledgements):

Dr. Lennart Elfgren, Tekn Dr.,
Emeritus Professor of Structural Engineering,
Dept. of Civil, Mining and Environmental Engineering
Luleå University of Technology, Sweden

ABSTRACT

Over 5 years ago, EMC Supplementary Cementitious Materials ("EMC-SCMs") entered the general concrete and concrete-products market in Texas.

Meeting key criteria for broad adoption in the marketplace, the EMC-SCM *CemPozz*® ("CemPozz") is a general-application product, using 95% fly-ash ("FA") treated by using EMC-SCM technologies ("EMC-SCM Technology"). To wit, over 4.5 millions of cubic yards of concrete have been cast using CemPozz, including over 500 miles of pavements for US-State and Federal highways, to confirm CemPozz can replace 50-70% Portland Cement ("PC") depending upon the design-mix.

This paper confirms CemPozz can now comprise natural pozzolans ("NPs") in place of its FA quotient (part or all). It focuses on the industrial application of CemPozz, comprising circa 5% PC and 95% FA or NPs – whether for paving, structural concrete or concrete products.

This paper summarizes the performance of significantly-reduced *carbon footprint* (high durability) concrete paving, industrially-produced using EMC-SCMs, that deliver life-cycle cost savings through enhanced durability and long-term strength, at a competitive up-front cost.

By implication, this paper confirms that, upon applying EMC-SCM Technology, the *carbon footprint* of industrially-produced concrete can be reduced by over 50%.

IMPORTANT EXPLANATORY NOTE:

EMC has produced many papers and journal publications through Dr. Vladimir Ronin, many of which have been written in conjunction with leading academics. As such, this Paper was peer-reviewed by Professor Lennart Elfgren, Emeritus Professor of Structural Engineering, Dept. of Civil, Mining and Environmental Engineering, Luleå University of Technology, Sweden. Professor Elfgren is regarded as a world-leading expert of noted academic standing.

This Paper was prepared for the **INTERNATIONAL CONFERENCE ON SUSTAINABLE CONCRETE PAVEMENTS: PRACTICES, CHALLENGES, AND DIRECTIONS**, held Sep. 15-17, 2010, in Sacramento, California ("**Conference**").

This Paper (together with its associated presentation) was first presented at Session 7 of the Conference, held on September 16, 2010: **INDUSTRY INNOVATIONS AND ASSESSMENT OF SUSTAINABLE STRATEGIES**, moderated by Gerald Voigt, American Concrete Pavement Association.

The Conference was organized by the Federal Highway Administration National Concrete Pavement Technology Center and sponsored by the American Association of State Highway and Transportation Officials, American Concrete Institute, American Concrete Pavement Association, California Department of Transportation, California Pavement Preservation Center at California State University, Cement Association of Canada, Federal Aviation Administration, International Society for Concrete Pavements, National Ready Mixed Concrete Association, Portland Cement Association, Transportation Research Board (**TRB**), University of California Pavement Research Center, University Transportation Center for Materials in Sustainable Transportation Infrastructure at Michigan Technological University.

This paper was typeset for publication according to the requirements of the Transportation Research Board of the National Acadamies, 500 Fifth Street, NW, Washington DC (**TRB**), "**Guide for Preparing and Submitting Manuscripts for Presentation at the TRB Annual Meeting and for Publication in TRB's Journal**."

About the Transportation Research Board of the National Acadamies (TRB):

The (U.S.) National Acadamies comprise The National Academy of Sciences, The National Academy of Engineering, The Institute of Medicine and The National Research Council. The TRB is one of six major divisions of the National Research Council. The mission of the TRB is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

1. INTRODUCTION

For over 5 years, $CemPozz_{FA}$ — an SCM containing about 95% FA and about 5% PC — has been widely used to comprise about 50% of the total cementitious content in high-volume pozzolan concrete ("HVPC"), for sustainable pavements and Texas-DOT ("TXDOT") engineering structures. $CemPozz_{FA}$ has yielded excellent performance, with significantly reduced cracking (due to its reduced drying shrinkage); high abrasion resistance; high freeze-thaw resistance; high sulfate resistance; and very low chloride permeability. (*See*, References: 1).

1.1 Summary of EMC-SCMs.

EMC-SCMs use raw materials in DOT specifications, whose characteristics are well known. This approach permits rapid DOT-adoption. For example, from the start of testing it took less than 6 months for Pennsylvania DOT's ("PENNDOT") approval of 50% $CemPozz_{FA}$. In short, EMC-SCMs:

(i) have demonstrated competitive pricing;

(ii) have demonstrated increased productivity in the paving process;

(iii) comprise a significantly-reduced *carbon footprint* through reduced PC content;

(iv) exhibit reduced cracking, required early-age performance (*i.e.,* workability, set-time and early-age strength), improved long-term strength, and vastly-increased durability.

1.2 Recent Additional and Significant Advances.

During 2009–10, two major advances have been completed vis-à-vis EMC-SCM Technology:

(i) In addition to the use of Class-F FA, preparation for the roll-out of CemPozz containing NPs complying with ASTM C-618 ("$CemPozz_{NP}$"). This will be particularly significant in the western U.S.A., where FA is scarce yet NPs are plentiful.

