EMC Cement BV

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High Volume Pozzolanic Concrete
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Important Explanatory Note:

Concrete In Focus magazine is the main publication for the U.S. National Ready Mixed Concrete Association.

Since this article was published in 2009, significant advances have been made in EMC Technology. These advances include (i) up to about 70% replacement of Portland cement in the concrete; (ii) compliance with the performance requirements of grade-120 slag at 50% fly ash CemPozz® content; and (iii) the ability to replace up to about 60% of Portland cement in the concrete with natural pozzolans (e.g. volcanic ash).

These further advances have significantly increased the uniqueness and value of EMC Technology. For example, grade-120 slag secures prices comparable to (and even in excess of) Portland cement. Further, the inclusion of natural pozzolans allows flexibility in the raw materials used. This is important, as many regions around the world have little or no fly ash yet an abundance of volcanic ash (for example Africa, the Middle East, Western U.S.A. and particularly California, to mention a few).

High Volume Pozzolan Concrete:

Three years of Industrial Experience in Texas with CemPozz

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Abstract

A High Volume Pozzolan Concrete (HVPC) can be manufactured with low carbon dioxide footprint and energy consumption with the help of a new technology based on Energetically Modified Cement (EMC). The technology consists of mechanical processing a blend of ordinary portland cement (PC) and a pozzolan (Class F fly ash) through multiple high intensity grinding mills. The process imparts an increased surface activation of the PC and the pozzolan particles. Fly ash may be processed with all cements forming ready-to-use cement. Alternatively, fly ash can be processed with a small amount of cement (circa 5% by weight) and used as a pozzolan added to the concrete mixer. The latter product is called CemPozz and has been produced from 2004 by Texas EMC Products, Ltd, at the Limestone plant in Jewett, Texas. It can replace up to 60% of the PC in concrete. The performance of CemPozz (mechanically processed pozzolan) in concrete is equivalent to Grade 100 blast furnace slag in accordance with ASTM C 989 "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars."

The strength of HVPC with 50% CemPozz is comparable to concrete made of ordinary portland cement, the setting time is similar, with improvements to alkali-silica reactivity mitigation and drying shrinkage. Concretes produced with CemPozz also have much higher sulfate resistance, very low permeability to chloride ions and are characterized by a significantly reduced cracking.

There are three environmental benefits with the EMC-based HVPC: (i) You can activate a fly ash that otherwise would not be suitable for high replacement of PC in concrete, (ii) You can reduce the CO_2 footprint by using a much less amount of clinker as concrete binder, and (iii) You can reduce the energy consumption associated with the binder. Calculations show that as much as 45% can be saved in energy with 45% less CO_2 emissions when 50% fly ash of cement mass is used with the EMC technology.

During the period 2004-2007, over two million cubic yards (1.5 million cubic meters) of High Volume Pozzolan Concrete (HVPC) made with CemPozz have been manufactured in Texas and effectively used for different applications in Texas (highway paving, housing concrete, shotcrete and blocks). TX DOT and PENNDOT have included CemPozz in their specifications, which allow 50% replacement of portland cement by weight.

Introduction

The energetically modified cement (EMC) technology was developed at Luleå University of Technology in Luleå, Sweden, by Dr. Vladimir Ronin and co-workers in the early 1990s. The EMC technology employs a high intensity mechanical activation process to increase the reactivity of ordinary portland cement (PC) with high filler and/or pozzolan replacements. The EMC technology consists of processing a blend of PC and filler/pozzolan through multiple high intensity grinding mills to impart increased surface activation of the PC and pozzolan particles. The high intensity grinding is typically accomplished by multiple stages of vibratory or stirred ball mills. The grinding circuit and type of grinding mills are typically custom designed for the raw materials to produce EMC low in Portland clinker with performance characteristics equivalent to parent PC. The process can be used to activate pozzolans of low reactivity (like certain fly ashes) and use them as a separate addition to the concrete mixer. Another possibility is to use the EMC technology with a PC clinker to obtain a concrete with superior properties compared to a concrete produced with the same amount of PC clinker without EMC processing.

A number of EMCs, and concretes based on them, have been tested at Luleå University of Technology (e.g. Hedlund et al., 1999, Johansson et al., 1999, Jonasson et al., 1996, Rao et al., 1997, and Ronin et al., 1994, 1997, 2004 and 2005) as well as at SINTEF (e.g. Justnes et al., 2005 and 2007a, b, c). Both performance based testing and microstructural investigations to understand the mechanisms have been carried out.