(ii) The roll-out of a new class of products, enabling up to about 70% pozzolanic content of the total cementitious content in the concrete.

1.3 About EMC-SCM Technology.

EMC-SCM Technology comprises the mechanical processing of the blends of pozzolans and small-volume PC, using multiple high-intensity milling systems. It imparts an increased surface activation of the pozzolan and PC particles, eschewing expensive chemical admixtures. Rather, the mix designs will generally require low-to-mid range water reducers, in line with traditional pozzolan content.

Typically, the high-intensity milling is accomplished by multiple stages of vibratory or stirred ball-mills. (*See*, e.g., References: 1, 2 , 3, 4, 9, 10, 11, 12, 13; as well as: 5, 6, 7, 8).

CemPozz can be added to PC cement in a conventional concrete mixer to about 70% FA (slightly lower when NPs are used).

The water-to-cementitious ratio is a key element for performance. Although there are some differences depending upon the NPs used, in both FA and NP-based products, the required slump, set time and workability is achieved using normal levels of low-to-mid range water-reducers.

Using different types of NPs, $CemPozz_{NP}$ correlates with the performance of $CemPozz_{FA}$. Field observations reveal that CemPozz concrete has significantly-less apparent cracks when producing highway pavings and slabs, as compared to using "traditional" PC concretes. Reference is made also to the drying-shrinkage of $CemPozz_{FA}$ and $CemPozz_{NP}$ discussed here.

2. CEMPOZZ MANUFACTURED WITH CLASS-F FA ($CEMPOZZ_{FA}$)

2.1 Experimental Program.

Material.

$CemPozz_{FA}$ was produced by Texas EMC Products, Ltd ("EMC") at the Limestone plant in Jawett, Texas. Raw materials comprised Class-F FA (from NRG's Limestone power-plant) and Type I PC. The physical and chemical characteristics of $CemPozz_{FA}$ were compared to that of PC, FA and conventional blends of PC and FA. $CemPozz_{FA}$ performance in mortar and concrete was compared to neat PC and PC with 20—50% FA replacement.

Chemical Analysis.

The chemical analyses were performed per ASTM D-4326 and ASTM C-114. The particle size distributions of $CemPozz_{FA}$ and the constituent raw materials (PC and FA) were obtained using Hariba laser-scattering particle-size analysis.

Setting Time.

The setting-time of $CemPozz_{FA}$ paste was compared to reference PC paste using Gilmore apparatus, per ASTM C-266. The paste consistency was verified using a Vicat needle, per ASTM C-187.

Compressive Strength.

The evaluation of water demand and compressive strength development of mortar and concrete were established per ASTM C-109, ASTM C-311 and ASTM C-192.

Sulfate Resistance.

Sulfate resistance ("SR") and alkali silica reactivity ("ASR") were evaluated respectively per ASTM C-1012 and ASTM C-441. Frost and abrasion resistances were tested per ASTM C-666 and C-944.

Shrinkage.

Shrinkage tests were performed for mortar specimens of size 1.8×1.8×7.2" (40×40×160 mm). After casting, using plastic foil they were sealed against moisture exchange, during the first day. After about 24 h, the specimens were then sealed by epoxy resin on the top, bottom and end surfaces, and then placed to dry-out indoors (temperature ~20°C), with one-dimensional double-sided moisture migration.

The shrinkage test for $CemPozz_{FA}$ concrete with 50% PC-replacement was performed per ASTM C-157. The mortars for the shrinkage test were prepared per ASTM C-109, with a water to cementitious materials ratio (w/cm) of 0.46, and sand-to-cementitious material ratio of 2.75. European norm (EN) sand was used. The cementitious materials were PC and ASTM Class-F FA.

The test specimens were cast on three contiguous days, ensuring the same environment during the entire test-period. Two length-measurements were obtained for each specimen, at each point in time.

The representative shrinkage strain ε_{shr} was calculated per Equation 1:

$$\varepsilon_{shr} = \frac{\Delta l_A + \Delta l_B}{2 \cdot l_{meas}} \qquad (1)$$

Δl_A = change in length side A [inch];
Δl_B = change in length side B [inch];
l_{meas} = measuring length = 4 inches (0.1 m).

2.2 Results and discussion.

Chemical Analysis.

The chemical analysis of CemPozz_{FA} and its constituents is listed in Table 1, with corresponding particle-size distributions in Table 2. The chemical analysis corresponds to ASTM Class-F FA. EMC-SCM Technology was effective in reducing the coarse fraction of the FA. The percentage of the blend retained on 325 Mesh was decreased from 12% to 3% by the EMC-SCM Technology. This specific type of FA is relatively coarse and has significantly lower pozzolanic activity as compared to the other ashes in the area.

Another study of EMC-SCMs using 50% ASTM Class-F FA revealed that fine particles of FA and cement formed agglomerates of outer size, comparable to cement grains, but with a considerable inner surface – explaining the increased reactivity. (*See*, References: 5).

Setting Time.

The setting times are shown in Table 3. The setting behavior of CemPozz_{FA} paste is very similar to that of the reference PC. Conventional high volume FA ("HVFA") PC-pozzolan blends typically have longer set times: 3—5 hours, initial set; 5—7 hours, final set.

Compressive Strength Development.

Table 4 comprises data for water-demand and compressive strength development of mortars, based on 1:1 blend of PC and CemPozz_{FA}, in comparison with reference blends: (i) standard PC; and (ii) standard PC with 20 and 40% of replacement using FA that has not been subjected to EMC-SCM Technology.

Per Table 4, the blend made by 50% PC and 50% CemPozz_{FA} exhibited slightly lower early-age strength development in comparison with pure PC, but was superior to PC mortar after 28 days. The 50% CemPozz_{FA} mix performed significantly better than Portland-pozzolan blended cements with 20% and 40% FA replacements. The workability of this EMC-SCM appears better than PC. The high FA content, in combination with optimized particle-size distribution, allows a 10% reduction in w/cm. Combined with the increased reactivity of FA, this contributes to a higher long-term strength.

Slump and Compressive Strength.

Table 5 comprises the strength development of 35—60% $\mathrm{CemPozz_{FA}}$ ready-mix concretes. Whence, 28-day strengths of 3000 psi (*ca.* 20 MPa) to 5000 psi (*ca.* 35 MPa) can be achieved with the same mix designs that ready-mix concrete producers use in their everyday operations. $\mathrm{CemPozz_{FA}}$ concretes demonstrate continuous strength-increase (up to 40%) during 28—56 days curing periods, having a very beneficial effect on concrete durability and the stability of the entire building cycle.

Sulfate Expansion.

Table 6 comprises the change in length of mortar bars exposed to sulfate solution, with the maximum permissible values for specimens. Six specimens for each type of cement were tested. The mortar bars made with 50% $\mathrm{CemPozz_{FA}}$ have slightly improved SR over the reference-PC. The expansion after 4 weeks was approximately one-fourth of the maximum permissible level for blended cement.

Table 6 also shows that mortar bars made with $\mathrm{CemPozz_{FA}}$ have a considerably better resistance (92% improvement) with respect to ASR, than PC equivalents.

Shrinkage.

Table 7 comprises the compositions of the mortars for the shrinkage tests. The shrinkage (*i.e.*, the combination of autogenous and drying shrinkage) results are plotted in Figure 1. The solid lines represent the average shrinkage for each test series of three specimens M1, M2, M3, with the individual results from each specimen represented as symbols. The spread in shrinkage for each series is ± 25×10^{-6}. The difference in the shrinkage for the studied mixtures after seven months (= 4704 h) of drying is about $130–180\times10^{-6}$. Thus, the "final" difference in shrinkage is significant across the different mixtures. However, the measured shrinkage for the first six weeks (= 1008 h) is approximately the same for all specimens tested.

To summarize the shrinkage tests, the empirical expressions are fitted into Equation 2:

$$\varepsilon_{shr} = \varepsilon_u \cdot e^{-(t_1/t)^{\eta_1}} \qquad (2)$$

ε_{shr} = test specimen shrinkage;

ε_{μ} = formal ultimate shrinkage;

t_1 = fitting parameter for time development, t = time from start of drying;

η_1 = fitting parameter for time development.

Table 8 comprises the fitting-parameters for the average results of mixes M1, M2 and M3.

A drawback of Equation 2 is that the results are not necessarily valid in all circumstances. Testing in different conditions is required to build more accurate models.

From Table 8, the formal ultimate shrinkage is significantly different for M1, M2, M3. The final shrinkage is smallest for the usage of 60% modified FA ($CemPozz_{FA}$ in M3) and largest for the use of pure PC (M1). The shrinkage of 20% non-modified FA is about in-between.

Assuming the increases in shrinkage for M1 and M2 are primarily related to drying shrinkage, then the risk of cracking at the surface of a concrete is increased, as drying-shrinkage is related to shrinkage-gradients inside the body. This logic is founded on the observation that the increase in shrinkage is rather late. By this stage, the chemical reaction is quite slow, and consequently the rate of autogenous shrinkage is likely very small.

A higher drying-shrinkage causes a higher cracking-risk, because drying-shrinkage causes high shrinkage-gradients related to the moisture profile, while the autogenous shrinkage is almost homogenous inside a concrete body. If the external restraint for a structure is small, per a slab cast on frictional ground, homogenous shrinkage results only in deformations, but without high stresses. Yet, shrinkage-gradients have to be balanced internally by deformations, to counterbalance tensile and compressive stresses. When drying starts, the surface of a concrete body is directly in balance with the surroundings, and consequently reaches the "final" shrinkage locally. This will cause high tensile stresses ("Stresses") near the surface, as that part continuously "moves" into the body as drying continues.