The present paper is focused on a recently developed energetically modified product - CemPozz, comprising fly ash with circa 5% PC treated in the specially designed milling system, containing vibration mills. CemPozz can be added together with portland cement in the production of a concrete in a conventional mixer. It has been shown that the amount of fly ash can be increased from about 20% with untreated fly ash to the level of 70% with modified fly ash maintaining the required strength level. CemPozz as a commercial product has been introduced in Texas in 2004 and now we can summarize more than three years of experience of CemPozz concrete performance. The main objective of this paper is to summarize the performance of CemPozz concretes with regular ready mix concrete mix designs with 28 days strength requirements of 3000 – 5000 psi (21 to 34.5 MPa), including durability.

One important field observation using concrete produced with CemPozz was that there seems to be significantly less appearance of cracks when producing slabs on ground and highway pavings in comparison with the general experience using traditional concretes. In order to study this phenomenon, drying shrinkage measurements are carried out and presented in this paper.

Experimental Program

Material. The material used in the major part of this study is CemPozz produced by Texas EMC Products, Ltd at the Limestone plant in Jawett, Texas. As raw materials Class F fly ash (FA) from the Limestone Power Plant (NRG Texas, LLC) and Type I portland cement have been used. The physical and chemical characteristics of the EMC are compared to that of PC, FA and conventional blends of PC and FA, while the EMC performance in mortar and concrete is compared to that of neat PC and PC with 20% - 50% FA replacement.

Chemical Analysis. The chemical analyses have been performed according to ASTM D-4326 and ASTM C-114 while the particle size distributions of EMC cement and the constituent raw materials (PC and FA) have been performed with the use of Hariba laser scattering particle size analysis.

Setting Time. The time of setting of EMC paste were compared to that of reference PC paste using the Gilmore apparatus according to ASTM C-266. The paste consistency and setting time were measured using the Vicat needle per ASTM C-187.

Compressive Strength. Evaluation of water demand and compressive strength development of mortar and concrete has been made in accordance with ASTM C-109, ASTM C-311 and ASTM C-192.

Sulfate Resistance, Freeze-thaw Resistance, and Abrasion Resistance. Sulfate resistance was evaluated according to ASTM C-1012, while alkali silica reactivity (ASR) was tested per ASTM C-441. Frost resistance and abrasion resistance were performed according to ASTM C-666 and C-944, correspondingly.

Shrinkage. The shrinkage tests are performed for cement mortar specimens of size 1.8 x 1.8 x 7.2 in (40×40×160 mm), which after casting have been completely sealed for moisture exchange by plastic foil during the first day. After about 24 hours the specimens were sealed by epoxy resin on top, bottom and end surfaces, and thereafter placed to dry out at indoor conditions (temperature about 20°C = 68°F and relative humidity 50%) with one-dimensional double-sided moisture migration as shown in Figures 1 and 2.

The shrinkage test for CemPozz concrete with 50% of portland cement replacement was performed according to ASTM C-157.

The mortars for the shrinkage test were prepared according to ASTM C-109 with a water-to-cementitious materials ratio (w/cm) of 0.46 and sand: cementitious material ratio of 2.75:1. European norm (EN) sand was used. Cementitious materials in this case were portland cement and ASTM Class F fly ash. The test specimens were cast on three subsequent days and thereafter they all experienced the same environment during the whole test period. Two length measurements were performed for each specimen, side A and side B in Figures 1 and 2, at each point of time. The representative shrinkage strain in the tests is calculated according to Equation 1.

$$® \quad \frac{\varsigma \qquad \varsigma}{\partial} \qquad \textbf{(1)}$$

where ς = change in length on side A [inch], ς = change in length on side B [inch], and l_{meas} = measuring length = 4 inches (0.1 m).

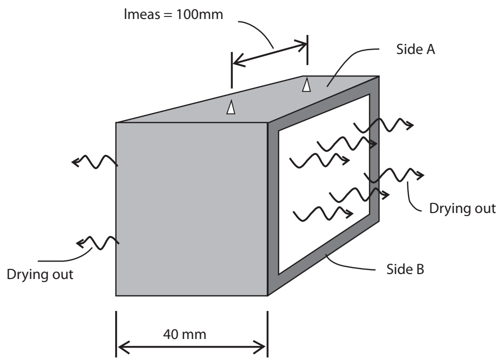


Figure 1. Type of test specimen for double-sided drying ($l_{meas} \approx 4$ in).

Figure 2. Shrinkage test specimens.

Results and discussion

Chemical Analysis. The chemical analysis of EMC and its constituents are listed in Table 1 and corresponding particle size distributions in Table 2. The chemical analysis corresponds to an ASTM Class F fly ash. The EMC grinding process was effective in reducing the coarse fraction of the fly ash. The percentage of the simple blend retained on 325 Mesh was decreased from 12% to 3% by the EMC method. This specific type of fly ash is relatively coarse and has significantly lower pozzolanic activity as compared to the other fly ashes in the area. Another study of EMC using 50% ASTM Class F fly ash replacement (Justnes *et al.*, 2005) revealed that fine particles of fly ash and cement formed agglomerates of size comparable to cement grains but with a higher inner surface explaining increased reactivity.

Table 1. Chemical composition of portland cement (PC), fly ash (FA), and an EMC blend of 50% PC and 50% CemPozz (which consists of 95% FA and 5% PC).

Compound	PC	FA	EMC
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 of portland cement (PC), fly ash (FA), a traditional blend of 50% PC and 50% FA and CemPozz (a blend of 5% PC and 95% FA)

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

Setting Time. The times of setting are shown in Table 3. The setting behavior of EMC paste is very similar to that of the reference PC. Conventional high volume fly ash (HVFA) portland-pozzolan blended cements have typically longer set times; 3 to 5 hours for initial set and 5 to 7 hours for final set.

Table 3. Time of Setting of Paste of PC and 50/50 PC/CemPozz

Property	PC	EMC
w/cm Initial Set Time (hours:min) Final Set Time (hours:min)	0.24 2:29 3:33	0.22 2:32 3:50

Mortar Compressive Strength Development. Table 4 represents the data for water-to-cementitious materials ratios (w/cm) for the ASTM C 109 mortars with similar flow and the compressive strength development of mortars based on 50/50 blend of PC and CemPozz in comparison with standard portland cement and standard portland cement with 20 and 40% of replacement with FA that has not been subjected to the EMC process (reference blends).

Table 4. Compressive Strength Development (MPa) according to ASTM C 109 (1 MPa = 145 psi)

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

PC-Type I cement from Texas.

According to Table 4, the blend made by 50% PC and 50% CemPozz had slightly lower early-age strength development in comparison with PC but had higher strengths after 28 days. The EMC (50% CemPozz) performed significantly better than portland-pozzolan blended cements with 20% and 40% fly ash replacements. The workability of this EMC appears better than the PC. The high fly ash content in combination with optimized particle size distribution allows 10% reduction in w/cm, which along with the increased reactivity of the processed pozzolan contributes to higher long-term strength.

Concrete Slump and Compressive Strength. Strength development of concretes made with 35%-60% CemPozz content is presented in the Table 5. It shows that 28 days strengths of about 20 to 35 MPa (circa 3000 to 5000 psi) can be achieved with the same mix designs, which ready mix concrete producers use in their every day operations. Concretes produced with CemPozz demonstrate strength increase (up to 40%) during 28-56 days curing periods, which has a very beneficial effect on the long-term concrete performance (improved durability and possibility to outperform strength requirements without changes in mix design).

Table 5. Concrete recipes using CemPozz, their slump and compressive strength development (MPa). 1 MPa = 145 psi

Mix No CemPozz(%)	#1 50	#2 55	#3 55	#4 35	#5 50	#6 60	#7 60
Cementitious materials* (kg/m^3)	273	273	273	256	249	249	243
CemPozz (kg/m^3)	136	150	150	93	125	149	146
Water (kg/m^3)	191	136	158	106	137	132	148
25 mm limestone aggreg. (kg/m^3)	1097	1097	1097	1127	1038	1068	1038
Fine aggregate (kg/m^3)	742	823	848	827	919	854	825
Air-entrainer (ml/m^3)	0	0	0	155	155	155	116
Water reducer (ml/m^3)	0	696	1005	580	657	657	464
w/cm	0.70	0.50	0.58	0.40	0.55	0.53	0.61
Slump (mm)	216	140	165	44	152	133	171
7 days compressive strength (MPa)	9.8	15.9	12.7	25.6	14.6	15.2	12.7
28 days compress. strength (MPa)	19.9	27.6	24.7	33.8	26.2	26.0	23.6
56 days compress. strength (MPa)	24.9	34.4	30.4	36.8	31.2	31.4	29.5

* portland cement + CemPozz

Sulfate Expansion. Table 6 represents the change in length of mortar bars exposed to sulfate solution and the maximum permissible values for specimens. Total six specimens for each type of cementitious combination have been tested. The mortar bars made with EMC cement (50% CemPozz) have significantly improved sulfate resistance over the reference PC, which samples have disintegrated after 13 weeks of testing. Although the change in length did not exceed permissible limits according to ASTM C 1157 requirements (max 0.050% after 6 months).