The reduction of surface Stresses might explain the observed improvements in cracking behavior in $CemPozz_{FA}$ concrete slabs. If there is high restraint between the newly-cast section and adjacent previously-cast section, homogeneous shrinkage might also be the cause of cracking near the casting joint — but note, in all cases a lower total-shrinkage imparts a lower cracking-risk. Finally, a very low diffusivity, due to smaller pores inside a body (which is expected for M3 with modified FA), likely also reduces water vapor-pressure over the pore menisci, producing a reduced moisture-loss rate. Reduced permeability will also reduce the rate of water-loss.

Some data on drying-shrinkage is shown in Table 9.

Frost-thaw and Abrasion Resistance.

Table 10 presents data on the frost-thaw and abrasion resistant for 50% $CemPozz_{FA}$ paving concrete of total cementitious content 342 kg/m^3 (580 lbs/cy), and water-to-cementitious ratios 0.40 and 0.45. The data confirms the excellent durability of HVFA made with $CemPozz_{FA}$.

A Paving Job Example.

Figures 2, 3 and 4 are photographs from paving jobs on IH-10 (East of Houston) in Texas, U.S.A. Table 5 comprises the concrete mix design. The 28-day strength was 49.7 MPa. This is significantly higher than TXDOT's requirements, respectively: 33.4 MPa (4400 psi) for paving and 35.9 MPa (5200 psi) for structural applications. Surface finish was excellent, with reduced labor requirements. According to TXDOT, pavements with $CemPozz_{FA}$ concrete demonstrated a 50% reduction in cracking compared to traditional pavement.

3. CEMPOZZ MANUFACTURED WITH NATURAL POZZOLANS (CEMPOZZ$_{NP}$)

3.1 Natural Pozzolans: An Abundant Source for CemPozz$_{NP}$

Since circa. B.C. 5–4000, diatomaceous earth and hydraulic binders (containing lime and NP) from the Persian Gulf were used for the production of mortars and concrete — long before the invention of PC in 1824. The use volcanic-ash natural pozzolans from eruptions on the Aegean island of Thera and Mt. Vesuvius, Italy, date as far back to B.C. 16–1500 and A.D. 79. Such ash contained about 80% highly-amorphous glasses (pumice and obsidian). Even then, civil engineers were using very high durability pozzolan concretes. After more than 2000 years, many such structures (*e.g.* the Roman coliseums and aqueducts) and harbors in the Black Sea and Mediterranean remain in good shape today.

In the twentieth-century, there has been some use of NPs in U.S. engineering projects. Examples include San Francisco's Golden Gate and Oakland Bridges, where 25% ground calcined Monterey shale was used in order to reduce the heat of hydration and the risk of thermo-cracking. During the '60s and early-'70s, NPs accounted for 42kg/m^3 (*ca.* 15% of total cementitious weight) in nearly all of the concrete in the California Aqueduct. This was the most extensive use of NPs in U.S. history. (*See,* References: 14). Yet, despite North America having millions of tons of NPs, the reasons for their limited use include the following:

(i) NPs typically have a low pozzolanic activity. Thermo-treatments to improve this (calcinations) make NPs more expensive that SCMs (*e.g.*, FA or blast furnace slag).

(ii) The porous structure of NP particles means NP concrete-mixes carry a much higher water demand, requiring higher levels of water-to-cementitious ratios to achieve the same slump as pure PC concretes.

(iii) Higher w/cm ratios lead to lower strength development (especially early-age) and increased drying shrinkage-deformations.

3.2 Resolution of NPs' Performance Limitations.

EMC-SCM Technology resolves the aforesaid performance-limitations of NPs, without the hitherto cost-implications thereby associated.

<u>Table 11</u> comprises setting-time and cement paste water-demand. <u>Figure 5</u> depicts the strong correlation between 50% CemPozz$_{FA}$ and 50% CemPozz$_{NP}$ concretes, viz. 28 days' compressive strength for 3000 psi (20 MPa), 4000 psi (28 MPa) and 5000 psi (35 MPa). <u>Table 12</u> comprises data viz. an ASTM C-157 drying shrinkage test, performed on ASTM C-109 mortar. These results have been obtained with CemPozz$_{NP}$ manufactured with Californian perlite. Importantly. datasets derived by using other ASTM C-618 NPs (*e.g.*, pumice, rhyolite, tuff, etc) reveal a very close correlation to the results presented here.

4. CONCLUSIONS

In no particular order of precedence:

4.1 Over 5 years' of full-scale industrial implementation of HVPC manufactured with CemPozz$_{FA}$ (using Class-F FA) confirms the consistent production of environmentally efficient high-performance concrete for sustainable pavements, replacing up to 50% PC.

4.2. 50% $CemPozz_{FA}$ concretes performed in line with traditional 20% FA mixes. Using traditional concrete mix designs, up to 70% PC can be replaced to achieve compressive strengths of 3000–5000 psi at 28 days.

4.3. 50% $CemPozz_{FA}$ concretes have less water requirements (and increased workability) than comparable traditional blends, which contributes to a higher strength with increased fineness.

4.4. 50% $CemPozz_{FA}$ mortar samples had improved SR. The change of length values stood at just over 1/4 of the permitted level after 4 weeks, and 1/10th of the permitted level after 15 weeks.

4.5. 50% $CemPozz_{FA}$ mortar samples had considerably higher resistance to alkali-silica reaction (up to 92% lower change in length) in comparison with standard PC.

4.6. Concrete and mortars containing up to 60% $CemPozz_{FA}$ are characterized by significantly lower drying-shrinkage as compared to PC and 20% FA concretes, demonstrating also much lower cracking tendency/development in pavements.

4.7. NPs subjected to EMC-SCM Technology demonstrated a contribution to a strength development that concords with $CemPozz_{FA}$. Both water demand and drying-shrinkage of resultant $CemPozz_{NP}$ concretes were similar to PC concretes.

5. ACKNOWLEDGEMENTS

Concrete strength-development test results are a summary of the tests performed by PENNDOT, TXDOT, paving contractors, EMC and CCRL, Texas. Datasets on ASR and SR were generated independently by TXDOT and CCRL. Data on the shrinkage measurements came from: EMC mortars; Luleå University of Technology, Sweden ("LTU"), concrete ASTM C-157 test; and CCRL. Tests on the frost–thaw and abrasion resistance were performed by PENNDOT.

Finally, a very special thanks to Dr. Lennart Elfgren, Emeritus Professor of Structural Engineering, Dept. of Civil, Mining and Environmental Engineering, LTU, for his kind review of this manuscript before submission.

6. REFERENCES

1. Pike, C., Ronin, V., and L. Elfgren. High volume pozzolan concrete: three years of industrial experience in Texas with CemPozz. *Concrete Infocus Magazine*, 2009, vol.8, nr.2. March/April, pp.22-27.

2. Hedlund, H., Ronin, V. and J.-E. Jonasson. Ecological Effective High Performance Cement Based Binders. *5th International Symposium on Utilization of High Strength/High Performance Cement, Sandefjord, Norway, 20-24 June 1999,* ed. by I. Holand and E. J. Sellevold, Norwegian Concrete Association, Oslo, 1999, pp.1144-1153, ISBN 82-91341-25-7.

3. Johansson, K., Larsson, C., Antzutkin, O. N., Forsling, W., Rao, K. H. and V. Ronin. Kinetics of the Hydration reactions in the Cement Paste with Mechanochemically Modified Cement by Si Magic-Angle-Spinning NMR Study. *Cement and Concrete Research,* Vol. 29, 1999, pp.1575-1581.

4. Jonasson, J.-E., Ronin, V. and H. Hedlund. High Strength Concretes with Energetically Modified Cement and Modeling of Shrinkage Caused by Self-desiccation. *Proceedings of the 4th International Symposium on the Utilization of High Strength/High Performance Concrete, Paris, France, August 1996,* Presses Pont et Chaussees, Paris, 1996, pp.245-254.

5. Justnes, H., Elfgren, L. and V. Ronin. Mechanism for Performance of Energetically Modified Cement versus Corresponding Blended Cement. *Cement and Concrete Research*, Vol. 35, 2005, pp.315-323.

6. Justnes, H, Dahl, P.A., Ronin, V., Jonasson, J.-E., and L. Elfgren. Microstructure and performance of energetically modified cement (EMC) with high filler content. *Cement and Concrete Composites*, Vol 29, 2007, pp.533-541, Elsevier.

7. Justnes, H., Ronin, V., Jonasson, J.-E., and Elfgren (2007b): Mechanochemical technology: Synthesis of energetically modified cements (EMC) with high volume fly ash content. *12th International Congress on the Chemistry of Cement. Montreal 2007.* 2007, 14 pp..

8. Justnes, H., Ronin, V., Jonasson, J.-E., and L. Elfgren. Mechanochemical technology: energetically modified cements (EMC) with high volume quartz or fly ash. *Proceedings of the International Conference on Sustainability in the Cement and Concrete Industry,* Norwegian Concrete Association, 2007. pp.163-177, ISBN: 978-82-8208-001-9.

9. Rao, K. H., Ronin, V. and K.S.E. Forsberg. High Performance Energetically Modified Portland Blast-furnace Cements. *Proceedings of the 10th International Congress of the Chemistry of Cement, Gothenburg, Sweden, June 1997.* ed. by H. Justnes, 1997, 3ii104, 9pp., Inform Trycket AB, Gothenburg, ISBN 91-630-5497-5.

10. Ronin, V. and J.-E. Jonasson. *Investigation of the Effective Winter Concreting with the Usage of Energetically Modified Cement (EMC) - Material Science Aspects.* Report 1994:03, Division of Structural Engineering, Luleå University of Technology, Luleå, Sweden, 1994, 24 pp..

11. Ronin, V., J.-E. Jonasson. Advanced modification technologies of the Portland cement based binders for different high performance applications. *Proceedings of the 10th International Congress of the Chemistry of Cement, Gothenburg, Sweden, June 1997.* ed. by H. Justnes, 1997, 2ii077, 8pp., Inform Trycket AB, Gothenburg, ISBN 91-630-5496-5.

12. Ronin, V., (2004). Method for the Treatment of Fly Ash. U.S. Patent 6,818,058.

13. Ronin, V., (2005). Process for Producing Blended Cements with Reduced carbon Dioxide Emissions. U.S. Patent 6, 936,098.