Table 6. Expansion of mortar due to sulfate exposure according to ASTM 1012. Change in length, %.

Exposure PC (reference) EMC (PC/CemPozz 50/50)
1 week 0.006 0.006
4 weeks 0.013 0.011
8 weeks 0.289 0.020
13 weeks failed 0.027
15 weeks 0.028
24 weeks (6 months) 0.030 (max 0.050)*

* maximum permissible value given in ASTM 1012

Alkali-silica reactivity. Table 7 shows that mortar bars made with CemPozz have a considerably better resistance (92% improvement) with respect to alkali-silica reactivity (ASR) than PC mortar bars according to ASTM C 441.

Table 7. Expansion of mortar due to ASR according to ASTM C441. Change in length, %

PC (ref.) EMC (PC/CemPozz 50/50) Reduction Results at 14 days: 0.026 0.002 92%

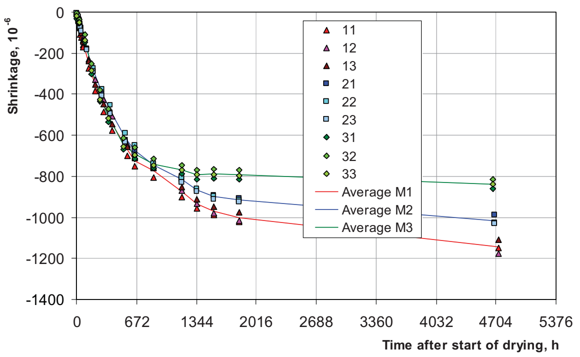
Shrinkage. The compositions of the mortars for shrinkage tests are given in Table 8 and the shrinkage (i.e. combination of autogenous and drying shrinkage) results are plotted in Figure 3 where the solid lines are the average shrinkage for each test series of three specimens, and the symbols are individual results from each specimen. As can be seen in the figure the spread in shrinkage for each series is in the order of ± 25 × 10^{-6}. The difference in shrinkage for the studied mixtures after seven months (= 4704 h) of drying is about 130 – 180 × 10^{-6}. This means that the "final" difference in shrinkage is significant for the different mixtures. However, the measured shrinkage for the first six weeks (= 1008 h) is approximately the same for all tested specimens.

Table 8. Material parameters for three types of test mixtures for linear shrinkage

Specimen	Mixture	Fly ash	Portland cement	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)

Figure 3. Measured drying shrinkage for three mixtures with three test specimens for each mixture. The solid lines show the average shrinkage for each mixture. Mixture M1 (100% PC) has the biggest shrinkage whereas mixture M3 (60% CemPozz) has the smallest shrinkage The horizontal scale is made for units of 672 h = 4 weeks.



One way of summarizing such shrinkage tests is to fit empirical expressions to the shrinkage developments as done here for Equation 2;

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

where ε_{shr} = shrinkage for the test specimen, ε_u = formal ultimate shrinkage, t_1= fitting time parameter for the time development, t = time from start of drying, η_1 = fitting parameter for the time development.

The fitting parameters for the average results of mixes M1, M2 and M3 are listed in Table 9.

Table 9. 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

One drawback for the use of Equation 2 is that the results are not necessarily valid for other circumstances than the tests performed. A lot more testing at different conditions are required to build more accurate models.

As can be seen from Table 9 the formal ultimate shrinkage, ε_u, is significantly different for the three mixtures studied. The final shrinkage is smallest for the mortar with 60% CemPozz (mix No. 3) and largest for PC mortar (mix No. 1). The shrinkage for the mortar with 20% non-modified fly ash is about halfway inbetween. If we assume that the increase in shrinkage for mixes Nos. 1 and 2 is primarily related to drying shrinkage, the risk of cracking at the surface of a concrete is increased as the drying shrinkage is related to shrinkage gradients inside the body. This assumption is based on the observation that the increase in shrinkage is rather late, see the splitting of the shrinkage curves from about four weeks (672 h) after the start of the drying and further on. At this time the rate of chemical reaction inside the test specimens is quite slow, and consequently the rate of autogenous shrinkage at this later stage is probably very small.

The experimental data on concrete drying shrinkage are shown in Table 10. It demonstrated a significant reduction (ca 46%) in drying shrinkage of HVPC compared to 100% portland cement concrete of similar mix design.