14. 232.1R-00, 2000: Use of Raw or Processed Natural Pozzolans in Concrete (Re-approved 2006). *American Concrete Institute of Publication,* 24pp..

LIST OF TABLES AND FIGURES

TABLE

1 Chemical Composition of $CemPozz_{FA}$ (1:1 PC/FA) and its Constituents.

2 Particle-Size Distribution.

3 Setting Time of (i) PC-Paste and (ii) 1:1 PC/$CemPozz_{FA}$ Paste.

4 Compressive Strength Development, ASTM C-109 (MPa).

5 Concrete Mix Designs using $CemPozz_{FA}$, Slump and Strength Development (MPa).

6 Expansion of Mortar Due to Sulfate Exposure and ASR.

7 Material Parameters for Test Mixtures M1, M2, M3: Linear Shrinkage.

8 Fitting Parameters According to Equation 2.

9 Drying-Shrinkage Test Results (ASTM C-157), 50% $CemPozz_{FA}$ Concrete.

10 Frost-Thaw and Abrasion Resistance.

11 Setting Times of PC Paste and 1:1 PC/$CemPozz_{NP}$

12 Drying-shrinkage Measurements (ASTM C-157) comparison between (i) PC; and (ii) 1:1 PC/$CemPozz_{NP\text{-}perlite}$

FIGURE

1 Measured Shrinkage for Test Mixtures M1, M2, M3 (three test-specimens for each mixture).

2 Laying the Concrete on IH 10, Texas, U.S.A.

3 Steel Ahead of Placer on IH 10, Texas, U.S.A.

4 Finishers Behind Slip Form on IH 10, Texas, U.S.A.

5 Compressive Strength Correlation: $CemPozz_{FA}$–*v*– $CemPozz_{NP}$ Formulations.

TABLE 1. Chemical Composition (%) of CemPozz_{FA} (1:1 PC/FA) and its Constituents (PC and FA)

Compound	PC	FA	CemPozz_{FA}
CaO	62.4	15.0	40.9
SiO_2	17.8	49.4	33.2
Al_2O_3	4.0	19.6	6.3
Fe_2O_3	3.9	5.2	4.1
SO_3	3.2	0.8	1.6
Na_2O	<0.1	0.3	0.1
K_2O	0.3	1.2	1.2
Insoluble residue	0.5	51.3	21.6

TABLE 2. Particle-Size Distribution

Parameter	PC	FA	Blend of 1:1 PC/FA	$CemPozz_{FA}$
Median Particle size (µm)	16.0	14.3	14.3	11.8
Min. Particle size (µm)	1.5	1.3	1.3	1.5
Max. Particle size (µm)	50	100	100	50
Specific surface (cm^2/cm^3)	5,624	6,624	6,075	7,520
Less than 10 µm (%)	61	38	52	65
Retained on 325 Mesh (%)	5	20	12	3

TABLE 3. Setting Time of (i) PC-Paste and (ii) 1:1 PC/CemPozz$_{FA}$ Paste

Property	PC	CemPozz$_{FA}$
w/cm	0.24	0.22
Initial Set Time (hours:min)	2:29	2:32
Final Set Time (hours:min)	3:33	3:50

TABLE 4. Compressive Strength Development, ASTM C-109 (MPa)

Cement type	w/cm	Curing time (days)			
		1	3	7	28
PC	0.48	10.3	26.6	30.0	38.6
50% CemPozz$_{FA}$*	0.43	9.1	21.9	27.2	41.1
80% PC1 + 20% FA	0.46	6.5	20.4	23.6	35.8
60% PC1 + 40% FA	0.44	3.8	15.1	17.7	29.6

* *PC from Texas, U.S.A.*

TABLE 5. Concrete Mix Designs Using CemPozz_{FA}, Slump and Strength Development (MPa).

CemPozz_{FA} (%)	70**	60**	50**	50***
Cementitious materials* (kg/m^3)	277	277	277	300
CemPozz_{FA} (kg/m^3)	194	166	139	150
Water (kg/m^3)	89	83	83	90
25 mm limestone aggregate (kg/m^3)	1106	1097	1047	1107
Fine aggregate (kg/m^3)	951	960	968	868
Air-entrainer (ml/m^3)	0	0	0	150
Water reducer (oz/cwt)	5	5	5	1
w/cm	0.32	0.30	0.30	0.30
Slump (mm)	169	175	175	5
7 days compressive strength (MPa)	16.5	17.9	19.7	25.8
28 days compress. strength (MPa)	27.6	29.4	34.3	40.9
56 days compress. strength (MPa)	36.5	38.9	43.4	49.7

* *Portland cement + CemPozz_{FA},*
** *Ready-Mix Concrete mix design,*
*** *TXDOT mix design*

TABLE 6. Expansion of Mortar Due to Sulfate Exposure and ASR.

SR per ASTM C-1012 (Change in length, %)			
		Portland cement	**Blended cement**
Maximum permissible values:		0.012	0.041
(after 4 weeks)		**PC (reference)**	**50 % CemPozz$_{FA}$**
Exposure	**1 week**	0.006	0.006
	2 weeks	0.012	0.011
	3 weeks	0.013	0.011
	4 weeks	0.013	0.011
ASR per ASTM C-441 (Change in length, %)			
		PC	**50 % CemPozz$_{FA}$**
Results at 14 days:		0.026	0.002

TABLE 7. Material Parameters for Test Mixtures M1, M2, M3: Linear Shrinkage.

Specimen	Mix	FA	PC	w/cm
11, 12, 13	M1	0%	100%	0.46
21, 22, 23	M2	20%	80%	0.46
31, 32, 33	M3	60%*	40%	0.46

* *Energetically modified fly ash* *(CemPozz$_{FA}$)*

TABLE 8. Fitting Parameters According to Equation 2.

Test No.	t_1, h	η_1	ε_u, 10^{-6}
Average, M1	385	0.548	–1500
Average, M2	303	0.697	–1200
Average, M3	188	1.065	– 880

TABLE 9. Drying-Shrinkage Test Results (ASTM C-157), 50% CemPozz$_{FA}$ Concrete

Time, days	**4**	**7**	**28**
Average shrinkage, %	– 0.009	– 0.010	– 0.013 – 0.019*

* *Average shrinkage for the concrete of the same mix design with pure PC*

TABLE 10. Frost-Thaw and Abrasion Resistance

Water-to-cement ratio	Total air content, %	Spacing factor, in	Durability factor, %	Abrasion resistance, mass loss after 180s
0.45	5.7	**0.0037**	92	**2.5**
0.40	4.0	**0.0034**	100	**5.0**

TABLE 11. Setting Time of (i) PC Paste and (ii) 1:1 PC/CemPozz$_{NP}$ Paste

Property	PC	EMC
Water demand for standard consistency	0.24	0.25
Initial Set Time (hours:min)	2:29	2:25
Final Set Time (hours:min)	3:33	3:57

TABLE 12. Drying-Shrinkage Measurements (ASTM C-157) comparison between (i) PC and (ii) 1:1 PC/CemPozz$_{NP}$-*perlite* ("CemPozz-NP")

Drying Time(days)	PC	CemPozz$_{NP}$
7	– 0.039	– 0.042
28	– 0.078	– 0.068
56	– 0.098	– 0.108

FIGURE 1: Measured Shrinkage for Test Mixtures M1, M2, M3 (three test-specimens for each mixture)

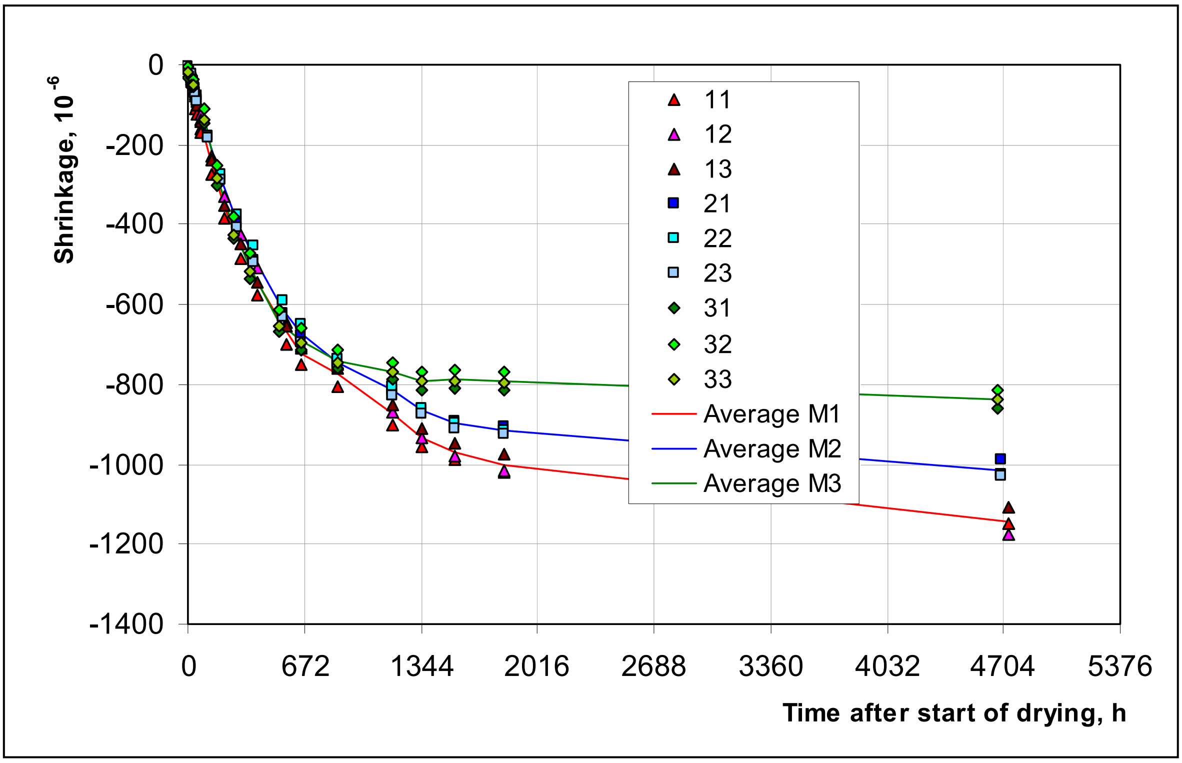

FIGURE 1: The solid lines show the average shrinkage for each mixture.