Table 10. Drying shrinkage test results (ASTM C 157) for a concrete with 50% CemPozz (cured 14 days in the moisture room prior to testing)

Time, days	4	7	14	28
Average shrinkage,%	- 0.009	- 0.010	- 0.010	-0.013* -0.019**

*Average shrinkage for the concrete mix design #5 in Table 5 with 50% PC and 50% CemPozz

**Average shrinkage for the concrete mix design #5 in Table 5 with 100% PC

Freeze-thaw and Abrasion Resistance. Data on the freeze-thaw and abrasion resistance for the paving concrete mixes (50% CemPozz) with total cementitious content 342 kg/m^3 (580 lbs/cy) and water-to-cementitious ratios 0.40 and 0.45 are presented in the Table 11. They show excellent durability of HVFA made with CemPozz.

Table 11. Freeze-thaw and abrasion resistance

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

Paving Job Example. Figures 4, 5 and 6 are presenting pictures from paving jobs on IH-10 east of Houston. A truck stop was made in 2007 using concrete with 255 kg/m^3 (433 lbs/cy), w/cm = 0.36 and 315 kg/m^3 (534 lbs/cy), w/cm=0.34. Both mixes had slump of about 4 inches and cementitious material (50% PC and 50% CemPozz). The 28 day strengths were 34 MPa

(4947 psi) and 49.2 MPa (7127 psi), which is significantly higher than TX DOT's requirements: 33.4 MPa (4400 psi) for paving and 35.9 MPa (5200 psi) for structural applications. The surface finish was excellent and reduced labor requirements.

According to Texas Department of Transportation, pavements with CemPozz concrete demonstrated 50% reduction in cracking compared to traditional pavement.

Figure 4. Laying the concrete for IH 10, Texas

Figure 5. Finished edges on IH 10, Texas

Figure 6. Overpass on IH 10, Texas

Energy and Environment. Regarding the energy consumption and environmental impact of producing CemPozz versus PC, the following statements can be made: The manufacturing process of PC consists primarily of quarrying or blasting of raw materials (limestone, clay), crushing, grinding, blending and conveying of the said raw meal to cement kilns where at high temperatures (about 1450°C = 2640°F) the formation of clinker takes place. The obtained clinker is further ground with gypsum to produce the final product-portland cement. The total energy consumption is circa 1000 kWh/tone. In the case of usage of an EMC product, the final cementitious material contains typically 50% of PC and 50% of CemPozz. Manufacturing of such product includes processing of fly ash with about 5% of portland cement through EMC vibrating milling system to obtain a fraction < 40 microns and further blending with PC. As the required energy to produce CemPozz doesn't exceed 30 kWh/tone, the final energy to produce 50/50 PC/CemPozz blend is about 540 kWh/ tone, which is only 54% of the energy required for 1 ton of PC production. 50% PC replacement should account for 50% less CO_2, but since EMC require somewhat more electrical energy in grinding the saving may be about 45% (providing that the energy production involves burning of fossil fuel).

Conclusions

Three years of full scale industrial implementation of High Volume Pozzolan Concrete manufactured with CemPozz (mechanically processed fly ash) reveals a possibility to produce environmentally friendly and efficient high-performance ready mix concrete with a replacement of up to 60% of the portland cement.

Concrete and mortars containing up to 60% CemPozz were characterized by significantly lower drying shrinkage in comparison with PC and 20% fly ash concretes. This could be an explanation of much lower cracking development of payments made with CemPozz concrete (about 50% according to Texas Department of Transportation).

EMC mortars and concretes (with 50% CemPozz) performed in line with traditional 20% fly ash mixes. Compressive strengths of 3000 - 5000 psi (20 – 35 MPa) at 28 days were achieved with traditional concrete mix designs by replacing up to 60% of the portland cement.

Mortars produced with 50% CemPozz were characterized by lower water demand to achieve the same flowability (workability) compared to PC mortars which contributes to higher strengths for concretes with CemPozz. Concretes with CemPozz also had improved sulfate resistance and resistance to alkali silica reaction (ASR). Change in length due to ASR was up to 92% lower in comparison with standard PC.

Replacement of portland cement by CemPozz allows creating of high performance cements and concretes with a significantly improved environmental profile, enabling 45% savings in energy and 45% less CO_2 emissions.

CemPozz (mechanically processed fly ash) has been included by TX DOT and PENNDOT in their specifications for paving and structural concrete allowing up to 50% of portland cement replacement.

Acknowledgements

Concrete strength development test results are a summary of the tests performed by TX DOT, PENNDOT, paving contractors, Texas EMC Products, Inc and CCRL in Texas. Data on ASR and sulphate resistance was generated by TX DOT and independently by CCRL. Data on the shrinkage measurements come from EMC (mortars), LTU (concrete C 157 test) and CCRL. The tests on the frost–thaw and abrasion resistance were performed by PENNDOT.

This article is presented for information only and does not necessarily represent the views and opinions of the National Ready Mixed Concrete Association.

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