FIGURE 2: Laying the Concrete on IH 10, Texas, U.S.A.

FIGURE 3: Steel Ahead of Placer on IH 10, Texas, U.S.A.

FIGURE 4: Finishers Behind Slip Form on IH 10, Texas, U.S.A.

FIGURE 5: Compressive Strength Correlation: CemPozz_{FA} –*v*– CemPozz_{NP} Formulations

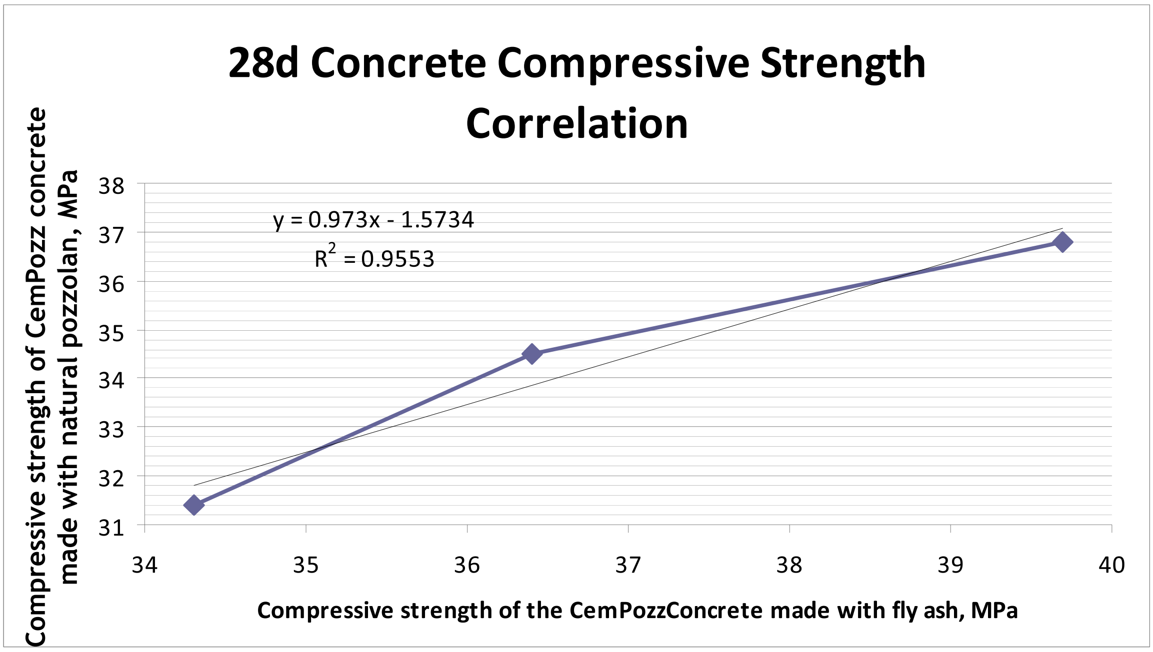

FIGURE 5: Comparison of 28-days' compressive strength for two kinds of CemPozz concretes made with NP (vertical axis) and with FA (horizontal axis)

Prepared By EMC Cement BV

Produced 2012-08

All Rights Reserved.

Copyright ©2012 EMC Cement BV.

This document is for internal evaluation use only. Copying or transmission of this document whole or in part, for purposes beyond those as set out in the previous sentence is strictly prohibited, except with our express prior consent.

The entire contents of this document are under copyright protection. The contents may not be copied other than as expressly permitted above without the express written consent of EMC Cement BV.

CemPozz, its associated logo and the three-leaf device whether not appearing in large print or with a "tm" or "®" trademark symbol, are trademarks of EMC Cement BV. The use or misuse of these trademarks or any other materials, except as may be permitted by us in writing, is hereby expressly prohibited and may be in violation of applicable law.

References to CemPozz® products and services do not per se imply that EMC Cement BV (or any of its subsidiaries) is bound to offer or provide such products and services in every country throughout the World. Product specifications upon deliver may vary according to ultimate options chosen. Specifications of products are a matter of continual evaluation and evolution. We reserve the absolute right to amend vary modify our products in any manner as we deem fit without any obligation of prior notice.

Other company, product and service names may be trademarks or service marks of others.

Please be advised that EMC Cement BV aggressively enforces its intellectual property rights to the fullest extent permitted by law. For further information please feel free to contact us.

EN

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

Superior Performance & Superior Profitability

EMC Cement B.V.
Alvägen 33
S-97333 Luleå
Sweden

T/F: +46 920 89178
Cell/GSM: +46 705498892
E-mail: emcdev@telia.com